How good are final year veterinary students at recognising normal abdominal organs on ultrasound videos?

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Abstract

Ultrasound is a widely used diagnostic imaging modality in veterinary medicine, yet lack of training and confidence are commonly reported barriers to its clinical use. In the United Kingdom, the Royal College of Veterinary Surgeons requires new graduates to demonstrate proficiency in capturing diagnostic-quality ultrasound images and interpreting “common findings,” though the scope of these findings is not clearly defined.

The present study aimed to evaluate final-year veterinary students’ ability and confidence in identifying abdominal organs on ultrasound videos, as a prerequisite to recognising common abnormalities, and to assess the impact of supplementary online teaching material. At the study location, practical ultrasound training is limited, with lectures predominating and practical sessions focusing on organs considered easier to identify, such as the liver, spleen, kidneys, and urinary bladder.

Students completed a test at the start (pre-rotation), end (post-rotation 1), and six weeks later (post-rotation 2) of their diagnostic imaging rotation. Two cohorts had access to online teaching material (test students), while one cohort did not (control students). The test assessed identification of 47 abdominal structures on ultrasound videos and self-reported confidence (Likert scale 1–5).

Test students showed significant improvements in correctly identifying several organs. Compared to controls, they were significantly more accurate at identifying the spleen (post-rotation 1), pancreas (post-rotation 2), and blood vessels (both post-rotation tests). Confidence in identifying kidneys, spleen, liver, gastrointestinal tract (except ileocaecocolic junction), pancreas, lymph nodes, and blood vessels increased significantly over time in test students, while control students showed smaller gains in confidence limited to the small and large intestine. However, increases in confidence were not always matched by corresponding improvements in accuracy. At post-rotation 2, test students were significantly more confident than controls in identifying kidneys, spleen, pancreas, lymph nodes, and blood vessels.

These findings indicate that final-year students can reliably identify commonly taught abdominal organs, while additional online resources can further improve identification and confidence for less familiar structures. The study provides evidence for the value of supplementary online teaching in undergraduate veterinary ultrasound education and highlights areas for future curriculum development.

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Dedication

I dedicate this dissertation to Gaspard, for always supporting me wherever my studies led us.

Declaration

I, Emilie Paran, declare that the work in this thesis is original and was carried out solely by myself or with due acknowledgements. It has not been submitted in any form for another degree or professional qualification.

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Abbreviations

3D – Three Dimensional

AGEP - accelerated graduate entry program

ACVR - American College of Veterinary Radiology

BVSc - Bachelor of Veterinary Science

CPD - Continuing Professional Development

CT - Computed Tomography

DI – Diagnostic Imaging

ECVDI - European College of Veterinary Diagnostic Imaging

FAST - Focused Assessment with Sonography for Trauma

FN – Female Neutered

GB - Gallbladder

GOR – Gastroesophageal Reflux

KHz – Kilohertz

LV - Langford Vets

MCQ – Multiple Choice Question

ME – Male Entire

MN – Male Neutered

OSCE – Objective Structured Clinical Examination

POCUS - Point-of-Care Ultrasound

RCVS - Royal College of Veterinary Surgeons

Vet-BLUE - Veterinary Bedside Lung Ultrasound Examination

CHAPTER ONE: General introduction

1. Origins and milestones: the evolution of diagnostic ultrasound technology

The development of diagnostic ultrasound started with the discovery of the piezoelectric properties of some crystals, in particular quartz, by the Curie brothers in 1880 (Curie & Curie, 1880). This breakthrough revealed that mechanical distortion of these crystals generates an electric charge. The converse effect was later proven by Lippmann in 1881. The application of electricity onto those crystals causes their deformation, leading to the emission of sound waves at frequencies exceeding 20 KHz, known as ultrasound. This discovery led to the development of ultrasound transducers which consist of arrays of piezoelectric crystals (Duck, 2021). Initially employed for submarine detection and the advancement of Sound Navigation and Ranging (SONAR) systems from the late 1910s to the 1940s, ultrasound found its way into clinical practice by the late 1940s (Duck, 2021).

In 1942, Dussik proposed the utilisation of ultrasound as a diagnostic tool, marking a significant shift towards medical applications (Dussik, 1942). The first contact ultrasound scanner was pioneered in Glasgow by Ian Donald and Tom Brown (Campbell, 2013). Their groundbreaking work, detailed in a paper on ultrasound physics, safety, and imaging of pregnancy, foetuses, and gynaecological conditions (Donald et al., 1958), paved the road for further advancements in diagnostic ultrasound.

2. Evolution of diagnostic ultrasound in Veterinary Medicine: a brief historical and contemporary perspective

The utilisation of diagnostic ultrasound in veterinary medicine traces back to its initial report in 1966 for pregnancy identification in sheep by Lindhal (1966). However, echocardiography in calves had already been performed by Inge Edler, a human cardiologist, in the early 1960s (Singh & Goyal, 2007). In the first 21 years of veterinary diagnostic ultrasound, a total of 492 references, including articles and textbooks, were published (Lamb et al., 1988). Of these, 169 publications focused on small animal applications, while 248 were dedicated to large animal (equine and farm animals) applications.

Most small animal publications centred around ultrasound examinations of the abdomen (including the reproductive tract) and echocardiography, with a small number addressing ocular ultrasound. In contrast, the focus of large animal publications primarily revolved around the reproductive system, accounting for nearly three-quarters of the literature. The remaining publications covered abdominal, thoracic, cardiac, and musculoskeletal ultrasound applications in horses (Lamb et al., 1988).

Since 1986, there has been a remarkable surge in publications related to ultrasound in veterinary medicine, as evidenced by an exponential increase in search results for the keywords “ultrasound veterinary medicine” on PubMed. A search conducted on 30/07/2024 revealed 16,838 occurrences within the specified timeframe (PubMed search). This exponential growth aligns with the assertion made by Johnson in 2013 that the introduction of ultrasound in veterinary practice stands as one of the most influential advancements of the last 50 years (Johnson, 2013).

3. Surveys insights: utilisation of ultrasound in small animal veterinary practices

Since 2018, five studies have investigated the use of ultrasound by small animal practitioners, primarily in the UK or Republic of Ireland (Booth et al., 2018; McDonald et al., 2023) or the United States and Canada (DeFrancesco & Royal, 2018; Pelchat et al., 2020; Zelachowski et al., 2024). Two of those studies predominantly focused on the utilisation of Point-of-Care Ultrasound (POCUS) (Pelchat et al., 2020; McDonald et al., 2023). The practitioners involved were predominantly from first opinion practices, with some also offering emergency, out-of-hours, or specialised services.

A high percentage of small animal practitioners have access to ultrasound machines, with reported access rates ranging from 84% to 93% (Booth et al., 2018; Zelachowski et al., 2024). However, one study indicated lower accessibility, with only 53% of respondents having access to an ultrasound machine (DeFrancesco & Royal, 2018).

The frequency of ultrasound usage varied, with practitioners utilising their machine daily (27%-68%), weekly (25%-99%) (DeFrancesco & Royal, 2018; Pelchat et al., 2020; McDonald et al., 2023; Zelachowski et al., 2024), or at least once a month (86%) (Booth et al., 2018).

The most common applications included ultrasound guided procedures such as cystocentesis, abdominocentesis and thoracocentesis, limited abdominal evaluation and pregnancy diagnosis (Zelachowski et al., 2024). Over 90% of practitioners used POCUS, with abdominal Focused Assessment with Sonography for Trauma (FAST) and thoracic FAST being the most frequently used protocols (Pelchat et al., 2020; McDonald et al., 2023).

Less commonly, practitioners utilised ultrasound for procedures like vascular access, nerve blocks, biopsies, assessment of ocular, muscular or thoracic structures (Zelachowski et al., 2024). The Vet-BLUE (Veterinary Bedside Lung Ultrasound Examination) POCUS protocol was among the less frequently performed assessments (McDonald et al., 2023).

Several studies have assessed the confidence levels of small animal practitioners in diagnosing various pathologies using ultrasound. Practitioners reported high confidence in detecting urinary bladder abnormalities, free fluid in the abdominal or thoracic cavities, pericardial effusion, splenic abnormalities, kidney abnormalities, and diagnosing pyometra (Pelchat et al., 2020; McDonald et al., 2023; Zelachowski et al., 2024). However, they expressed lower confidence in evaluating pancreatic abnormalities, ureteral obstructions, gastrointestinal foreign bodies, intussusception, paralytic ileus, adrenal abnormalities, prostatitis, and cardiac tumours (McDonald et al., 2023; Zelachowski et al., 2024).

When assessing confidence in identifying abdominal organs, over 90% of practitioners felt confident in locating the gallbladder, spleen, liver, kidneys, urinary bladder, and detecting free fluid (McDonald et al., 2023). However, they found it more challenging to identify the ureters, ovaries, ileocaecocolic junction, adrenal glands, mesenteric lymph nodes, and pancreas.

Disparities in training backgrounds were evident among practitioners. According to Zelachowski et al. (2024), 62% of practitioners received in-person Continuing Professional Development (CPD), 38% were trained during veterinary school, and 26% had online training courses. Informal training, including the use of textbooks, learning from colleagues, or ultrasound vendors, was also common. For those using POCUS, 50% reported self-teaching through journal articles and online videos, while 24% received training from a colleague (McDonald et al., 2023). Only 17% had formal training through specific practical courses, and less than 4% had undergraduate education in POCUS techniques (McDonald et al., 2023). Most respondents reported having less than 25 hours of total ultrasound training (Pelchat et al., 2020; McDonald et al., 2023).

Interestingly, practitioners who underwent formal training courses were more likely to use ultrasound, and the frequency of use increased with more hours of training (Zelachowski et al., 2024). However, participation in practical diagnostic imaging CPD did not significantly enhance median confidence scores across eight abdominal or thoracic POCUS areas compared to those without such training (McDonald et al., 2023). The limited number of practitioners in this category may have affected the statistical power of this finding (McDonald et al., 2023).

Common reasons for not performing or limiting the use of ultrasound, despite having access to an ultrasound machine, included lack of training, lack of confidence, other colleagues performing ultrasound examinations within the practice, a preference for referring cases for ultrasound, and cost considerations for clients (Pelchat et al., 2020; McDonald et al., 2023; Zelachowski et al., 2024).

These findings underscore a substantial rise in ultrasound adoption since the 1990s, where only 30% of practices employed the technology (Dennis, 1992), emphasizing the growing professional necessity for veterinary students to receive comprehensive ultrasound training. Additionally, alumni and employer surveys indicate that new graduates are expected to have basic ultrasound competencies (Ward et al., 2024).

4. Ultrasound applications in small animal veterinary medicine

The most common conditions encountered in small animal practice, based on epidemiological studies and pet health insurance data, include gastrointestinal signs such as vomiting and diarrhoea, diseases of the urinary tract and kidneys, and traumatic injuries, particularly those associated with road traffic accidents (O'Neill et al., 2023; PR Newswire website, consulted on 23/04/2024). Diagnostic ultrasound, including both focused point-of-care ultrasound (POCUS) and comprehensive abdominal ultrasound examinations, plays a central role in the investigation and management of these presentations in first-opinion practice.

For newly graduated veterinarians, ultrasound is likely most frequently applied to a core group of clinical scenarios that require rapid organ identification and pattern recognition rather than exhaustive specialist assessment. One of the most common and clinically valuable applications is the detection of abnormal fluid accumulation within body cavities, including peritoneal, pleural, and pericardial effusions. The identification of free fluid using POCUS can guide emergency decision-making in both traumatised and non-traumatised patients and is routinely incorporated into protocols such as AFAST and TFAST (Boysen & Lisciandro, 2013; McMurray et al., 2016).

Urogenital applications also represent a substantial proportion of ultrasound use in general practice. These include assessment of the urinary bladder for urolithiasis, cystitis, and intraluminal or mural masses, evaluation of the kidneys for changes such as nephromegaly, renal masses, nephrolithiasis, and renal pelvic dilation. Ultrasound is particularly valuable for confirming pyelectasia and assisting in differentiation between ureteral obstruction and inflammatory renal disease (D'Anjou et al., 2011; Robotti & Lanfranchi, 2013). Examination of the reproductive tract for conditions such as pyometra and pregnancy is also frequent.

The spleen and liver are also commonly assessed during abdominal ultrasound examinations. Frequent splenic findings encountered by general practitioners include splenomegaly, focal or multifocal splenic masses, altered echotexture such as a honeycomb appearance, and, less commonly, splenic torsion. Hepatobiliary applications include the detection of hepatic masses or diffuse parenchymal changes, gallbladder wall oedema, biliary obstruction, and gallbladder mucocele, all of which may be identified during routine abdominal scanning in patients presenting with nonspecific clinical signs.

Gastrointestinal ultrasound represents another key application area, particularly for the evaluation of suspected mechanical obstruction, gastrointestinal foreign bodies, intussusception, and mural abnormalities. While definitive differentiation between neoplastic and inflammatory disease typically requires histopathology, ultrasound enables the identification of abnormal wall layering, segmental thickening, altered motility, and secondary changes such as mesenteric lymphadenopathy, thereby informing clinical decision-making (Leib et al., 2010; Tyrrell & Beck, 2006).

In addition to diagnostic imaging, ultrasound is routinely used to guide minimally invasive procedures in first-opinion practice, including cystocentesis, abdominocentesis, and thoracocentesis. The ability to safely identify organs and small fluid pockets is thought to be essential for reducing procedural risk and improving diagnostic yield (Muehlbauer et al., 2023). Ultrasound can also be used to detect complications after the procedure (Muehlbauer et al., 2023).

Collectively, these applications represent a proposed core set of ultrasound competencies that newly graduated veterinarians are likely to encounter frequently in small animal practice. Effective use of both POCUS and abdominal ultrasound relies fundamentally on accurate recognition of normal abdominal organs and their sonographic appearance. Consequently, evaluating the ability of final-year veterinary students to identify normal structures on ultrasound is a critical step in assessing preparedness for clinical practice.

5. Small animal veterinary guidelines for performing POCUS and abdominal ultrasound

Diagnostic ultrasound is widely used in small animal veterinary practice; however, there is limited formal oversight or systematic monitoring of practitioner competence in performing and interpreting ultrasound examinations. Although veterinarians and veterinary nurses are required to undertake continuing professional development (CPD) throughout their careers, there is no mandatory requirement for regular or structured CPD specifically related to ultrasound. Instead, practitioners are free to select ultrasound-related training according to individual interest, despite the technical and operator-dependent nature of this imaging modality.

Nevertheless, several professional organisations have published guidelines that standardise how abdominal ultrasound examinations should be performed in small animals. In 2022, a consensus statement produced by the American College of Veterinary Radiology (ACVR) and the European College of Veterinary Diagnostic Imaging (ECVDI) was published with the aim of harmonising abdominal ultrasound examinations in dogs and cats (Seiler et al., 2022). This document provides detailed recommendations on examination technique and image acquisition and outlines the minimum set of images that should be obtained for each abdominal system, including the hepatobiliary system, spleen, gastrointestinal tract, pancreas, urinary tract, adrenal glands, genital tract, lymph nodes, great vessels, and the peritoneal and retroperitoneal spaces. Although primarily intended for practising veterinarians and veterinary sonographers, this consensus statement also represents an important reference for veterinary students and residents in diagnostic imaging.

In parallel, practice guidelines have been published for non-veterinary ultrasound practitioners, such as registered veterinary nurses and sonographers with qualifications in human diagnostic ultrasound, notably through the British Medical Ultrasound Society (BMUS) Small Animal Veterinary Guidelines for Professional Ultrasound Practice. Together, these documents establish expectations for image acquisition and anatomical assessment during small animal abdominal ultrasound examinations.

Focused point-of-care ultrasound (POCUS) protocols have also been developed and are widely adopted in veterinary emergency and general practice. The abdominal focused assessment with sonography for trauma (A-FAST) and thoracic focused assessment with sonography for trauma (T-FAST) protocols provide standardised scanning windows and defined anatomical targets to allow rapid assessment of critical patients (Lisciandro et al., 2008; Lisciandro, 2011; Boysen & Lisciandro, 2013; McMurray et al., 2016). A complete A-FAST examination includes evaluation of the diaphragmatico-hepatic, splenorenal, cystocolic, and hepatocolic windows, with the more recent addition of the umbilical site (Boysen, 2025), while the T-FAST protocol incorporates bilateral pericardial and chest tube sites in addition to the diaphragmatico-hepatic window. These protocols clearly define what structures should be assessed, reinforcing the importance of consistent anatomical recognition.

Despite the existence of these guidelines for performing abdominal ultrasound and POCUS, there are currently no standardised recommendations in veterinary medicine regarding how these protocols should be taught, assessed, or maintained. Specifically, there are no published guidelines defining minimum training duration, number of supervised examinations, competency benchmarks, or requirements for ongoing CPD in ultrasound, despite the growing number of commercial and academic providers offering ultrasound courses to veterinary professionals.

In contrast, human medicine has established detailed, competency-based frameworks for ultrasound training. For example, the Royal College of Radiologists has developed structured recommendations for ultrasound training across medical and surgical specialties, with defined training levels, minimum examination numbers, and core competencies. At Level 1, which represents the minimum standard for independent practice, trainees performing urological ultrasound are expected to complete at least 250 supervised examinations over a 3–6-month period and demonstrate competence in acquiring diagnostic images, recognising normal anatomy, and identifying common pathological conditions.

While these human medical guidelines are not directly transferable to veterinary undergraduate education, they illustrate a structured approach to ultrasound training that is currently lacking in veterinary medicine. Recent work from the Iowa State University College of Veterinary Medicine highlights emerging efforts to address this gap. Prior to implementing a basic ultrasound curriculum, Ward et al. (2024) identified key educational priorities, including teaching students how to generate and optimise images, select appropriate probes and machine settings, scan safely and systematically, recognise normal anatomy, and understand the clinical utility and limitations of POCUS in general practice settings.

Taken together, these observations highlight a clear disconnect between well-defined expectations for performing abdominal ultrasound examinations and the absence of formal guidance on training and competency development in veterinary ultrasound. This gap is particularly relevant for undergraduate veterinary education, where early acquisition of normal anatomical recognition is fundamental to the safe and effective use of ultrasound in clinical practice.

6. RCVS requirements in Diagnostic Imaging for undergraduates and newly graduated veterinarians

Undergraduate veterinary education in the United Kingdom is regulated by the Royal College of Veterinary Surgeons (RCVS), which oversees the accreditation of the 11 UK veterinary schools. Central to this regulatory framework are the RCVS Day One Competences, which define the “knowledge, skills and attributes required of veterinary students upon graduation to ensure that they are prepared for their first role in the profession and safe to practise independently” (RCVS, consulted on 18/06/2023).

Within the domain of diagnostic imaging, the Day One Competences state that new graduates should be able to obtain diagnostic-quality images and interpret “common findings” using “basic equipment”, including radiography and ultrasound. However, there is currently no formal guidance clarifying what constitutes “common findings” or what is meant by “basic equipment” in this context. As ultrasound technology becomes increasingly available in first-opinion practice, this lack of specificity creates ambiguity regarding the expected level of competence of new graduates. The proposed core applications and skills discussed in Section 4 of this introduction could help to operationalise these expectations for small animal practice.

Following graduation, veterinary surgeons entering practice in the UK are required to complete the Veterinary Graduate Development Programme (VetGDP). This structured programme, typically completed over 12 to 18 months, is delivered within the workplace and is organised around Entrustable Professional Activities (EPAs), defined as “tasks relevant to the graduate’s role that they are expected to be able to perform competently and confidently by the end of the programme”. At present, there is no EPA dedicated specifically to diagnostic imaging. Relevant competencies are instead embedded within broader EPAs, particularly EPA 2 ("Develop a diagnostic plan, obtain informed consent and interpret test results") and EPA 4 ("Recognise a patient requiring urgent or emergent care and initiate evaluation and management"). In contrast, other clinical areas such as anaesthesia are addressed in greater detail, with EPA 7 providing expectations for induction, maintenance, and recovery of anaesthesia in stable patients.

This relative lack of explicit focus on diagnostic imaging within the VetGDP is notable given the increasing reliance on imaging, particularly ultrasound and POCUS, in first-opinion practice. The development of new EPAs is acknowledged to be challenging, as they must remain "high-level and adaptable across different species, workplace settings and veterinary roles". Nevertheless, consultation with practitioners across a range of clinical environments could help to define core diagnostic imaging activities that are both broadly applicable and clinically relevant. For small animal practice, the set of core ultrasound skills proposed in Section 4 may provide a useful foundation for such development.

In this context, a dedicated EPA for basic diagnostic ultrasound and POCUS could be considered within the VetGDP framework. In keeping with the structure and language used in existing RCVS EPAs, a proposed EPA might be outlined as follows:

Proposed EPA: Perform and interpret basic diagnostic ultrasound examinations appropriate to the clinical setting

Description:
Perform focused and basic diagnostic ultrasound examinations across species to support clinical decision-making in first opinion and emergency settings. Generate diagnostic-quality images, recognise normal anatomy, identify common abnormalities, and understand the clinical utility and limitations of ultrasound and POCUS.

Scope:
Applicable to companion animals, exotic species, equids, and farm animals in general practice, referral, ambulatory, and hospital-based settings.

- *By the end of the programme, the graduate should be able to:*
- Select appropriate ultrasound probes and machine settings for the species, patient size, and clinical question.
- Generate and optimise diagnostic-quality images using a safe and systematic scanning approach.
- Identify and recognise normal sonographic anatomy of major organ systems relevant to the species examined.
- Use focused ultrasound (POCUS) to answer specific clinical questions in emergency and first-opinion contexts.
- Interpret common sonographic findings in conjunction with history and clinical examination.
- Recognise the limitations of ultrasound and identify situations requiring further imaging, referral, or specialist input.
- Perform basic ultrasound-guided procedures safely, where appropriate, under supervision.

Limitations:
This EPA does not imply competence in advanced or specialist diagnostic imaging, comprehensive echocardiography, or definitive ultrasonographic diagnosis of complex disease processes.

The inclusion of such an EPA would help to align the expectations of the Day One Competences with the realities of contemporary veterinary practice, while providing a structured framework for the development and assessment of ultrasound competence in newly graduated veterinarians. Importantly, the ability to recognise normal anatomy underpins all ultrasound applications, reinforcing the relevance of evaluating undergraduate students' proficiency in this fundamental skill.

7. Exploring varied approaches to education in veterinary medicine

7.1. Learners' styles and teaching methods

The concept of "learning styles" has been widely discussed as an educational framework and is generally based on three assumptions: (1) individuals express preferences for particular ways of learning; (2) individuals differ in their ability to learn certain types of information; and (3) learning outcomes are improved when instructional design is matched to an individual's preferred learning style (Newton, 2015). The educational literature contains more than 70 overlapping learning style classification systems, many with multiple subtypes and inconsistent terminology (Coffield et al., 2004). Some models categorise learners according to preferred sensory modalities (e.g. visual, auditory), while others focus on how learners perceive and process information.

Despite their popularity, there is currently no robust evidence supporting the educational benefit of learning styles, particularly with respect to the third assumption—that matching teaching methods to an individual's learning style improves learning outcomes (Newton, 2015). Furthermore, as most learning tasks require integration of multiple types of information and cognitive processes, the practical utility of categorising learners according to a dominant learning style is questionable.

Within veterinary education, limited work has explored learning style profiles. Neel and Grindem (2010) assessed veterinary students using the Felder-Silverman Index of Learning Styles and reported that many undergraduates exhibited preferences for active, sensing, visual, and sequential learning. However, substantial variability was observed, reinforcing the complexity of learner profiles. Importantly, as in other disciplines, there is no evidence that tailoring educational material to these preferences enhances learning outcomes for veterinary students.

In contrast, there is strong evidence supporting the effectiveness of specific teaching and learning strategies across disciplines. (Weinstein et al., 2018) detailed six evidence-based techniques that consistently improve learning: spaced practice, interleaving, retrieval practice, elaboration, use of concrete examples, and dual coding. Although these strategies are well established in general education research, they have not been systematically evaluated within veterinary undergraduate curricula, including in the context of diagnostic imaging or ultrasound education.

7.2. Competency-based education in veterinary medicine

In response to the limitations of time-based curricula, the American Association of Veterinary Medical Colleges (AAVMC) developed the Competency-Based Veterinary Education (CBVE) framework. CBVE is organised around nine domains of competence (for example, clinical reasoning and decision-making) and aims to provide learner-centred educational and assessment experiences while de-emphasising fixed instructional time in favour of clearly defined outcomes (AAVMC, consulted on 27/12/2025).

Within CBVE, competence is developed progressively through milestones, ranging from pre-novice (expected from entry into the veterinary programme) to proficient (an aspirational level achieved after sustained workplace experience). A key operational feature of CBVE is the use of Entrustable Professional Activities (EPAs), which are units of professional practice requiring integration of multiple competencies across domains and performance in authentic clinical contexts. EPAs are intended to be activities that graduates can perform independently at the point of graduation.

Currently, there is no EPA specifically dedicated to diagnostic imaging, in contrast to areas such as surgery or anaesthesia. Nevertheless, ultrasound competence clearly intersects with multiple CBVE domains, including Domain 1 (clinical reasoning and decision-making), Domain 2 (individual animal care and management), Domain 5 (communication), Domain 6 (collaboration), Domain 7 (professionalism and professional identity), and Domain 9 (scholarship). Given the increasing role of ultrasound—particularly POCUS—in general practice, the absence of a clearly articulated EPA in this area represents a notable gap.

A proposed EPA addressing this gap could be framed as follows:

EPA X: Performs a diagnostic ultrasound examination on a stable patient

Description of activity	Performs a diagnostic ultrasound examination on a stable patient to generate diagnostic-quality images, recognise normal anatomy, identify common abnormalities relevant to

	the clinical context, and understand the utility and limitations of the examination in general practice
Commentary	This activity involves the safe and systematic performance of an ultrasound scan on a stable patient, including appropriate probe selection, machine setting optimisation, image acquisition, and preliminary interpretation of findings. Graduates must integrate clinical reasoning with technical skills and professional behaviour in real-world clinical settings. Ultrasound performance includes both general abdominal scans and focused point-of-care applications (POCUS) as needed to address specific clinical questions. The graduate must be able to justify the use of ultrasound, recognise when the examination is outside their scope, and communicate findings appropriately.
Most relevant domains	1: Clinical reasoning & decision-making 2: Individual animal care & management 5: Communication 6: Collaboration 7: Professionalism & professional identity
Secondary domains	9: Scholarship
Elements within activity	• Prepare the patient and equipment, including appropriate probe selection and patient handling • Generate and optimise diagnostic-quality images using a systematic scanning approach • Recognise normal sonographic anatomy and common findings • Apply clinical reasoning to integrate ultrasound findings with other diagnostic information • Communicate and document findings clearly and professionally

	• Maintain patient safety and recognise limitations requiring referral or further imaging

7.3. Ultrasound Teaching

Despite the growing clinical importance of ultrasound, there is limited published evidence regarding how ultrasound should be taught at the undergraduate veterinary level. Existing studies have focused primarily on delivery methods rather than curriculum structure or competency benchmarks.

Davy et al. (2019) compared live-animal instruction with video-based teaching for abdominal focused assessment with sonography for trauma (A-FAST) in first- and second-year veterinary students. While overall performance was similar between groups for most scanning windows, students who received live instruction performed better in the diaphragmaticohepatic view. Notably, difficulties in identifying key views were observed across both groups, highlighting challenges in anatomical recognition.

Scallan et al. (2021) evaluated three teaching modalities—small-group self-directed learning, instructor-led demonstrations, and online modules—for ultrasound knobology and image quality recognition in first-year veterinary students. Small-group self-directed learning resulted in superior short- and long-term knowledge retention. However, this approach required substantial resources, including the use of 20 ultrasound machines.

In equine education, Navas de Solis et al. (2021) compared digital interactive multimedia tutorials with textbook reading and traditional lectures. Students using multimedia tutorials demonstrated improved practical performance compared to textbook reading, while written assessment outcomes were similar across groups. Students emphasised the importance of time for practice, trial-and-error learning, expert feedback, and understanding clinical relevance.

Collectively, these studies suggest that active learning, opportunities for deliberate practice, and contextualised instruction may enhance ultrasound skill acquisition. However, there remains no consensus regarding the optimal content, duration, timing, or delivery methods for ultrasound teaching in veterinary curricula.

8. Undergraduate veterinary programs and ultrasound education at the University of Bristol

The University of Bristol offers two undergraduate programs in veterinary science, each leading to a Bachelor of Veterinary Science (BVSc). The first program is a traditional 5-year pathway (BVSc), typically pursued after A-levels (at age 18+). The second program, an accelerated graduate entry program (BVSc AGEP), spans 4 years and is open to candidates who have completed a first degree (at age 21+) in a related field such as biology or zoology. While the BVSc program has a longstanding history, the BVSc AGEP program was introduced more recently, commencing in the academic year 2019-2020.

Students enrolled in the BVSc program engage in a curriculum that blends animal health science and management during the initial two years, followed by clinical veterinary science and the One Health concept in the third year. The final two years of the program primarily focus on clinical veterinary science. Conversely, students in the BVSc AGEP program undergo a condensed version of the curriculum, compressing the content from the first three years into two years. Subsequently, they integrate with the BVSc program in years 4 and 5. Throughout both programs, core themes such as veterinary public health, evidence-based veterinary medicine, and practical clinical skills are woven into the curriculum.

Within the BVSc program at the University of Bristol, ultrasound introduction begins in the first year, elucidating fundamental principles and image interpretation basics. Year 2 extends this knowledge to the equine musculoskeletal system, where students gain hands-on experience with ultrasound scanner controls. Preclinical ultrasound instruction is primarily delivered by clinical demonstrators and anatomy school lecturers.

In the third year, students receive extensive lectures on diagnostic imaging, encompassing ultrasound physics, equipment, and small animal abdominal ultrasonography. They are expected to grasp concepts such as ultrasound wave production and detection, transducer types, and common artefacts, alongside recognising normal abdominal organ appearances. These lectures are conducted by a specialist diagnostic imaging faculty member through a combination of live and recorded sessions.

Moving into the fourth year, students refine their ultrasound skills, learning transducer manipulation and image optimisation techniques using models. Ultrasound scanning basics are demonstrated in bovine fertility modules spanning years 3 and 4. Integration of ultrasound in clinical scenarios is explored in cases of small animal respiratory disease (year 3) and equine colic (year 4).

Finally, during their fifth and final year, students undergo rotations in various clinical settings, including small animal teaching hospitals, first opinion practices, farm, and equine hospitals. They also spend a week in the diagnostic imaging department at Langford Vets Small Animal Referral Hospital. Opportunities to engage with diagnostic imaging equipment are also available during extramural studies and elective rotations.

9. Integration of ultrasound training in medical education

In human medicine, the utilisation of ultrasound technology has experienced a rapid expansion, propelled by the increased affordability of ultrasound machines and transducers within medical practices. This expansion has emphasized the escalating necessity for physicians to attain proficiency in ultrasound usage. Consequently, it has instigated critical investigations into the integration of ultrasound training within medical school curricula, as well as the continual assessment of ultrasound skills among both recent graduates and practicing physicians throughout their careers (Tolsgaard et al., 2013).

Medical institutions in both the United States and Germany have outlined comprehensive approaches to incorporating ultrasound training into their educational programs (Bahner & Royall, 2013; Celebi, Griewatz, Malek, et al., 2019; Hoppmann et al., 2011; Rathbun et al., 2023; Teichgräber et al., 2022). The primary aim of such initiatives is to equip medical students with the skills necessary to conduct focused ultrasonography, including POCUS, enabling them to capture ultrasound images and videos, interpret findings, and integrate them into clinical decision-making processes (Bahner & Royall, 2013). Certain authors have suggested key topics for inclusion in medical student ultrasound training, such as focused abdominal ultrasound encompassing evaluation of the gallbladder, kidneys, urinary bladder, aorta, and caudal vena cava, as well as ultrasound-guided puncture techniques (Celebi et al., 2019). Nevertheless, until recently, there has been a lack of consensus regarding the specific content of ultrasound education in medical school curricula.

9.1. International consensus recommendations on ultrasound education for medical schools

In 2022, a consortium of experts comprising clinicians, scientists, educators, and researchers released a consensus statement on ultrasound education for undergraduate medical students (Hoppmann et al., 2022). This landmark document provides comprehensive guidelines for medical school curricula, outlining specific intended learning outcomes aimed at equipping students with essential ultrasound skills. The curriculum is designed to prepare students for various ultrasound techniques, including POCUS, while integrating fundamental and clinical sciences to enhance physical examination and clinical problem-solving using ultrasound modalities.

The consensus statement offers detailed recommendations on curricular content, covering essential topics such as the basic physics of ultrasound, fundamental principles of ultrasound imaging, components and limitations of ultrasound probes, transducer manipulations, sonographic terminology (including ultrasound modes, views, and tissue characteristics), image optimisation techniques, and identification of ultrasound artefacts. Additionally, the document proposes a structured approach to familiarising students with specific ultrasound views, anatomical structures, and pathological findings, categorising recommendations on a three-point scale (not recommended, recommended, strongly recommended).

However, while providing invaluable insights into curricular content, the consensus falls short in addressing key logistical considerations such as the timing, location, and implementation strategies for integrating ultrasound teaching into existing medical school curricula.

9.2. Advancing ultrasound education in medical schools: pioneering integrated curricula

The University of South Carolina's pioneering work in integrating ultrasound education into medical school curricula, as documented in their 2011 publication (Hoppmann et al., 2011), marked a significant milestone in medical education. Over the course of four years, ultrasound was seamlessly woven into various aspects of the program, serving as a valuable tool for both learning and clinical practice.

In the first two years, ultrasound served as a fundamental teaching tool for anatomy and physiology, with dedicated sessions focusing on ultrasound physics and knobology. Students engaged in hands-on practice sessions where they learned to perform scans of vital organs such as the heart, neck (including carotid artery, jugular vein, and thyroid gland), abdomen (covering liver, gallbladder, kidneys, and spleen), and pelvis (including urinary bladder and ureteric jets), all while reinforcing their understanding of anatomy and physiology. Practical evaluations assessed students' proficiency in organ identification and their ability to apply ultrasound in clinical scenarios.

Moving into the third year, ultrasound became an integral part of clinical rotations, enhancing students' diagnostic skills across various specialties including internal medicine, obstetrics/gynaecology, paediatrics, surgery, and critical care medicine. By incorporating ultrasound into real-world clinical cases, students gained valuable practical experience that complemented their theoretical knowledge.

In the fourth year, students were offered elective opportunities to further hone their ultrasound skills, with options ranging from emergency medicine ultrasound rotations to participation in ultrasound research. Additional courses and hands-on sessions were available to prepare students for internship, ensuring they were well-equipped for their transition into clinical practice.

Building upon this foundation, the University of South Carolina continued to refine its ultrasound curriculum, as evidenced by their 2015 report (Hoppmann et al., 2015). New laboratory sessions were introduced, including musculoskeletal ultrasound in the first year and ultrasound evaluation of the pancreas in the second year, further enriching students' ultrasound training.

Parallel efforts at the Ohio State University College of Medicine, detailed in a 2013 publication (Bahner & Royall, 2013), mirrored the integrated approach taken by the University of South Carolina. Spread across all four years of medical school, ultrasound education was comprehensive and immersive, with an emphasis on hands-on learning. Expanded musculoskeletal ultrasound programs in the first year and elective modules supplemented by additional hands-on sessions underscored the commitment to providing students with robust ultrasound training.

Both institutions prioritised practical experience, requiring students to document ultrasound images and videos across various protocols, ensuring proficiency in a wide range of ultrasound examinations. These initiatives reflect a growing recognition of the pivotal role ultrasound plays in modern medical practice, highlighting the importance of comprehensive ultrasound education in medical school curricula.

9.3. Enhancing medical education through preclinical and clinical ultrasound integration

One group has proposed the integration of ultrasound into various aspects of medical education, spanning from preclinical to clinical courses, with an emphasis on its utility as a problem-solving tool in disease diagnosis (Celebi, et al., 2019). Extending beyond traditional applications, ultrasound has been evaluated as a teaching tool in diverse subjects such as anatomy (Patten, 2015), neck and vascular anatomy (Brown et al., 2012), musculoskeletal anatomy (Swamy & Searle, 2012), cardiac anatomy and physiology (Hammoudi et al., 2013; Bell et al., 2015), and physical examination skills for both adult (Dinh et al., 2015) and paediatric (Camilo et al., 2021) patients.

Integrating ultrasound into medical education proves beneficial for teaching physical examination skills, allowing students to confirm findings such as thyroid gland location and size during neck inspection, liver size and location during abdominal palpation, and the presence of pleural effusion and resonance of normal lung during thoracic auscultation (Hoppmann et al., 2022). This underscores the significance of incorporating ultrasound training throughout the preclinical and clinical years of medical school.

9.4. Ultrasound education: diverse teaching modalities

At the University of South Carolina Medical School, a range of teaching modalities were employed to foster comprehensive ultrasound education (Hoppmann et al., 2011). Lectures and demonstrations primarily focused on ultrasound physics and scanning techniques, optimising the utilisation of traditional formats. This strategic allocation of resources allowed ample time for practical, hands-on experience during laboratory sessions. These sessions, conducted in smaller groups comprising four to five students, facilitated direct interaction with standardised patients using allocated ultrasound machines, ensuring personalised learning experiences. Moreover, students benefited from open laboratory sessions held once to twice weekly, offering opportunities to practice scanning techniques on each other.

In parallel, the curriculum at the University of South Carolina Medical School embraced modern educational tools and resources. Online teaching materials, including learning modules and an ultrasound image review portal, were readily accessible to students throughout their program, augmenting their learning journey.

Contemporary research has explored innovative teaching methods to complement traditional lectures in ultrasound education. Studies have demonstrated the efficacy of self-teaching through e-learning software combined with self-practice for cardiac ultrasound examinations, yielding results comparable to traditional instruction (Fuchs et al., 2018). Peer teaching has emerged as a promising alternative for imparting ultrasound skills, with peer-led sessions proving effective for teaching cardiac (Ben-Sasson et al., 2019) and abdominal ultrasound (Eimer et al., 2020) techniques to students. Notably, student-led sessions in abdominal ultrasound technique instruction, compared to instruction by staff sonographers, have shown equivalent efficacy in student learning outcomes (Celebi et al., 2012; Celebi et al., 2019).

Moreover, studies have investigated novel approaches such as competition events and computer-based teaching with social media integration, offering engaging platforms to reinforce ultrasound concepts and FAST protocols (Bahner, Adkins, et al., 2012; Bahner, Jasne, et al., 2012; Florescu et al., 2015). Webinars combined with hands-on practical sessions have also proven effective in enhancing ultrasound education, providing interactive learning experiences tailored to the needs of modern medical learners (Florescu et al., 2015).

9.5. Ultrasound assessment

Enhancing assessment methods: Objective Structured Clinical Examinations (OSCE) at the University of South Carolina Medical School

The University of South Carolina Medical School employed objective structured clinical examinations (OSCE) to evaluate students during their first two years of study (Hoppmann et al., 2011). These OSCEs were tailored to reflect the content covered in ultrasound teaching during the preceding semester, ensuring alignment with the curriculum. Ultrasound-related questions were integrated into written course examinations, supplemented by practical assessments. During practical examinations, students were allotted a specific time frame to perform designated ultrasound scans under the supervision of faculty members. Their proficiency in operating ultrasound machines, capturing predetermined anatomical structures, and accurately identifying these structures was evaluated.

In addition to OSCEs, various other assessment methods were employed, including MCQ on ultrasound and image interpretations during practical sessions held in conjunction with anatomy classes.

Transitioning into the third year, OSCEs evolved into case-based assessments conducted at the culmination of clinical rotations. These assessments evaluated students' ability to perform ultrasounds, detect abnormal findings, and correlate ultrasound results with patient history and physical examination findings. For instance, in internal medicine rotations, students encountered a patient with a history of thyroid symptoms and were tasked with scanning the thyroid gland to identify and measure a cyst. Similarly, in surgery rotations, students performed FAST scans on trauma patients to assess for fluid accumulation in the chest, abdomen, and pelvis. Obstetrics/gynaecology rotations presented scenarios such as a patient with vaginal bleeding at 27 weeks of pregnancy, requiring students to conduct obstetrical ultrasound examinations to determine foetal number, heart rate, placental location, and foetal orientation.

Subsequent innovations: implementation of online ultrasound image review portal

Building upon these assessment methods, the University of South Carolina Medical School introduced an online ultrasound image review portal (Hoppmann et al., 2015). During laboratory sessions in the first two years, students were tasked with capturing labelled ultrasound images and submitting them to the portal. Faculty members then evaluated these images for quality, focusing on factors such as focus, depth, gain, and accurate labelling, providing constructive feedback to students.

Furthermore, a "Gate OSCE" was introduced in the third year to gauge students' ultrasound proficiency as they progressed to the fourth year. This assessment required students to perform specific cardiac views to estimate heart function and volume status and record high-quality images on standardised patients. Additionally, students reviewed ultrasound videos related to the same topics to further assess their understanding and competency.

9.6. Student feedback and perceptions of integrated ultrasound curriculum

At the University of South Carolina Medical School, the newly integrated curriculum received overwhelmingly positive feedback from students, as documented by Hoppmann et al. (2011). A significant majority of students expressed appreciation for the use of ultrasound in learning anatomy and physiology, with 81.2% and 69.8% respectively, endorsing its benefits. Practical hands-on sessions and open laboratory opportunities were particularly well-received. Nearly three-quarters of students indicated a desire for further integration of ultrasound into the curriculum. These sentiments were echoed in a comprehensive review of their 9-year experience (Hoppmann et al., 2015).

Similar commendations emerged from students enrolled in medical programs featuring integrated ultrasound curricula or dedicated ultrasound teaching studies. Across various studies (Brown et al., 2012; Dickerson et al., 2017; Ang et al., 2018), students consistently lauded hands-on practical sessions and small-group teaching methods. They expressed a belief that ultrasound-based instruction enriched their understanding of anatomy and enhanced their proficiency in performing POCUS. Furthermore, students perceived the incorporation of ultrasound training as elevating the quality of their medical education, fostering stronger connections between clinical practice and foundational science, and refining their skills in physical examination techniques (Hoppmann et al., 2015).

9.7. Guidelines for integrating ultrasound into medical school curricula

Four and nine years after the introduction of their integrated ultrasound curriculum, authors from the University of South Carolina also published recommendations for other medical schools interested in integrating ultrasound into their programs (Hoppmann et al., 2011, 2015). They suggest that ultrasound should be introduced early in the curriculum, with opportunities for students to practice beyond scheduled laboratory sessions. Various teaching methods, such as online modules, videos, and open laboratory sessions, should be provided, with a reduction in traditional lectures. This approach allows for self-directed, self-paced study, accommodating individual differences in learning styles. They also recommend a gradual implementation of the curriculum in collaboration with course and clinical rotation directors to ensure seamless integration into existing programs. However, they stress the importance of not overwhelming faculty staff with the creation of a new curriculum, suggesting the use of readily available, high-quality ultrasound educational materials. For instance, the University of South Carolina offers an open-access YouTube channel (Ultrasound at U of SC School of Medicine) as a valuable resource.

10. Summary and aims of the study

Diagnostic ultrasound has become an integral component of small animal veterinary practice, with widespread access to ultrasound equipment and frequent use of both comprehensive abdominal ultrasound and point-of-care ultrasound (POCUS) in first-opinion settings. Surveys of practising veterinarians consistently demonstrate that new graduates are expected to possess basic ultrasound competencies, particularly in organ identification, detection of free fluid, and ultrasound-guided procedures. However, despite the increasing clinical reliance on ultrasound, veterinary education lacks clearly defined, standardised frameworks outlining how ultrasound competence should be taught, assessed, and maintained.

While professional bodies have produced detailed guidelines describing how ultrasound examinations should be performed, there is a notable absence of guidance regarding how these skills should be acquired. In contrast to human medicine—where competency-based ultrasound curricula, minimum examination numbers, structured assessment methods, and national consensus recommendations are well established—veterinary ultrasound education remains heterogeneous, largely opportunistic, and dependent on local resources. This discrepancy is further reflected in the RCVS Day One Competences and the VetGDP, which acknowledge the importance of diagnostic imaging but provide limited specificity regarding expected ultrasound proficiency or structured pathways for skill development.

Competency-based frameworks such as CBVE and the use of Entrustable Professional Activities (EPAs) offer a promising structure for defining and assessing ultrasound competence in veterinary graduates. However, ultrasound-specific EPAs are currently lacking, despite the modality's relevance across multiple specialties of veterinary medicine. Foundational skills—particularly the ability to recognise normal anatomy on ultrasound—underpin all subsequent applications, including lesion detection, interpretation, and clinical decision-making.

Within this context, the present study addresses a clearly defined and necessary component of ultrasound competence: the recognition of normal abdominal organs on ultrasound images and videos by final-year veterinary students. By evaluating students' performance and confidence before and after a diagnostic imaging rotation, and by assessing the impact of supplementary online teaching materials, this work contributes objective data to an area where educational standards remain poorly defined. Although recognition of normal anatomy alone is insufficient for full diagnostic proficiency, it represents an essential prerequisite upon which more advanced ultrasound skills must be built. As such, this study provides evidence to inform curriculum development and highlights the need for more structured, competency-based approaches to ultrasound education in veterinary medicine.

The entire study was performed at the University of Bristol Veterinary School due to a change of institution of the author from the University of Glasgow Veterinary School to Langford Vets Small Animal Referral Hospital, the teaching hospital of the University of Bristol Veterinary School.

CHAPTER TWO: Investigation of online material to teach ultrasound.

1. Introduction

In recent years, the field of veterinary medicine has witnessed significant advancements in diagnostic imaging technologies, with ultrasound emerging as a valuable tool for non-invasive visualisation of internal organs and tissues in animals. As veterinary practice continues to evolve, proficiency in ultrasound has become increasingly important for diagnosing and managing a wide range of medical conditions in companion animals, livestock, and exotic species.

Ultrasound education plays a crucial role in equipping veterinary students with the skills and knowledge necessary to effectively utilise this imaging modality in clinical practice. Traditionally, ultrasound training has been delivered through lectures, hands-on workshops, and supervised clinical rotations. However, with the widespread availability of online resources and the growing demand for flexible learning modalities, there has been a shift towards incorporating online teaching materials into veterinary curricula.

The integration of online teaching materials offers several potential advantages, including accessibility, flexibility, and scalability. By leveraging digital platforms, educators can provide students with on-demand access to interactive tutorials, case studies, and instructional videos, enhancing their understanding of ultrasound principles and techniques. Furthermore, online teaching materials can supplement traditional teaching methods, allowing students to reinforce their learning at their own pace and convenience.

Despite the increasing popularity of online education in veterinary medicine, the efficacy of online teaching materials in improving students' ultrasound proficiency and confidence remains an area of ongoing research. While previous studies have demonstrated the effectiveness of online learning in other domains of veterinary education, such as anatomy and pathology, limited research has been conducted specifically on the use of online teaching materials in ultrasound training.

Therefore, the present study aims to investigate the impact of online teaching materials on final year veterinary students' ability to correctly identify abdominal organs on ultrasound videos and their confidence levels in identifying those organs. By assessing students' performance before and after exposure to online teaching materials, we seek to provide valuable insights into the potential benefits of incorporating digital resources into veterinary ultrasound education.

2. Material and methods

Overall description of the study

This study investigates the impact of online webinars on final-year veterinary students' knowledge and confidence in identifying abdominal structures via ultrasound.

Ethical approval

This prospective study was accredited by the Faculty of Health Sciences Research Ethics Committee of the University of Bristol (2021-8521-8468, 2022-8521-10269, and 2023-8521). All Computed Tomography (CT) images, ultrasound images and videos included in this study are intellectual property of Langford Vets.

Study population

Final year veterinary students at the University of Bristol attend a one-week diagnostic imaging rotation at Langford Vets (LV) Small Animal Referral Hospital in small groups (typically 4 to 5 students). Students are split to cover ultrasound (2x half days for 2021-2022 and 2022-2023 students, 3x half days for 2023-2024 students), radiographs (on clinic, helping to take radiographs on patients; 2x half days for 2021-2022 and 2022-2023 students, 3x half days for 2023-2024 students) and radiology (off clinic time; 4x half days for 2021-2022 and 2022-2023 students, 2x half days for 2023-2024 students). An example of the student rota is presented on Figure 2.1. When on ultrasound, students are on clinic with one imager (imaging resident or imaging specialist clinician), attending ultrasound examinations (abdomen is by far the most frequent; thorax, neck and musculoskeletal system are less frequent) on clinical patients (dogs and cats) presented for investigations of their clinical signs by one of LV departments (Internal Medicine, Oncology, Surgery, First Opinion Small Animal Practice). Students can be with a different or the same imager at each session in a random fashion (but according to the rota of the imaging department).

Group allocation

Students were allocated to the test or control group based on cohort membership rather than individual randomisation. Participants from the 2021–2022 and 2022–2023 cohorts formed the test group, and students from the 2023–2024 cohort constituted the control group. A control cohort was introduced after the initial phase of data collection when the need for non-intervention comparators became apparent.

Student's	Monday		Tuesday		Wednesday		Thursday		Friday	
NAME	am	pm	am	pm	am	pm	am	pm	am	pm
Student 1	Online induction etc	XR	US	XR	US	radiology	XR	US	radiology	Tutorial 3pm
Student 2	Online induction etc	US	XR	US	radiology	XR	radiology	XR	US	Tutorial 3pm
Student 3	Online induction etc	radiology	US	XR	US	XR	US	radiology	XR	Tutorial 3pm
Student 4	Online induction etc	XR	radiology	US	XR	US	XR	US	radiology	Tutorial 3pm
Student 5	Online induction etc	US	XR	radiology	XR	US	US	XR	radiology	Tutorial 3pm

Figure 2.1. Example of the rota of the final year veterinary students during the diagnostic imaging rotation week at the University of Bristol. XR: radiography, US: ultrasound.

2.1. Description of the timeline of the study

A description of the timeline of the study is presented in Figure 2.2.

2.1.1. First contact

Final year students starting their clinical rotation in diagnostic imaging received an email (Appendix 1) on the Friday before or on the Monday of the imaging rotation with a copy of the Consent form (Appendix 2) and Participant Information Sheet (Appendix 3) explaining the purpose of the study.

Clarification of study aims compared to Participant Information Sheet:

At the time of participant recruitment and consent, the study was presented to students as an evaluation of the usefulness of targeted teaching in sonographic anatomy, using pancreas identification as a representative learning objective. However, the ultrasound cine loops used for assessment included multiple abdominal organs, and students were required to identify a range of normal anatomical structures (see below for details). Following data collection, the study aims were refined to more accurately reflect the scope of the assessment and the outcomes measured, namely overall abdominal organ recognition and student confidence. This refinement did not alter the study design, educational intervention, data collection procedures, or participant experience and remained within the scope of the original ethical approval.

2.1.2. Start of the Diagnostic Imaging rotation - Pre-rotation test

Students who voluntarily enrolled in the study were asked to undertake a quiz to assess their baseline knowledge and confidence in identifying 47 abdominal structures on ultrasound videos (see 2.2. Description of the test ultrasound videos) that were made available on Blackboard, the University of Bristol's online learning environment. Students could play and rewind the same video as much as they needed. Students could review all videos in the order and amount of time they wished. Students had to use the answer sheet (Appendix 4) provided to record their answers and rate their confidence in their identification using a Likert's scale from 1 to 5 (1: not confident to 5: very confident).

2.1.3. Diagnostic Imaging rotation week

2.1.3.1. Online webinars

Test students enrolled in the study were asked to watch 10 online webinars (also available on Blackboard) explaining the sonographic anatomy and landmarks to find all abdominal structures (parenchymal organs such as liver and spleen but also lymph nodes and large blood vessels). A description of the teaching videos can be found below (see 2.3. Description of the online webinars).

Control students did not have access to that additional online training at the time of their imaging rotation. However, they were free to use any material they felt needed during their rotation. The possible material they used was not recorded.

2.1.3.2. Ultrasound practical

During their imaging rotation, students have a 90-minutes ultrasound practical with a clinical demonstrator (from the teaching team of the University of Bristol) using a healthy teaching dog, typically on Tuesdays at 2pm (this can vary slightly depending on the clinical demonstrator's diary).

The intended learning outcomes of that practical are:

- to list the basic ultrasound controls (time gain compensation, depth, focus, overall gain, freeze),
- to know how to optimise an ultrasound image,
- to correctly hold the probe and perform probe movements (motor skills),
- to have a systematic approach to assess the abdominal cavity and examine each abdominal organ,
- and to identify the layers of the intestinal wall on an image.

During the practical, the clinical demonstrator introduces students to the basic ultrasound controls, and the different types of ultrasound probe. Students are taught how to correctly hold the probe and the range of movements they can used to assess one structure. Then, using a non-clipped teaching dog (spirit is used instead of clipping) held in right lateral recumbency, each student is asked to find one abdominal organ (liver, spleen, left kidney or urinary bladder). If time and teaching dog permit, students can attempt to find more than one of the listed abdominal organs.

The ultrasound practical is performed using an available ultrasound machine. An ACUSON S2000 ultrasound machine with linear transducers (14L5) (Siemens Healthineers, Germany) were typically available from 2021 to mid 2023 and a Sonoscape E1V ultrasound machine with microconvex (C613) and linear (L741) transducers (Sonoscape Medical Corp, China) were available thereafter (mid 2023-2024).

2.1.3.3. End of the Diagnostic Imaging rotation – post-rotation test 1

At the end of the imaging rotation, students enrolled in the study were asked to undertake the ultrasound quiz again (same test videos as for the pre-rotation test).

2.1.3.4. Six weeks after Diagnostic Imaging rotation – post-rotation test 2

Six weeks after the imaging rotation, students enrolled in the study were asked to undertake the ultrasound quiz again (same test videos as for the pre-rotation test).

A follow-up session was organised with the enrolled students to release the answers. These sessions were online (Zoom) or in-person.

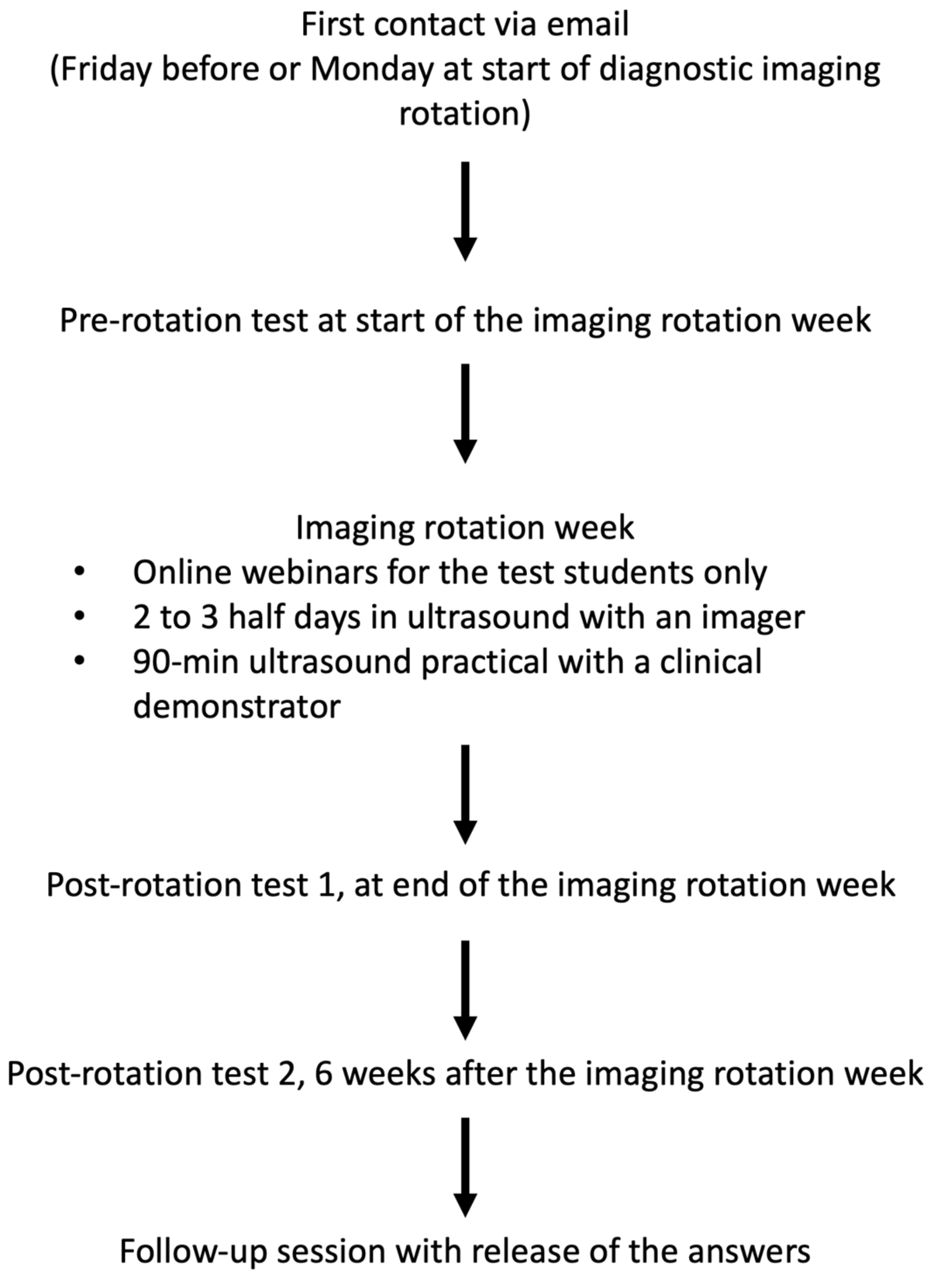


Figure 2.2. Timeline of the study.

2.2. Description of the test ultrasound videos

The test ultrasound videos were specifically designed for this study to assess students' ability to recognise abdominal structures on ultrasound cine loops. Items were created by the lead researcher based on established anatomical landmarks for canine and feline abdominal ultrasonography and the recommended organ coverage in standardised scanning protocols (Seiler et al., 2022; Penninck & d'Anjou, 2025). To ensure face validity, a colleague (Diagnostic Imaging lecturer at the University of Bristol) with experience in small-animal ultrasonography independently reviewed the draft quiz for content relevance, clarity of items, and alignment with expected undergraduate competencies. No formal psychometric validation (such as pilot testing, item analysis, or reliability assessment) was performed prior to deployment.

The ultrasonographic videos were acquired on a young adult, small breed dog presented at LV for evaluation of chronic vomiting in May 2021 (Table 2.1.), using an ultrasound machine ACUSON S3000 and a linear transducer (14L5) (Siemens Healthineers, Germany). Minimal changes were present on ultrasound examination with subtle hyperechoic striations within the mucosa layer of the duodenal wall and mild thickening of the urinary bladder wall likely related to its relatively small size. The dog also presented an incidental congenital duplication of the caudal portion of the caudal vena cava from the level of the renal veins. These findings were deemed suitable to test the students on abdominal organs identification.

Ten videos were recorded and assembled in a PowerPoint presentation which was available on Blackboard. The abdominal structures displayed on these videos were labelled (1, 2, 3, etc…) using iMovie (version 10.3.6, Apple Inc., United States). Each video was focused on a specific area of the abdomen which was indicated using a schematic with the probe location (depicted as a triangle with a large base pointing toward the evaluated abdominal area) and movement (depicted as an arrow pointing toward the position of the transducer at the end of the video) on a ventral view of the abdomen of a dog.

Screenshots of the 47 abdominal structures to identify are presented in full in Appendix 5. Figure 2.3 illustrates an example of the test. Labels of the abdominal organs used in the videos are presented in Appendix 6. In total, the liver, spleen and kidneys were presented four, three and five time respectively. The pancreas and adrenal glands appeared four and two times respectively. The prostate, urinary bladder and gallbladder were seen once each. There were 18 occurrences of a portion of the gastrointestinal tract: stomach (3), pylorus (3), small intestine (6), and large intestine (6). Amongst the small intestinal segments, the duodenum and jejunum could be identified twice each, ileum once and another loop of small intestine could not be confidently distinguished between duodenum and jejunum. Amongst the large intestinal segment, the colon was presented five times and the ileocaecocolic junction once. A blood vessel was illustrated six times: twice each for the aorta, and caudal vena cava, and once each for the portal vein and mesenteric vessels (artery and vein). Two groups of abdominal lymph nodes were presented with medial iliac lymph node (1) and mesenteric lymph node (1). Those abdominal structures were given a number (from organ 1 to organ 47) for the analysis (see Appendix 6).

The test ultrasound video presentation can be consulted on Figshare using the following DOI: 10.6084/m9.figshare.26830840.

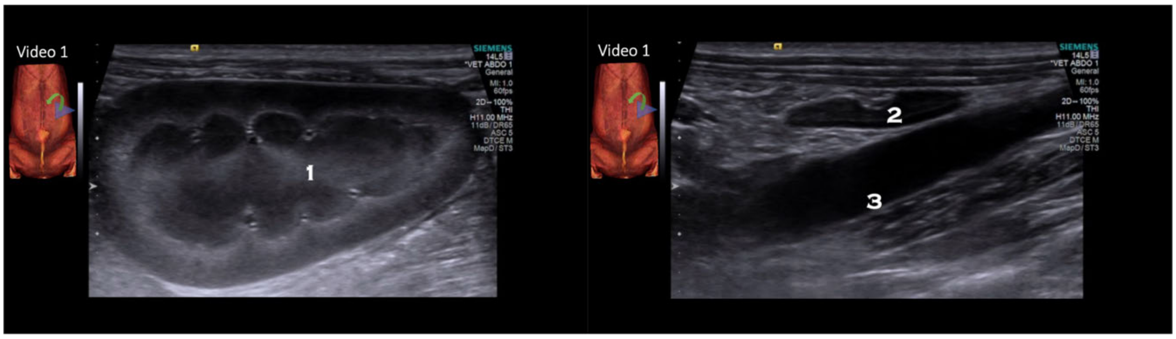


Figure 2.3. Screenshot of the labelled abdominal organs on the ultrasound test video 1. Video 1 shows the left kidney (1), the left adrenal gland (2) and a long axis view of the abdominal aorta (3).

Table 2-1. Information on the dog used to make the test videos.

Dog	Breed	Sex	Age	Clinical signs	Ultrasound findings	Working clinical diagnosis	Images used for
1	Shih tzu cross	ME	2y 2m	Chronic vomiting and haematemesis, low B12	Subtle hyperechoic striations in the mucosa layer of the duodenal wall Incidental split of the caudal vena cava	Chronic enteropathy	Test videos

ME: male entire

2.2.1. Video 1

The transducer marker is in a sagittal plane on the left-hand side of the mid part of the abdomen. An arrow indicates the movement from that location to the midline of the abdomen. On this video, the left kidney is labelled 1, the left adrenal is labelled 2, and the aorta is labelled 3.

2.2.2. Video 2

The transducer marker is in a sagittal plane on the left-hand side of the mid part of the abdomen (similar location as in the video 1 but slightly more cranial). An arrow indicates the movement from that location to the right cranial quadrant of the abdomen. On this video, the spleen is labelled 1, the stomach is labelled 2, the liver is labelled 3, the pylorus is labelled 4, and the gallbladder is labelled 5.

2.2.3. Video 3

The transducer marker is in a sagittal plane on the left-hand side of the mid part of the abdomen (similar location as in the video 1). An arrow indicates the movement from that location to slightly cranial and right to the midline of the abdomen. On this video, the spleen is labelled 1, the left kidney is labelled 2, the stomach is labelled 3, and the left pancreatic lobe is labelled 4.

2.2.4. Video 4

The transducer marker is in a sagittal plane on the left-hand side of the mid part of the abdomen (similar location as in the video 1 but slightly more medial). An arrow indicates the movement from that location to the right cranial quadrant of the abdomen. On this video, the pancreatic body is labelled 1, the spleen is labelled 2, the liver is labelled 3, the portal vein is labelled 4, the pylorus is labelled 5, and the transverse part of the colon is labelled 6.

2.2.5. Video 5

The transducer marker is in a transverse plane in the caudal part of the abdomen. On this video, the aorta is labelled 1, the caudal vena cava is labelled 2, the medial iliac lymph node is labelled 3, and the descending part of the colon is labelled 4.

2.2.6. Video 6

The transducer marker is in a sagittal plane on the left-hand side of the mid part of the abdomen (similar location as in the video 1 but slightly more medial). On this video, the mesenteric lymph node is labelled 1, the mesenteric vessels are labelled 2, and the small intestine is labelled 3.

2.2.7. Video 7

The transducer marker is in a sagittal plane in the central part of the abdomen (similar location as in the video 6 but slightly more medial). An arrow indicates the movement from that location to the right cranial quadrant of the abdomen (similar location as in the video 2 slightly more caudal). On this video, the stomach is labelled 1, the liver is labelled 2, the right pancreatic lobe is labelled 3, the pylorus is labelled 4, the descending part of the duodenum is labelled 5, and the right kidney is labelled 6.

2.2.8. Video 8

The transducer marker is in a sagittal plane in the central caudal part of the abdomen (similar location as in the video 7 but in sagittal plane). An arrow indicates the movement from that location to the very caudal part of the abdomen. On this video, the small intestine (jejunum) is labelled 1, the urinary bladder is labelled 2, the prostate is labelled 3, and the descending part of the colon is labelled 4.

2.2.9. Video 9

The transducer marker is in a sagittal plane on the right-hand side of the mid part of the abdomen (similar location as at the end of the video 7). An arrow indicates the movement from that location to medially in the right mid part of the abdomen. On this video, the descending duodenum is labelled 1, the right kidney is labelled 2, the liver is labelled 3, the right pancreatic lobe is labelled 4, the caudal vena cava is labelled 5, the right adrenal gland is labelled 6 and the colon is labelled 7.

2.2.10. Video 10

The transducer marker is in a sagittal plane on the left-hand side of the mid part of the abdomen (similar location as in the video 9 but slightly more caudal). An arrow indicates the movement from that location to the right mid part of the abdomen (slightly more caudal than in the video 9). On this video, the small intestine (duodenum or jejunum) is labelled 1, the ascending part of the colon is labelled 2, the small intestine (ileum) is labelled 3, the right kidney is labelled 4, and the ileocaecocolic junction is labelled 5.

2.3. Description of the online webinars

Ten webinars and an introduction video were recorded in May 2021 using Zoom and PowerPoint presentations. The mp4 format of the eleven videos were embedded on Blackboard and made available to all students. Each webinar is built in a similar way starting with topographic anatomical reminders using illustration from a textbook of anatomy (Hermanson, de Lahunta, Evans, 2019), and from CT images in dorsal, transverse, and sagittal planes. Then, still ultrasound images and ultrasound videos are used to describe the sonographic appearance of the abdominal organ subject of the presentation. The ultrasonographic images and videos were acquired on young adult, small dogs presented at LV for evaluation of chronic vomiting in April and May 2021. The details of their clinical presentation and brief working clinical diagnosis are presented in Table 2.2. (dogs 2-5).

Table 2-2. Information on the dogs used to make the online training videos (1/2)

Dog	Breed	Sex	Age	Clinical signs	Ultrasound findings	Working clinical diagnosis	Images used for
2	Kerry Blue terrier	ME	2y 5m	Chronic vomiting, diarrhoea, anorexia	Mild thickening of the small intestinal wall with thickening of the muscularis Mild mesenteric lymphadenomegaly Mildly heterogeneous prostate with striations Mild left medial iliac lymphadenomegaly Scant volume of ascites	Chronic enteropathy	Large intestine Adrenals Urinary bladder Lymph nodes
3	Yorkshire terrier	MN	2y 6m	Lifelong history of intermittent vomiting, 2 days of haematemesis	Mild thickening of the muscularis layer of the jejunum Small amount of mobile sludge in the gallbladder Scant volume of ascites	Chronic enteropathy	Stomach Small intestine Large intestine Pancreas Kidneys Adrenals Large vessels Lymph nodes

ME: male entire; MN: male neutered

Table 2.2. Information on the dogs used to make the online training videos (2/2)

Dog	Breed	Sex	Age	Clinical signs	Ultrasound findings	Working clinical diagnosis	Images used for
4	Havanese	MN	4y 3m	6-month history of vomiting, lip smacking and flatulence	Gastric lymph node round and hypoechoic	Chronic enteropathy, suspected GOR	Spleen Stomach Small intestine Large intestine Kidneys Large vessels Lymph nodes
5	Cockerpoo	FN	2y 1m	Lifelong history haematochezia, 6-month history of loss of appetite, grass eating, lip smacking	Abdominal structures within normal limits	Open, large intestinal disease	Liver and GB Stomach Small intestine Large intestine Pancreas Kidneys Adrenals Urinary bladder Large vessels

FN: female neutered; GB: gallbladder; GOR: gastroesophageal reflux; MN: male neutered

2.3.1. Introduction to the course

On the first video, students were introduced to the purpose of the study and the content of the course including reminders of the orientation terminology used. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830624.

2.3.2. Liver, gallbladder

This presentation contains 8 slides. The first three slides are refreshers on the position of the liver and gallbladder within the abdomen. The liver is the most cranial abdominal organ in contact with the diaphragm cranially. On the left, the liver is cranial to the stomach and spleen. On the right, the liver is cranial to the stomach/pylorus, duodenum, and right kidney. The gallbladder is positioned on the right side of the liver. The caudal vena cava and portal vein are also slightly right sided. The position of the liver and gallbladder is then illustrated on ultrasonographic still images and videos. The slides of the liver and gallbladder PowerPoint are presented in Appendix 8. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830711.

2.3.3. Spleen

This presentation contains 11 slides. The first three slides are refreshers on the position of the spleen within the abdomen. The spleen is the most left lateralised abdominal organs. The spleen is caudal to the liver and stomach, medial to the abdominal wall. The spleen is cranial and lateral to the left kidney, stomach and left pancreatic lobe. The spleen is cranial and lateral to the small intestine, descending portion of the colon and urinary bladder. The position of the spleen is then illustrated on ultrasonographic still images and videos. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830780.

2.3.4. Gastrointestinal tract: stomach and small intestine

This presentation contains 13 slides. The first four slides are refreshers on the position of the stomach and small intestine within the abdomen. The fundus of the stomach is on the left-hand side of the abdomen, caudal to the liver and medial to the spleen. The gastric body is on the left and at the midline of the abdomen, caudal to the liver, medial to the spleen, and cranial to the left pancreatic lobe and transverse portion of the colon. The pyloric antrum and pylorus are on the right-hand side of the abdomen, caudal to the liver and gallbladder, cranial to the body and right pancreatic lobe, and ventral to the portal vein. The descending part of the duodenum is medial and along the right abdominal wall, caudal to the liver, ventral to the right kidney, and ventral or ventrolateral to the right pancreatic lobe. The jejunum is positioned in the middle of the peritoneal cavity and typically slightly right sided. The ileum is usually traced from the ileocaecocolic junction. The position of the stomach and small intestine is then illustrated on ultrasonographic still images and videos. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830783.

2.3.5. Gastrointestinal tract: large intestine

This presentation contains 11 slides. The first two slides are refreshers on the position of the large intestine within the abdomen. The ileocaecocolic junction is in the middle of the peritoneal cavity and slightly right lateralised. The ascending part of the colon is medial to the descending part of the duodenum and right pancreatic lobe. The transverse portion of the colon is caudal to the body and left pancreatic lobe and gastric body, and cranial to the small intestine. The descending part of the colon is medial to the spleen, lateral to the small intestine, dorsal to the urinary bladder and ventral to the aorta and caudal vena cava. The position of the large intestine is then illustrated on ultrasonographic still images and videos. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830789.

2.3.6. Pancreas

This presentation contains 16 slides. The first two slides are refreshers on the position of the pancreas within the abdomen. The left pancreatic lobe extends along the gastric greater curvature, caudal to the stomach, medial to the spleen, and cranial to the left kidney and transverse part of the colon. The pancreatic body is caudal to the pyloroduodenal angle and ventral to the portal vein. The right pancreatic lobe extends along the descending part of the duodenum. The pancreaticoduodenal vein runs in the central part of the right pancreatic lobe and can be seen parallel to the descending part of the duodenum. The right pancreatic lobe is medial or dorsomedial to the descending part of the duodenum, and medial to the right kidney. The position of the pancreas is then illustrated on ultrasonographic still images and videos. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830792.

2.3.7. Kidneys

This presentation contains 9 slides. The first two slides are refreshers on the position of the kidneys within the abdomen. Both kidneys are in the retroperitoneum, dorsally in the abdomen. The left kidney is dorsal to the descending part of the colon, medial to the spleen, and caudal to the stomach and left pancreatic lobe. The right kidney is dorsomedial to the descending part of the duodenum, and caudal to the caudate process of the caudate lobe of the liver. The position of the kidneys is then illustrated on ultrasonographic still images and videos. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830795.

2.3.8. Adrenals

This presentation contains 9 slides. The first two slides are refreshers on the position of the adrenal glands within the abdomen. Both adrenal glands are in the retroperitoneum, dorsally in the abdomen. The left adrenal gland is along the left lateral aspect of the aorta, medial to the left kidney and cranial to the left renal artery. The right adrenal gland is in close contact with the right lateral aspect of the caudal vena cava, medial to the right kidney and cranial to the right renal vein. The position of the adrenal glands is then illustrated on ultrasonographic still images and videos. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830807.

2.3.9. Urinary bladder

This presentation contains 7 slides. The first two slides are refreshers on the position of the urinary bladder within the abdomen. The urinary bladder is in the central part of the caudal aspect of the peritoneal cavity, ventral to the descending part of the colon, dorsal to the abdominal wall, and caudal to the small intestine. The position of the urinary bladder is then illustrated on ultrasonographic still images and videos. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830810.

2.3.10. Large abdominal vessels

This presentation contains 17 slides. The first five slides are refreshers on the position of the aorta, caudal vena cava and portal vein within the abdomen. The aorta is in the midline of the retroperitoneum, ventral to the vertebral column, dorsal to the caudal vena cava cranially and ventral to the caudal vena cava caudally. The caudal vena cava is slightly right sided cranially within the abdomen and then have a more sagittal position caudally. The caudal vena cava is ventral to the aorta cranially and dorsal to the aorta caudally. The portal vein is in the middle of the peritoneal cavity, running to the right of the liver at the porta hepatis. The portal vein is dorsal to the transverse part of the colon and left pancreatic lobe and pyloric antrum. The position of the mentioned large abdominal vessels is then illustrated on ultrasonographic still images and videos. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830813.

2.3.11. Abdominal lymph nodes

This presentation contains 12 slides. The first three slides are refreshers on the position of the mesenteric, ileocaecocolic and medial iliac lymph nodes within the abdomen. The mesenteric lymph nodes (also called jejunal) are positioned along the mesenteric vessels (artery and veins), centrally in the peritoneal cavity. The ileocaecocolic lymph nodes (also called right colic) are along the ileocaecocolic junction, in the middle of the peritoneal cavity and slightly right lateralised. The medial iliac lymph nodes are located along the lateral aspect of the external iliac arteries. The position of the mentioned lymph nodes is then illustrated on ultrasonographic still images and videos. The webinar can be found on Figshare using the following DOI: 10.6084/m9.figshare.26830819.

2.4. Students' background

Enrolled students were asked to complete an information questionnaire on their background (any experience or degree prior to start of Vet School), potential experience in ultrasound examination, and preferred career choice at the time of DI rotation week. Students had to rate their anatomy knowledge and if they held a position of anatomy tutor. The questionnaire is presented in Appendix 8.

2.5. Students' answers

Students used the provided answer sheet to record their answers and rate their confidence (Appendix 4) using a Likert's scale (1-5) from 1 not confident to 5 very confident. Their answer sheet recorded their name and the date they undertook the test. Students were asked to send their answer sheet via email to the lead researcher. If the date was not filled, then the date at which they sent their answer sheet was considered to be the date at which they undertook the test. Students answering the pre-rotation test before the rotation week (for example over the weekend prior to the imaging rotation), on the Monday or the Tuesday of the imaging rotation week were included in the study. The results from students who answered the pre-rotation test later during that week (for example on the Wednesday, Thursday, or Friday) or after the imaging rotation week were excluded from the analysis. For those students, the results from their post-rotation tests were included as long as they do not meet the exclusion criteria for the post-rotation test 1.

Students answering the post-rotation test 1 on the Thursday or on the Friday or later after the imaging rotation week were included in the study. The results from students who answered the post-rotation test 1 prior to the imaging week, or on the Monday, Tuesday or Wednesday of the imaging rotation week were excluded from the analysis. For those students, the results from their pre-rotation test were included as long as they do not meet the exclusion criteria for the pre-rotation test. All answers to the post-rotation test 2 were included.

Answer sheets were anonymised replacing the student's name by a number (1, 2, 3, etc…). The number of weeks in clinical rotation was recorded for each student.

Students' answers and confidence were compiled in an Excel spreadsheet (Excel, Microsoft 365 Online, Microsoft Corporation, United States). The first column was dedicated to the student's number; the second column was for the student's group ("1" for test student, "0" for control student); the third column was for the number of the test (pre-rotation test was mentioned as "1", post-rotation test 1 as "2", post-rotation test 2 as "3"). The other columns were used for the students' answers for one organ (from 1 to 47) and their confidence in identifying that structure. If no identification answer was given by the student, then the cell was left blank.

Confidence in organ identification was recorded on a five-point Likert scale (1 = not confident, 5 = very confident). In instances where a student identified an abdominal organ but did not provide an associated confidence rating, the confidence score was recorded as 1. This conservative assumption was made to avoid overestimating confidence while retaining valid identification data. Excluding these responses would have resulted in unnecessary data loss; moreover, missing confidence ratings were rare (70 of approximately 6,500 responses, <0.1%) and therefore unlikely to have a meaningful impact on the overall analysis.

Students were free to write the answer (as opposed to selecting an answer) which led to multiple variations of a correct answer. For example, to identify a portion of “jejunum”, student could write “gastrointestinal tract” (GIT), “GIT”, “small intestine” (SI), or “SI”. The excel spreadsheet can be found on Figshare using the following DOI: 10.6084/m9.figshare.26840239. In that first spreadsheet, the answers were written exactly as the students wrote them. Two different spreadsheets were used to record the answers of the test students and the control students. From these results, histograms of answers’ frequencies were made.

Students’ answers were compared to the expected answers (Appendix 6). To prepare the data for statistical analysis, their answers were then modified using a binary method (1/0) and recorded in another spreadsheet (with the name “data for R analysis”). For example, if the student gave “kidney” for one of the kidneys, then they would be marked as “1” (= correct answer); any other answer would lead to a “0” (= incorrect answer). For the aorta, caudal vena cava or portal vein, the name of any blood vessel would be marked as “1” (= correct answer) to recognise the student’s ability to identify a blood vessel; any other answer would lead to a “0” (= incorrect answer). The detail of that method is presented in Appendix 9. In that new spreadsheet, results from the test students and from the control students were combined. A “group” column was added; the test students were identified with “1”, while the control students were identified with “0”.

2.6. Statistical analysis

A formal a priori power calculation was not conducted. At the time of study design, no previous data were available to estimate expected effect sizes for student performance on abdominal organ identification from ultrasound videos. Therefore, the study used a convenience sample approach, including all eligible students in each participating cohort.

Data were transferred into a commercially free statistical software (R 4.3.1 GUI 1.79 Big Sur Intel build (8238) and R studio, Version 2023.12.1+402, Posit software, USA) for statistical analysis.

To limit the number of comparisons executed, the organs (1-47) were grouped into abdominal systems. Fifteen abdominal systems were used: kidneys, urinary bladder, spleen, liver, gallbladder, stomach, pylorus, small intestine, large intestine, ileocaecocolic junction (ICCJ), pancreas, lymph nodes, adrenal glands, prostate, and blood vessels. The detail of the repartition of the organs into those abdominal systems is presented in Appendix 10.

To investigate the question "is the proportion of correct answer higher overtime?", a McNemar paired sample test was performed. The variable "correct/incorrect answer" (= binary variable) was compared between two time points (pre-rotation test vs post-rotation test 1, or post-rotation test 1 vs post-rotation test 2, or pre-rotation test vs post-rotation test 2) for each abdominal system. Students who did not answer to both tested time points were excluded from the analysis. This was performed for the test students and for the control students. The null hypothesis was that there is no difference in the proportion of correct answer over time.

To evaluate the possible differences in the answers between the test students and the control students, a chi square test or a Fisher's exact test was performed. The number of correct and incorrect answers for one abdominal system was recorded for both groups (test vs control students) and implemented in a contingency table. Mosaic plots representing the proportion of correct and incorrect answers for test and control students were made. A chi-square test to retrieve the expected frequencies was then performed. If one cell in the expected frequencies contingency table was below 5, then a Fisher's exact test was performed; if not, then a chi square test was used. The null hypothesis was that there is no difference between the test students and the control students.

Histograms of the confidence for each abdominal system at each time point were produced for the test students and for the control students. Visual inspection was initially used to check for normality. A Shapiro-Wilk's method was also added to ascertain whether data were normal or not. All of them had a significant p-value (<0.05), therefore rejecting the null hypothesis for normal distribution. Non-parametric tests were then carried out. Confidence was reported as median (minimum; maximum).

To investigate the question "does the confidence increase over time?", a Friedman test was performed. The variable "confidence" (= ordinal variable) was compared in between the related three time points (pre-rotation test, post-rotation test 1 and post-rotation test 2) for each abdominal system. Students who did not answer to all tested time points were excluded from the analysis. If the Friedman test was significant, then a Wilcoxon signed-rank test was performed for identifying which time points were different. This was performed for the test students and for the control students. The null hypothesis was that there is no difference between the confidence at any time point.

To investigate the question "is the confidence higher if the answer is correct at one time point?", a Mann Whitney U test was performed. The variable "confidence" (= ordinal variable) was compared to the type of answer (correct vs incorrect) given at each time point (pre-rotation test, post-rotation test 1 and post-rotation test 2) for each abdominal system. This was performed for the test students and for the control students. The null hypothesis was that there is no correlation between the confidence and the type of answer given at any time point.

Given the multiple comparisons used to evaluate those questions, a Bonferroni correction was conducted to counteract the increase of likelihood of incorrectly rejecting a null hypothesis (increase in type I error). The desired overall alpha level of 0.05 was divided by the number of hypotheses (15*3 in this case). A p-value <0.001 was considered significant.

3. Results

3.1. Students

3.1.1. Test students

Fifty-six students completed the pre-rotation test (28 in 2021-2022 cohort and 28 in 2022-2023 cohort). Four students answered the pre-rotation test before the imaging rotation. Thirty-three students answered the pre-rotation test on the Monday of the imaging rotation, four students answered on the Tuesday. Five students answered on the Wednesday, and ten students answered the pre-rotation test even later during the imaging rotation (6/10) or after the rotation (4/10). The pre-rotation test's answers from those 15 students were excluded from analysis.

Fifty students completed the post-rotation test 1 (24 in 2021-2022 cohort and 26 in 2022-2023 cohort). One student answered the post-rotation test 1 before the imaging rotation, one student on the Monday and one student answered on the Wednesday of the imaging rotation week. The post-rotation test 1 answers from those three students were excluded from analysis. Nine students answered the post-rotation test 1 within the following two weeks post imaging rotation, presumably after having received the reminders to complete the study.

Twenty-eight students completed the post-rotation test 2 (12 in 2021-2022 cohort and 16 in 2022-2023 cohort).

The details of the excluded and included answers can be found in Table 3.1.

Amongst the 56 students, 52 were enrolled in the BVSc program and 4 were enrolled in the BVSc AGEP program. Students who participated in the study had their imaging rotation in the first two third of the year (Figure 3.1.).

3.1.2. Control students

Eleven students completed the pre-rotation test. Two students answered the pre-rotation test before the imaging rotation. Three students answered the pre-rotation test on the Monday of the imaging rotation, three students answered on the Tuesday. One student answered on the Wednesday, and two students answered the pre-rotation test even later during the imaging rotation (1/2) or after the rotation (1/2). The pre-rotation test answers from those three students were excluded from analysis.

Nine students completed the post-rotation test 1, on the Friday of rotation (2/9) or within the following two weeks post imaging rotation, presumably after having received the reminders to complete the study (see Table 3.1. for included and excluded answers). Eight students completed the post-rotation test 2.

Amongst the 11 students, eight were enrolled in the BVSc program and three were enrolled in the BVSc AGEP program. Students who participated in the study had their imaging rotation in the first two third of the year (see Figure 3.1.).

Table 3-1. Summary of the excluded and included answers.

Excluded answers	Weekdays	Student number
Pre-rotation test	Wednesday	1, 2, 21, 36, 45, 61
	Thursday	4, 18, 37, 53
	Friday	25, 47, 62
	Later	29, 43, 46, 55, 63
Post-rotation test 1	Wednesday	12
	Tuesday	
	Monday	13
	Prior	7
Included answers		
Pre-rotation test	Prior	7, 22, 26, 59, 64, 67
	Monday	3, 5, 6, 8, 9, 10, 11, 12, 13, 15, 16, 17, 23, 24, 27, 28, 30, 32, 33, 34, 35, 38, 39, 40, 41, 42, 48, 49, 51, 52, 54, 56, 58, 60, 68, 70
	Tuesday	14, 31, 44, 50, 65, 66, 69
Post-rotation test 1	Thursday	2, 4, 9, 21, 23, 27, 30, 32, 54
	Friday	1, 3, 5, 6, 8, 14, 15, 16, 18, 24, 26, 34, 35, 42, 45, 50, 51, 56, 58, 67, 68
	Later	17, 22, 29, 31, 33, 36, 37, 38, 39, 40, 41, 43, 46, 47, 48, 49, 52, 53, 55, 61, 62, 63, 64, 65, 69, 70

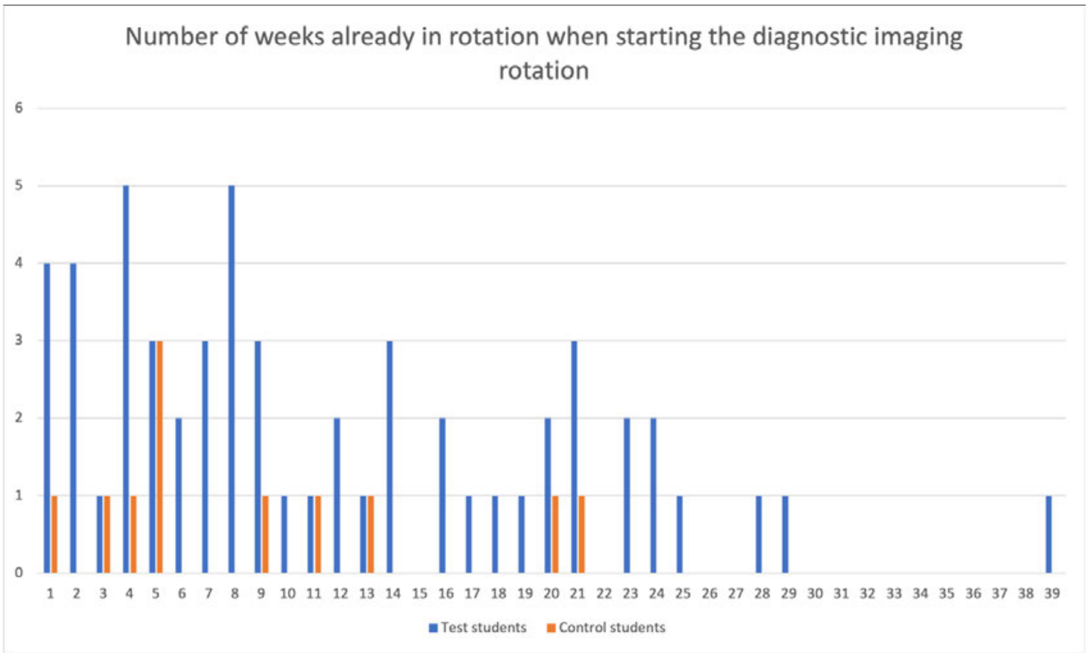


Figure 3.1. Distribution of the students depending on the time of the year for the test students (2021-2022 and 2022-2023 cohorts) and control students (2023-2024 cohort). In X axis, week number already done in rotation (1= first week of rotation). In Y axis, number of students participating. In blue (left-sided bars) are the test students; in orange (right-sided bars) are the control students.

3.2. Students background

Thirty-two test students (57%) and seven control students (64%) answered the information questionnaire. None of the students had been employed as a vet technician before Vet School except for one test student (#43) who was employed for more than five years.

The students had a moderate interest in abdominal ultrasound (Figure 3.2.A).

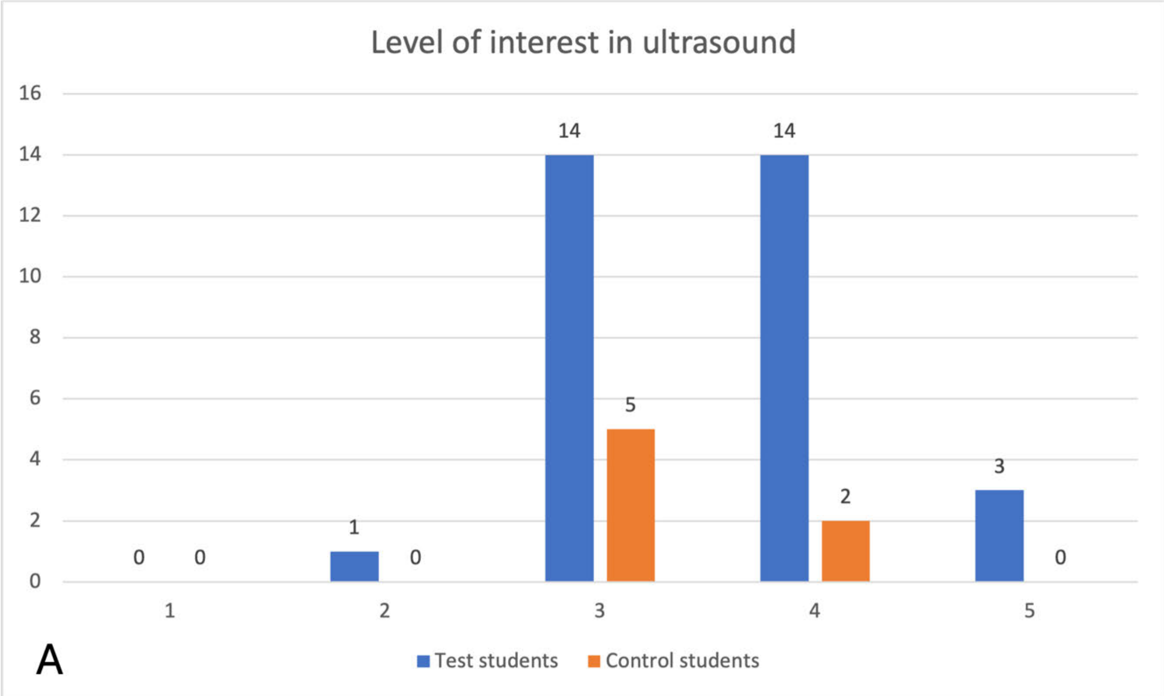
One test student (#7) had undergone an ultrasound training outside of Vet School.

Most test students (91%) and all control students had observed an abdominal ultrasound more than twice before their imaging rotation (Figure 3.2.B).

Fifteen test students (47%) and eight test students (25%) had performed an abdominal ultrasound once or twice respectively before their imaging rotation while the control students had never performed one (43%) or only once (43%) (Figure 3.2.C).

One test student (3%) held a position of anatomy tutor during the anatomy sessions and revision in first and second year. Twenty-five test students (78%) and five control students (74%) rated their knowledge of anatomy as moderate (Figure 3.2.D).

The most common career choice was small animal veterinarian (50% of test students and 71% of control students). The detail of the students' preferred career choice is presented in Figure 3.2.E.



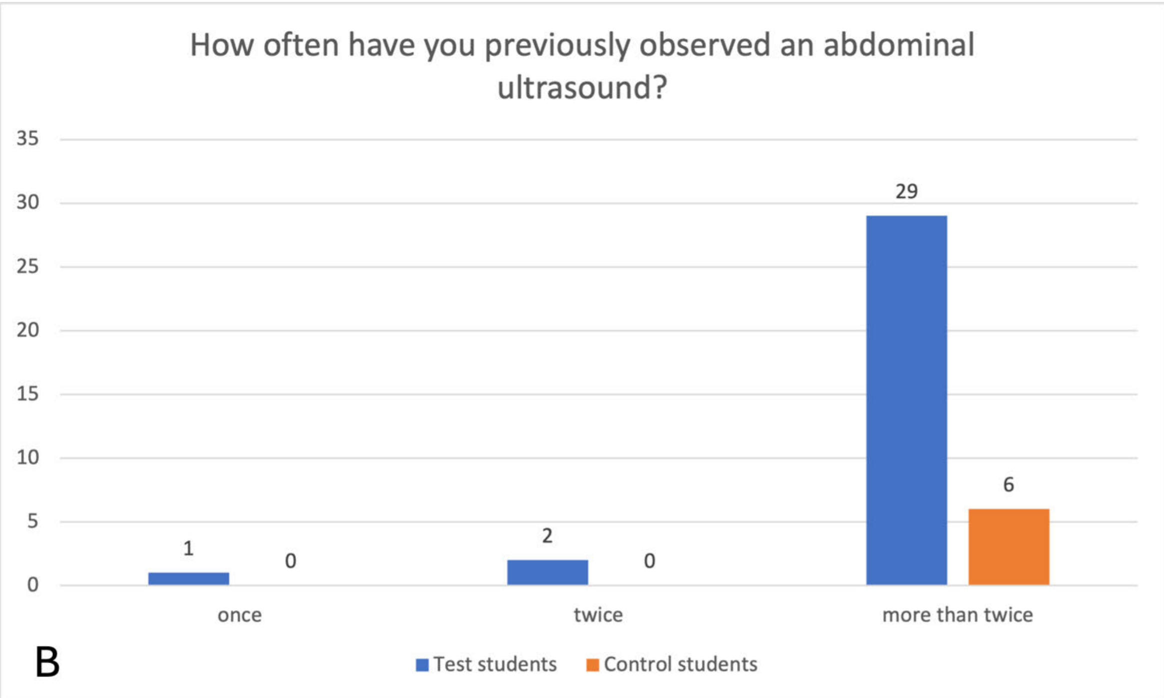
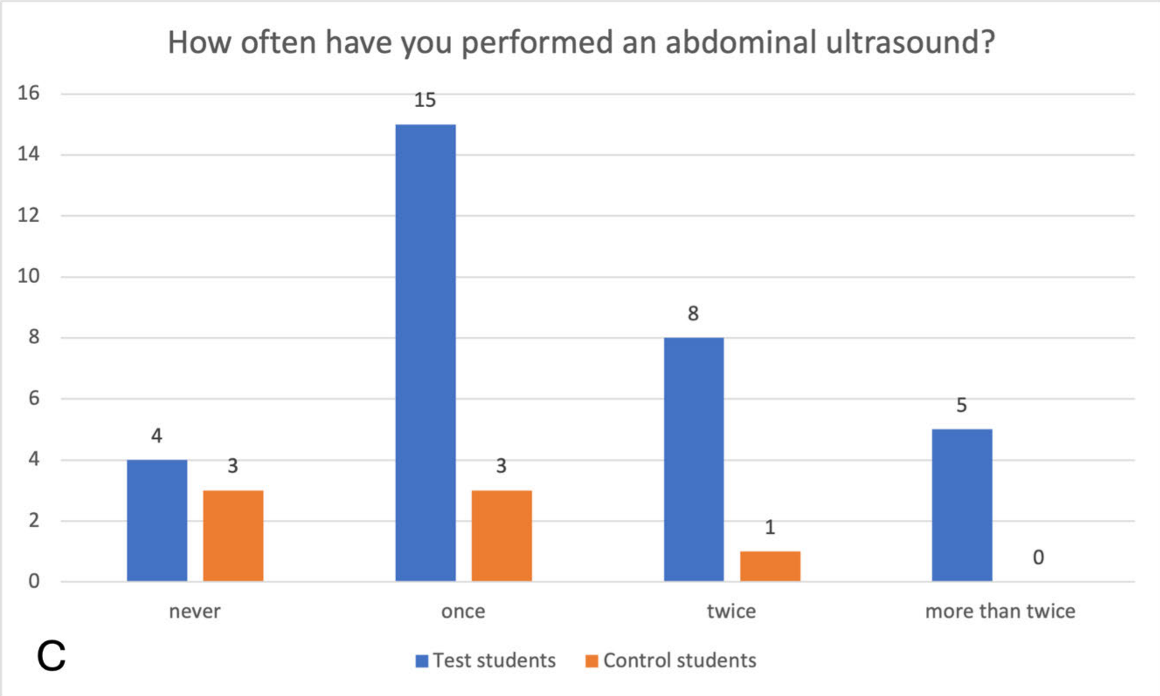


Figure 3.2. Bar charts illustrating the results from the students' background questionnaire (1/3): level of interest in abdominal ultrasound graded by the students on a 1-5 Likert scale (1=no interest, 5=very interested) (A), observation of abdominal ultrasound by the students before diagnostic imaging rotation (B). In blue (left-sided bars) are the test students, in orange (right-sided bars) are the control students. On the X axis, are the categories provided in the questionnaire. On the Y axis, is the number of students (note that the maximum value changes from one bar chart to another). At the top of the bars is the number of students giving a particular answer.



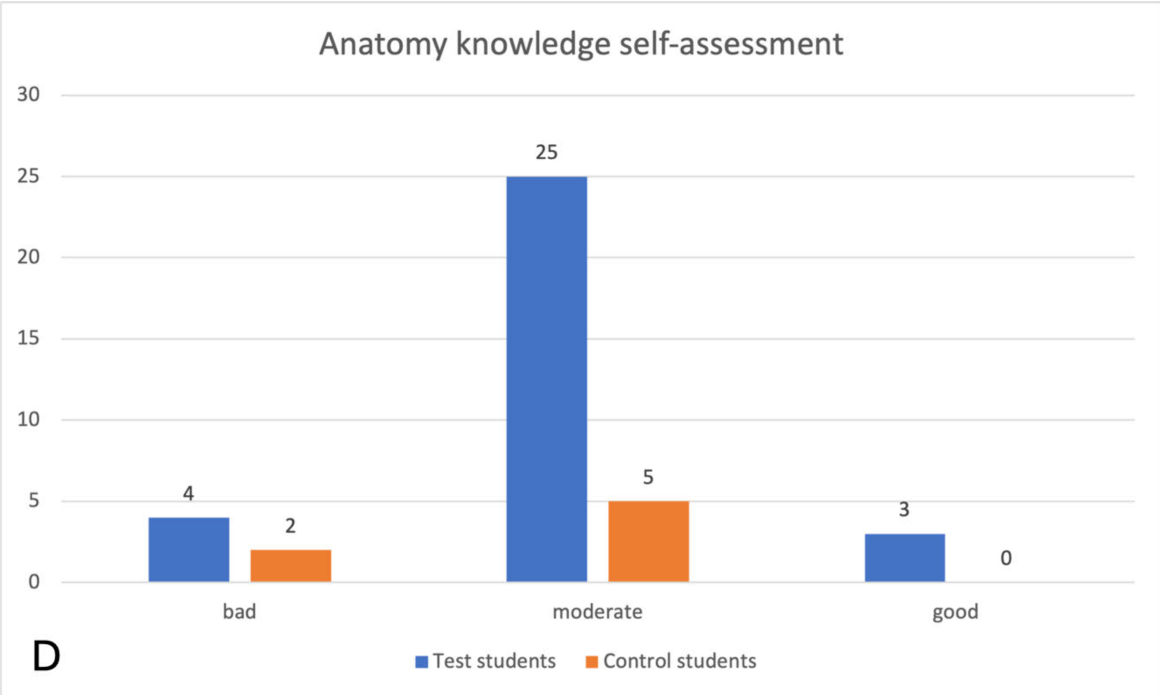


Figure 3.3. Bar charts illustrating the results from the students' background questionnaire (2/3): experience in performing abdominal ultrasound by the students before diagnostic imaging rotation (C), self-assessment of the anatomy knowledge of students prior to the diagnostic imaging rotation (D). In blue (left-sided bars) are the test students, in orange (right-sided bars) are the control students. On the X axis, are the categories provided in the questionnaire. On the Y axis, is the number of students (note that the maximum value changes from one bar chart to another). At the top of the bars, is the number of students giving a particular answer.

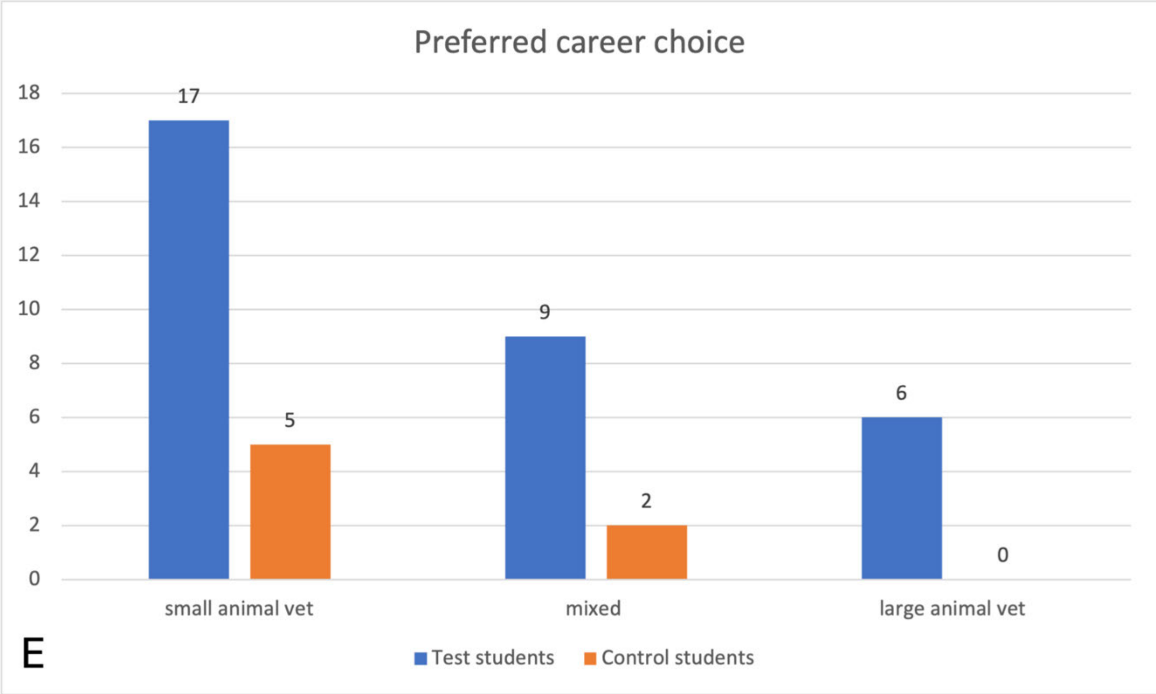


Figure 3.4. Bar charts illustrating the results from the students' background questionnaire (3/3): preferred career choice of the students (E). In blue (left-sided bars) are the test students; in orange (right-sided bars) are the control students. On the X axis, are the categories provided in the questionnaire. On the Y axis, is the number of students (note that the maximum value changes from one bar chart to another). At the top of the bars, is the number of students giving a particular answer.

3.3. Students' answers and confidence

The students' answers are presented by abdominal system. The "baseline knowledge" paragraphs present the results of the pre-rotation tests. The "evolution of knowledge over time" paragraphs present the results of the post-rotation tests 1 and 2. For each system, a mosaic plot with the correct/incorrect answer distribution is presented. Detailed answer distributions are provided in Appendix 11.

In the paragraphs below, the confidence median will be presented adjacent to minimum and maximum numbers as follows: median (minimum-maximum). For each system, a histogram presents the students' confidence. Detailed confidence results are provided in Appendix 12.

Statistical outputs for the students' knowledge and confidence are provided in the Table 3-2 at the end of the results section. All statistical outcomes are presented in Appendices 13.

3.3.1. Kidneys

The kidneys were presented in five instances (organs 1, 10, 31, 37 and 46).

The pre-rotation test was completed by 39 (out of 40), 36, 40, 40 and 29 test students. Forty-seven (out of 47), 46, 47, 47, and 45 test students answered the post-rotation test 1. Twenty-eight (out of 28), 28, 28, 28, and 23 test students answered the post-rotation test 2.

For the control group, eight out of eight students completed the pre-rotation test for all organs except for organ 10, where only seven students responded. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively, for all organs.

Baseline knowledge

Students showed high baseline recognition of typical kidney appearances, with >80% correctly identifying the kidneys in three of the five cine loops (organs 1, 31, 37). Recognition was lower for organ 10 (≈60% correct in both groups), with frequent misclassification as gastrointestinal tract. The most challenging clip was organ 46, with <15% correct responses and frequent confusion with gastrointestinal tract or gallbladder.

Evolution of knowledge over time

Following the rotation, correct identification increased markedly for both groups (Figure 3.3). Test students reached >95% accuracy for organs 1, 31 and 37 after the first post-rotation test and 100% accuracy at the second. Control students showed similar patterns for these organs. Accuracy for organ 10 improved substantially in both groups (>90% in test students and >75% in control students). In contrast, organ 46 remained difficult, with <15% accuracy at all time points for both groups.

Statistical outcomes

There were no significant differences between test and control groups at any time point. Test students demonstrated significant improvement between the pre-rotation and first post-rotation tests, whereas this change was not significant for the control group. Comparisons involving the second post-rotation test could not be performed for some organs due to complete accuracy.

Confidence

Median confidence in kidney identification increased over time in both groups (Figure 3.4). Test students' confidence significantly improved from 4 (1–5) pre-rotation to 5 (1–5) at both post-rotation tests. Control students' confidence improved from a median of 3 (1-5) to 4 (1–5); although the Friedman test indicated an overall time effect, pairwise comparisons were not significant.
In both groups, confidence was consistently higher when answers were correct. Test students reported significantly higher confidence than control students at the second post-rotation test.

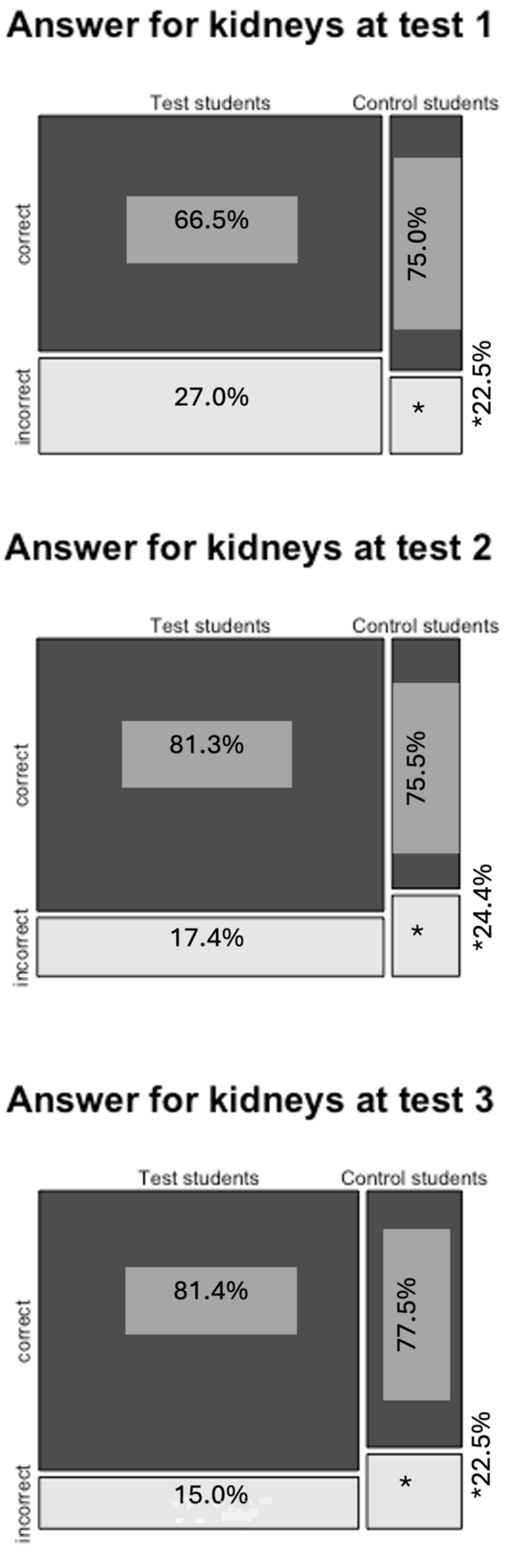


Figure 3.5 Mosaic plots for the kidneys representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

Figure 3.6: Bar charts illustrating the confidence levels for the identification of kidneys of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.2. Urinary bladder

The urinary bladder was presented only once (organ 33). The pre-rotation test was completed by 39 out of 40 test students. Forty-five out of 47 students answered the post-rotation test 1 and 27 out of 28 students answered the post-rotation test 2.

For the control group, eight out of eight students completed the pre-rotation test. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively.

Baseline knowledge

Students demonstrated excellent baseline recognition of the urinary bladder (Figure 3.5). Ninety-five percent of test students and all control students correctly identified organ 33 as the urinary bladder.

Evolution of knowledge over time

Accuracy remained high across subsequent assessments. Among test students, correct responses were 93.6% at post-rotation test 1 and 96.4% at post-rotation test 2. Control students maintained 100% accuracy at both time points.

Statistical outcomes

No significant differences were detected between test and control groups at any time point. Within-group comparisons showed no significant change for test students between the pre-rotation and post-rotation test 1. McNemar testing was not possible for later comparisons in either group due to all responses being correct.

Confidence

Median confidence increased slightly for test students, from 4 (1–5) pre-rotation to 5 (2–5) and 5 (3–5) at the two post-rotation assessments (Figure 3.6). Although the Friedman test indicated an overall time effect, pairwise comparisons were not significant. Confidence did not differ between correct and incorrect responses, and comparisons were not possible at the second post-rotation test because all answers were correct.

Control students also showed high confidence throughout, increasing from 4 (2–5) to 5 (3–5) and 5 (4–5), without significant changes over time. Because all responses were correct at each assessment, confidence could not be analysed by answer correctness.

Confidence did not differ between test and control groups at any time point.

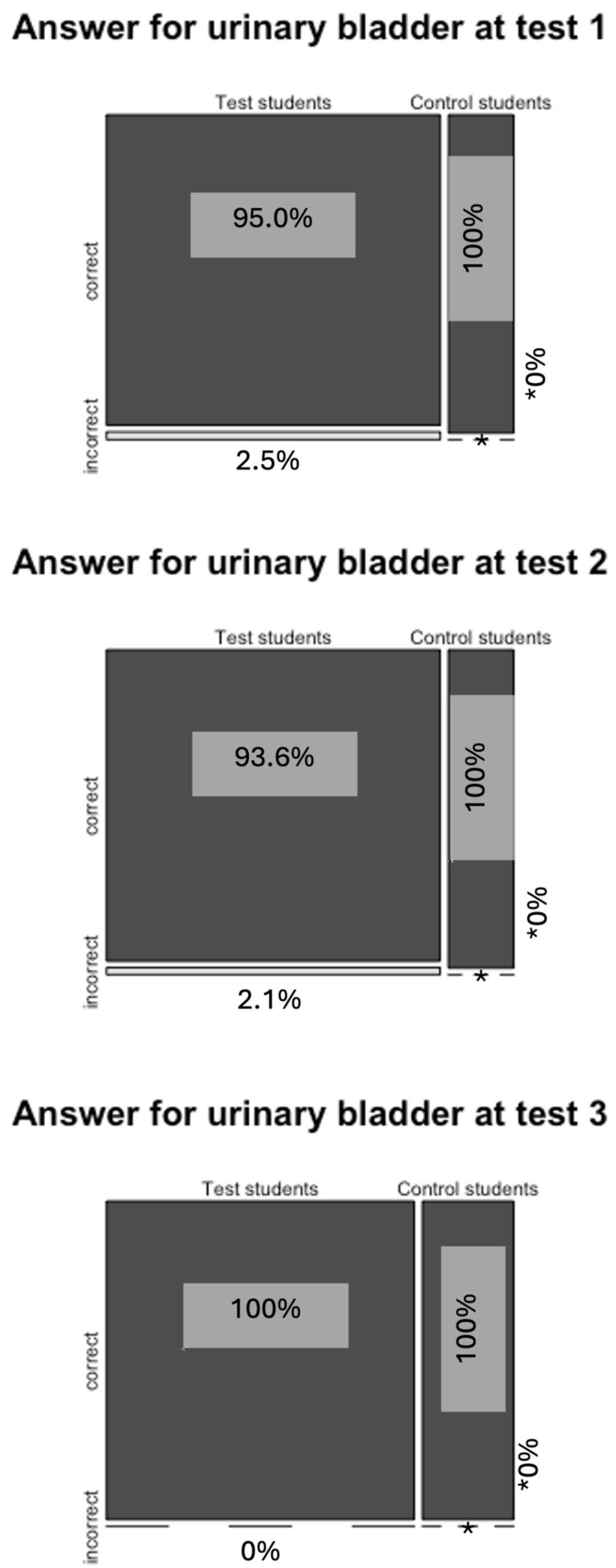


Figure 3.7. Mosaic plots for the urinary bladder representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

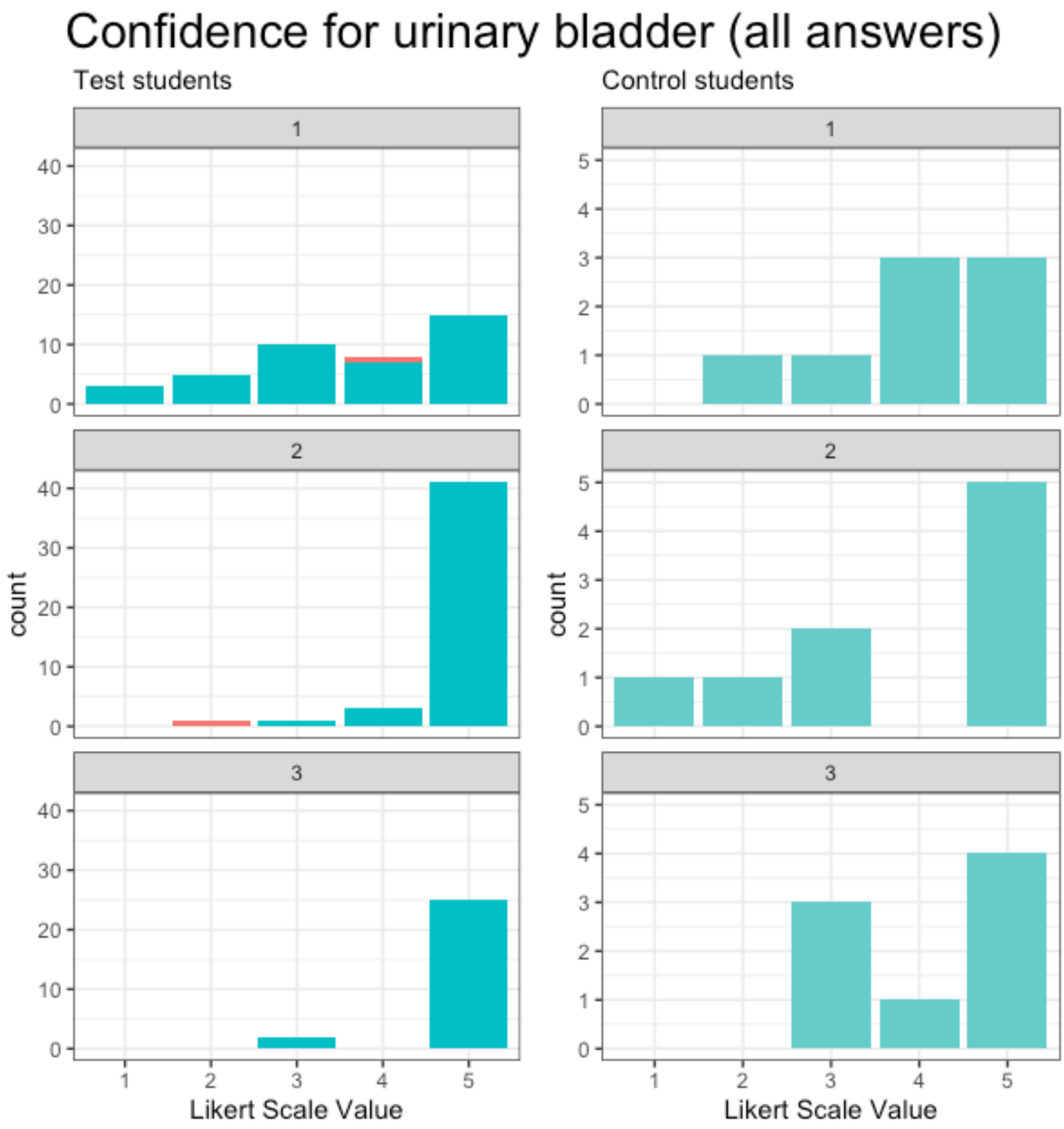


Figure 3.8 Bar charts illustrating the confidence levels for the identification of the urinary bladder of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.3. Spleen

The spleen was presented in three instances (organs 4, 9 and 14). The pre-rotation test was completed by 40 out of 40 test students for organ 4, and 39 test students for organs 9 and 14. All 47 and 28 test students completed the post-rotation tests 1 and 2, respectively.

For the control group, eight out of eight students completed the pre-rotation test. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively, for all organs.

Baseline knowledge

Students demonstrated reasonable baseline recognition of the spleen (Figure 3.7). For organs 9 and 14, over 70% of test and control students responded correctly. For organ 4, test students performed slightly better (77.5%) than control students (62.5%). "Liver" was the most frequent incorrect response across all three clips.

Evolution of knowledge over time

Accuracy increased after the rotation, particularly for test students. More than 95% correctly identified the spleen in organ 9 at both post-rotation assessments, and all test students answered correctly for organs 4 and 14. Control students also improved, with >75% accuracy at post-rotation test 1 and >85% at post-rotation test 2, although "liver" remained a frequent error at the first post-rotation test.

Statistical outcomes

No group differences were detected at baseline or at post-rotation test 2, but test students performed significantly better than control students at post-rotation test 1. McNemar test could not be performed for test students due to the complete accuracy at the post-rotation tests. No significant within-group changes were detected for control students.

Confidence

Median confidence for test students increased from 3 (1–5) pre-rotation to 5 (1–5) and 5 (2–5) at the two post-rotation assessments, with significant improvement over time (Figure 3.8). Confidence did not differ between correct and incorrect answers at any time point, likely due to the low number of incorrect responses post-rotation.

Control students showed median confidence values of 3 (2–5), 5 (1–5), and 4 (1–5) at the three assessments, with no significant change over time. Confidence did not differ between correct and incorrect responses, likely reflecting overlapping confidence ranges among correct and incorrect answers.

Test students were significantly more confident than control students at post-rotation test 2.

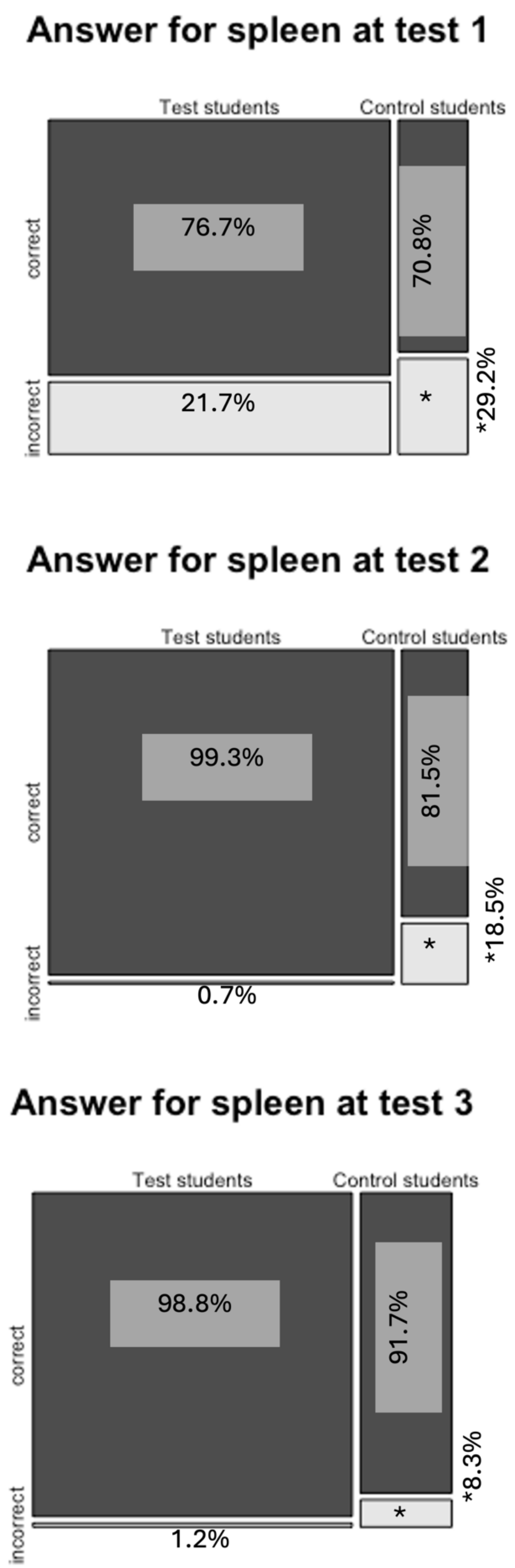


Figure 3.9. Mosaic plots for the spleen representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

Figure 3.10. Bar charts illustrating the confidence levels for the identification of the spleen of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.4. Liver

The liver was presented in four instances (organs 6, 15, 27 and 38). The pre-rotation test was completed by 38, 37, 34, and 37 out of 40 test students. The post-rotation test 1 was completed by 36 out of 47 test students for organs 6, 15 and 27, and by 47 out of 47 test students for organ 38. The post-rotation test 2 was completed by 28 out of 28 test students for organs 6 and 38, and by 28 out of 28 test students for organs 15 and 27.

For the control group, eight out of eight students completed the pre-rotation test for all organs except for the organ 15 where only seven control students answered. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively, for all organs.

Baseline knowledge

Baseline identification of the liver was generally low (Figure 3.9). Fewer than 40% of test students correctly identified organs 6, 15, and 27 as liver; similar results were seen for control students for organs 6 and 15, although 50% correctly identified organ 27. The most frequent incorrect responses were gastrointestinal structures (25–62.5%). In contrast, organ 38 was recognised correctly by approximately 65% of students in both groups.

Evolution of knowledge over time

Correct identification improved after the rotation, particularly among test students. For organs 6 and 38, over 80% of test students answered correctly at post-rotation test 1, and over 75% at test 2. Improvement was more modest for organs 15 and 27 (66–75% at post-rotation assessments). Control students showed smaller gains: for organ 6, correct responses rose from 22.2% to 62.5% across the two post-rotation tests, and for organs 15, 27, and 38, accuracy exceeded 65% at both post-rotation time points.

Statistical outcomes

No significant group differences were found at baseline or the two post-rotation assessments. Test students demonstrated significant improvement between pre-rotation and both post-rotation tests. No significant within-group change was detected for control students.

Confidence

Median confidence increased for test students from 2 (1–5) pre-rotation to 4 (1–5) and 3 (1–5) at post-rotation tests 1 and 2, with significant overall improvement (Figure 3.10). At all three assessments, test students showed higher confidence when their answers were correct.

Control students showed lower initial confidence (median 1 [1–4]) but improved to 3 (1–5) and 2 (1–5) at the two post-rotation tests. Although the Friedman test indicated a time effect, pairwise comparisons were not significant. Confidence did not differ between correct and incorrect answers at any assessment.

There were no significant confidence differences between test and control groups at any time point.

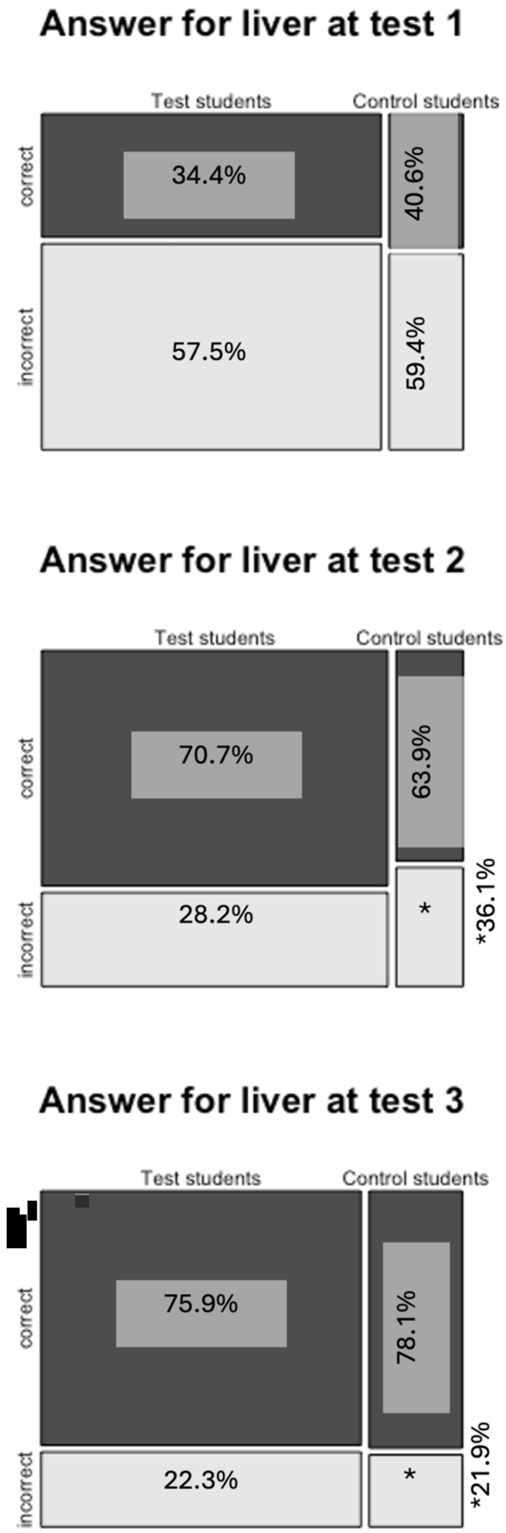


Figure 3.11. Mosaic plots for the liver representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

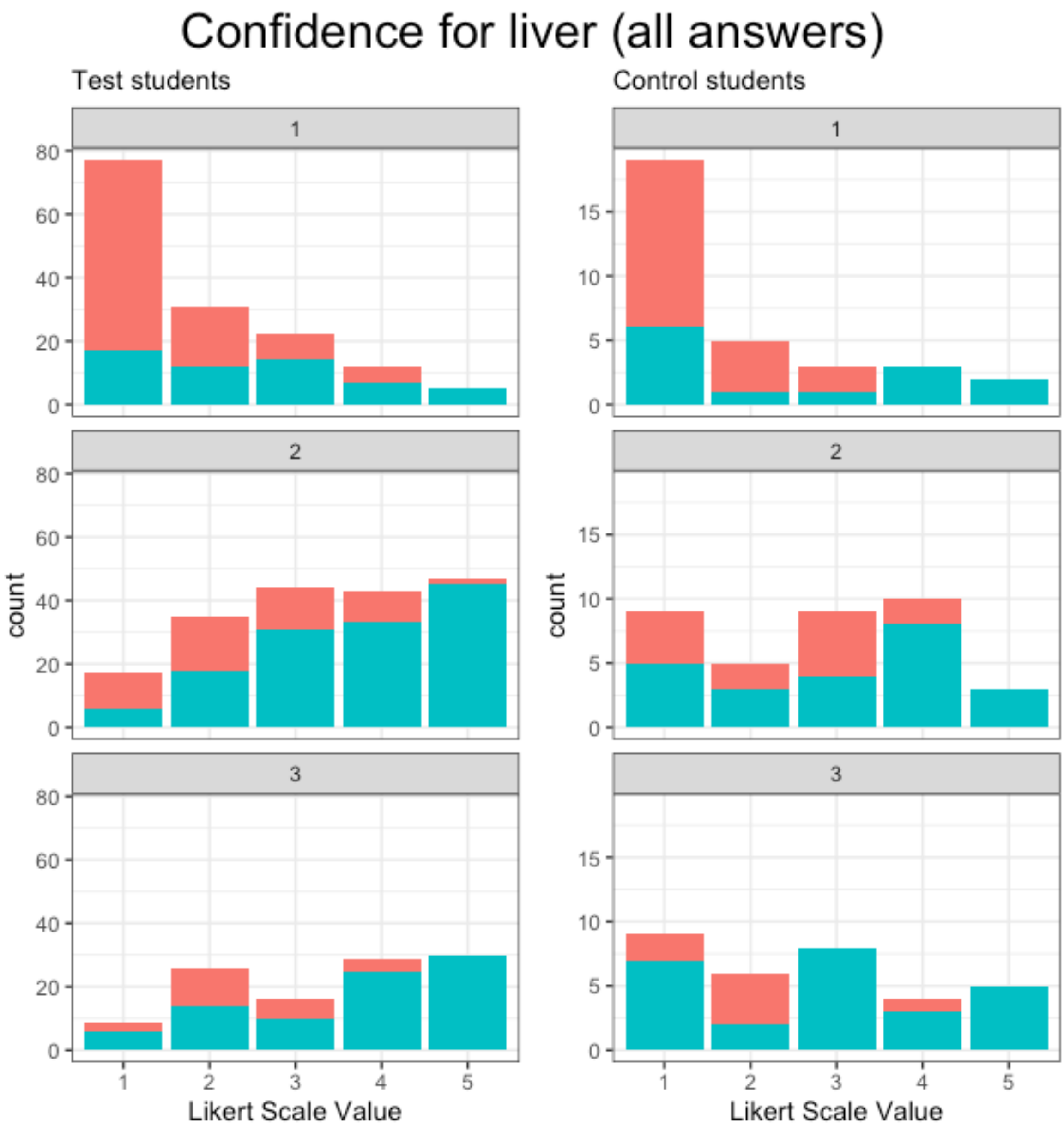


Figure 3.12. Bar charts illustrating the confidence levels for the identification of liver of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.5. Gallbladder

The gallbladder was presented only once (organ 8). The pre-rotation test was completed by 38 out of 40 test students. Forty-six out of 47 students answered the post-rotation test 1 and 28 out of 28 students answered the post-rotation test 2.

For the control group, eight out of eight students completed the pre-rotation test. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively.

Baseline knowledge

Baseline recognition of the gallbladder was moderate (Figure 3.11). Approximately half of both test and control students correctly identified organ 8 as the gallbladder. Common incorrect responses included gastrointestinal structures (25–30%) and “urinary bladder” (10–25%).

Evolution of knowledge over time

Correct identification increased markedly at the first post-rotation test, reaching 91.5% in test students and 77.8% in control students. At the second post-rotation test, accuracy remained high for test students (≈90%) but declined in control students to pre-rotation levels (50%), with frequent misclassification as “stomach” (37.5%) or “urinary bladder” (12.5%).

Statistical outcomes

No significant differences were found between groups at baseline or either post-rotation assessment. Test students showed significant improvement between the pre-rotation and first post-rotation tests, whereas no significant within-group changes were observed for control students.

Confidence

Median confidence increased for test students from 3 (1–5) pre-rotation to 4.5 (3–5) at post-rotation test 1 and 4 (1–5) at test 2 (Figure 3.12). Although the Friedman test indicated a time effect, pairwise comparisons were not significant. Confidence did not differ between correct and incorrect responses at any time point.

Control students reported lower confidence overall, with medians of 2 (1–4), 3 (1–4), and 3 (1–5) across the three assessments. No significant changes over time were detected, and confidence did not differ between correct and incorrect answers.

Confidence did not differ significantly between test and control students at any time point.

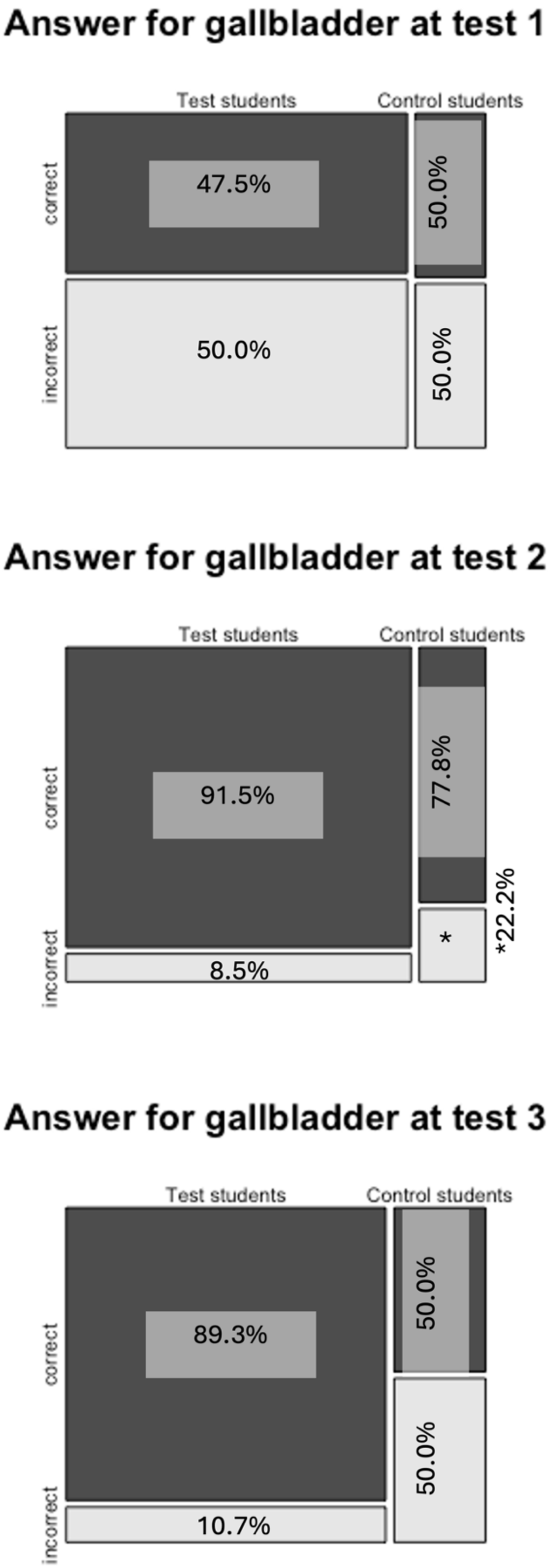


Figure 3.13. Mosaic plots for the gallbladder representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

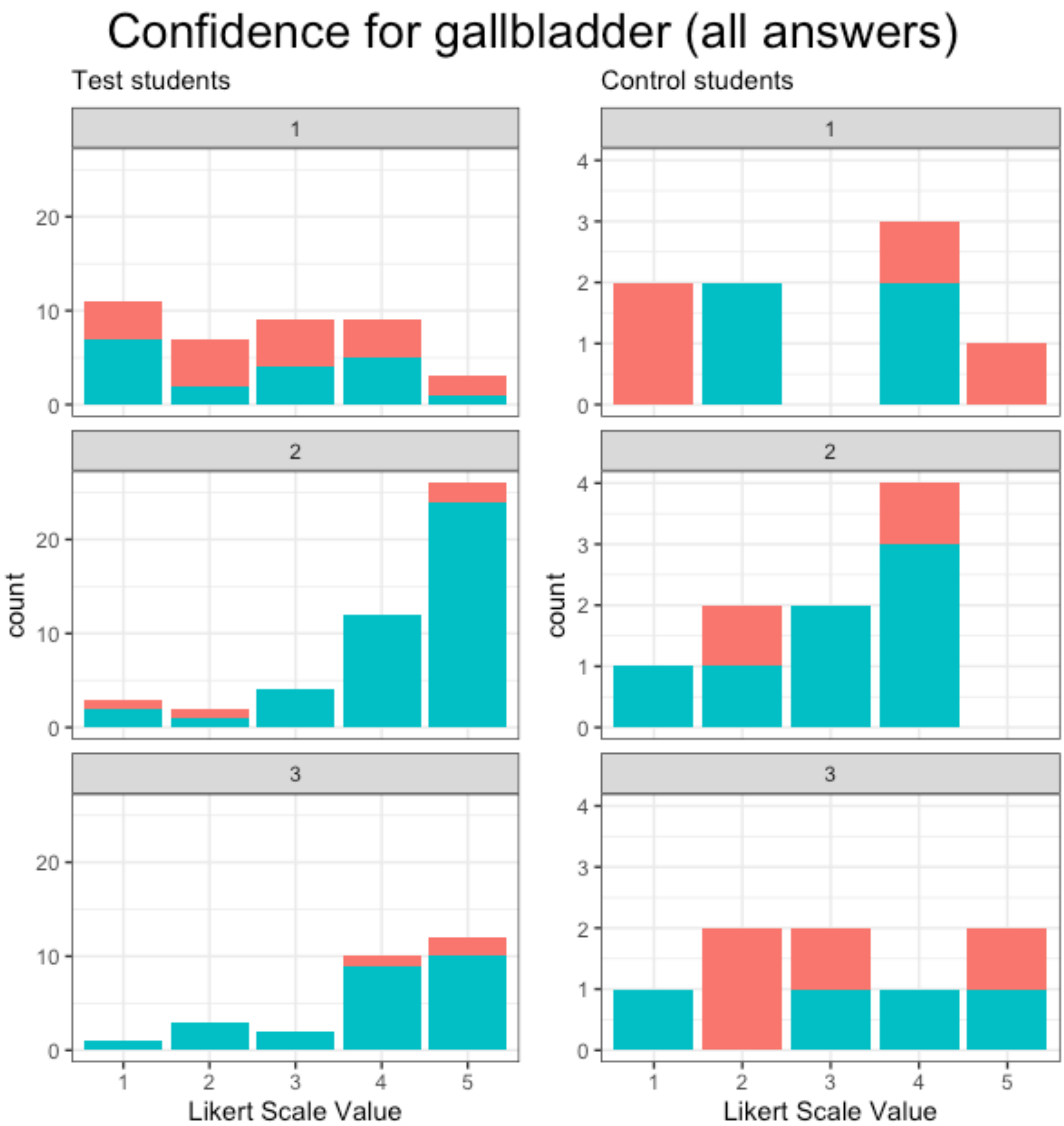


Figure 3.14. Bar charts illustrating the confidence levels for the identification of the gallbladder of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.6. Gastrointestinal tract

3.3.6.1. Stomach

The stomach was presented in three instances (organs 5, 11 and 26). The pre-rotation test was completed by 40, 38, and 39 out of 40 test students. The post-rotation tests were completed by all test students (47 for the post-rotation test 1 and 28 for the post-rotation test 2) for all organs.

For the control group, eight out of eight students completed the pre-rotation test for all organs except for the organ 15 where only seven control students answered. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively, for all organs.

Baseline knowledge

Baseline identification of the stomach varied across the three cine loops (Figure 3.13). Among test students, correct responses were 55% (organ 5), 35% (organ 11), and 45% (organ 26). Control students performed better for organs 5 (62.5%) and 26 (75%), but fewer identified organ 11 correctly (25%). Incorrect answers commonly involved other gastrointestinal structures, particularly small intestine.

Evolution of knowledge over time

Correct identification improved substantially for test students at the first post-rotation test (85.1–93.6% across all three organs), with a slight decline at the second test (71.4–85.7%). Control students exceeded 75% accuracy for organs 5 and 26 at post-rotation test 1 but were less accurate for organ 11 (55.6%). At post-rotation test 2, accuracy decreased slightly for organs 5 and 26 and increased modestly for organ 11 (75%).

Statistical outcomes

No significant differences were detected between test and control groups at any time point. Test students improved significantly between the pre-rotation test and both post-rotation assessments. No significant within-group changes were found for control students.

Confidence

Median confidence for test students increased from 2 (1–5) pre-rotation to 4 (1–5) at both post-rotation assessments, with significant improvement over time (Figure 3.14). Confidence did not differ between correct and incorrect responses at any assessment.

Control students reported similar median confidence at baseline (2 [1–5]) and improved to 4 (1–5) and 3 (1–5) at the two post-rotation tests, although this change was not statistically significant. Confidence did not differ between correct and incorrect answers.

No significant confidence differences were found between test and control students at any time point.

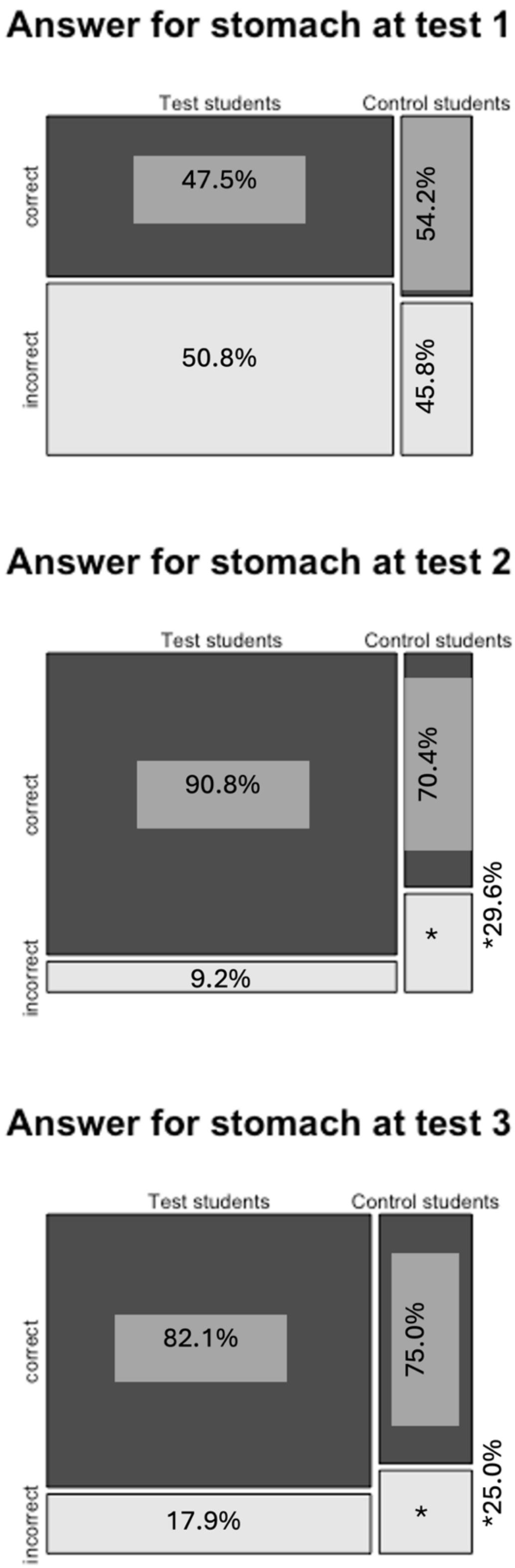


Figure 3.15. Mosaic plots for the stomach representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

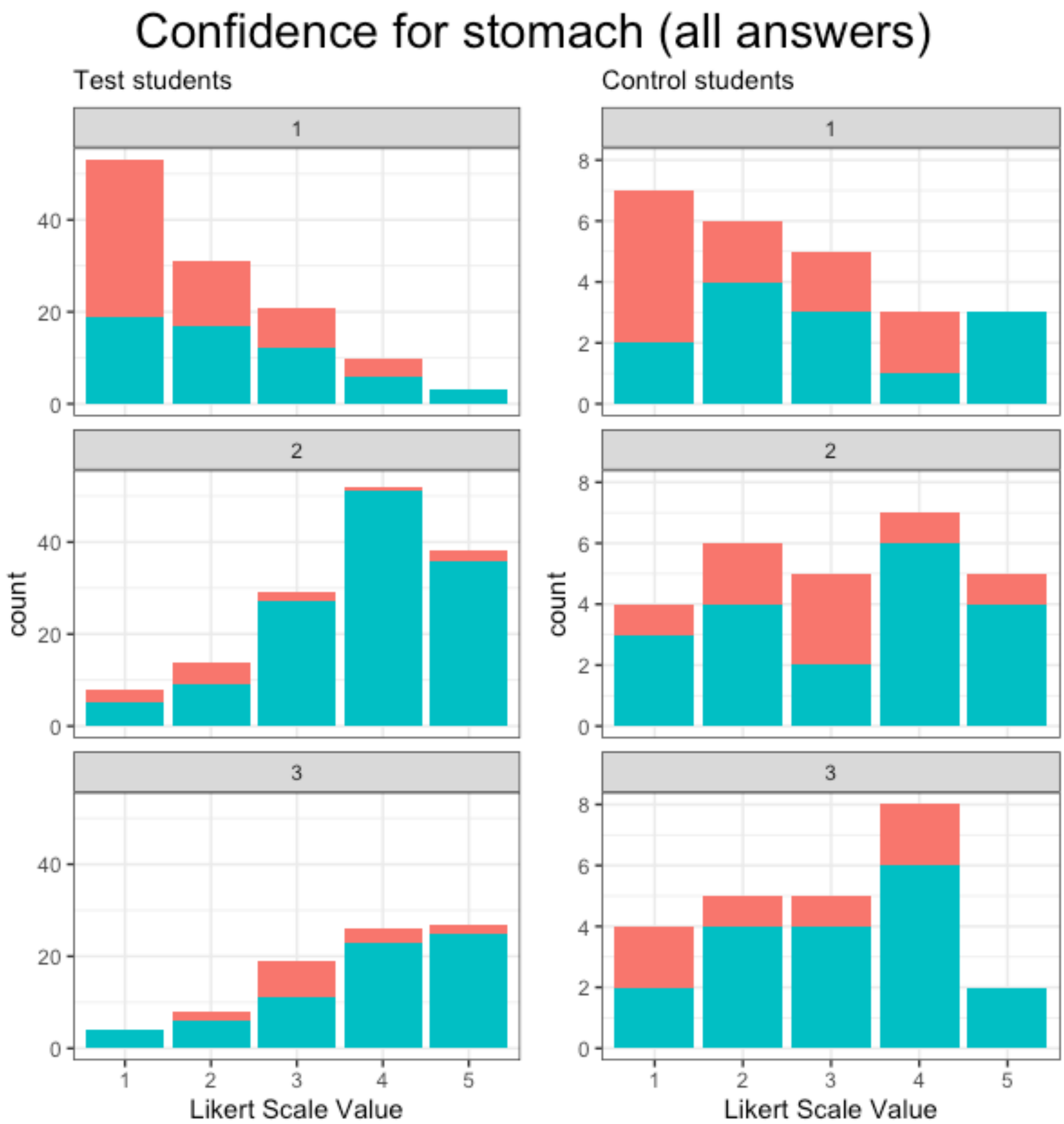


Figure 3.16. Bar charts illustrating the confidence levels for the identification of the stomach of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.6.2. Pylorus

The pylorus was presented in three instances (organs 7, 17 and 29). The pre-rotation test was completed by 35, 35 and 30 out of 40 test students. The post-rotation test 1 was completed by 46, 45 and 45 out of 47 test students. The post-rotation test 2 was completed by 28, 28 and 27 out of 28 test students.

For the control group, eight out of eight students completed the pre-rotation test for all organs except for the organ 15 where only seven control students answered. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively, for all organs.

Baseline knowledge

Baseline identification of the pylorus was very low across all three cine loops (Figure 3.15). Test students rarely identified organs 7 (7.5%) or 17 (0%), and only 2.5% identified organ 29 correctly. Control students performed similarly for organs 7 (0%) and 17 (2.5%) but were more often correct for organ 29 (25%). Most incorrect responses involved other gastrointestinal structures, particularly small intestine.

Evolution of knowledge over time

For organ 17, both groups remained incorrect at both post-rotation assessments, most often selecting duodenum or other small intestinal segments. Identification improved among test students for organ 29 (≈50–55% correct), whereas accuracy remained below 25% in the control group. For organ 7, only a small number of test students and no control students identified the pylorus at either post-rotation test.

Statistical outcomes

No significant differences were detected between test and control groups at any time point. Test students showed significant improvement between the pre-rotation test and post-rotation test 1, whereas no significant within-group changes occurred for the control students.

Confidence

Median confidence increased modestly among test students from 1 (1–3) pre-rotation to 2 (1–5) at both post-rotation tests, with a significant overall improvement (Figure 3.16). Confidence did not differ between correct and incorrect answers at any time point, likely reflecting the predominance of incorrect responses.

Control students demonstrated a similar pattern: median confidence increased from 1 (1–2) to 3 (1–4) at post-rotation test 1 and 2 (1–4) at test 2, with the Friedman test indicating a time effect but no significant pairwise differences. Confidence did not differ between correct and incorrect answers due to the high proportion of incorrect responses.

There were no significant confidence differences between test and control groups at any assessment point.

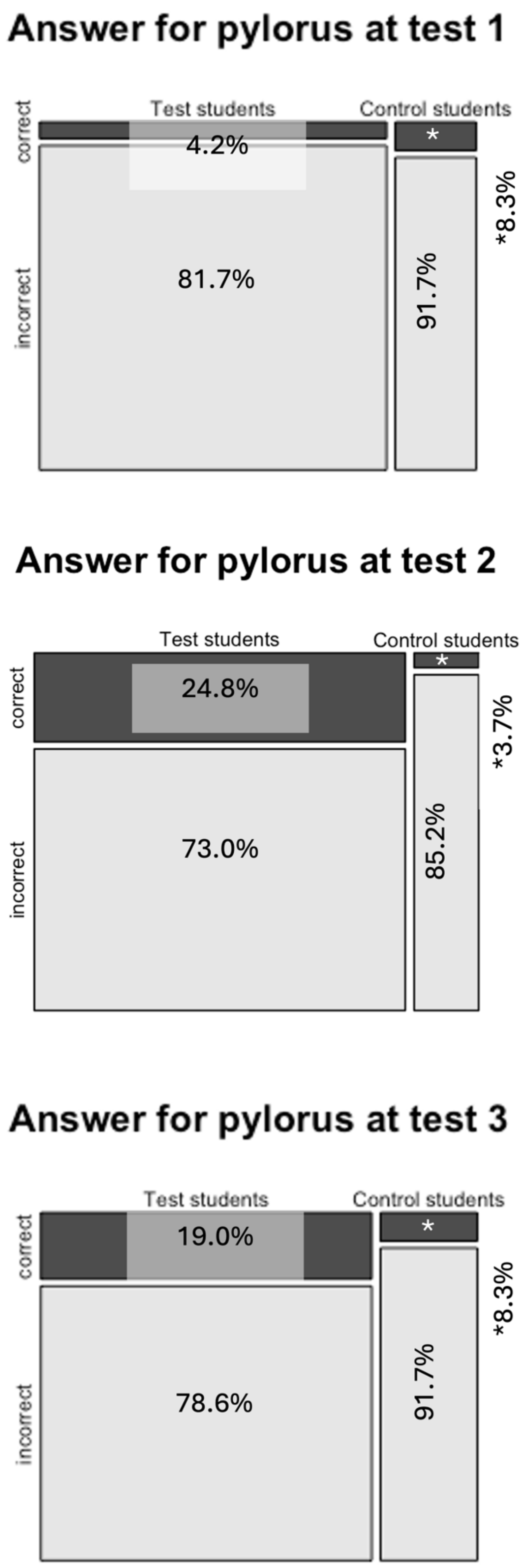


Figure 3.17. Mosaic plots for the pylorus representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

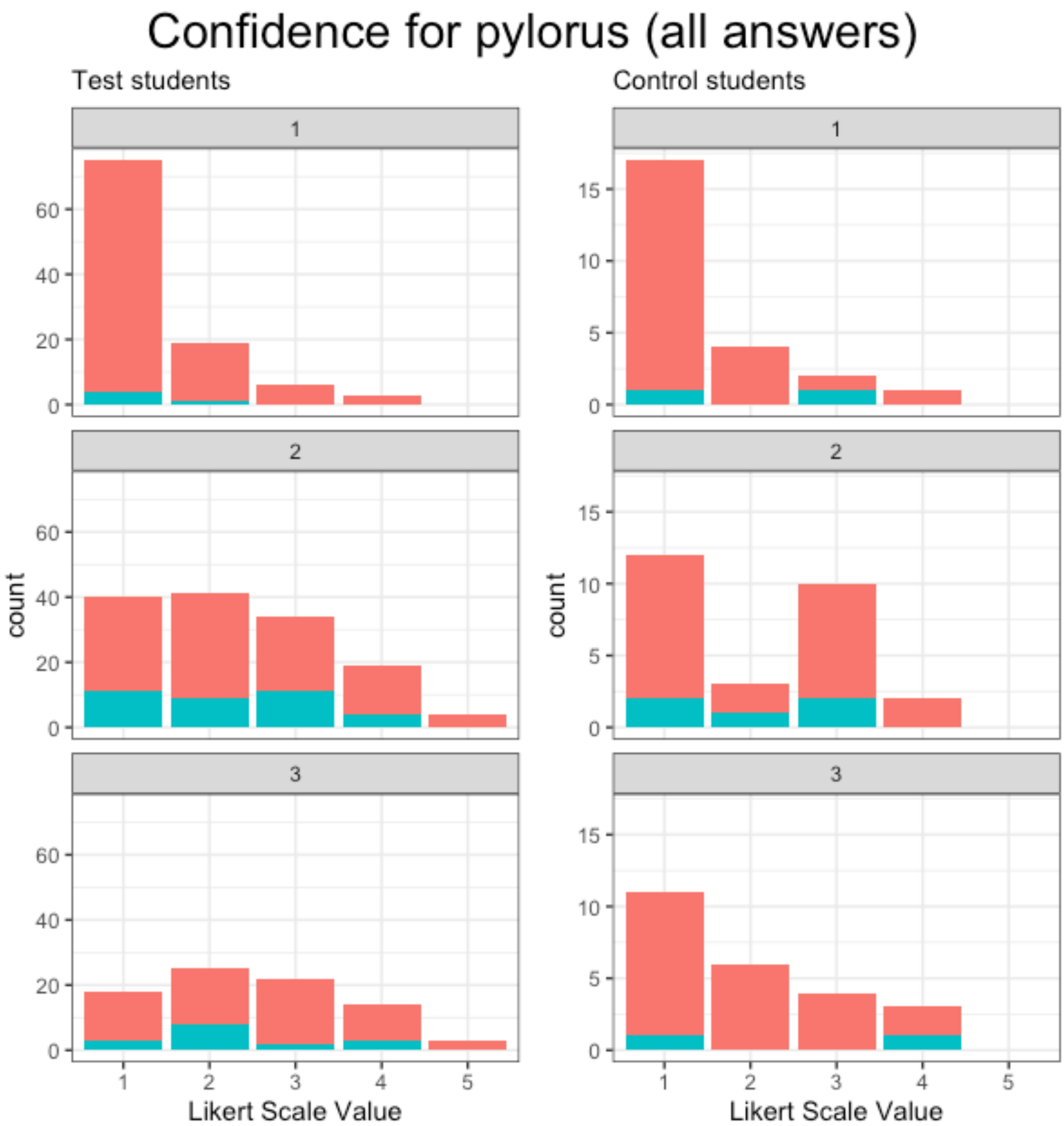


Figure 3.18. Bar charts illustrating the confidence levels for the identification of the pylorus of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.6.3. Small intestine

The small intestine was presented in six instances (organs 25, 30, 32, 36, 43 and 45). The pre-rotation test was completed by 37, 37, 39, 38, 36, and 30 out of 40 test students. The post-rotation test 1 was completed by 44, 46, 47, 47, 46, and 44 out of 47 test students. The post-rotation test 2 was completed by 25, 27, 28, 27, 28, and 25 out of 28 test students.

For the control group, eight out of eight students completed the pre-rotation test for all organs except for the organ 45 where only seven control students answered. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively, for all organs.

Baseline knowledge

Baseline recognition of the small intestine varied across cine loops (Figure 3.17). Test students most frequently identified organs 32 (72.5%), 36 (62.5%), and 43 (65%) correctly, whereas accuracy was lower for organs 25 and 30 (40% each). Organ 45 was the most difficult, with only 20% of test students answering correctly and frequent misclassification as stomach or large intestine. Control students showed similar patterns across all organs.

Evolution of knowledge over time

Test students demonstrated large post-rotation gains for organs 25 (83%), 30 (76.2%), 32 (89.4%), 36 (76.6%), and 43 (91.5%) at post-rotation test 1, with high accuracy maintained at test 2 except for organ 25, which decreased to 53.6%. Control students showed a similar pattern of improvement for organs 30, 32, 36, and 43, and continued to improve for organ 25 across both post-rotation tests.
Organ 45 remained highly challenging. Fewer than 20% of test students identified it as small intestine at either post-rotation assessment, instead most frequently selecting stomach or large intestine. Control students performed similarly, with only 11.1% correct at post-rotation test 1 and none correct at test 2.
Statistical outcomes

There were no significant differences between test and control groups at any time point. Test students showed significant improvement between the pre-rotation and first post-rotation assessments, whereas no significant within-group changes were observed for control students.

Confidence

Median confidence increased for test students from 1 (1–5) pre-rotation to 3 (1–5) at both post-rotation assessments, with significant improvement over time (Figure 3.18). Confidence was significantly higher when answers were correct at all three assessments.

Control students also showed increased confidence from 2 (1–5) to 3 (1–5) at the post-rotation tests, with significant change between the pre-rotation test and post-rotation test 1. Confidence did not differ between correct and incorrect answers at any time point.

No significant differences in confidence were found between test and control students at any assessment.

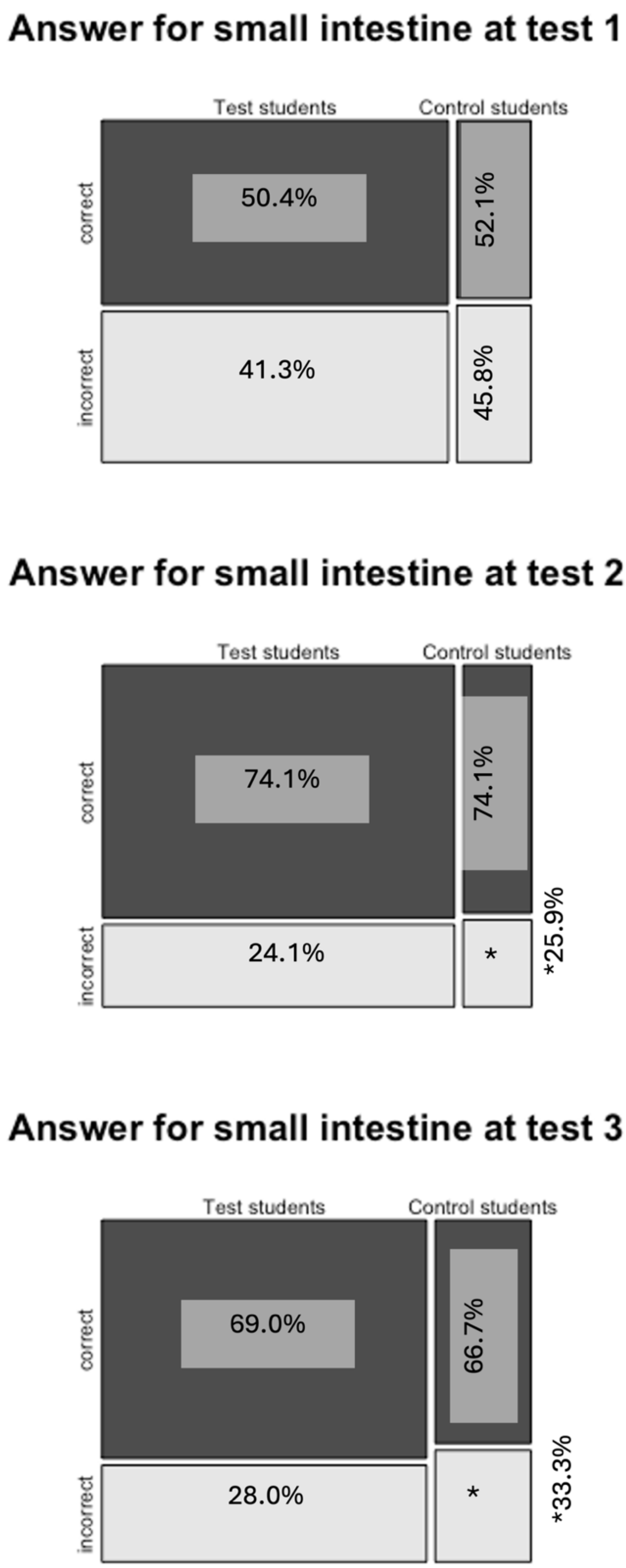


Figure 3.19. Mosaic plots for the small intestine representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

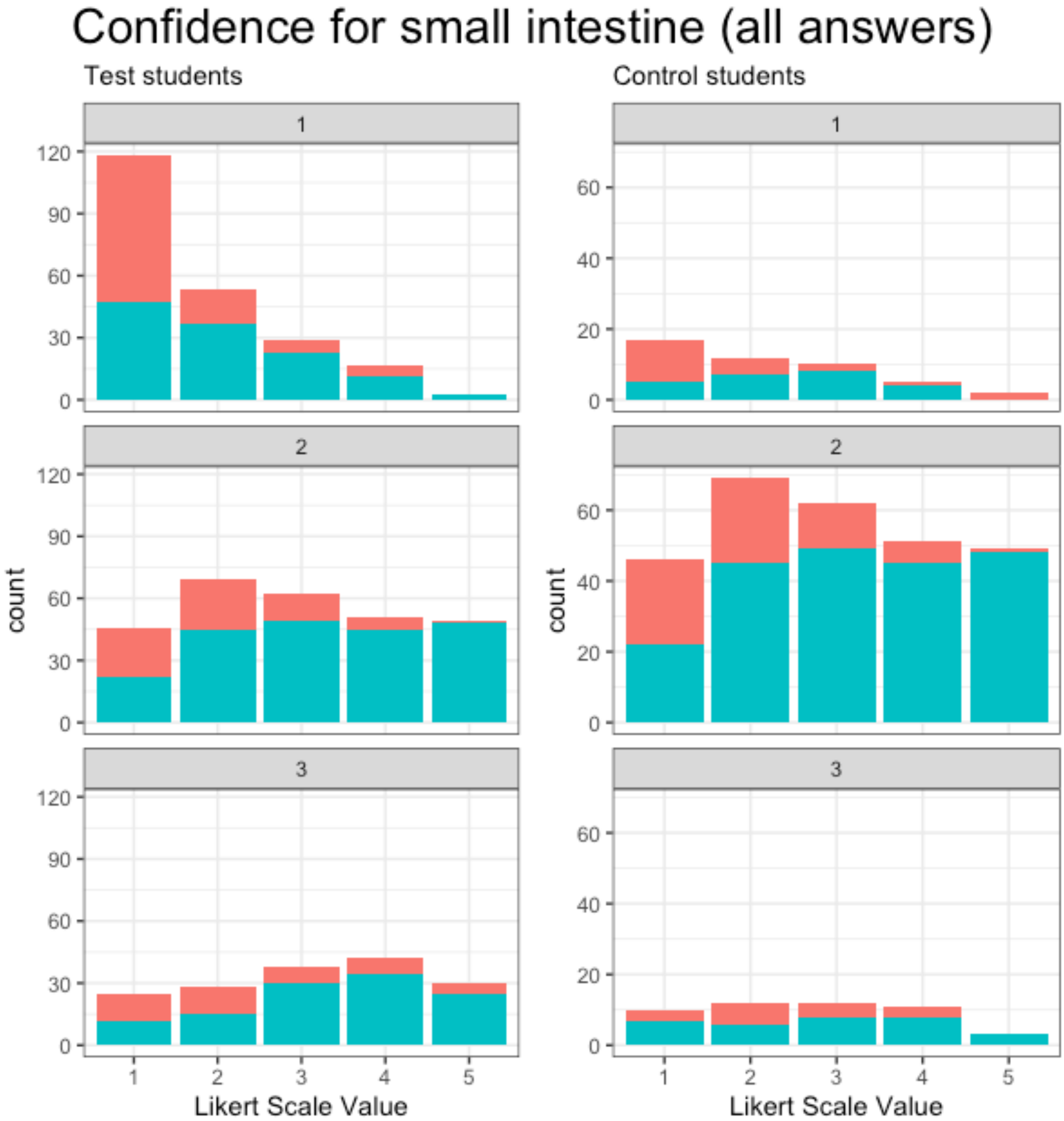


Figure 3.20. Bar charts illustrating the confidence levels for the identification of the small intestine of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.6.4. Large intestine

The large intestine was presented in six instances (organs 18, 22, 35, 42, and 44). The pre-rotation test was completed by 34, 32, 31, 31, and 32 out of 40 test students. The post-rotation test 1 was completed by 44, 47, 41, 43, and 45 out of 47 test students. The post-rotation test 2 was completed by 27, 26, 26, 26, and 27 out of 28 test students.

For the control group, eight out of eight students completed the pre-rotation test for all organs except for the organs 22, 42 and 45 where only seven control students answered. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively, for all organs except for the organ 22 where only eight students answered the post-rotation test 1 and organ 35 where only seven students answered the post-rotation test 2.

Baseline knowledge

Baseline recognition of the large intestine was low across all cine loops (Figure 3.19). Only 5–15% of test students correctly identified organs 18, 22, 35, 42, and 44, with similarly low proportions in the control group (0–25%). Misidentifications commonly included pancreas or lymph nodes (particularly for organ 44), kidney (organ 18), urogenital structures (organs 18 and 35), and small intestine (organs 42 and 44).

Evolution of knowledge over time

Test students showed modest improvement for organs 18 and 42 (to 20–25%) and a more substantial increase for organ 22 (>50%) at both post-rotation assessments. Correct identification remained uncommon for organs 35 and 44 at all time points. Control students demonstrated minimal improvement for organs 18 and 42 (<25%) and modest gains for organs 22 (44.4% and 37.5%) and 35 (11.1% and 37.5%) at post-rotation tests 1 and 2. Incorrect answer patterns remained similar to baseline, with persistent confusion between large intestine, pancreas, lymph nodes, and urogenital structures.

Statistical outcomes

There were no significant differences between test and control groups at any assessment. Test students showed significant improvement between pre-rotation and post-rotation tests, whereas no significant within-group changes were observed for control students.

Confidence

Median confidence increased for test students from 1 (1–4) pre-rotation to 2 (1–5) at both post-rotation assessments, with significant improvement across time (Figure 3.20). Confidence did not differ significantly between correct and incorrect responses at any assessment.

Control students showed a similar pattern, improving from 1 (1–2) to 2 (1–4) at the post-rotation tests, with the Friedman test indicating a time effect but no significant pairwise differences. Confidence did not differ between correct and incorrect answers.

There were no significant differences in confidence between test and control groups at any of the three assessments.

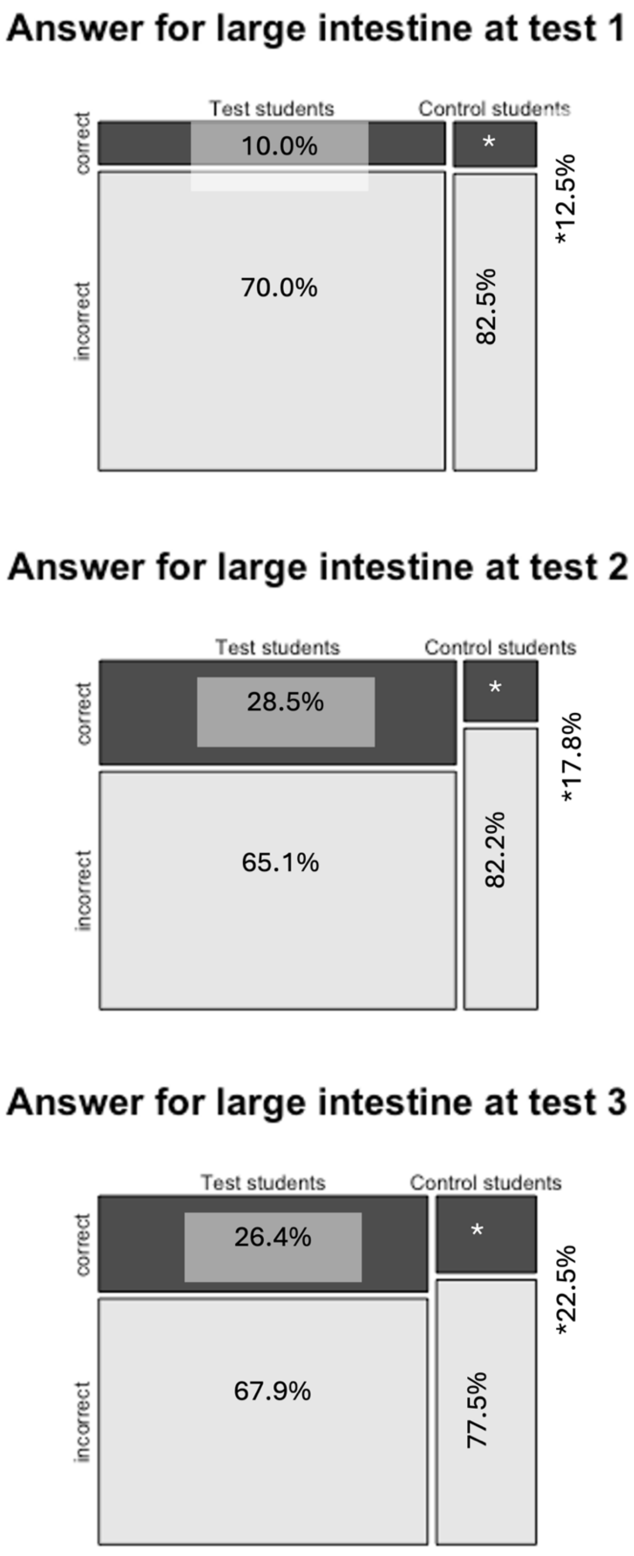


Figure 3.21. Mosaic plots for the large intestine representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

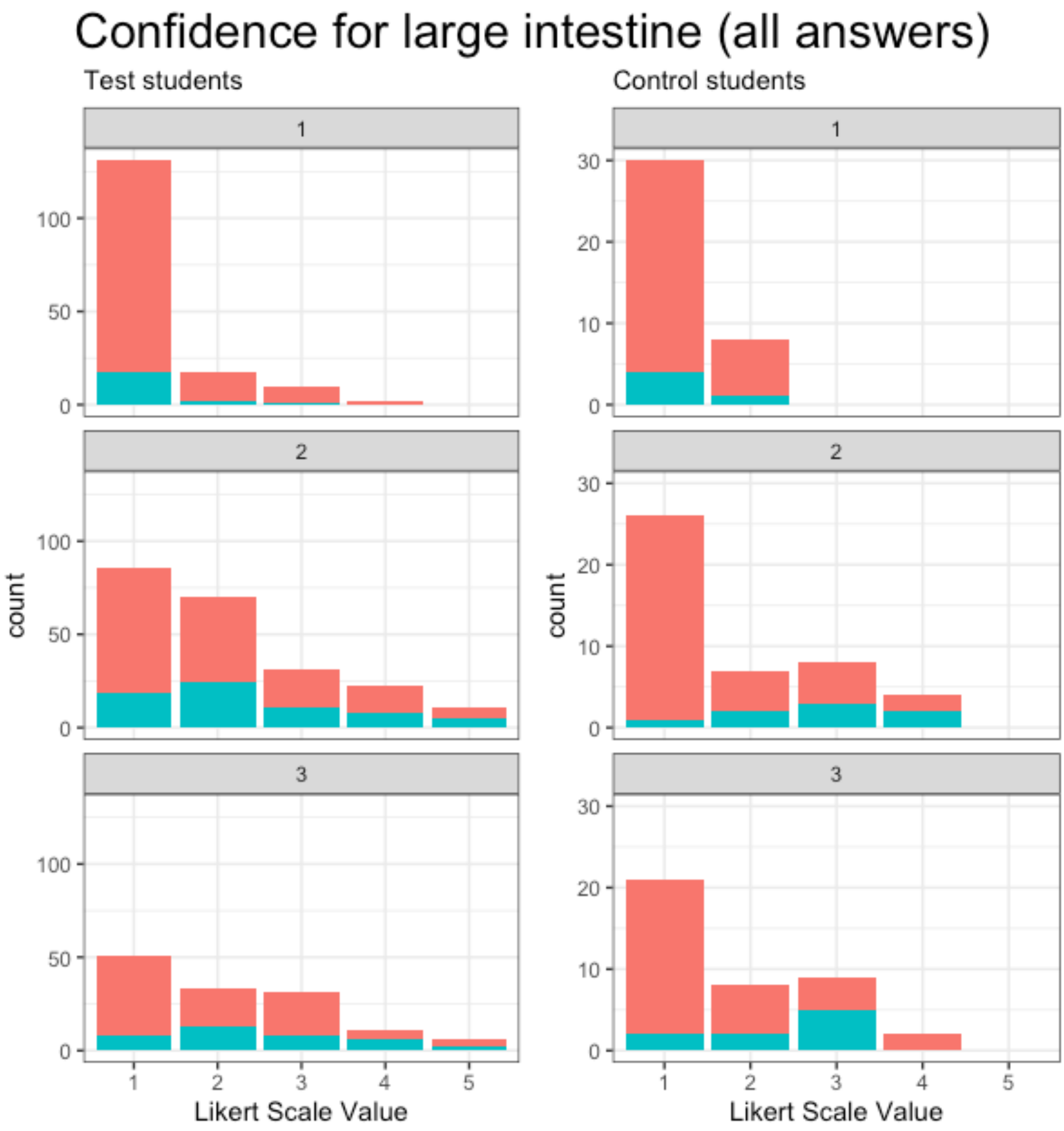


Figure 3.22. Bar charts illustrating the confidence levels for the identification of the large intestine of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.6.5. Ileocaecocolic junction

The ileocaecocolic junction (ICCJ) was presented only once (organ 47). Thirty-one (out of 40) students answered the pre-rotation test, 42 (out of 47) answered the post-rotation test 1 and 25 (out of 28) answered the post-rotation test 2.

For the control group, six out of eight students completed the pre-rotation test. Post-rotation tests 1 and 2 were completed by eight out of nine students and eight out of eight students, respectively.

Baseline knowledge

Baseline recognition of the ileocaecocolic junction was absent in both groups: no test or control students identified the ICCJ at the pre-rotation assessment (Figure 3.21). Most responses referred to other gastrointestinal structures, while 25% of control students misidentified the structure as “kidney”.

Evolution of knowledge over time

Correct identification improved modestly in the test group, reaching approximately 25–30% at both post-rotation assessments. No control students identified the ICCJ correctly at any time point. Misclassification as other gastrointestinal structures remained common in both groups.

Statistical outcomes

There were no significant differences between test and control groups at any assessment. No significant within-group changes were observed for test students. McNemar tests could not be performed for the control group because all responses remained incorrect across time.

Confidence

Median confidence for identifying the ICCJ remained low in both groups. Test students reported confidence levels of 1 (1–3) pre-rotation, increasing to 2 (1-4) at post-rotation test 1 before returning to 1 (1-3) at test 2; no significant changes were detected (Figure 3.22). Confidence did not differ between correct and incorrect responses.

Control students showed similarly low confidence throughout, with medians of 1 (1–3), 1 (1–4), and 1 (1–3) at the three assessments. No significant changes were observed. Because all responses at post-rotation tests were incorrect, comparisons by correctness could not be performed.

Confidence did not differ between test and control groups at any time point.

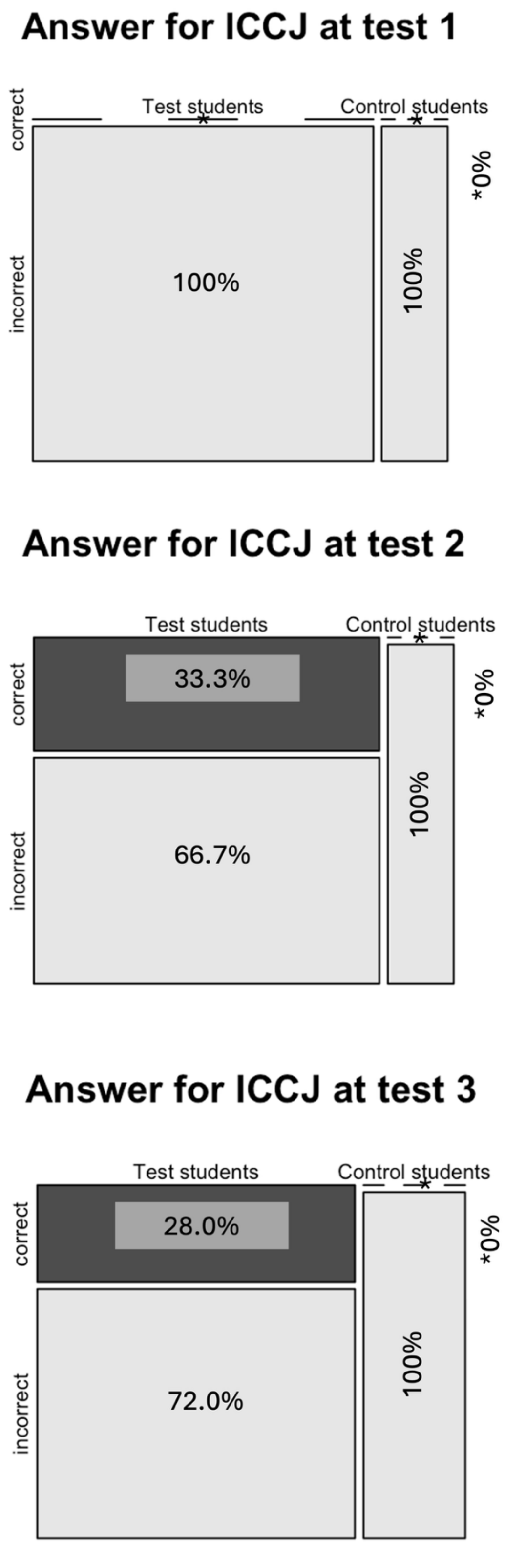


Figure 3.23. Mosaic plots for the ileocaecocolic junction (ICCJ) representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

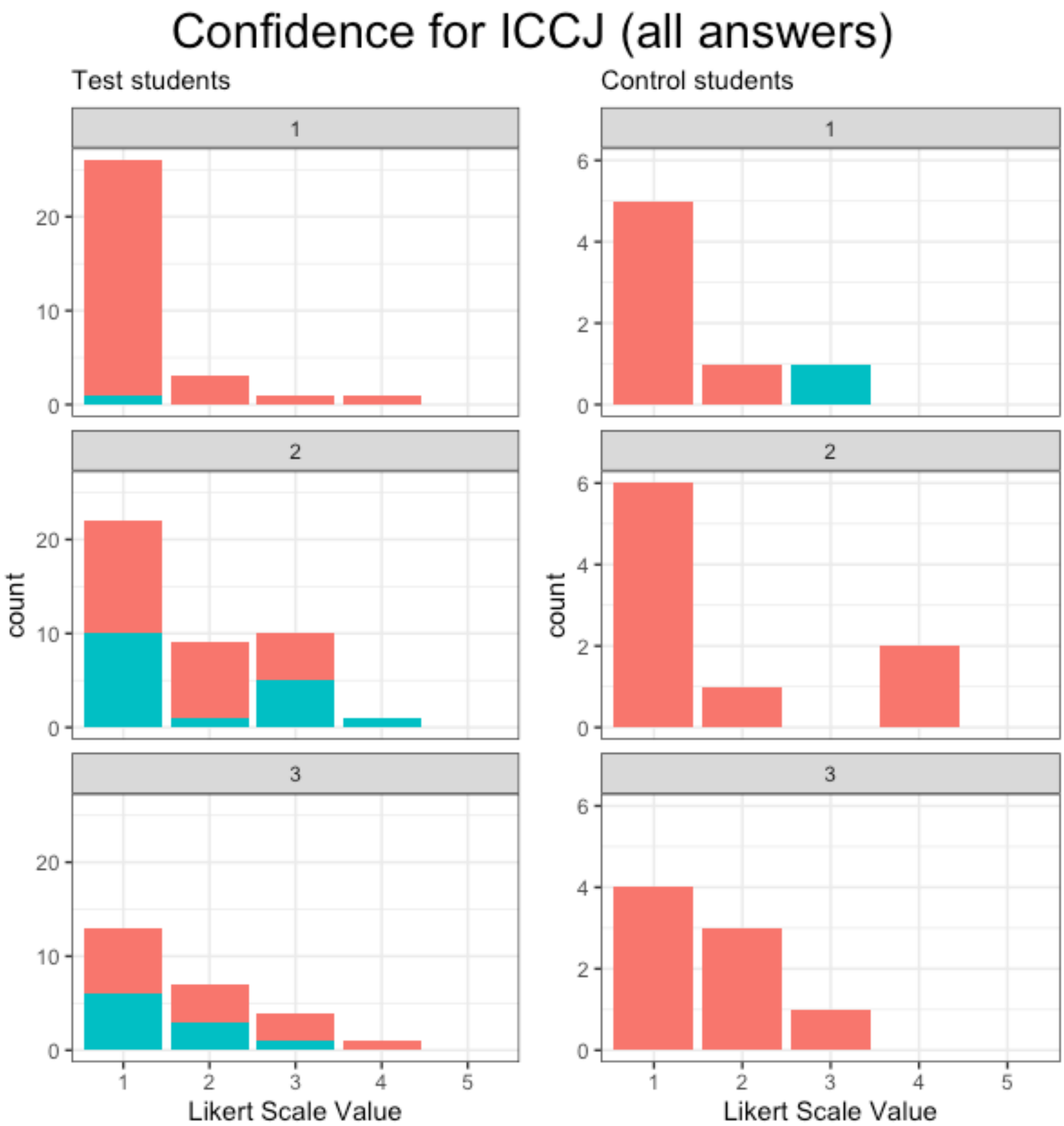


Figure 3.24. Bar charts illustrating the confidence levels for the identification of the ileocaecocolic junction (ICCJ) of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.7. Pancreas

The pancreas was presented in four instances (organs 12, 13, 28 and 39). The pre-rotation test was completed by 37, 37, 32, and 32 out of 40 test students. The post-rotation test 1 was completed by 47, 47, 47, and 46 out of 47 test students. The post-rotation test 2 was completed by 28, 28, 27, and 25 out of 28 test students.

For the control group, eight out of eight students completed the pre-rotation test for all organs except for the organs 39 where only seven control students answered. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively, for all organs.

Baseline knowledge

Recognition of the pancreas varied by cine loop (Figure 3.23). More than half of test and control students correctly identified organs 12 and 13, whereas only ~25% recognised organs 28 and 39. Common misclassifications included gastrointestinal tract, liver, and spleen.

Evolution of knowledge over time

Test students showed substantial improvement across all clips. Correct identification exceeded 80% for organs 12 and 13 at both post-rotation assessments and increased to ~70% for organ 28 and >50% for organ 39. Control students demonstrated similar improvements for organs 12, 13, and 28. However, for organ 39, control students split between "pancreas" and "spleen" at post-rotation test 1 (33.3% each), and by post-rotation test 2 mostly selected "spleen" (62.5%), with only 25% answering "pancreas."

Statistical outcomes

There were no significant differences between groups at the pre-rotation test, but test students had significantly more correct answers than controls at post-rotation test 2. Within the test group, performance improved significantly between pre-rotation and both post-rotation assessments. No significant changes were observed within the control group.

Confidence

Median confidence among test students increased from 1 (1–4) pre-rotation to 3 (1–5) at both post-rotation assessments, with statistically significant improvement over time (Figure 3.24). Confidence did not differ significantly between correct and incorrect responses.

Control students demonstrated lower confidence overall, with medians of 1.5 (1–3), 2 (1–4), and 2 (1–4) at the three time points, without significant improvement. Confidence did not differ between correct and incorrect responses.

Test students were significantly more confident than controls at post-rotation test 1, but not at other time points.

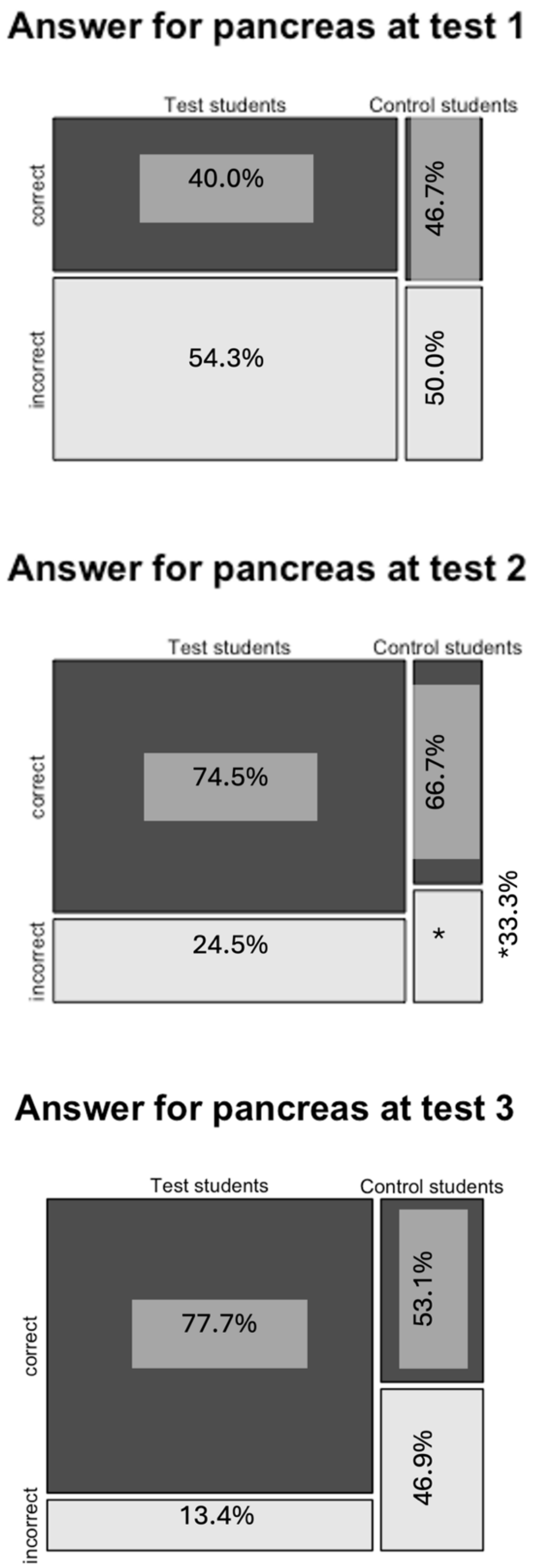


Figure 3.25. Mosaic plots for the pancreas representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

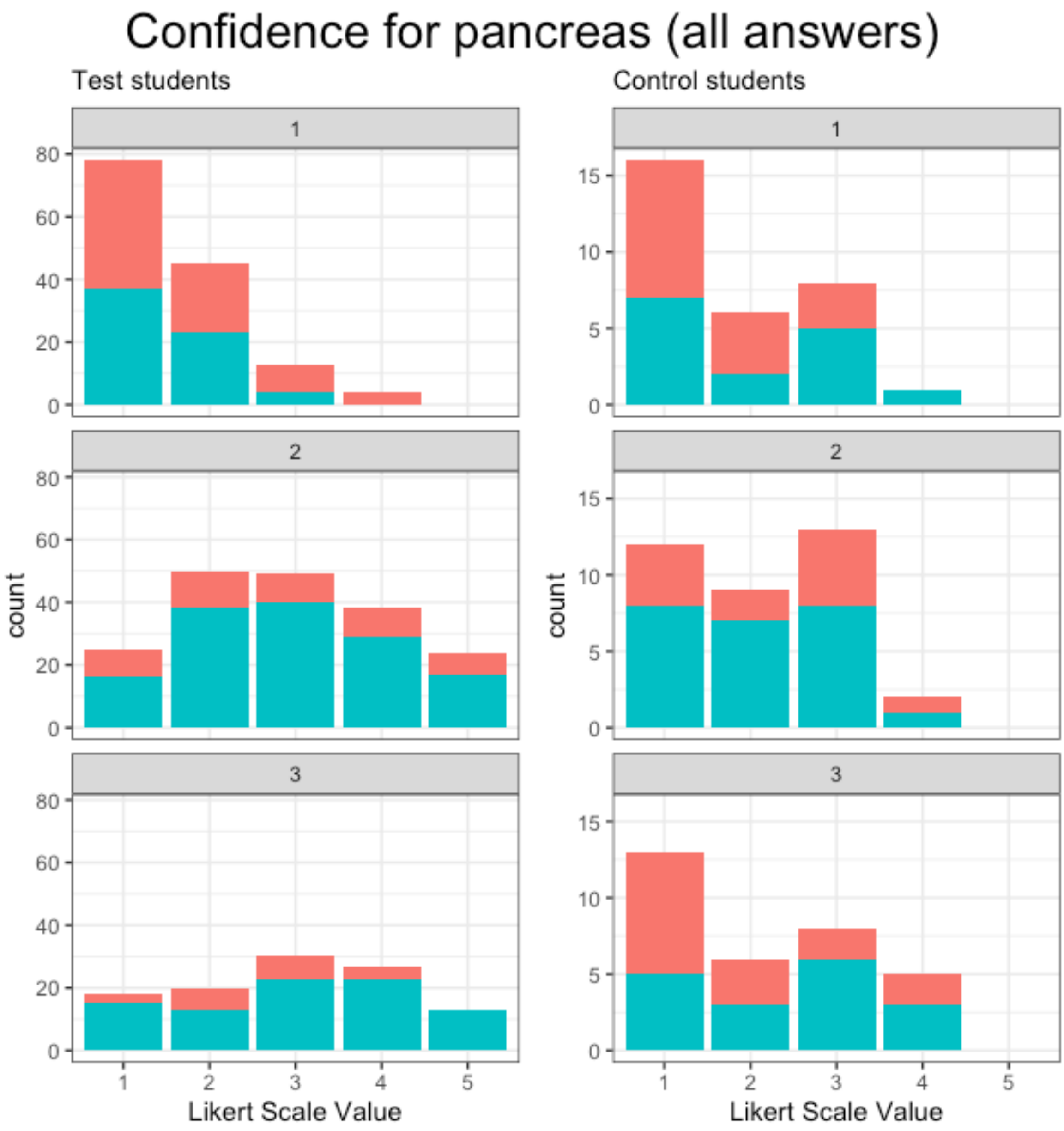


Figure 3.26. Bar charts illustrating the confidence levels for the identification of the pancreas of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.8. Lymph nodes

The lymph nodes were presented twice (organs 21 and 23). The pre-rotation test was completed by 34, and 35 out of 40 test students. The post-rotation test 1 was completed by 46 out of 47 test students for both organs. The post-rotation test 2 was completed by 27 and 25 out of 28 test students.

For the control group, eight out of eight students completed the pre-rotation test for the organs 21 and only seven control students answered for organ 23. Post-rotation tests 1 was completed by all nine control students, and post-rotation test 2 was completed by seven out of eight students for organ 21 and eight out of eight students, respectively, for all organs.

Baseline knowledge

Baseline identification of lymph nodes was limited (Figure 3.25). Thirty percent of test students and 25% of control students recognised organ 21 as a lymph node, while very few test students and no control students identified organ 23 correctly. Common misclassifications included urogenital structures (organ 21) and gastrointestinal structures (organ 23).

Evolution of knowledge over time

Test students showed marked improvement for organ 21, with >60% correct identification at both post-rotation assessments. For organ 23, however, correct responses remained low (~25%). Control students also improved for organ 21, albeit to a lesser degree (~40%), and showed minimal improvement for organ 23, where lymph node identification remained uncommon.

Statistical outcomes

No significant differences were observed between test and control groups for either organ at any time point, and no significant within-group changes were detected for either group.

Confidence

Test students' median confidence increased from 1 (1–4) pre-rotation to 2 (1–5) at both post-rotation assessments, with a significant increase between the pre-rotation and post-rotation test 1 (Figure 3.26). Confidence was significantly higher for correct answers only at post-rotation test 1.

Control students demonstrated low confidence throughout, with medians of 1 (1–3), 2 (1–3), and 2 (1–4) at the three time points, without significant improvement. Confidence did not differ between correct and incorrect answers.

Test students were significantly more confident than control students at post-rotation test 2.

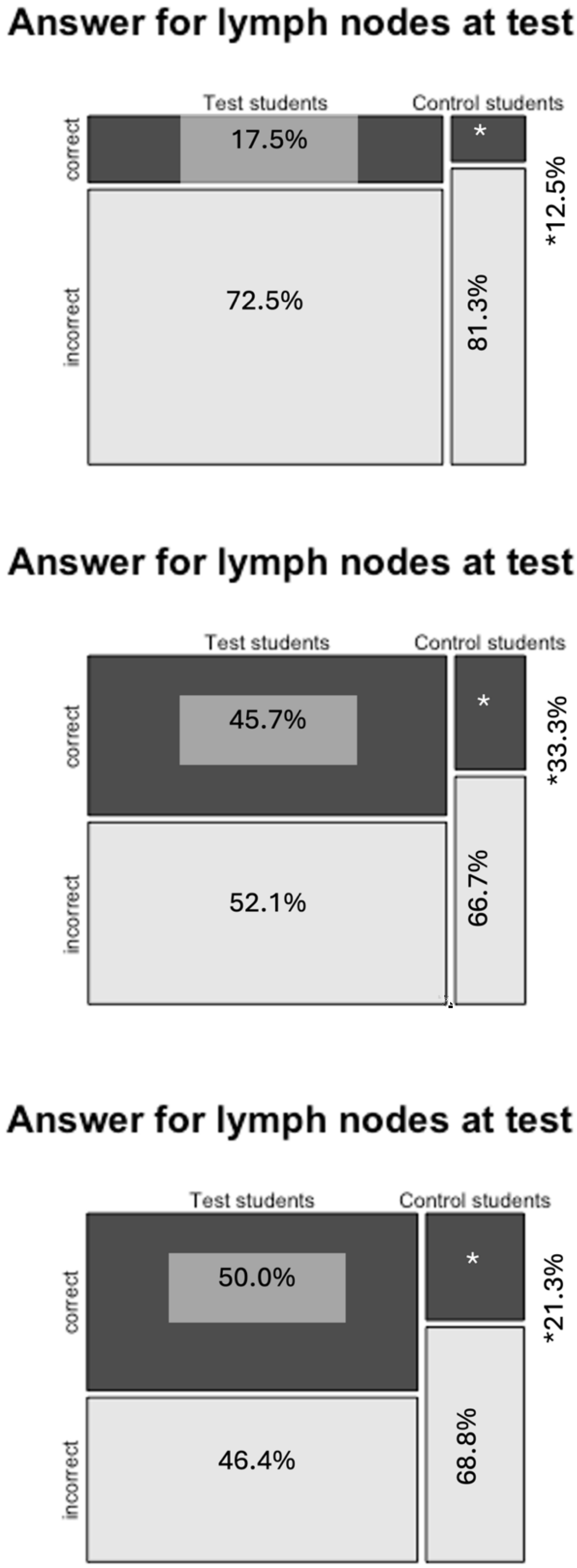


Figure 3.27. Mosaic plots for the lymph nodes representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

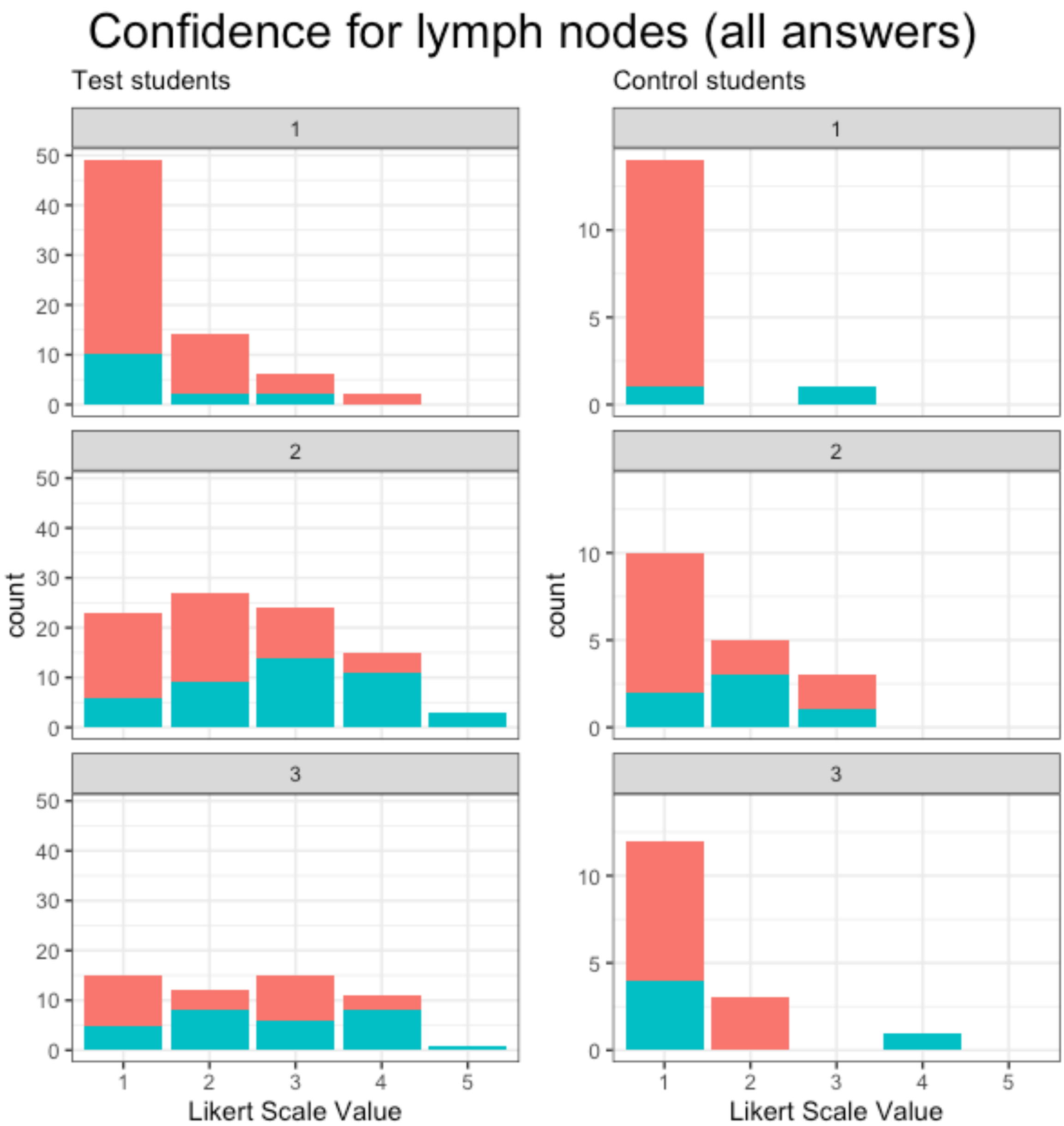


Figure 3.28. Bar charts illustrating the confidence levels for the identification of the lymph nodes of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.9. Adrenal gland

The adrenal glands were presented twice (organs 2 and 41). The pre-rotation test was completed by 39, and 36 out of 40 test students. The post-rotation test 1 was completed by 44 out of 46 test students for both organs. The post-rotation test 2 was completed by 27 and 28 out of 28 test students.

For the control group, eight out of eight students completed the pre-rotation test for both organs. Post-rotation tests 1 was completed by all nine control students, and post-rotation test 2 was completed by eight control students.

Baseline knowledge

Baseline recognition of the adrenal glands was very low (Figure 3.27). Only 20% of test students and 12.5% of control students correctly identified organ 2, and even fewer recognised organ 41 (5% of test students; 0% of control students). Most incorrect responses referred to gastrointestinal structures.

Evolution of knowledge over time

Test students showed marked improvement for organ 2, with correct identification exceeding 50% at both post-rotation assessments. Control students demonstrated modest improvement for this organ (≈25%). For organ 41, test students showed only limited gains (17.9–25.5%), and none of the control students answered correctly at any time point.

Statistical outcomes

No significant differences were observed between test and control groups at any assessment. Within-group comparisons showed no significant changes over time for either test or control students.

Confidence

Median confidence for test students increased from 1 (1–3) at the pre-rotation test to 3 (1–5) at post-rotation test 1, before decreasing to 2 (1–4) at test 2 (Figure

3.28). This represented a significant increase followed by a significant decline. Confidence was significantly higher for correct answers only at post-rotation test 1.

Control students reported low to moderate confidence throughout, with medians of 1 (1–2) et the pre-rotation test, and 2 (1–4) at the post-rotation tests, without significant change over time. Confidence did not differ significantly between correct and incorrect answers.

There were no significant confidence differences between test and control groups at any assessment point.

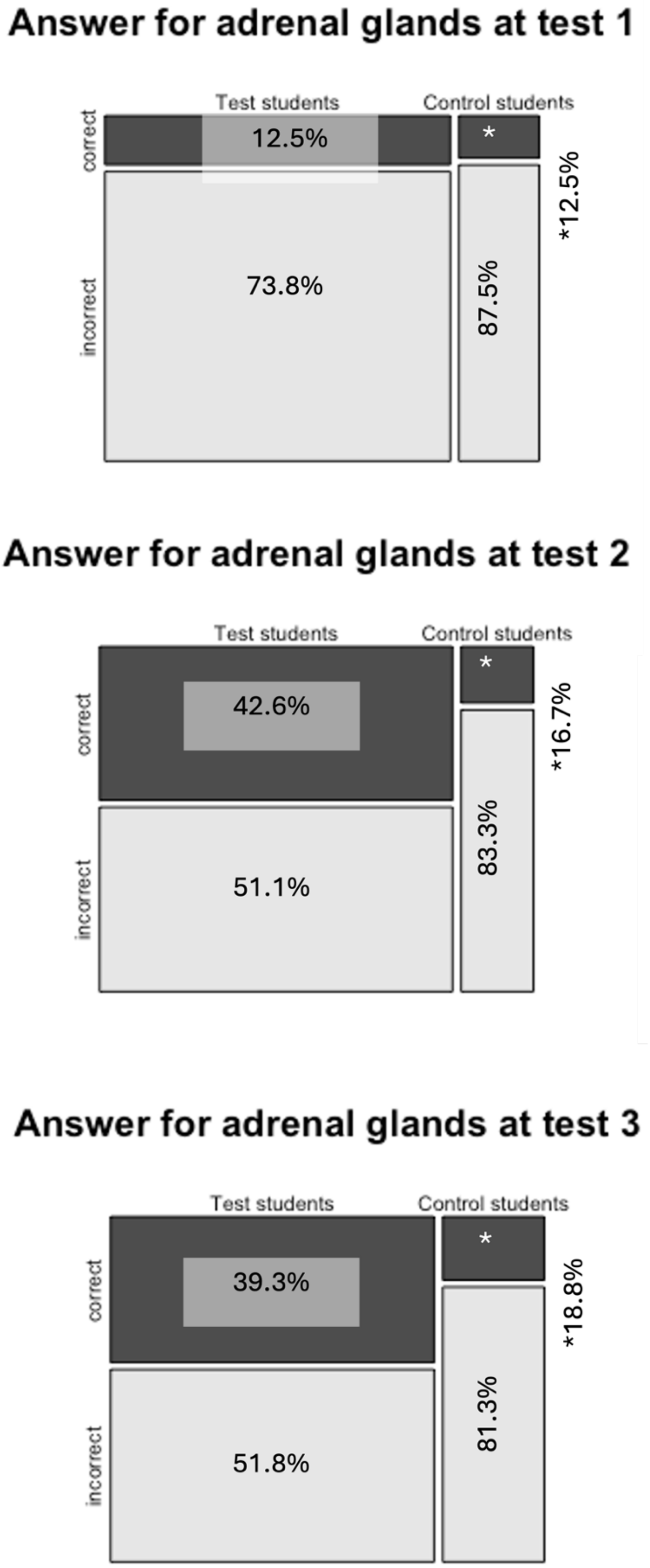


Figure 3.29. Mosaic plots for the adrenal glands representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

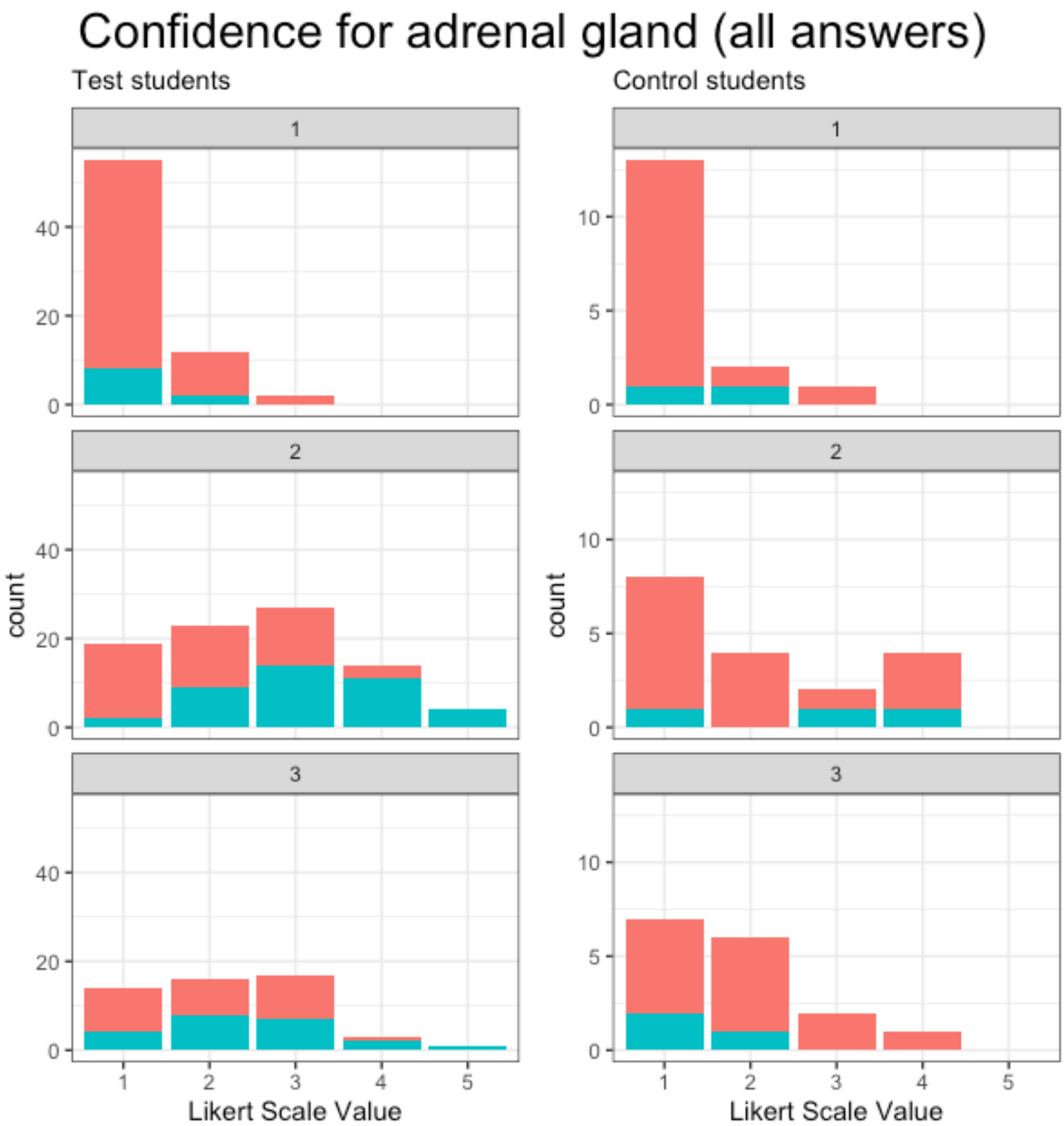


Figure 3.30. Bar charts illustrating the confidence levels for the identification of the adrenal glands of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.10. Prostate

The prostate was presented only once (organ 34). Thirty-six out of 40 test students answered the pre-rotation test, 45 out of 47 test students answered the post-rotation test 1 and 27 out of 28 test students answered the post-rotation test 2.

For the control group, eight out of eight students completed the pre-rotation test for both organs. Post-rotation tests 1 was completed by all nine control students, and post-rotation test 2 was completed by eight control students.

Baseline knowledge

Baseline identification of the prostate was moderate (Figure 3.29). Just under half of test students and 37.5% of control students correctly recognised organ 34.

Evolution of knowledge over time

Correct identification improved for both groups. Approximately 75% of test students identified the prostate correctly at both post-rotation assessments. Control students showed similar improvement at post-rotation test 1 but slightly lower accuracy at test 2 (62.5%).

Statistical outcomes

There were no significant differences between test and control groups at any assessment, nor were there significant within-group changes over time for either group.

Confidence

Test students showed an increase in median confidence from 1 (1–4) pre-rotation to 4 (1–5) at post-rotation test 1, followed by a decrease to 2 (1–5) at test 2 (Figure 3.30). Although the Friedman test detected an overall time effect, pairwise comparisons were not significant. Confidence did not differ between correct and incorrect responses.

Control students demonstrated a similar pattern, with confidence rising from 1 (1–3) to 4 (2–5) at post-rotation test 1 and decreasing to 3 (1–4) at test 2, without significant changes over time. Confidence did not significantly differ by correctness.

There were no significant confidence differences between test and control students at any time point.

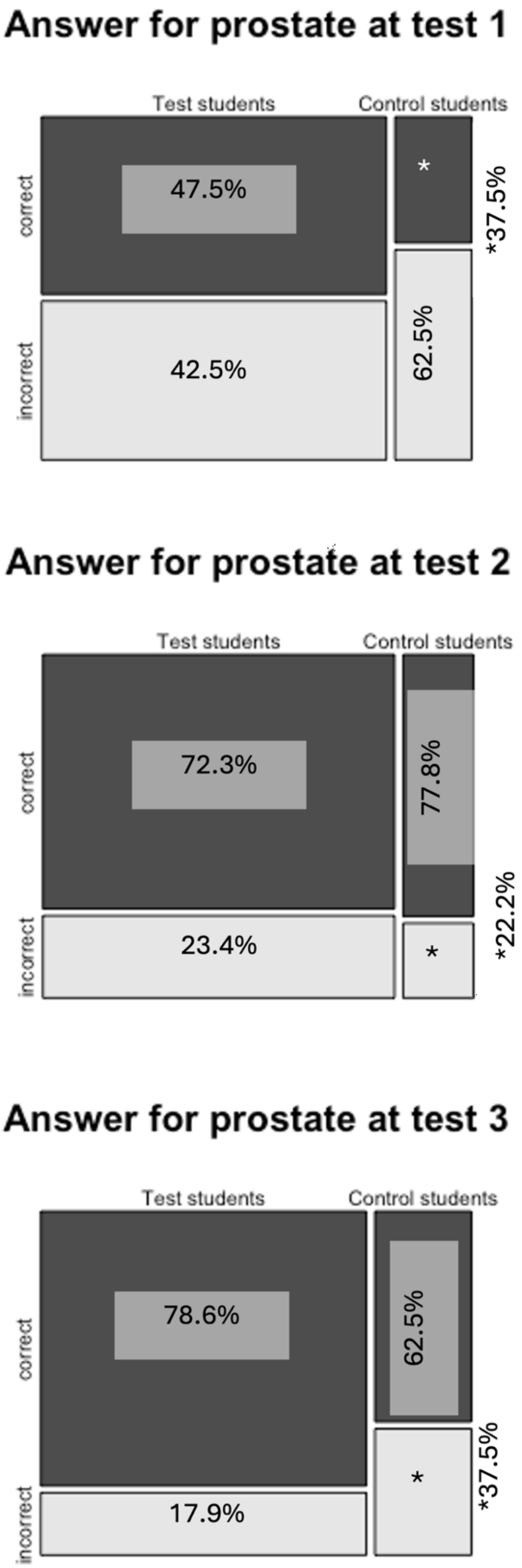


Figure 3.31. Mosaic plots for the prostate representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

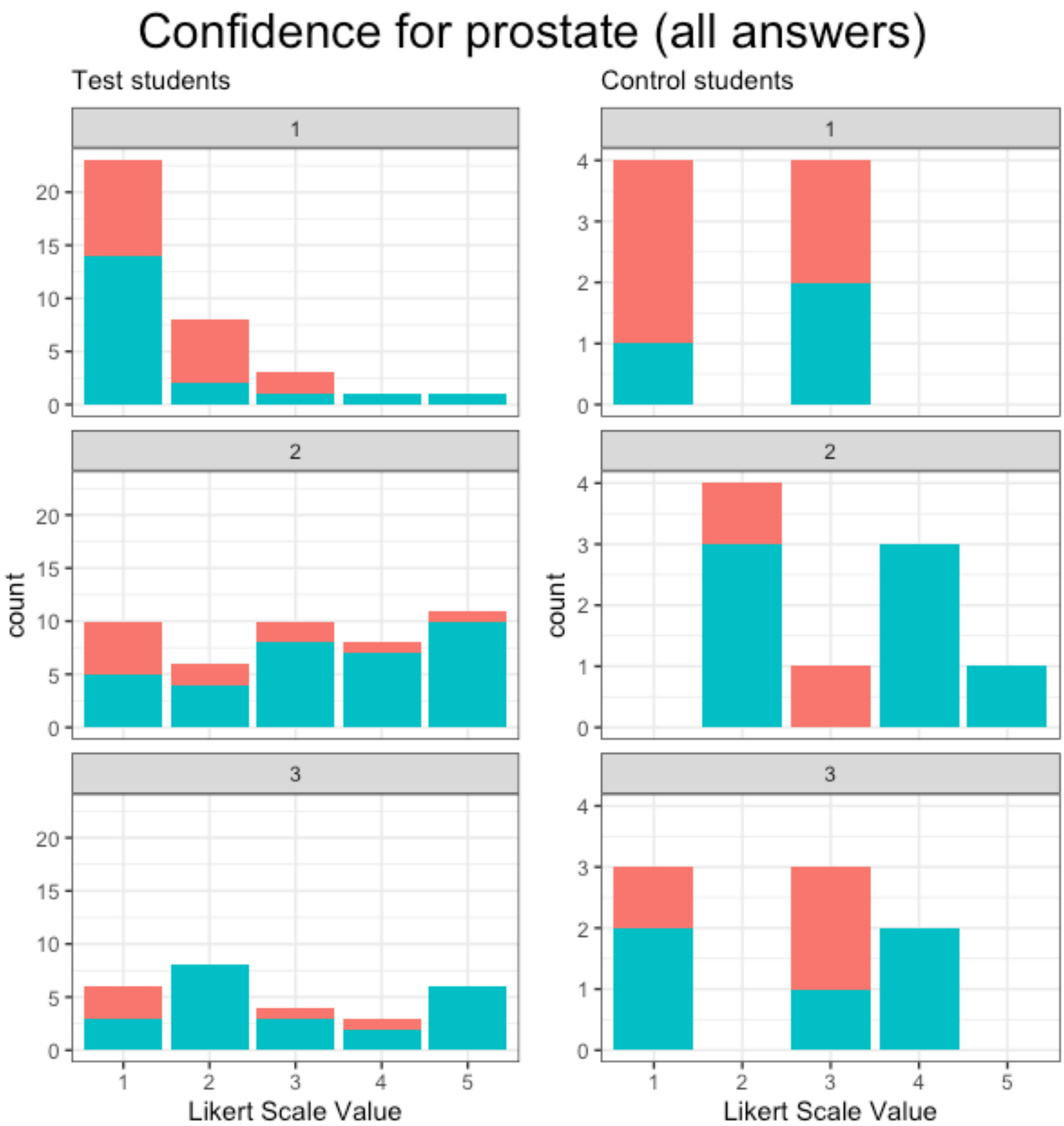


Figure 3.32. Bar charts illustrating the confidence levels for the identification of the prostate of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

3.3.11. Blood vessels

The blood vessels were presented in six instances (organs 3, 16, 19, 20, 24 and 40). The pre-rotation test was completed by 40, 37, 37, 35, 33, and 31 out of 40 test students. The post-rotation test 1 was completed by 47, 47, 47, 45, 43 and 47 out of 47 test students. The post-rotation test 2 was completed by 28, 28, 28, 28, 26 and 26 out of 28 test students.

For the control group, eight out of eight students completed the pre-rotation test for all organs except for the organ 24 where only seven control students answered. Post-rotation tests 1 and 2 were completed by nine out of nine students and eight out of eight students, respectively, for all organs, except for organ 3 where only seven students answered the post-rotation test 2.

Baseline knowledge

Baseline identification of abdominal blood vessels was low across all cine loops (Figure 3.31). Between 10% and 35% of test students correctly identified organs 3, 16, 19, 20, 24, and 40 as blood vessels, with similarly low proportions in the control group (12.5–37.5%). Common misclassifications included gastrointestinal structures (organs 3, 16, 24, 40) and urogenital structures (organs 19, 20).

Evolution of knowledge over time

Test students demonstrated substantial improvement, with correct identification exceeding 65–95% for most organs at both post-rotation assessments. Control students improved as well, though to a lesser degree, reaching 37.5–62.5% for most organs. Identification of organ 40 remained low in the control group (11–37.5%).

Statistical outcomes

There were no significant differences between groups at the pre-rotation assessment. Test students performed significantly better than control students at both post-rotation tests. Within-group comparisons showed significant improvement for test students between pre-rotation and both post-rotation assessments, whereas no significant changes were observed for control students.

Confidence

Median confidence for test students increased from 1 (1–4) pre-rotation to 3 (1–5) at post-rotation test 1, then decreased slightly to 2 (1–4) at test 2, with significant improvement over time (Figure 3.32). Confidence did not differ significantly between correct and incorrect answers.

Control students showed a modest increase from 1 (1–3) to 2.5 (1–5) at post-rotation test 1 and 2 (1–4) at test 2, with a significant overall time effect but no significant pairwise differences. Confidence did not differ by correctness at any time point.

Test students were significantly more confident than control students at both post-rotation assessments.

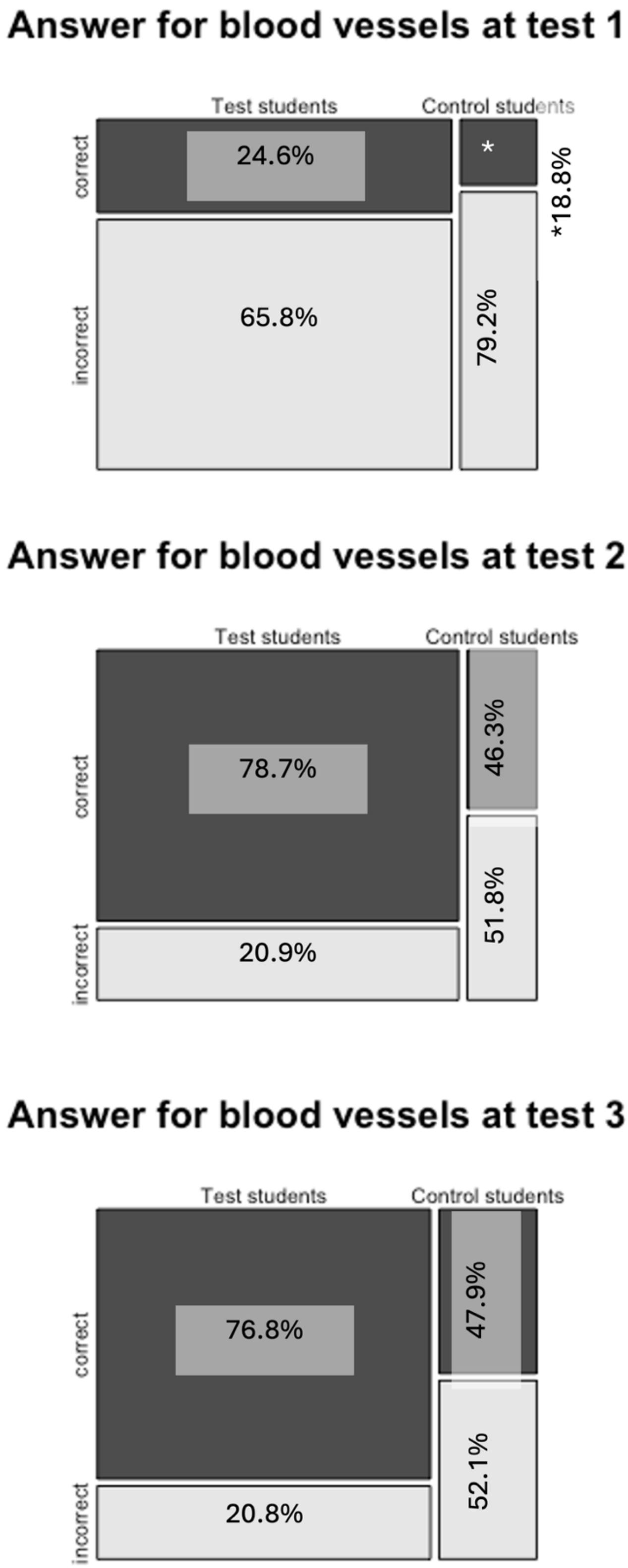


Figure 3.33. Mosaic plots for the blood vessels representing the proportion of correct and incorrect answers of the test students and control students at the pre-rotation test (test 1), the post-rotation test 1 (test 2) and the post-rotation test 2 (test 3).

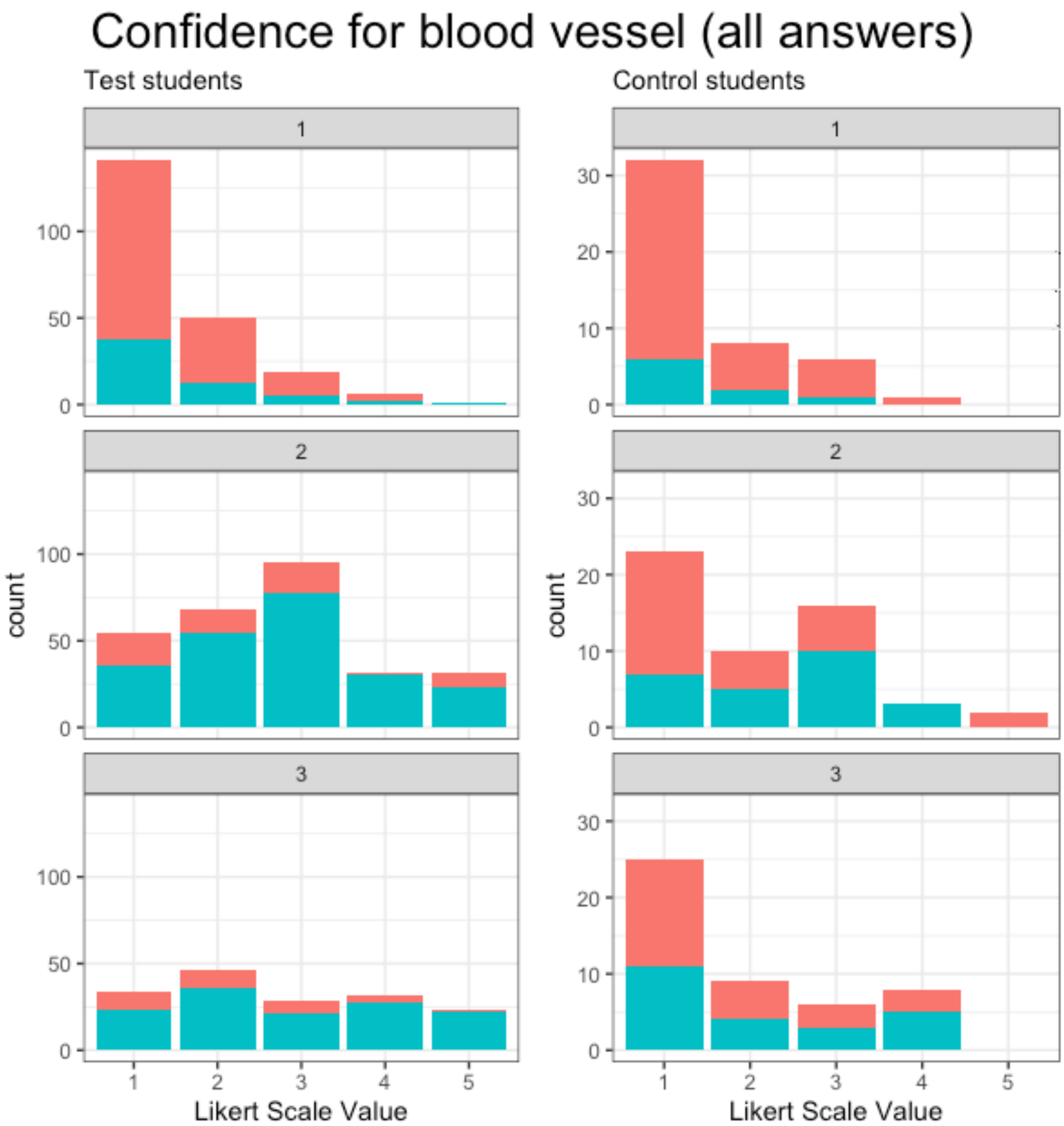


Figure 3.34. Bar charts illustrating the confidence levels for the identification of the blood vessels of both test and control students. Confidence is differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3).

Table 3-2. Summary of significant statistical findings across organ systems (1/6)

Organ System	Significant Test Student Improvement (Pre → Post 1 / Post 2)*	Significant Control Student Improvement (Pre → Post 1 / Post 2)*	Test vs Control Difference (Post 1 / Post 2)**	Significant Confidence Changes (Test students / Control students)***	Significant Confidence Difference****	Significantly Higher Confidence When Correct*****
Kidneys	Yes (Pre → Post 1)	No	None	**Test:** ↑ confidence (Pre → Post 1 and Pre → Post 2) **Control:** overall effect but no pairwise significance	Test students more confident at Post 1	Test: Yes, at Pre and Post 1 Control: Yes, at all tests
Urinary bladder	No (not testable, ceiling effect)	No	None	**Test:** overall effect but no pairwise significance **Control:** none	None	No (ceiling effect)
Spleen	Not testable (ceiling effect)	No	Test > Control at Post 1	**Test:** ↑ confidence (Pre → Post 1 and Pre → Post 2) **Control:** none	Test students more confident at Post 2	No

Table 3-3. Summary of significant statistical findings across organ systems (2/6)

Organ System	Significant Test Student Improvement (Pre → Post 1 / Post 2)*	Significant Control Student Improvement (Pre → Post 1 / Post 2)*	Test vs Control Difference (Post 1 / Post 2)**	Significant Confidence Changes (Test students / Control students)***	Significant Confidence Difference****	Significantly Higher Confidence When Correct*****
Liver	Yes (Pre → Post 1 and Pre → Post 2)	No	None	**Test:** ↑ confidence (Pre → Post 1 and Pre → Post 2) **Control:** overall effect but no pairwise differences	None	Test: Yes, at all tests
Gallbladder	Yes (Pre → Post 1)	No	None	**Test:** overall effect but no pairwise significance **Control:** none	None	No
Stomach	Yes (Pre → Post 1 and Pre → Post 2)	No	None	**Test:** ↑ confidence (Pre → Post 1 and Pre → Post 2) **Control:** none	None	No

Table 3-4. Summary of significant statistical findings across organ systems (3/6)

Organ System	Significant Test Student Improvement (Pre → Post 1 / Post 2)*	Significant Control Student Improvement (Pre → Post 1 / Post 2)*	Test vs Control Difference (Post 1 / Post 2)**	Significant Confidence Changes (Test students / Control students)***	Significant Confidence Difference****	Significantly Higher Confidence When Correct*****
Pylorus	Yes (Pre → Post 1)	No	None	**Test:** ↑ confidence (Pre → Post 1 and Pre → Post 2) **Control:** overall effect but no pairwise differences	None	No
Small intestine	Yes (Pre → Post 1)	No	None	**Test:** ↑ confidence (Pre → Post 1 and Pre → Post 2) **Control:** ↑ confidence (Pre → Post 1)	None	Test: Yes, at all tests

Table 3-5. Summary of significant statistical findings across organ systems (4/6)

Organ System	Significant Test Student Improvement (Pre → Post 1 / Post 2)*	Significant Control Student Improvement (Pre → Post 1 / Post 2)*	Test vs Control Difference (Post 1 / Post 2)**	Significant Confidence Changes (Test students / Control students)***	Significant Confidence Difference****	Significantly Higher Confidence When Correct*****
Large intestine	Yes (Pre → Post 1 and Pre → Post 2)	No	None	**Test:** ↑ confidence (Pre → Post 1 and Pre → Post 2) **Control:** ↑ overall effect but no pairwise significance	None	No
ICCJ	No	No	None	No significant changes	None	No
Pancreas	Yes (Pre → Post 1 and Pre → Post 2)	No	Test > Control at Post 2	**Test:** ↑ confidence (Pre → Post 1 and Pre → Post 2) **Control:** none	Test students more confident at Post 1	No

Table 3-6. Summary of significant statistical findings across organ systems (5/6)

Organ System	Significant Test Student Improvement (Pre → Post 1 / Post 2)*	Significant Control Student Improvement (Pre → Post 1 / Post 2)*	Test vs Control Difference (Post 1 / Post 2)**	Significant Confidence Changes (Test students / Control students)***	Significant Confidence Difference****	Significantly Higher Confidence When Correct*****
Lymph nodes	No	No	None	**Test:** ↑ confidence (Pre → Post 1) **Control:** none	Test students more confident at Post 2	Test: Yes, at Post 1
Adrenal glands	No	No	None	**Test:** ↑ confidence (Pre → Post 1) then ↓ confidence (Post 1→ Post 2) **Control:** none	None	Test: Yes, at Post 1
Prostate	No	No	None	**Test:** overall effect but no pairwise significance **Control:** none	None	No

Table 3-7. Summary of significant statistical findings across organ systems (6/6)

Organ System	Significant Test Student Improvement (Pre → Post 1 / Post 2)*	Significant Control Student Improvement (Pre → Post 1 / Post 2)*	Test vs Control Difference (Post 1 / Post 2)**	Significant Confidence Changes (Test students / Control students)***	Significant Confidence Difference****	Significantly Higher Confidence When Correct*****
Blood vessels	Yes (Pre → Post 1 and Pre → Post 2)	No	Test > Control at Post 1 & Post 2	**Test:** ↑ confidence (Pre → Post 1 and Pre → Post 2) **Control:** overall effect but no pairwise significance	Test students more confident at Post 1 and Post 2	No

All statistical outcomes are presented in Appendix 13

*Results from the McNemar test (Table 2 for the test students, Table 3 for the control students)

** Results from the Fisher's exact test (Table 1)

***Results from the Friedman test (Table 4 for the test students, Table 6 for the control students)

**** Results from the Mann Whitney U test (Table 8)

***** Results from the Mann Whitney U test (Table 5 for the test students, Table 7 for the control students)

4. DISCUSSION

4.1. Summary of key findings

This study evaluated the ability of final-year veterinary students to recognise normal abdominal organs on ultrasound cine loops and explored the impact of supplementary online teaching material on both performance and self-reported confidence. Overall, students demonstrated strong baseline recognition of several major abdominal organs, particularly those that are large, consistently positioned, and commonly encountered in clinical practice, such as the kidneys, urinary bladder, and spleen. In contrast, recognition of more anatomically complex, smaller or less consistently visualised structures, including the pancreas, pylorus, adrenal glands, and abdominal lymph nodes, was variable and frequently poor.

After the diagnostic imaging rotation, most students were able to recognise the kidneys, urinary bladder, spleen, liver and stomach. This represents the expected level of knowledge for a final year veterinary student.

Access to targeted online teaching material was associated with improved recognition of several of the more challenging organs (eg., GIT, gallbladder, pancreas, prostate and blood vessels), and in some cases this improvement persisted six weeks after the diagnostic imaging rotation (eg., pancreas and blood vessels), suggesting a degree of knowledge retention. Student confidence in organ identification increased over time and was higher in students with access to additional learning resources for identification of the kidneys, spleen, pancreas, lymph nodes and blood vessels, although increases in confidence were not always matched by corresponding improvements in accuracy (eg., pylorus and large intestine). Collectively, these findings highlight both the educational value and the limitations of short, targeted instructional interventions focused on ultrasound anatomy.

4.2. Anatomical recognition as a foundational ultrasound competency

Correct identification of normal abdominal organs is a fundamental prerequisite for meaningful ultrasound interpretation.

4.2.1. Recognition of commonly taught Day One abdominal ultrasound structures

While the RCVS Day One Competences do not specify individual abdominal structures, our selection reflects organs commonly prioritised by educators and clinicians as foundational for safe early practice.

Structures such as the kidneys, urinary bladder, and spleen benefit from relatively consistent anatomical positioning (Hermanson, de Lahunta, Evans, 2019), characteristic sonographic appearance (Penninck & d'Anjou, 2025), and frequent clinical exposure during undergraduate training, which likely contributes to higher baseline recognition rates. At the University of Bristol, these structures are introduced during Year 3 teaching and are likely further reinforced during extra-mural studies (EMS) and intramural clinical rotations at Langford Vets.

Although no published studies have specifically evaluated the ultrasound exposure of undergraduate veterinary students during clinical placements, it is reasonable to infer that students are frequently exposed to ultrasound examinations of the urinary bladder, kidneys, and spleen during EMS as these examinations represent the three most commonly performed abdominal ultrasound assessments in general practice (Zelachowski et al., 2024). Moreover, given that general practitioners report greater confidence in identifying the urinary bladder, kidneys, and spleen on ultrasound (McDonald et al., 2023), as well as in detecting abnormalities affecting these organs (Zelachowski et al., 2024), it is reasonable to hypothesise that they would share their knowledge with the undergraduate students.

Furthermore, because students completed their diagnostic imaging rotations at different points throughout the final year (see Figure 3.1), varying degrees of informal reinforcement of these skills may have occurred across clinical disciplines at Langford Vets. Collectively, these factors suggest that undergraduate training is relatively effective in supporting recognition of these commonly imaged organs.

4.2.2. Gaps in Day One ultrasound competence: differentiation of small and large intestine

Overall, students demonstrated poor ability to recognise the large intestine on ultrasound. Accurate differentiation between the small and large intestine is a clinically important ultrasound skill, as gastrointestinal presentations such as vomiting and diarrhoea are among the most common reasons for consultation in small animal practice and frequently prompt abdominal ultrasound examination (O'Neill et al., 2023; PR Newswire website). Given the high prevalence of gastrointestinal tract (GIT) pathology in first-opinion practice, new graduate veterinarians should be able to distinguish shadowing material within the small intestine, which may indicate foreign material and intestinal obstruction, from shadowing associated with faecal content within the large intestine. This distinction is clinically critical, as it directly influences diagnostic reasoning and case management, with timely recognition and intervention being particularly important for improving outcomes in cases of gastrointestinal obstruction (Hayes, 2009).

The consistently low recognition rates for the large intestine observed in this study highlight a potential misalignment between the implicit expectations outlined in the Royal College of Veterinary Surgeons (RCVS) Day One Competences and the demonstrable abilities of final-year veterinary students. These findings suggest that greater emphasis should be placed within the undergraduate curriculum on the sonographic features that distinguish the large intestine from the small intestine, including wall layering, luminal contents, and anatomical location. Without targeted teaching and reinforcement of these distinctions, graduates may enter clinical practice without sufficient proficiency in an ultrasound skill that is highly relevant to routine case presentation and decision-making.

4.2.3. Recognition of technically challenging abdominal structures beyond Day One expectations

In contrast, organs such as the pancreas, adrenal glands, and abdominal lymph nodes pose greater challenges for undergraduate learners. These structures are typically small, exhibit more subtle echogenic differences relative to surrounding adipose tissue, and are highly influenced by patient conformation, body condition, and artefact arising from adjacent gastrointestinal structures (Penninck & d'Anjou, 2015b). It is also likely that these organs receive less emphasis during undergraduate teaching, as not consistently regarded as core Day One ultrasound competencies, despite being commonly used in practice (Zelachowski et al., 2024). This is supported by evidence that general practitioners report lower confidence in identifying the pancreas, adrenal glands, and abdominal lymph nodes (McDonald et al., 2023), as well as in detecting pathology affecting these structures (Zelachowski et al., 2024). Reduced confidence among clinical supervisors may, in turn, limit the extent to which these structures are taught and reinforced during undergraduate placements.

In the present study, students demonstrated higher recognition rates for the medial iliac lymph nodes compared with the mesenteric lymph nodes. A plausible explanation for this disparity may relate to the clinical caseload encountered at Langford Vets (LV). In particular, the LV Oncology service routinely relies on serial ultrasonographic evaluation of the medial iliac lymph nodes in dogs diagnosed with anal sac adenocarcinoma (Sutton et al., 2022). Final-year students undertaking diagnostic imaging rotations are therefore likely to observe repeated examinations of this specific lymph node group when assisting with clinical cases. Such exposure may have resulted in a relative increase in familiarity with medial iliac lymph nodes and contributed to the higher performance observed. This contrasts with the mesenteric lymph nodes, which are less consistently targeted for routine monitoring and therefore likely receive less focused exposure during clinical teaching. Consequently, the differential recognition rates reported here may in part reflect uneven clinical case exposure rather than innate differences in anatomical recognisability or pedagogical emphasis.

The present findings are consistent with patterns reported in veterinary ultrasound and POCUS education, where learner confidence and accuracy are lower for ultrasound targets that are technically more complex or less frequently imaged in routine practice (Guillaumin et al., 2025; McDonald et al., 2023). This variability in performance highlights that, even at the end of undergraduate veterinary training, anatomical recognition of abdominal structures on ultrasound remains incomplete for a substantial proportion of students.

4.2.4. Methodological considerations and limitations

Several limitations related to the design of the ultrasound test videos may have influenced students' performance in organ recognition. Although all videos incorporated anatomical landmarks to facilitate identification of the labelled structures, in some instances the landmarks typically used to locate a given organ (e.g. gallbladder, pylorus) were visible but not themselves labelled. This may have reduced students' ability to correctly interpret the spatial relationships required for accurate identification, particularly if insufficient attention was paid to adjacent anatomical context. In addition, poorer performance was observed when labelled organs were only partially included within the field of view (e.g. right kidney), particularly among students who did not have access to the supplementary teaching material. The presence of image artefacts, such as focal contact artefact (e.g. right kidney) or distal acoustic shadowing from gastrointestinal contents (e.g. right adrenal gland), may have further compromised image interpretation and negatively affected recognition accuracy. The number of labelled structures per test video was also not standardised, ranging from three structures in some videos to seven in others. It remains unclear whether the number of structures to identify should be standardised, limited, or deliberately varied. However, the requirement to identify multiple structures within a single video may have increased cognitive load and contributed to reduced performance, particularly in later videos. If students completed the test videos sequentially, by the final video they had been required to identify more than 35 structures in total, which may have resulted in cognitive overload (Sweller, 2011). Further research is warranted to determine the optimal number of structures to include per video to balance educational value with cognitive demands.

Finally, the frequency with which individual organs appeared across the test videos was not standardised. Some structures, such as the gallbladder, prostate, and urinary bladder, were presented only once, whereas others, including the liver and pancreas, appeared multiple times. When gastrointestinal structures were considered collectively, they were presented far more frequently than other organ systems. This unequal representation may have influenced recognition rates and suggests that the test videos themselves may have functioned as an additional learning opportunity rather than a purely summative assessment tool. Future studies should consider standardising organ frequency to minimise this potential confounding effect.

4.3. Beyond anatomical recognition: broader ultrasound competencies

While this study specifically evaluated students' ability to recognise normal abdominal anatomy on ultrasound cine loops, anatomical recognition represents only one component of overall ultrasound competence. Proficient ultrasound use additionally requires the ability to acquire diagnostic-quality images through appropriate probe handling, optimisation of machine settings, systematic scanning techniques, recognition of artefacts, detection of lesions, and integration of imaging findings into clinical reasoning and decision-making.

4.3.1. Probe handling and psychomotor ultrasound skills

Psychomotor skills in medical ultrasound imaging have been defined as "the unique mental and motor activities required to execute a manual task safely and efficiently for each clinical situation" (Nicholls et al., 2014). In the context of ultrasound, these skills are inherently variable and must be continuously adapted in response to patient-related factors such as body condition, organ orientation and position, pathological changes, and post-surgical alterations. Consequently, ultrasound probe handling cannot be learned through rote repetition, as the transducer movements required to achieve a diagnostic image differ with each examination (Nicholls et al., 2014).

Core psychomotor skills underpinning ultrasound performance across clinical disciplines include: (1) the ability to mentally reconstruct three-dimensional anatomical relationships while viewing two-dimensional images in real time (visuospatial skills); (2) effective manipulation of the transducer through sliding, rocking, sweeping, fanning, application of pressure or compression, and rotation; (3) systematic assessment of anatomical structures in at least two orthogonal planes; and (4) optimisation of image quality to depict the structure of interest in a manner appropriate to the clinical question (visuomotor skills) (Nicholls et al., 2014). Both visuospatial and visuomotor skills rely on prior exposure to visual exemplars of normal sonographic anatomy, which serve as reference standards against which real-time images can be interpreted.

Within undergraduate medical education, several studies have explored methods to support the acquisition of ultrasound-related psychomotor skills. For example, Olgers et al. (2022) demonstrated that a serious game designed for ultrasound training improved eye–hand coordination and probe stability among novice learners. Similarly, virtual simulation platforms have been developed to teach transducer manipulation and image optimisation, allowing learners to practise psychomotor skills in a controlled environment before clinical application (Meuwly et al., 2021). In veterinary education, simulation-based approaches have also been explored, including the use of silicone models to develop visuospatial and visuomotor skills, with the aim of demonstrating transfer of these skills from simulation to live animal scanning (Wichtel et al., 2022).

The present study intentionally isolated the skill of anatomical recognition by utilising pre-recorded ultrasound cine loops, thereby removing the psychomotor and technical demands associated with image acquisition. This methodological choice allowed focused evaluation of students' ability to visually recognise normal abdominal anatomy without the confounding influence of probe handling, machine optimisation, or patient-related variability. Accordingly, the findings should be interpreted as reflecting students' foundational visual recognition abilities rather than their capacity to independently perform or interpret ultrasound examinations in a clinical setting.

While accurate identification of normal anatomy represents a prerequisite for meaningful ultrasound interpretation, it does not in itself constitute diagnostic competence. Proficiency in ultrasound additionally requires integration of psychomotor skills, systematic scanning technique, recognition of artefacts, lesion detection, and synthesis of imaging findings within the clinical context. Therefore, improvements in anatomical recognition observed in this study should be viewed as an early step within a broader competency framework, upon which more advanced ultrasound skills must be progressively developed through hands-on training, supervised clinical exposure, and structured competency-based assessment.

4.3.2. Ultrasound knobology and technical image optimisation

Ultrasound knobology, defined as the ability to understand and appropriately manipulate machine controls such as depth, overall and time-gain compensation, focal zone placement, frequency selection, and Doppler settings, constitutes a fundamental technical competency in ultrasound practice. Mastery of these controls directly influences image quality and determines whether acquired images are diagnostically meaningful or potentially misleading, particularly in time-pressured clinical environments such as emergency and point-of-care settings (Jang et al., 2012; Pinto et al., 2013).

Reviews of error in emergency and point-of-care ultrasound consistently identify insufficient understanding of ultrasound equipment, inappropriate transducer or preset selection, and inadequate image optimisation as recurrent contributors to diagnostic failure (Pinto et al., 2013).

Evidence from studies involving sonography students and emergency ultrasound trainees further suggests that novice learners frequently underutilise available optimisation tools, with key machine settings often left unadjusted or unchecked during image acquisition (Jang et al., 2012; Mallard et al., 2022). Moreover, proficiency in knobology has been shown to deteriorate over time in the absence of deliberate practice and structured reinforcement, resulting in preventable technical errors and inefficient use of ultrasound technology (Mallard et al., 2022).

Collectively, this body of literature supports the treatment of ultrasound knobology as an explicit learning objective and assessment domain, rather than an implicit or assumed skill, within veterinary ultrasound education. When teaching point-of-care ultrasound to veterinary students and new graduates, structured training in machine optimisation should be embedded alongside instruction in anatomical recognition and image interpretation. Robust control of ultrasound settings is essential to minimise technical error and to ensure that rapid bedside examinations yield diagnostic-quality images.

In the present study, the ultrasound images used in the teaching material and test videos were carefully reviewed prior to inclusion to ensure that depth, focal zone placement, and overall gain were generally appropriate, and that most images were of good to very good diagnostic quality. This deliberate attention to image optimisation was intended to support accurate anatomical recognition and, implicitly, to familiarise students with examples of well-optimised ultrasound images.

4.3.3. Systematic scanning techniques

Formal guidance outlining the recommended performance and documentation of high-quality abdominal ultrasound examinations in companion animals has recently been published (Seiler et al., 2022). These guidelines provide a structured framework that can support both educators and learners in developing a comprehensive and systematic approach to abdominal ultrasonography. Seiler et al. (2022) specify the anatomical regions that should be assessed during a complete abdominal scan—including the hepatobiliary system, spleen, gastrointestinal tract, pancreas, urinary tract, adrenal glands, reproductive structures, and smaller structures such as abdominal lymph nodes, mesentery, omentum, major vessels, and both peritoneal and retroperitoneal spaces—as well as the recommended still images and cine loops required for documentation.

Although the present study sought to expose students to all major abdominal organ systems, it did not encompass the full breadth of views advocated in these guidelines. For example, only longitudinal images of the liver lobes and kidneys were included, and structures such as the ureters and female reproductive tract (ovaries and uterine horns) were not represented. As such, while the teaching materials aligned broadly with the scope of comprehensive abdominal ultrasound, they did not replicate the systematic coverage expected during a complete clinical examination. This limitation should be considered when interpreting students' recognition performance, as exposure to a wider range of standardised image projections may have further supported anatomical identification.

4.3.4. Recognition of artefacts

Ultrasound examinations routinely generate visual artefacts, some of which can hinder interpretation, whereas others provide clinically useful clues about tissue characteristics. Artefacts therefore occupy an important dual role: they contribute to the diagnostic value of ultrasonography, yet they also represent a potential source of misinterpretation or diagnostic oversight. Most arise when the physical behaviour of sound waves diverges from the simplified assumptions underpinning image formation (Kremkau, 2019). Consequently, a sound understanding of ultrasound physics—and how these deviations produce artefact patterns—is essential for accurate image evaluation and reliable clinical decision-making.

In this study, there were several occasions where sonographic artefacts were present in the teaching and assessment videos. Students encountered a range of artefacts including mirror artefact at the diaphragm–liver interface, reverberation from gas within the gastrointestinal tract, distal acoustic enhancement deep to the gallbladder and urinary bladder, and distal acoustic shadowing originating from faecal material or ribs when scanning intercostally. Student performance for organ 46 (right kidney) may have been negatively affected by these limitations. While the focus of this video was to demonstrate intestinal structures rather than include adjacent liver landmarks needed to guide kidney identification, only part of the kidney was visible and positioned obliquely. In addition, coupling artefact caused focal darkening and a reduction in image resolution. These combined factors likely contributed to the absence of improvement on post-rotation testing. A similar issue was noted for organ 41 (right adrenal gland), where distal acoustic shadowing from faecal content in the transverse colon hindered visibility. Gas, ingesta and faeces are recognised limitations for adrenal evaluation (d'Anjou & Penninck, 2025). Although artefact recognition forms part of the Bristol Vet School curriculum, it remains uncertain whether reduced scores for organs 41 and 46 were driven primarily by artefacts, anatomical complexity or both. Notably, these artefacts are routinely encountered during clinical ultrasonography, meaning their presence reflects real-world scanning conditions that new graduates will face.

During our study, we tested our videos on a second-year diagnostic imaging resident. All their answers were correct, as expected at this stage, except for organ 7 where they answered duodenum when the expected answer was the pylorus.

The difficulty encountered by both students and a second-year diagnostic imaging resident in accurately identifying certain structures, such as the pylorus, highlights that challenges in interpretation may arise not only from learner inexperience but also from suboptimal image presentation or incomplete depiction of anatomical context. This observation underscores that ultrasound test material should ideally be piloted on clinicians with varying levels of expertise prior to formal assessment, to ensure that performance reflects anatomical recognition ability rather than limitations imposed by image quality or acquisition technique.

4.3.5. Detection of lesions and integration of imaging findings into clinical reasoning and decision-making

Lesion detection in ultrasonography requires learners to first internalise the appearance of normal anatomy so that deviations can be recognised and interpreted as abnormal. This ability depends not only on anatomical knowledge, but also on competence in probe manipulation, image optimisation, systematic scanning, and artefact recognition—all of which contribute to obtaining diagnostic-quality images. Effective teaching should therefore combine structured introduction to systematic scanning techniques with visual exemplars of both normal and abnormal findings, followed by supervised hands-on training that reinforces normal organ appearance and develops the skills needed to detect simulated or real lesions.

In the present study, the teaching material was designed to support final-year veterinary students in developing this foundation by providing annotated images to assist with accurate identification of normal abdominal organs.

Once lesions are identified, ultrasound findings must be interpreted within the broader clinical context. Learners must integrate imaging observations with history, physical examination, and laboratory data to formulate differential diagnoses and determine whether additional imaging, further diagnostic testing, or surgical or medical intervention is indicated. Developing this capacity for clinical integration is essential to ensure that ultrasonography informs clinical decision making.

The observed improvement in anatomical recognition following targeted online teaching suggests that this foundational component can be effectively supported through asynchronous learning. However, these results should not be interpreted as evidence of comprehensive diagnostic ultrasound competence. Rather, anatomical recognition should be viewed as a prerequisite skill upon which more advanced technical and interpretative competencies must be built. This distinction is particularly relevant in the context of point-of-care ultrasound (POCUS), where clinicians must rapidly acquire and interpret images under real-world constraints.

The study therefore underscores a broader issue in veterinary ultrasound education: while anatomy recognition can be effectively supported through video-based learning, additional educational strategies are required to develop scanning technique, image optimisation, and lesion recognition skills. Without structured opportunities to integrate these competencies, graduates may struggle to translate theoretical knowledge into clinical practice.

4.4. Role of online and asynchronous learning in ultrasound education

The supplementary teaching material used in this study represents a form of asynchronous, self-directed learning, allowing students to engage with ultrasound content at their own pace and revisit challenging concepts as needed.

4.4.1. Asynchronous online learning in ultrasound education for medical students

A recent meta-analysis evaluating the role of e-learning in point-of-care ultrasound (POCUS) education for medical students reviewed nine studies incorporating asynchronous online learning (Harel-Sterling, 2023). Seven of these were single-group evaluations with no comparison cohort (Chenkin et al., 2008; Krishnan et al., 2013; Ray et al., 2017; Kwan et al., 2020; Brown et al., 2020; Moro et al., 2021; Situ-LaCasse et al., 2021). The remaining two compared asynchronous delivery with traditional teaching formats: a one-day course combining lectures and hands-on practical training (Cuca et al., 2013), and live lectures plus workshops, alongside a reading-only control group (Socransky et al., 2017).

Consistent improvement in post-training performance was reported for image interpretation across the majority of studies (Brown et al., 2020; Chenkin et al., 2015; Cuca et al., 2013; Krishnan et al., 2013; Kwan et al., 2020; Moro et al., 2021). Outcomes for image acquisition were variable: Situ-LaCasse et al. (2021) demonstrated a positive correlation between online module scores and hands-on scanning performance, whereas Ray et al. (2017) reported low-quality image acquisition following asynchronous learning alone. Furthermore, students who received live teaching were more likely to continue using POCUS in subsequent clinical encounters compared to those who completed only online modules (Socransky et al., 2017).

Overall, Harel-Sterling (2023) concluded that the effectiveness of asynchronous e-learning depends on the specific POCUS skill targeted. Online-only training appears well suited for knowledge acquisition and image interpretation but may be insufficient for developing practical image acquisition skills without complementary hands-on experience.

4.4.2. Asynchronous learning in ultrasound education for veterinary students

Evidence supporting asynchronous learning in veterinary ultrasound education remains limited. To date, only two published studies have examined digital or self-directed approaches. One compared an instructional video teaching the A-FAST scan with live instructor-led training (Davy et al., 2019), while the other evaluated equine limb ultrasonography taught through three modalities: asynchronous tutorials, traditional lecture, and textbook-based study (Navas de Solis et al., 2021). Across both studies, asynchronous learning produced knowledge gains comparable to traditional delivery (Davy et al., 2019; Navas de Solis et al., 2021). Practical performance was superior to textbook-based self-study, and largely equivalent to live teaching (Navas de Solis et al., 2021). In Davy et al. (2019), students taught asynchronously performed similarly to those receiving live instruction across most A-FAST views; however, students in the live-training group outperformed their peers in obtaining the diaphragmaticohepatic view.

Beyond ultrasound, several veterinary studies evaluating practical skills training—including animal handling and preparing students for clinical skills laboratory sessions (Catterall et al., 2024), basic surgical skills (Decloedt et al., 2021), cytology sample collection (Marcos et al., 2023), pulmonary patterns recognition (Sukut et al., 2021), and communication skills (Janke et al., 2022) have reported similar findings: asynchronous or flipped-classroom formats associated with in-person practice and feedback can effectively introduce core knowledge and procedural concepts. These blended designs have notably emerged during and after the COVID-19 pandemic to maximise limited contact time and optimise academic staff's time, with online delivery providing foundational cognitive preparation and in-person sessions reinforcing psychomotor execution and clinical decision-making.

Taken together, current veterinary literature suggests that asynchronous learning is a valuable mechanism for knowledge transfer and early skill development, particularly when introducing complex procedures such as ultrasound. However, digital resources alone are unlikely to ensure mastery of image acquisition or interpretation in clinical settings without structured opportunities for supervised practice.

4.4.3. Conclusions regarding the use of asynchronous learning in this study and more generally

Asynchronous learning has become increasingly prevalent in veterinary and medical education, specially following the COVID-19 pandemic, particularly for image-based disciplines such as ultrasound, where training using live-patient/model is deemed essential and where repeated exposure and visual pattern recognition are critical.

The observed improvements in recognition of specific organs following access to online material support the educational value of asynchronous resources for developing cognitive ultrasound skills such as organ recognition. Similar findings have been reported in both veterinary and human medical education, where video libraries, annotated cine loops, and online modules have been shown to enhance learner confidence and knowledge acquisition.

However, asynchronous learning alone is insufficient for developing psychomotor ultrasound skills. The absence of real-time feedback, probe handling practice, and supervised scanning limits its ability to support full competency development. A multimodal approach, combining asynchronous online resources with hands-on training, supervised scanning sessions, and formative feedback, is therefore likely to be most effective. Such an approach also accommodates diverse learning preferences and aligns with contemporary principles of inclusive curriculum design.

4.5. Confidence versus competence in ultrasound education

In the context of ultrasound teaching, confidence refers to a trainee's self-perceived belief in their ability to independently and effectively perform a given task (e.g., acquiring diagnostic images or interpreting sonographic findings) (Gottlieb et al., 2022). Confidence plays a critical role in enabling learners to transfer skills from supervised training to autonomous clinical practice. However, problems arise when confidence and competence diverge. Underconfident clinicians may hesitate to use point-of-care ultrasound even when capable, whereas overconfident practitioners may misinterpret findings or make inappropriate clinical decisions—both of which risk compromising patient care (Gottlieb et al., 2021). Thus, the dynamic relationship between confidence and competence carries significant educational and clinical implications.

An important finding of the present study was the discrepancy between student confidence and actual performance for certain abdominal organs. While confidence generally increased over time and with access to additional resources, it did not always correlate with accurate organ identification. In some cases, students expressed high confidence despite low recognition accuracy, particularly for anatomically challenging structures such as the pylorus and large intestine. This is probably not so much of a problem for the pylorus as students most commonly identified the pylorus as part of the gastrointestinal system (giving "small intestine" as the most common answer). The low accuracy recorded in our study therefore largely reflects the analytical approach adopted, as discussed further in Section 4.7. In contrast, errors related to the large intestine predominantly arose from misclassification as urogenital structures, indicating a more fundamental anatomical misunderstanding. If competence in this area remains low at the point of graduation, such confusion may increase the risk of misinterpretation during clinical scanning and could contribute to inappropriate diagnostic conclusions early in practice.

Recent work has outlined strategies to better align the confidence–competence relationship, including structured discussion with learners to explore the roots of miscalibration—whether due to knowledge gaps, cognitive biases, preconceived assumptions, imposter syndrome, or the influence of hierarchical learning environments (Gottlieb et al 2021). In the present study, because performance analysis occurred after data collection, we could not identify specific individuals exhibiting overconfidence, and therefore no targeted discussion or remediation was undertaken. However, all participants received the correct answers after testing, with the intention of addressing potential knowledge gaps and preventing the persistence of misconceptions.

Overall, these findings underscore the need for robust assessment and feedback systems in ultrasound curricula rather than relying on self-reported readiness alone. Gottlieb et al. (2021) advocate embedding confidence metrics within competency-based frameworks—for example, using confidence-competence ratios within entrustable professional activities—and designing training approaches that actively support optimal alignment between perceived and demonstrated ability.

4.6. Implications for curriculum design and competency-based frameworks

The findings of the present study provide insight into one foundational dimension of ultrasound learning—students' ability to recognise normal abdominal organs on pre-recorded ultrasound cine loops. This focused evaluation was intentionally limited to visual anatomical identification, rather than assessing students' broader ultrasound competencies such as probe manipulation, image optimisation, systematic scanning, or lesion detection. Nonetheless, the patterns observed highlight both strengths and weaknesses in final-year veterinary students' readiness to interpret normal ultrasound appearances and indicate that, while anatomical recognition can be supported effectively through targeted resources, additional training modalities are required to prepare graduates for independent ultrasound scanning.

Accordingly, there is a growing need to define clear and realistic expectations for Day One ultrasound capability within competency-based frameworks. In the introduction, we proposed a framework of Entrustable Professional Activities (EPAs) for ultrasound, outlining foundational competencies suitable for undergraduate training (e.g. correct probe handling, imaging of major abdominal organs, recognition of normal anatomy, POCUS) and advanced competencies more appropriate for postgraduate development (e.g. interpretation of pathological findings, full abdominal protocols). By articulating expectations explicitly, EPAs can ensure that confidence, competence, and professional responsibility develop in parallel.

Importantly, the EPA framework should incorporate both performance assessment and self-evaluation of confidence, as recent literature highlights the potential clinical implications of misaligned confidence and competence (Gottlieb et al 2021). Embedding confidence appraisal encourages students to calibrate their self-belief against objective performance, helping avoid misdiagnosis or underutilisation of ultrasound in practice.

A structured integration of ultrasound across the curriculum is therefore recommended. Foundational skills—particularly probe positioning, image optimisation (including depth, gain and focal zone setting), artefact recognition and identification of normal abdominal anatomy—could be embedded in preclinical study, using ultrasound to reinforce anatomy, physiology, and palpation. Asynchronous digital material, curated image banks, and self-directed scanning sessions could strengthen cognitive mapping before clinical exposure. During clinical years, ultrasound should be applied in relevant contexts such as internal medicine, surgery, and emergency care, not as a standalone discipline. Foundational skills should be repeated simultaneously to expansion of the core competencies to the detection of abnormal findings through supervised scanning, simulation and case exposure. However, exposure to pathology should be managed carefully; while understanding common patterns is valuable (for example, identification of free fluid or small intestinal obstruction), responsibility for diagnosing or excluding disease should remain beyond undergraduate scope and reserved for structured clinical development following graduation.

To support teaching alignment, validated assessment tools are needed. Objective Structured Clinical Examinations (OSCEs), simulation models, and structured workplace-based assessments such as the Objective Structured Assessment of Ultrasound Skills (OSAUS) could evaluate technical skill acquisition and anatomical recognition (Hoppmann et al., 2022; Tolsgaard et al., 2013). These should be complemented by formal self-assessment of confidence, feeding back into personalised learning plans and EPA progression.

Finally, it is essential that responsibility for developing deeper ultrasound competence extends beyond veterinary school. Full abdominal examinations, interpretation of specific disease patterns, and integration of ultrasound findings into case management are more realistically placed within the Vet Graduate Development Programme (VetGDP) or equivalent early-career stages, supported by trained supervisors and access to structured CPD or postgraduate certification. Such an approach both protects patient safety and recognises the time required to achieve proficiency with a complex, operator-dependent imaging modality.

Taken together, these findings underscore that ultrasound education should follow a continuum of learning, beginning with foundational recognition of normal anatomy during undergraduate studies and advancing towards diagnostic and interpretative competence through structured early-career development. Establishing explicit expectations through EPAs, embedding confidence evaluation, expanding learning opportunities, and monitoring performance through validated assessment tools will ensure graduates enter practice prepared to learn safely, rather than being assumed competent in a skill that has not yet been fully mastered.

4.7. Limitations and future directions

While this study provides insight into the use of online teaching material for veterinary abdominal ultrasound, several methodological and pedagogical limitations must be considered. The following subsections explore these issues in detail. First, we reflect on the study design and cohort comparisons, including the implications of an A versus A+B format. Second, we discuss the approach to response interpretation and scoring, highlighting how assessment criteria may have influenced outcomes. Third, we examine the teaching resources themselves, including content structure, slide allocation, and multimodal elements. Fourth, we consider technical factors and scanning conditions, such as transducer type and canine body conformation, that may have affected image quality and student performance. Finally, we outline recommendations and directions for future research aimed at enhancing the rigour, clinical relevance, and educational impact of ultrasound training for veterinary students.

4.7.1. Study design and cohort comparison

This study evaluated the impact of online teaching material as an adjunct to existing instruction by enrolling two student cohorts: a test group with access to the resource and a control group without access. This created a comparison of A (diagnostic imaging rotation week alone) versus A+B (rotation week plus online teaching material). However, experts in veterinary education caution against this type of design where an intervention is added on top of standard teaching, as A+B is generally expected to outperform A (Hunt et al., 2022). Instead, they recommend evaluating one teaching modality against another—for example, online material versus textbook reading, lecture attendance, or face-to-face instruction.

In our study, the theoretical assumption that A+B would consistently outperform A was not supported across all abdominal structures. Access to the online material did not significantly enhance the test students' ability to identify commonly recognised organs, including the kidneys, urinary bladder, spleen, liver, and stomach—likely because baseline recognition in both groups was already strong. Conversely, test students demonstrated improved identification and retention for more challenging structures such as the gallbladder, pancreas, prostate, and major blood vessels. This effect is consistent with the expected outcomes of an A+B vs A design, suggesting that supplemental resources may be particularly valuable when addressing less familiar anatomy.

Similarly, the online material improved the accuracy of gastrointestinal tract identification, indicating that structured visual learning may support understanding of more complex or nuanced anatomical segments. Taken together, these findings suggest that the added benefit of online teaching material is organ-specific rather than universal.

The same pattern emerged when analysing students' self-reported confidence. Test students were significantly more confident than controls in identifying only certain structures—namely the kidney, spleen, pancreas, lymph nodes and blood vessels at post-rotation tests. This variability highlights the need for further work to clarify where online tools offer the greatest benefit and how best they can be incorporated into existing teaching frameworks.

4.7.2. Response interpretation and scoring framework

To analyse student responses, we applied a binary scoring system in which answers were classified as either correct or incorrect. For vascular and lymphatic structures, any response indicating recognition of a vessel or a lymph node was accepted as correct. For example, naming the caudal vena cava as the “aorta” was considered acceptable. Although this approach does not differentiate between specific vessels (such as the portal vein or mesenteric arteries) or individual lymph node groups, we considered this an appropriate level of knowledge for final-year students. In first-opinion practice, abnormalities affecting these structures are frequently referred for specialist imaging, and therefore broad recognition rather than precise naming was deemed sufficient at this point in training.

In contrast, gastrointestinal structures were assessed using more exacting criteria. Students were expected to differentiate between key regions of the gastrointestinal tract based on anatomical position and wall layering characteristics—specifically the stomach (typically left-sided with visible rugal folds), pylorus (right-sided with a prominent submucosa), small intestine (mid-abdominal with a thicker wall where mucosa comprises approximately two-thirds of total thickness), and large intestine (thinner wall with layers of similar thickness) (Agut, Wood & Martin, 1996; Penninck & d’Anjou, 2015a). As discussed previously, given the frequency with which vomiting, diarrhoea, and suspected intestinal obstruction present in first-opinion practice, the ability to correctly distinguish between small and large intestine is clinically significant. Misclassification may obscure early recognition of foreign material lodged within the small intestine—where urgent intervention can be lifesaving (Hayes, 2009)—versus shadowing caused by faecal content in the large intestine, which carries very different management implications. Allowing any portion of the gastrointestinal tract to be scored as correct, regardless of the region presented, would likely have improved students’ performance. However, we deliberately retained stricter criteria to better reflect the diagnostic distinctions that new graduates are expected to apply when interpreting abdominal ultrasound in clinical practice.

4.7.3. Teaching resource design and image selection

The educational resources provided in this study comprised narrated PowerPoint presentations, offering students a flexible, accessible, and low-cost means of engaging with ultrasound material at their own pace. These presentations were developed using a standardised format and combined multiple complementary visual modalities. Schematic diagrams extracted from *Miller's Anatomy of the Dog* (Hermanson, de Lahunta, Evans, 2019) were used to reinforce core anatomical concepts, while selected computed tomography (CT) images were included to illustrate three-dimensional (3D) organ topography and spatial relationships within the abdomen. Annotated ultrasound stills and cine loops were embedded to demonstrate the sonographic appearance of abdominal organs and highlight adjacent landmarks that support organ localisation during live scanning.

This multimodal approach aligns with recent findings in anatomy education, where printed and electronic resources have been rated as helpful in supporting anatomical recall and conceptual understanding (Abdullah et al., 2021). In that study, cadaveric prosection was perceived as the most valuable format, but its omission in the current project was a deliberate pedagogical choice, as the primary aim was to develop students' ability to recognise abdominal organs on ultrasound rather than teach gross anatomy directly. The learning design incorporated several cognitive load management principles, including segmentation and isolated element presentation (Sweller, 2011): labelled still images were introduced prior to dynamic ultrasound videos, enabling students to first anchor visual recognition before interpreting more complex spatial relationships in motion.

The optimal diagnostic imaging modality for teaching anatomy in the veterinary curriculum remains a subject of debate. Survey-based studies have reported that veterinary and medical students often perceive radiographs as more important than CT to understand the anatomy, whereas practising veterinary surgeons favour CT as the most informative modality (Delisser & Carwardine, 2018; Jack & Burbridge, 2012; Sheikh et al., 2016). The inclusion of CT in this project was based on the premise that cross-sectional imaging supports students in conceptualising organ geometry and positional relationships, thereby strengthening their ability to interpret corresponding ultrasound images. Meanwhile, embedding ultrasound videos was intended to approximate the practical experience of real-time scanning without requiring staff supervision. This aligns with a medical education study in which students expressed a preference for live or video-based ultrasound to support anatomical learning compared with lectures, textbooks, or 3D datasets (Bowman et al., 2016).

Informed by student recommendations (Delisser & Carwardine, 2018), CT images within the teaching modules were labelled consistently across dorsal, sagittal, and transverse planes, and ultrasound stills and videos were annotated extensively to maximise clarity. This design reflects the worked-example principle of cognitive load theory, whereby learners benefit from observing expert-prepared solutions paired with visual guidance rather than independently finding the solution (Sweller, 2011). A limitation of the current materials is that ultrasound examples predominantly depicted organs in long-axis orientation, with fewer short-axis views presented. While this may have constrained students' exposure to the full range of standard imaging planes, alignment between teaching and testing formats ensured that assessment remained fair and internally consistent.

A further limitation relates to variation in slide volume across organ presentations. Organs widely perceived as Day One Competences were associated with comparatively shorter presentations (e.g., liver and gallbladder: 8 slides; spleen: 11 slides; kidneys: 9 slides; urinary bladder: 7 slides), whereas other organs received considerably greater emphasis (e.g., pancreas: 16 slides; major abdominal vessels: 17 slides; abdominal lymph nodes: 12 slides). This likely reflects an unconscious assumption by the researcher regarding students' baseline knowledge, such that "routine" structures were allocated less instructional time. Whether differing slide allocation influenced performance—positively or negatively—remains unclear and warrants systematic exploration in future work.

4.7.4. Technology, transducers and scanning conditions

Image selection represents an additional consideration. All teaching videos were acquired from young, small-breed, lean dogs using a high-frequency linear transducer. Linear probes typically operate between 9–18 MHz, generating images with high spatial resolution but reduced depth penetration, whereas microconvex probes commonly used in general practice operate at 5–8 MHz and provide broader field of view with lower resolution (Berry & Mauragis, 2015). Consequently, students were exposed predominantly to ultrasound images of exceptionally high clarity, which may not reflect the range of image quality encountered in clinical settings.

During practical sessions, the test group used an ultrasound machine equipped with linear probes, while the control group used a portable unit featuring both linear and microconvex transducers. Test students may therefore have benefited from continuity between their online learning and hands-on experience. Conversely, it could be argued that the use of higher-resolution probes enhanced learning opportunities for both groups by making anatomical structures easier to visualise. Further studies are needed to evaluate systematically how transducer type influence the development of novice ultrasound skills.

Finally, variation in canine body conformation may have influenced students' performance. It is well-established that pancreas identification becomes increasingly challenging as body condition score rises owing to reduced contrast between the gland and surrounding mesentery and fat (Mattoon, Berry & Nyland, 2015). In contrast, adrenal glands may be easier to detect in overweight animals due to enhanced retroperitoneal fat providing improved anatomical separation from the aorta (d'Anjou & Penninck, 2015). The dogs used for our teaching and assessment videos generally displayed body conditions beneficial to visualising the pancreas, potentially simplifying identification for students relative to typical clinical scenarios. Future research should evaluate student proficiency when scanning a wider range of body sizes and conformations, thereby better reflecting the diversity of cases encountered in practice.

4.7.5. Implications and future research directions

Based on our findings and experience, we would recommend to:

- Pilot ultrasound test videos with veterinarians of varied experience to refine content and difficulty.
- Incorporate focus groups or interviews after testing to explore reasoning behind correct and incorrect answers, improving understanding of how students interpret ultrasound cues.

- Consider test design carefully: in this study, students completed open-ended answer sheets, but results may differ with multiple-choice or drop-down formats. Test structure should align with the specific research question.
- Examine how online modules interface with simulation-based teaching, cadaver scanning and live animal work to support a progressive acquisition of clinical imaging capability.

Collectively, these recommendations aim to guide more rigorous and clinically relevant evaluation of ultrasound teaching, ensuring that undergraduate training translates effectively into competent, confident practice.

Conclusion

In conclusion, the analysis of final-year veterinary students' performance in identifying abdominal organs during their diagnostic imaging rotation week demonstrates both strengths and areas requiring continued development. The test group exhibited clear improvement in knowledge and retention for key abdominal organs, particularly those aligned with RCVS Day One Competences. These gains were evident at both short- and longer-term assessments and were most notable for the pancreas, spleen, and blood vessels, where test students outperformed the control cohort.

However, challenges persisted in recognising more complex or less commonly emphasised structures, including the pylorus, large intestine, and mesenteric lymph nodes. These findings indicate that while students developed confidence and competency in identifying several core organs, accurate recognition of all abdominal structures remains inconsistent.

The teaching materials and methods used — narrated PowerPoint sessions supported by annotated CT and ultrasound images — appeared effective in reinforcing sonographic anatomy. Nonetheless, several contextual limitations may have influenced outcomes, including variation in slide content, ultrasound transducers, and cine-loop quality. These considerations highlight opportunities to further refine and standardise teaching resources.

Importantly, the study evaluated students' ability to recognise **normal abdominal anatomy**, which represents a foundational but partial component of the broader skills required to perform diagnostic ultrasound. Competence in image acquisition, interpretation of artefacts, and recognition of common pathological findings were outside the scope of this investigation and remain essential future targets for curriculum development.

Overall, the study contributes evidence supporting the value of structured and supplemented teaching in improving anatomical recognition on ultrasound and identifies areas where additional training and practical exposure are needed. Rather than concluding that students are fully prepared for clinical ultrasound, the findings highlight a progressive developmental pathway and the need for continued educational reinforcement to ensure graduates ultimately achieve the full range of competencies required for diagnostic ultrasound practice.

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Appendix 1: Emails sent to the final year students.

1. Email sent to the final year students of the test students group.

Good afternoon,

You will attend your Imaging rotation next week and we look forward to meeting you.
As part of your training, we would like to invite you to take part in our research project on 'How useful is a specific training on sonographic anatomy for identification of the pancreas on cine loops of ultrasound by final year veterinary students?' This project forms part of my Master's degree and residency training.

Currently, ultrasound of the pancreas is not considered as a RCVS day one competency. So, teaching priority is given to other abdominal organs (spleen, liver, kidneys, gastrointestinal tract and urinary bladder). The aims of this study are to assess your ability and confidence in identifying abdominal organs (in particular the pancreas) on ultrasound videos before and after a specific training. This is an educational project, and your participation is entirely voluntary. This means that it is up to you to decide whether you wish to take part. If you agree to take part of this study, you will be asked to participate in the specific training and answer short quizzes relating to the videos you watch.

This study will be anonymised, and it will not be possible to identify any individual participant in the final dataset. Moreover, the results of this study will not count in your final rotation grading, so there is no pressure on you to get the answers right!

Should you wish to withdraw from the study, you can do it at any time by sending me an email (XXXXXXX@bristol.ac.uk).

Please find attached the participation information sheet and consent form. I would ask you to read the information sheet and, if you are happy to take part, send me back the signed consent form before the end of next week to my email address XXXXXXX@bristol.ac.uk.

Participation in the study is one way for you to refresh your memory on anatomy, expand your knowledge on ultrasound, and learn from additional teaching material that will be helpful in your future career. We would value your participation; however please remember it is a voluntary study and participation (or not) is entirely your decision.

If you have any questions, please feel free to ask me.

Best wishes,
Emilie

2. Email sent to the final year students of the control students group.

Good morning,

You are about to start your Imaging rotation week and we look forward to meeting you.
As part of your training, we would like to invite you to take part in our research project on 'How useful is a specific training on sonographic anatomy for identification of the pancreas on cine loops of ultrasound by final year veterinary students?' This project forms part of my Master's degree and we are now entering a new phase with the recruitment of control students.

Currently, ultrasound of the pancreas is not considered as a RCVS day one competency. So, teaching priority is given to other abdominal organs (spleen, liver, kidneys, gastrointestinal tract and urinary bladder). The aims of this study are to assess your ability and confidence in identifying normal abdominal organs on ultrasound videos before and after your week in Diagnostic Imaging. This is an educational project, and your participation is entirely voluntary. This means that it is up to you to decide whether you wish to take part.

If you agree to take part of this study, you will be asked to answer short quizzes on ultrasound videos (about 15 minutes) at the start and at the end of your rotation week in Diagnostic Imaging and 6 weeks after that. Please find the link to the test videos here: (link inserted here).

After completion of the 6+ weeks quiz, you will have access to the additional teaching material made available for the last two cohorts of final year students. You will also be able to save a pdf version for your records.

This study will be anonymised, and it will not be possible to identify any individual participant in the final dataset. Moreover, the results of this study will not count in your final rotation grading, so there is no pressure on you to get the answers right!

Should you wish to withdraw from the study, you can do it at any time by sending me an email (XXXXXXX@bristol.ac.uk).

Please find attached the participation information sheet and consent form. I would ask you to read the information sheet and, if you are happy to take part, send me back the signed consent form before the end of next week to my email address XXXXXXX@bristol.ac.uk.

Participation in the study is one way for you to refresh your memory on anatomy, expand your knowledge on ultrasound, and learn from additional teaching material that will be helpful in your future career. We would value your participation; however please remember it is a voluntary study and participation (or not) is entirely your decision.

If you have any questions, please feel free to ask me.

Best wishes,
Emilie

Appendix 2: Consent form

Bristol Veterinary School
Emilie Paran
[redacted]@bristol.ac.uk

University of BRISTOL

CONSENT FORM

How useful is a specific training on sonographic anatomy for identification of the pancreas on cine loops of ultrasound by final year veterinary students?

Please answer the following questions to the best of your knowledge

	YES	NO
DO YOU CONFIRM THAT YOU:		
• are a final year veterinary student?	☐	☐
• are going to attend your imaging rotation week?	☐	☐
HAVE YOU:		
• been given information explaining about the study?	☐	☐
• had an opportunity to ask questions and discuss this study?	☐	☐
• received satisfactory answers to all questions you asked?	☐	☐
• received enough information about the study for you to make a decision about your participation?	☐	☐
DO YOU UNDERSTAND: that you are free to withdraw from the study and free to withdraw your data prior to publication		
• at any time?	☐	☐
• without having to give a reason for withdrawing?	☐	☐

I hereby fully and freely consent to my participation in this study

I understand the nature and purpose of the procedures involved in this study. These have been communicated to me on the information sheet accompanying this form.

I understand and acknowledge that the investigation is designed to promote scientific knowledge and that the University of Bristol will use the data I provide for no purpose other than research.

I understand the data I provide will be kept **confidential**. My name or other identifying information will not be disclosed in any presentation or publication of the research.

I understand that the University of Bristol may use the data collected for this project in a future research project but that the conditions on this form under which I have provided the data will still apply.

Participant's signature: ______________________ Date: __________

Name in BLOCK Letters: ______________________

Final consent
Having participated in this study

I agree to the University of Bristol keeping and processing the data I have provided during the course of this study. I understand that these data will be used only for the purpose(s) set out in the information sheet, and my consent is conditional upon the University complying with its duties and obligations under the Data Protection Act.

Participant's signature: ______________________ Date: __________

Name in BLOCK Letters: ______________________

If you have any concerns related to your participation in this study, please direct them to the Faculty of Health Science Student Research Ethics Committee (HSSREC), via the Research Governance Team; research-governance@bristol.ac.uk

Appendix 3: Participant Information Sheet

Faculty of Health Science

PARTICIPANT INFORMATION SHEET

University of BRISTOL

Participant Information Sheet

Project title:
How useful is a specific training on sonographic anatomy for identification of the pancreas on cine loops of ultrasound by final year veterinary students?

Invitation paragraph

As a final year BVSc student, we are inviting you to take part in our research project. Before you decide whether or not to participate, we would like you to understand why the research is being conducted and what it would involve for you. Talk to others about the study if you wish. Please ask us questions if anything is unclear.

What is the purpose of the project?

Currently, ultrasound of the pancreas is not considered as a RCVS day one competency. Teaching priority is therefore given to the other abdominal organs that are considered easier to recognise (e.g. spleen, liver, kidneys, gastrointestinal tract and urinary bladder).

The aims of this study are:
- To assess the confidence of final year veterinary students starting the diagnostic imaging rotation in ultrasonographic identification of the canine pancreas and other abdominal organs on cine loops videos.
- To train students with additional online teaching material (anatomy reminders, static ultrasonographic images and videos) in the imaging week and then to reassess their confidence at the end of the rotation (short term memory) and 6 weeks after (longer term memory).
- To determine whether identification of the pancreas on ultrasound could be considered a day one competency for veterinary practice (currently this is not the case).

This is part of my Masters' thesis on Imaging of the pancreas.

Why have I been invited to participate?

We would really appreciate students taking part in this study as it has a significant impact on the future of teaching ultrasonography to undergraduates, a common diagnostic imaging modality for any future General Practitioner. All students from the BVSc class 2023-2024 will be invited to participate at the beginning of their Imaging rotation week.

Version 1.5 15.10.15

From your perspective, as part of this study we will make additional teaching resources available to you, which have been designed to increase your confidence in recognising a wide range of abdominal organs on ultrasound scans.

Do I have to take part?

Participation in this study is entirely voluntary and it is up to you to decide whether you wish to take part. We will describe the study and go through this information sheet with you before you participate, and we can answer any questions you might have. If you agree to take part, we will then ask you to sign a consent form. You will be asked to answer 3 quizzes (estimated duration for each one is 30 minutes, including watching the videos and completing the quiz): one at the beginning and at the end of your Imaging rotation week and a third 6 weeks after. You are free to withdraw at any time, without giving a reason. Your answers will not be assessed and participation (or not) in the study will not be linked to your assessment for the imaging week. Should you wish to withdraw from the study, you can do it at any time by sending me an email ([redacted]**@bristol.ac.uk).**

What will happen to me if I take part and what will I have to do?

The study is in the **control student recruitment phase**.

1) You will be asked to complete a short questionnaire when starting the imaging rotation giving your imaging/anatomy knowledge and background (e.g. any additional imaging courses/conferences you have attended). You will also complete a short spot quiz requiring you to identify the pancreas and other abdominal organs on a series of ultrasound videos – approximately 30 minutes.

2) During the imaging rotation, when in the ultrasound room, you will be shown specific landmarks for identification of the pancreas (using the stomach to identify the pylorus, the duodenum and then the pancreas) and other abdominal organs using clinical cases presenting to the imaging service. You will not be asked/expected to find the pancreas or other abdominal organs yourself on these dogs.

3) At the end of the rotation, you will watch the videos again and complete a 2nd copy of the quiz – approximately 30 minutes.

4) A third quiz will be emailed to you 6 weeks after your imaging rotation.

5) The online teaching material (72 minutes split in 10 videos) displayed for the last two cohorts of final year students will be made available for you to review and you will be able to save a pdf version.

What are the possible disadvantages and risks involved in taking part in the project?

There will be no disadvantages/risks for students as the results of the questionnaire/quiz will not be taken into account in any assessment.

Version 1.5 15.10.15

What are the possible benefits of taking part?

Dogs presented with gastrointestinal signs (vomiting, diarrhoea, inappetence) are very common in general practice. To determine the cause of the clinical signs (gastrointestinal tract, pancreas, liver, other), it may be indicated to perform an abdominal ultrasound. Students enrolled in this study will have additional teaching material which is expected to improve their confidence in identifying the pancreas (not currently a day one competency) in addition to other abdominal organs you will see in the videos. The results of this study may change the training and teaching of future undergraduate veterinary students.

Will my participation in this project be kept confidential?

You will be asked to answer a questionnaire on your imaging 'background' and level of interest in abdominal ultrasound. You will watch ultrasound video clips to identify abdominal organs (including the pancreas) and then answer questions including identifying organs (e.g. pancreas, liver, stomach etc…) and the confidence in your answer (1: not confident – 5: very confident).
Student information and answer sheets will initially be 'pseudo-anonymised' to be able to link your information to all your answer sheets in the first part of the study. An Excel spreadsheet will contain your name and a number linked to you (e.g. 1, 2, 3 etc..). At the end of the data gathering period, this Excel spreadsheet will be deleted. So, it will not be possible to identify any individual participant through the numbering of the answer sheets.
We will consult and comply with the University's guidance on information security: http://www.bris.ac.uk/infosec/uobdata/research/. Data will be kept in a repository (password -protected UoB server) for long term storage. At that point, it will not be able to identify any individual student from data held.

What will happen to the results of the research project?

The results of this study will be part of my Masters' thesis on Imaging of the pancreas. This will be free to access online on the Glasgow University website. The results of this study may be published in a veterinary education journal. An email will be sent to all participants to inform them about the outcome of this study. No student will be individually identifiable in any publications resulting from this work.

Who is organising and funding the research?

No funding is involved in this research project.

Who has reviewed the study?

The design of this study has been reviewed by Chris Warren-Smith and Kate Bradley (Langford Vets, University of Bristol) and Ian Ramsay (University of Glasgow).
The project design has undergone ethical review by the Faculty of Health Sciences

Further information and contact details

Participants may contact me via my email address: [redacted]@bristol.ac.uk.

Version 1.5 15.10.15

If participants have any concerns related to your participation in this study, please direct them to the Faculty of Health Science Research Ethics Committee, via the Research Governance Team, research-governance@bristol.ac.uk

Appendix 4: Answer sheet provided to the students.

Student Name:

Date:

Student Answer sheet

Identify the abdominal organs marked with a number on the ultrasound videos and rate your confidence in their identification (1: not confident – 5: very confident)

Please send your completed answer sheet by email to Emilie XXXXXXX@bristol.ac.uk

Video 1:

Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Video 2:

Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
4		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
5		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Video 3:

Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
4		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Video 4:

Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
4		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
5		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
6		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Video 5:

Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
4		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Video 6:

Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Video 7:

Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
4		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
5		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
6		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Video 8:

Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
4		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Video 9:

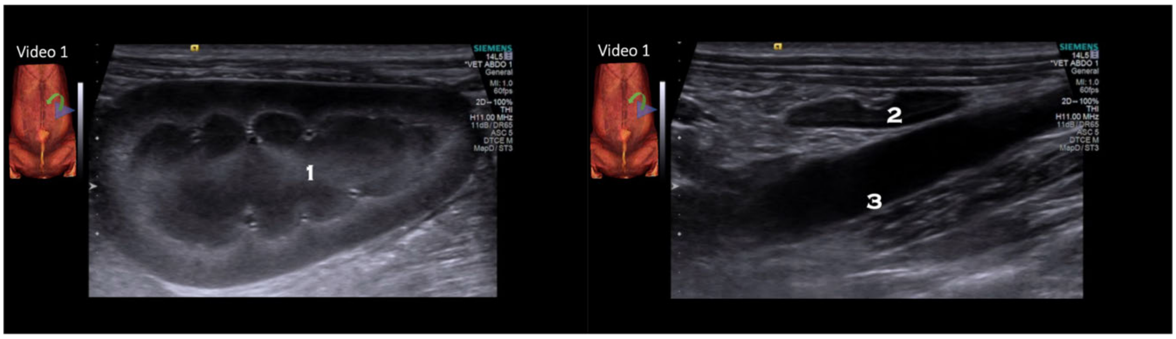
Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
4		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
5		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
6		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
7		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Video 10:

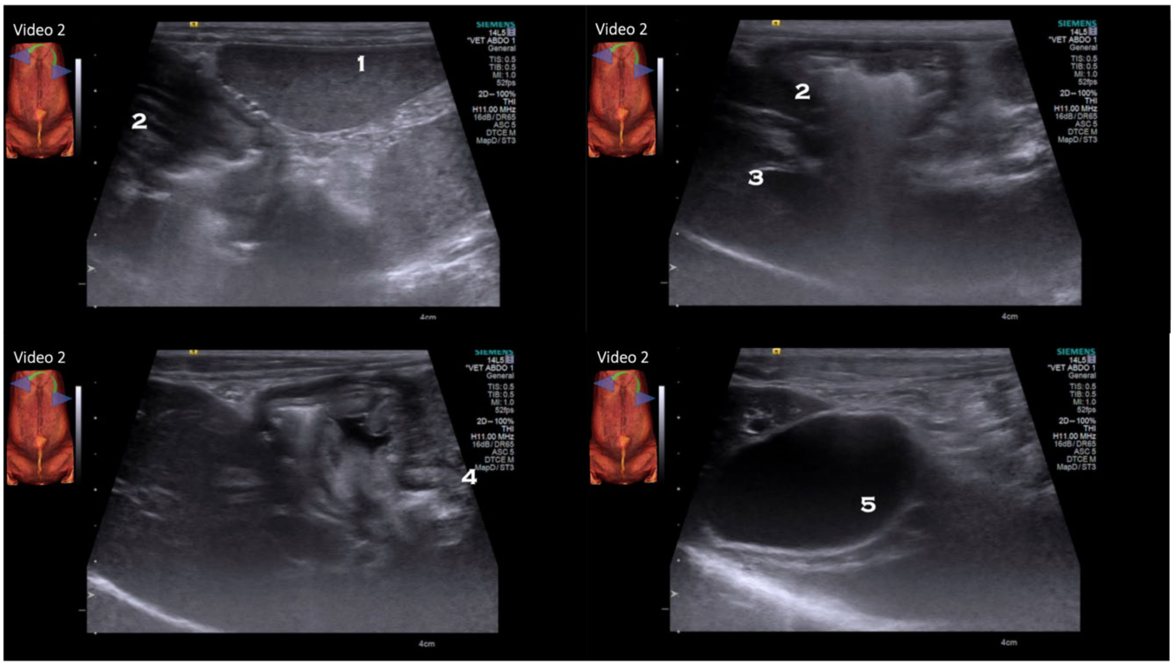
Number	Abdominal organ	Confidence
1		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
2		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
4		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
5		1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Appendix 5: Screenshot of the labelled abdominal organs on the ultrasound test videos

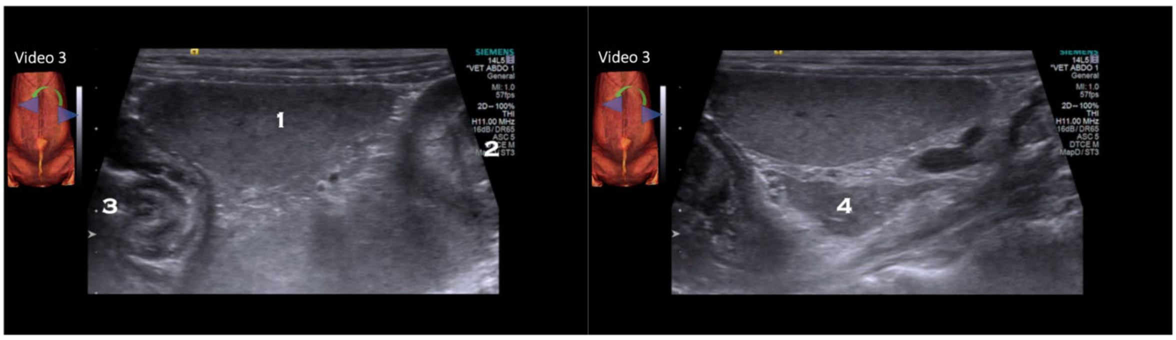
Video 1 shows the left kidney (1), the left adrenal gland (2) and a long axis view of the abdominal aorta (3).



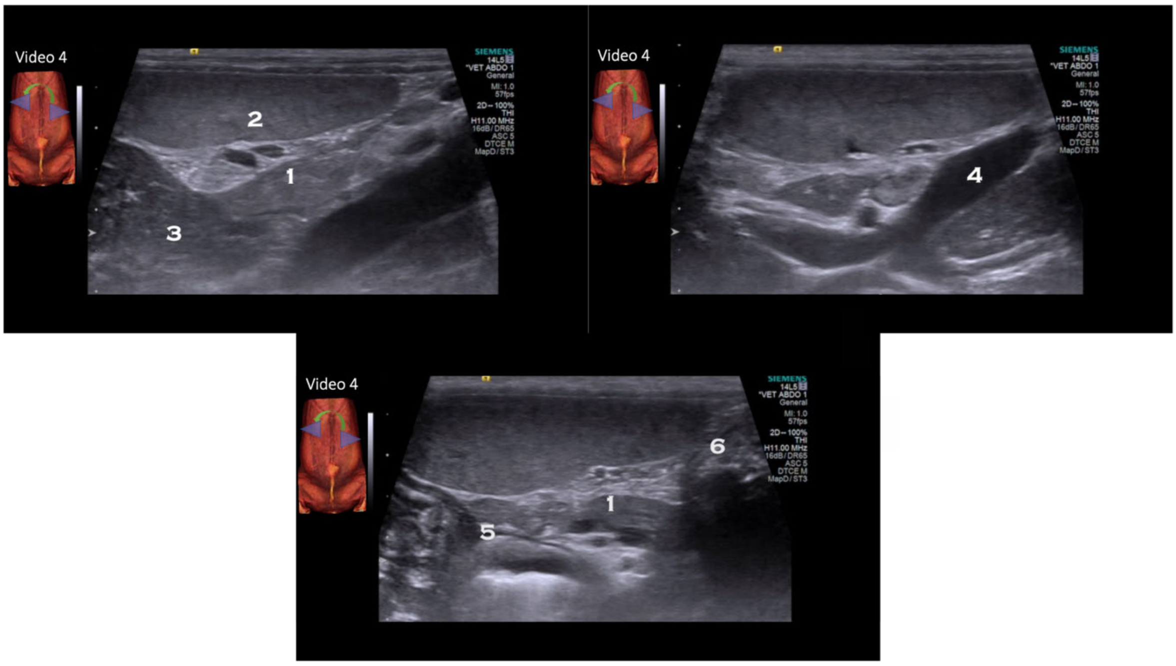
Video 2 shows the spleen (1), the stomach (2), the liver (3), the pylorus (4) and the gallbladder (5).



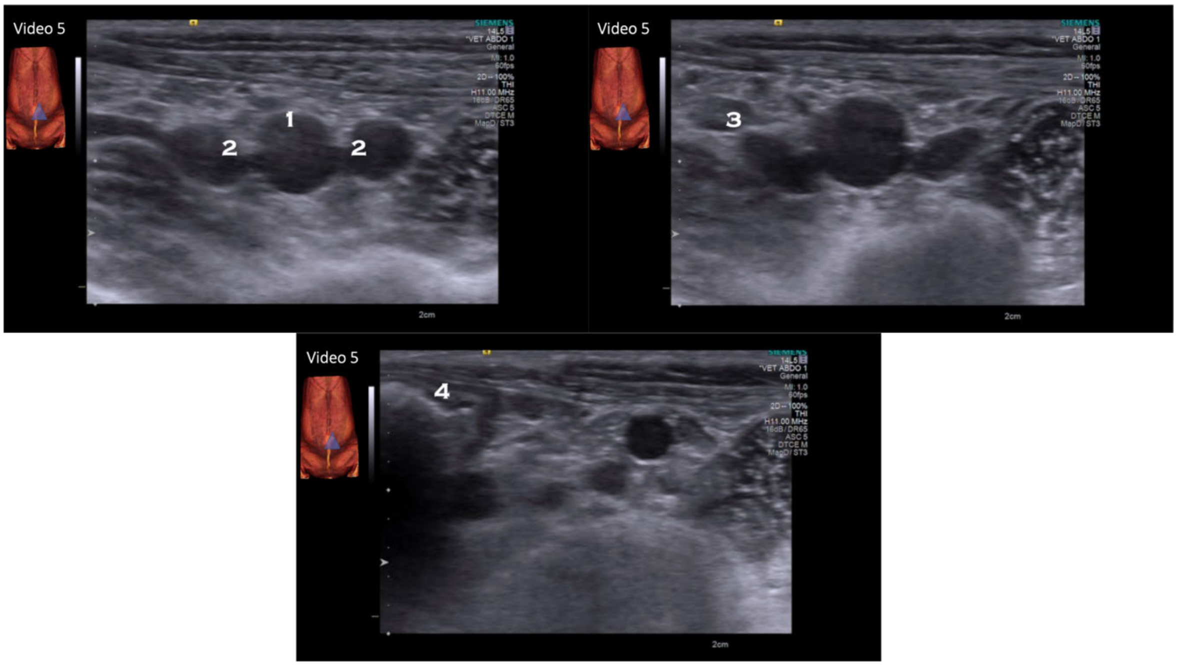
Video 3 shows the spleen (1), the left kidney (2), the stomach (3) and the left pancreatic lobe (4).



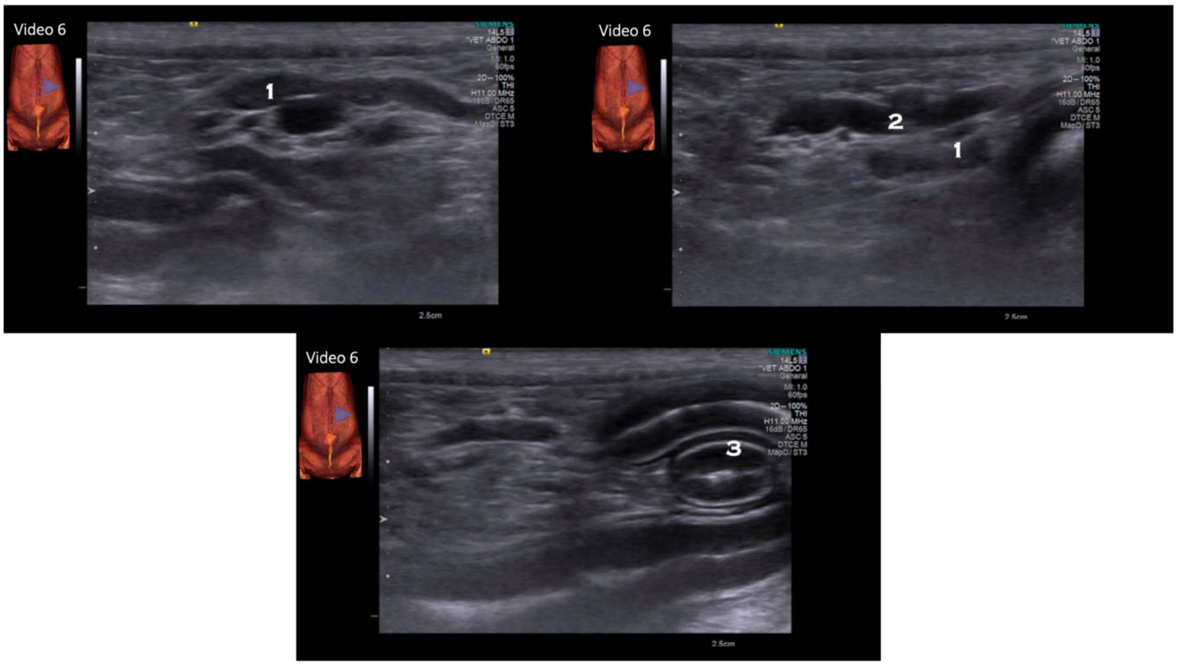
Video 4 shows the pancreatic body (1), the spleen (2), the liver (3), the portal vein (4), the pylorus (5), the transverse portion of the colon (6).



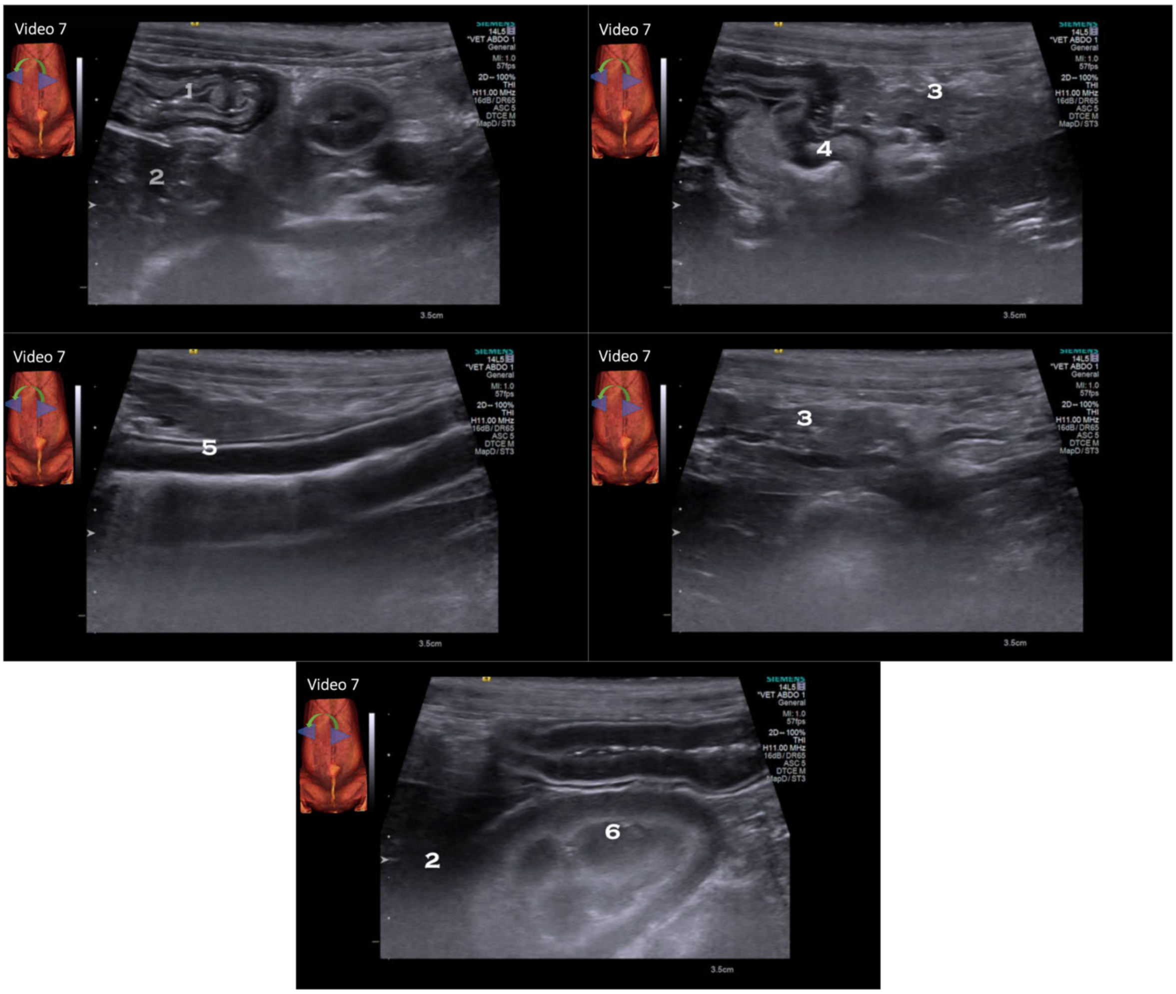
Video 5 shows the aorta (1), the caudal vena cava (2), the medial iliac lymph node (3) and the descending portion of the colon (4).



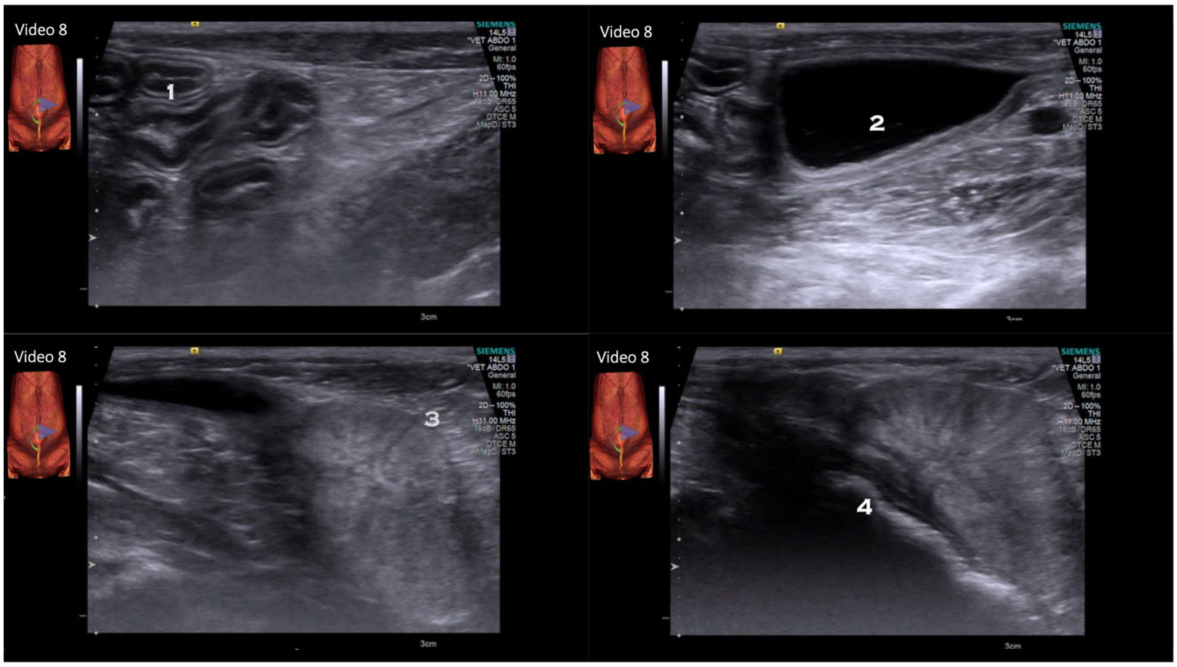
Video 6 shows one of the mesenteric lymph nodes (1), the mesenteric vessels (2), and a portion of the small intestine (3).



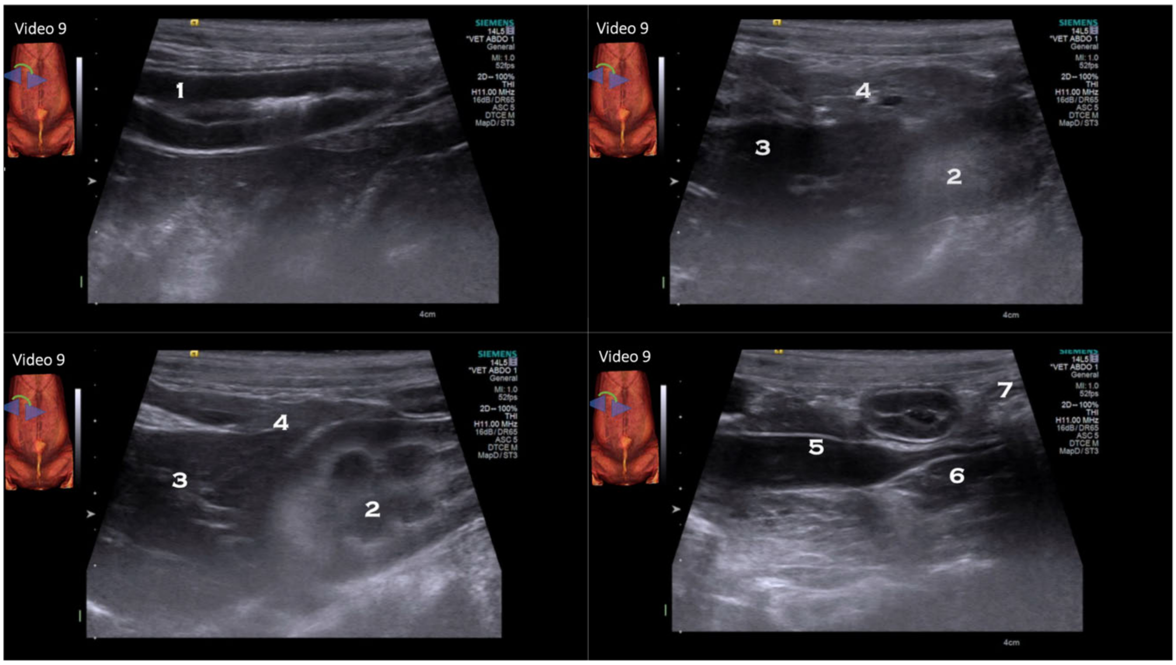
Video 7 shows the stomach (1), the liver (2), the right pancreatic lobe (3), the pylorus (4), the descending portion of the duodenum (5), and the right kidney (6).



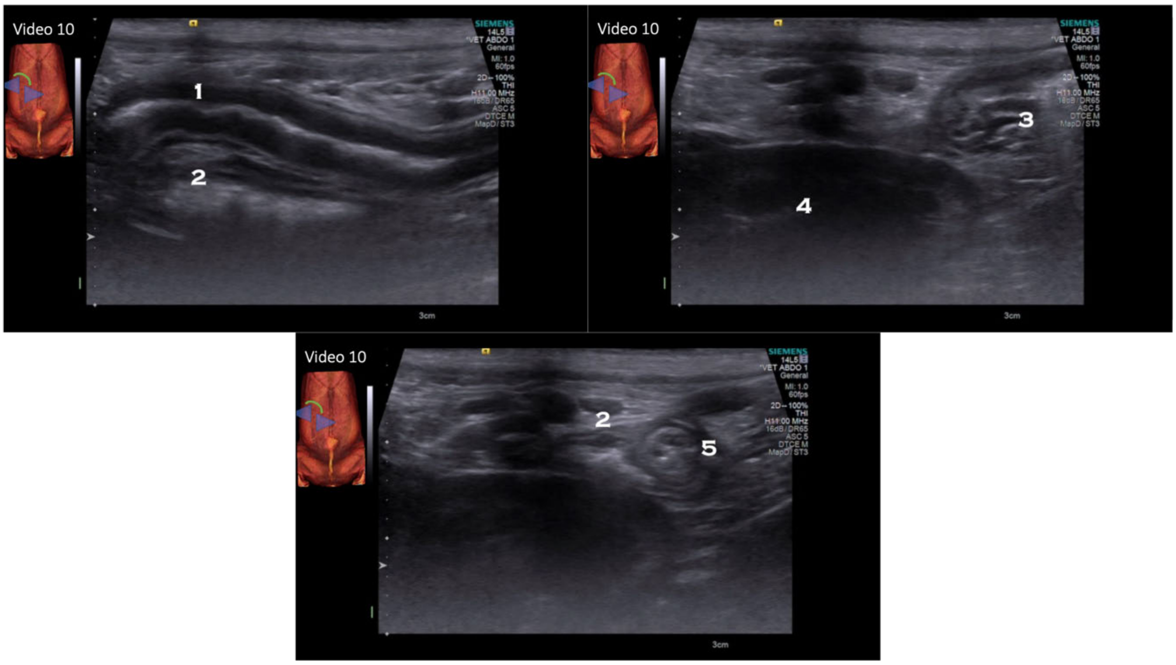
Video 8 shows portions of small intestinal loops (1), the urinary bladder (2), the prostate (3) and the descending portion of the colon (4).



Video 9 shows the descending duodenum (1), the right kidney (2), the liver (3), the right pancreatic lobe (4), the caudal vena cava (5), the right adrenal (6), and the colon (7).



Video 10 shows small intestinal loops (1), the ascending part of the colon (2), a portion of the small intestine (ileum, 3) going to the ileocaecocolic junction (5) and the right kidney (4)


Video 10
1
2
3cm
Video 10
3
4
3cm
Video 10
2
5
3cm

Appendix 6: Numbering system of the abdominal organs for analysis.

Video number	Organ number in video	Organ number for analysis	Abdominal organ
1	1	1	Left kidney
	2	2	Left adrenal
	3	3	Aorta
2	1	4	Spleen
	2	5	Stomach
	3	6	Liver
	4	7	Pylorus
	5	8	Gallbladder
3	1	9	Spleen
	2	10	Left kidney
	3	11	Stomach
	4	12	Pancreas (left)
4	1	13	Pancreas (body)
	2	14	Spleen
	3	15	Liver
	4	16	Portal vein
	5	17	Pylorus
	6	18	Colon (transverse)
5	1	19	Aorta
	2	20	Caudal vena cava
	3	21	Medial iliac lymph node
	4	22	Colon (descending)
6	1	23	Mesenteric lymph node
	2	24	Mesenteric vessels
	3	25	Small intestine (jejunum)
7	1	26	Stomach
	2	27	Liver
	3	28	Pancreas (right)
	4	29	Pylorus
	5	30	Duodenum (descending)

	6	31	Right kidney
8	1	32	Small intestine (jejunum)
	2	33	Urinary bladder
	3	34	Prostate
	4	35	Colon (descending)
9	1	36	Duodenum (descending)
	2	37	Right kidney
	3	38	Liver
	4	39	Pancreas (right)
	5	40	Caudal vena cava
	6	41	Right adrenal
	7	42	Colon
10	1	43	Small intestine
	2	44	Colon (ascending)
	3	45	Small intestine (ileum)
	4	46	Right kidney
	5	47	ICCJ

Appendix 7: Liver and gallbladder PowerPoint slides. Slides 7 and 8 are videos. Four screenshots of the main teaching points were made from those slides for the purpose of this manuscript.

1.
Liver, Gallbladder

1

1. Liver, Gallbladder

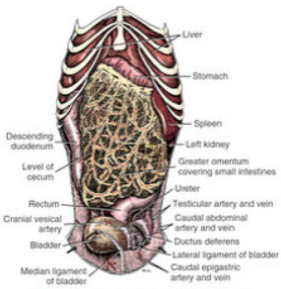
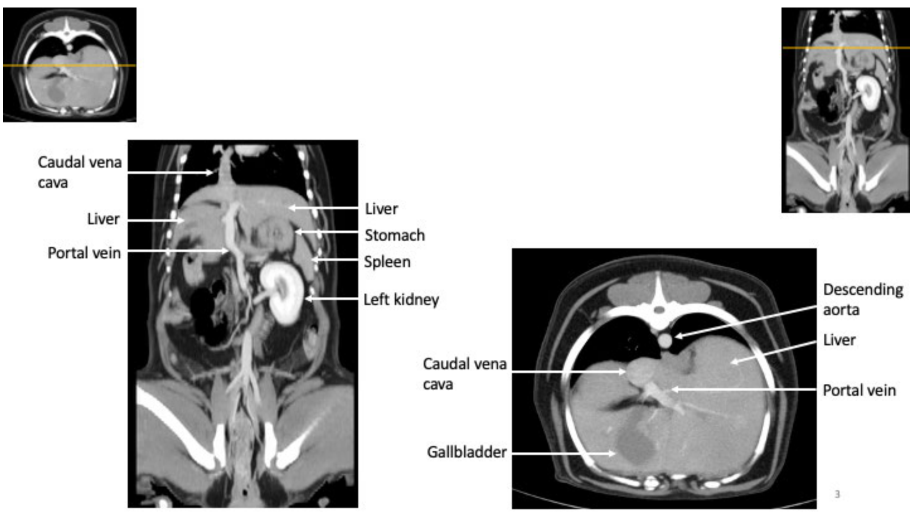


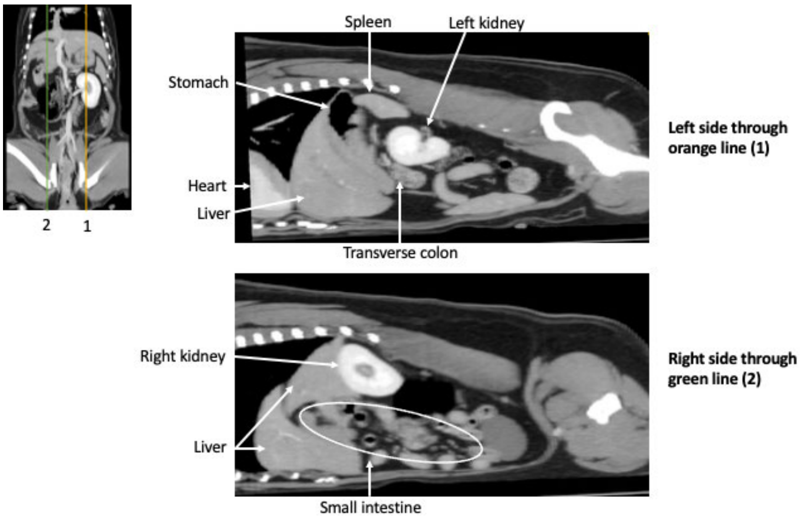
FIGURE 7-33 Abdominal viscera of male dog, ventral aspect.

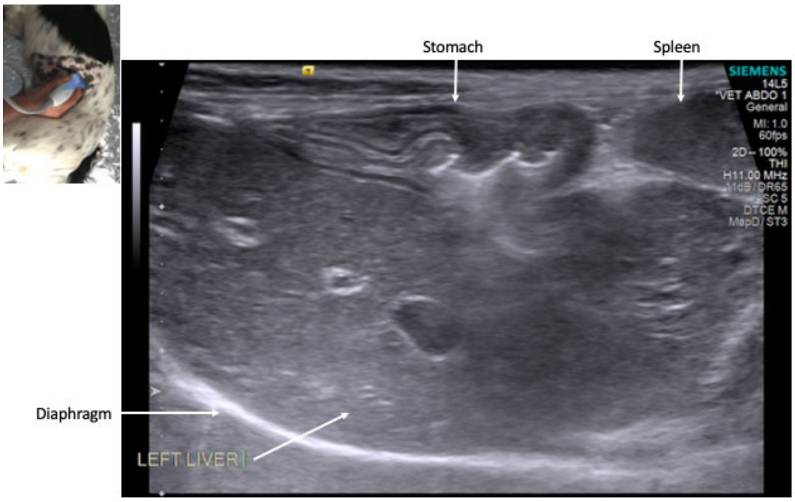
- Most cranial abdominal organ
- Cranially in contact with the diaphragm
- On the left, cranial to:
  - Stomach
  - Spleen
- On the right, cranial to:
  - Stomach, pylorus
  - Duodenum
  - Right kidney
- Gallbladder on the right side
- Caudal vena cava and portal vein slightly right sided

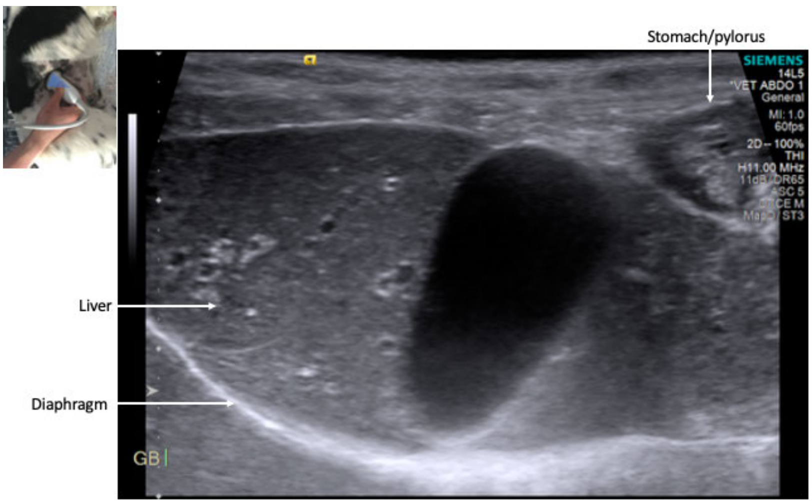
2

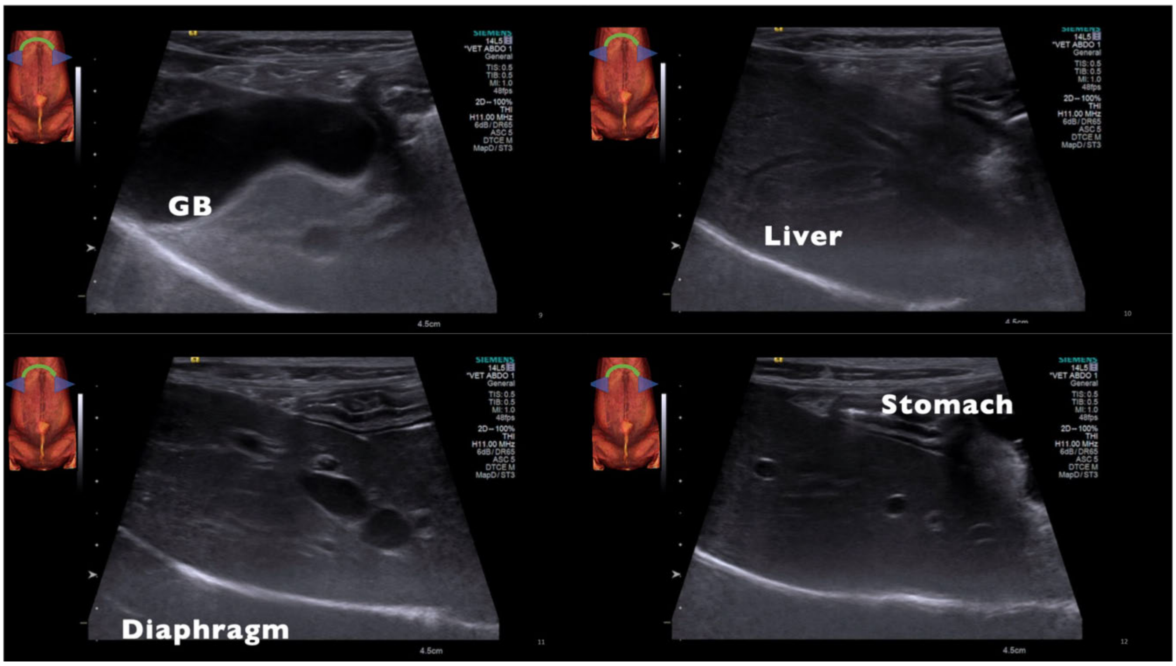


3


2
1
Spleen
Left kidney
Stomach
Heart
Liver
Transverse colon
Left side through orange line (1)
Right kidney
Liver
Small intestine
Right side through green line (2)
4


Stomach
Spleen
SIEMENS
Diaphragm
LEFT LIVER
5


Stomach/pylorus
SIEMENS
Liver
Diaphragm
GB
6


GB
Liver
Diaphragm
Stomach

Appendix 8: Student information questionnaire.

Students Information

Study:

How useful is a specific training on sonographic anatomy for identification of the pancreas on cine loops of ultrasound by final year veterinary students?

Student Name:

- Have you been employed as a vet technician before? Yes ☐ No ☐
    - If Yes, how many years? 1-2 ☐ 3-5 ☐ >5 ☐

- What is your level of interest in abdominal US (1-5; with 1 not interested and 5 very interested)?
  1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

- Have you had any ultrasound training outside/before VetSchool? Yes ☐
  No ☐

- How often have you previously observed an abdominal ultrasound being performed? never ☐ once ☐ twice ☐ more than twice ☐

- How often have you performed an abdominal ultrasound?
  never ☐ once ☐ twice ☐ more than twice ☐

- Have you previously held the position of anatomy tutor (teaching anatomy to other vet students)? Yes ☐ No ☐

- Rate your anatomy knowledge:
  good ☐ moderate ☐ bad ☐ very bad ☐ missing ☐

- What would be your preferential career choice?

small animal vet ☐ large animal vet ☐ mixed vet ☐ industry ☐

For researcher only

Student number in the study:

Appendix 9: Simplified code for statistical analysis

Organ	Expected answer	Mark	Incorrect answers	Partially correct/incorrect answer
Kidney	Kidney	1	0 for any other abdominal structure	1 if "kidney" no matter the lateralisation
Adrenal gland	Adrenal gland or adrenal	1	0 for any other abdominal structure	1 if "adrenal" or "adrenal gland" no matter the lateralisation
Liver	Liver	1	0 for any other abdominal structure	N/A
Gallbladder	Gallbladder	1	0 for any other abdominal structure	N/A
Spleen	Spleen	1	0 for any other abdominal structure	N/A
Pancreas	Pancreas	1	0 for any other abdominal structure	1 if "pancreas" for any part of the pancreas or if the region of pancreas is incorrect
Stomach • Stomach (gastric body, fundus) • Pylorus	Stomach Pylorus	1	0 for any other abdominal structure	• 1 if "stomach" for stomach

				• 0 if “stomach” for pylorus • 1 if “pylorus” for pylorus
Small intestine • Duodenum (descending, ascending) • Jejunum • Ileum	Small intestine	1	0 for any other abdominal structure	• 0 if “intestine” for any part of intestine • 1 if “small intestine” or “large intestine” for any part of the small or large intestinal tract respectively • 1 if incorrect name of small or large intestine for any segment of small or large intestinal tract respectively
Large intestine • Ileocaecocolic junction (ICCJ) • Caecum • Colon (ascending, transverse, descending)	Large intestine	1	0 for any other abdominal structure	

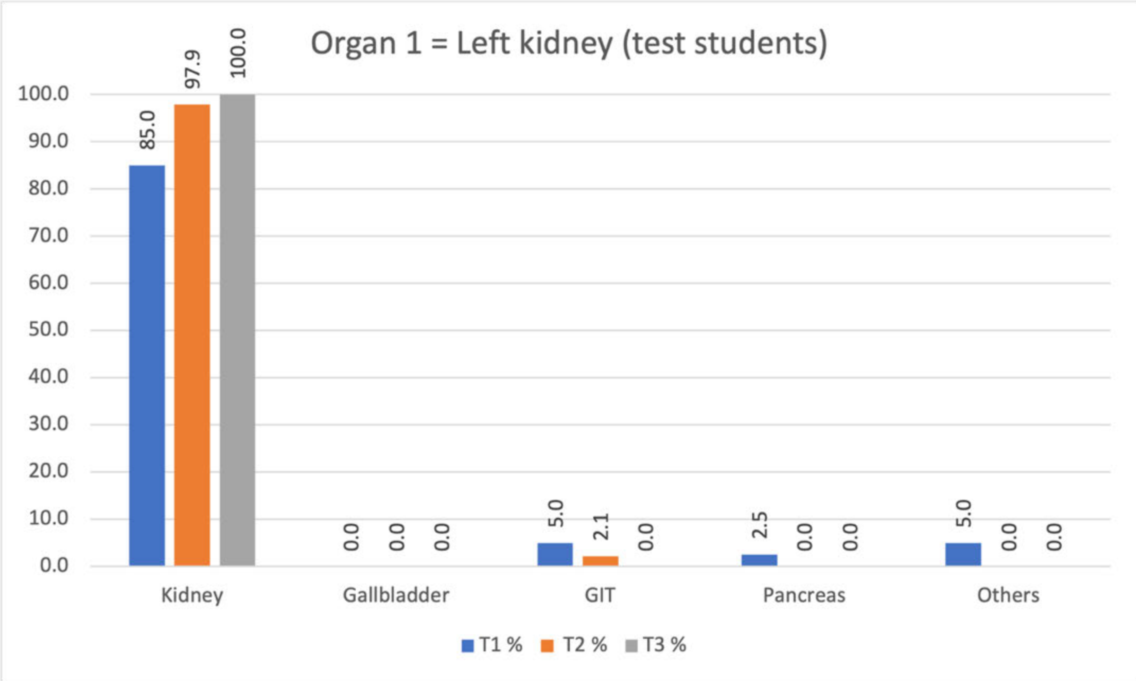
				• 0 if segment of small intestine for any segment of large intestinal tract and vice versa • 1 if "ICCJ" for ICCJ
Urinary bladder	Urinary bladder or bladder	1	0 for any other abdominal structure	N/A
Prostate	Prostate	1	0 for any other abdominal structure	N/A
Aorta	Blood vessel	1	0 for any other abdominal structure	1 if incorrect name of an abdominal blood vessel to recognise the ability to identify a blood vessel 1 for "internal iliac" or "external iliac" as students are presumably referring to the vessel even if there is no mention of
Caudal vena cava	Blood vessel	1	0 for any other abdominal structure	
Portal vein	Blood vessel	1	0 for any other abdominal structure	
Mesenteric vessels	Blood vessel	1	0 for any other	

			abdominal structure	"vessel", "artery" or "vein"
Medial iliac lymph node	Lymph node	1	0 for any other abdominal structure	1 if incorrect name of the lymph node to recognize the ability of the student to identify a lymph node
Mesenteric lymph node	Lymph node	1	0 for any other abdominal structure	

Appendix 10: Abdominal systems for statistical analysis

Abdominal systems	Number of organs
Kidneys	1, 10, 31, 37, 46
Urinary bladder	33
Spleen	4, 9, 14
Liver	6, 15, 27, 38
Gallbladder	8
Stomach	5, 11, 26
Pylorus	7, 17, 29
Small intestine	25, 30, 32, 36, 43, 45
Large intestine	18, 22, 35, 42, 44
Ileocaecocolic junction	47
Pancreas	12, 13, 28, 39
Lymph nodes	21, 23
Adrenal glands	2, 41
Prostate	34
Blood vessels	3, 16, 19, 20, 24, 40

Appendix 11: Students' answers



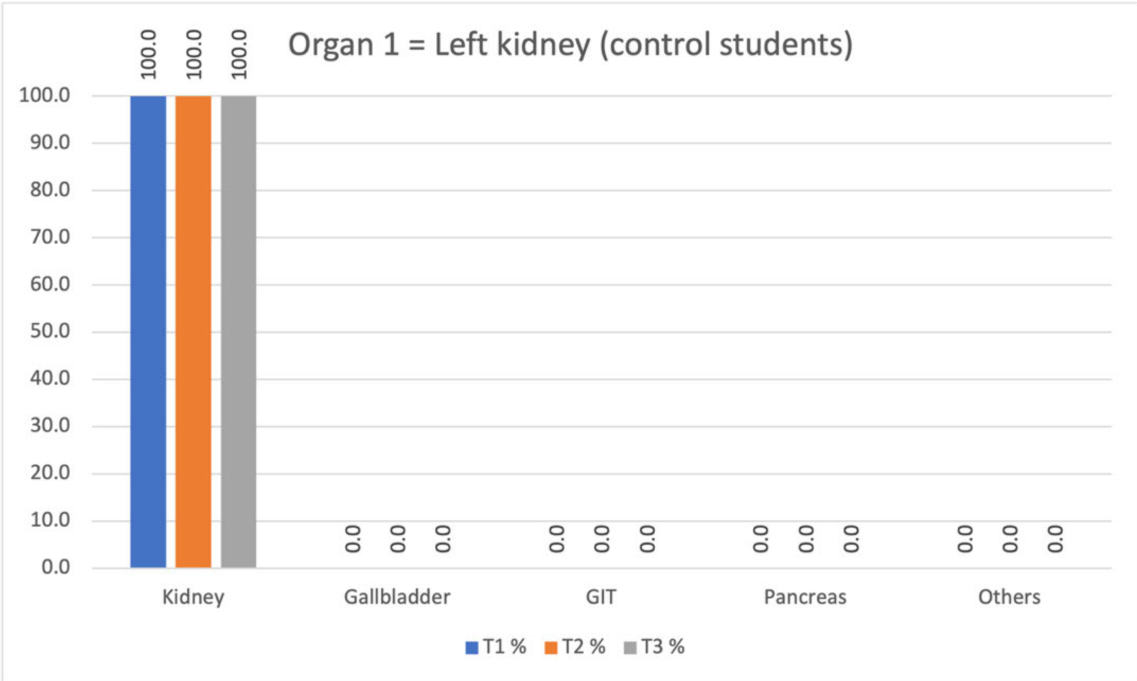
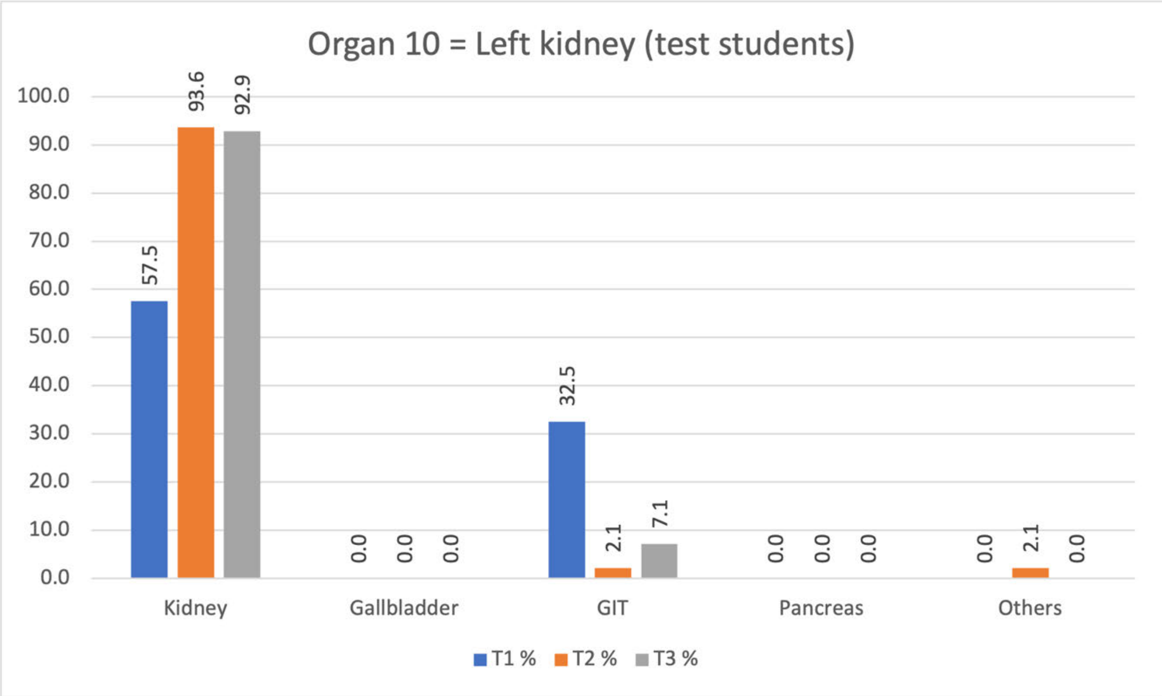


Figure 1 (1/5) Bar charts representing the relative frequencies of students' answers for identification of the kidneys (organs 1, 10, 31, 37, and 46). The X axis displays organ categories, including kidney, gallbladder, gastrointestinal tract (GIT), pancreas, and others, organised from left to right based on student responses. The Y axis represents the percentage of students giving a particular answer. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



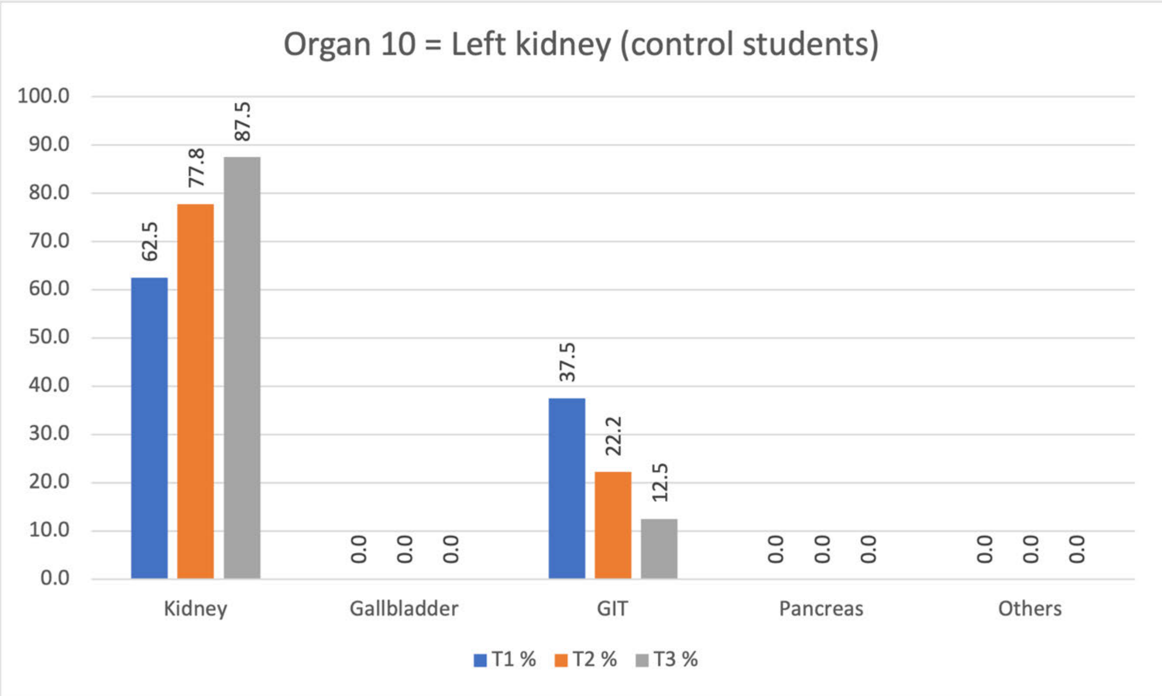


Figure 1 (2/5) Bar charts representing the relative frequencies of students' answers for identification of the kidneys (organs 1, 10, 31, 37, and 46). The X axis displays organ categories, including kidney, gallbladder, gastrointestinal tract (GIT), pancreas, and others, organised from left to right based on student responses. The Y axis represents the percentage of students giving a particular answer. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

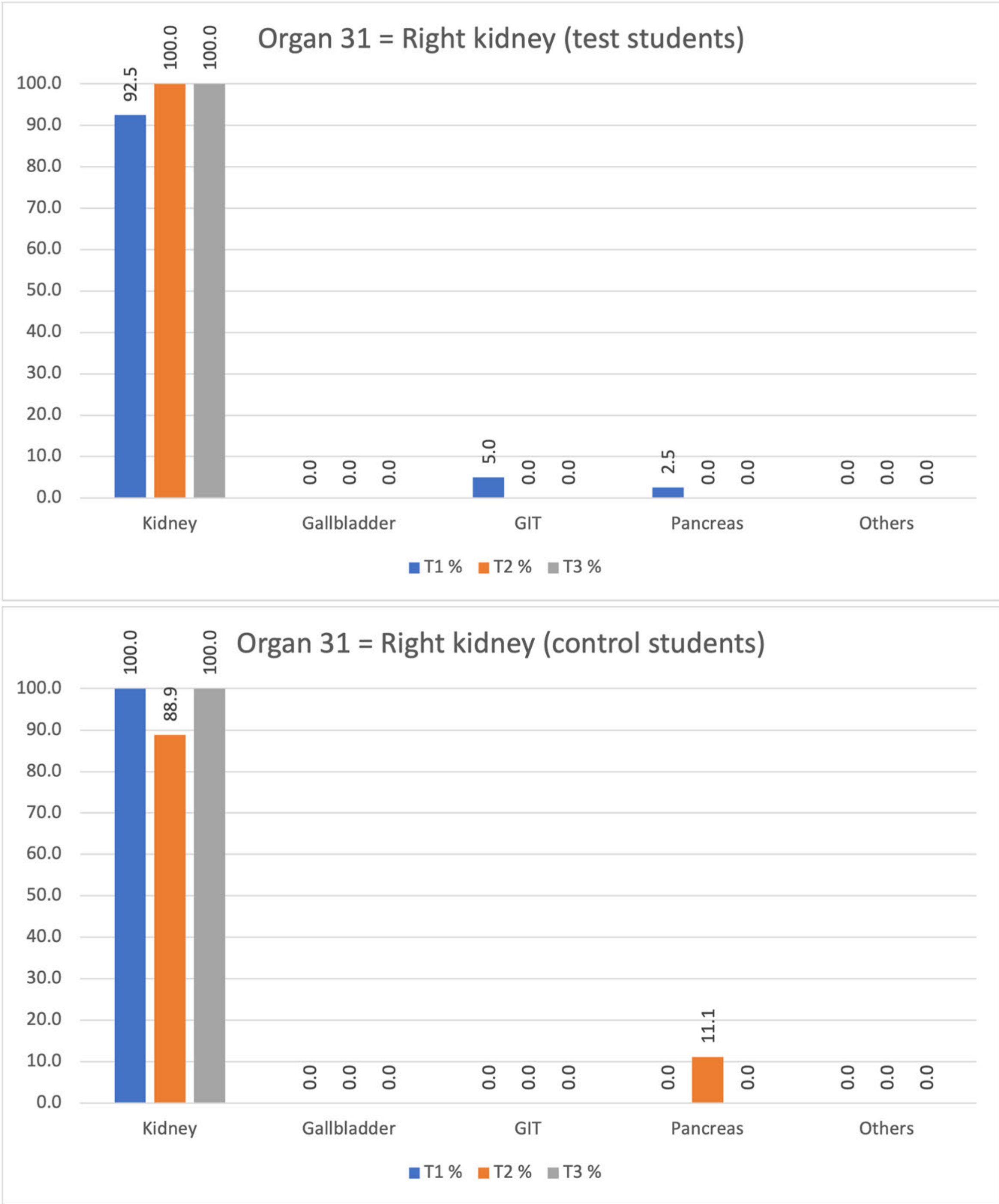
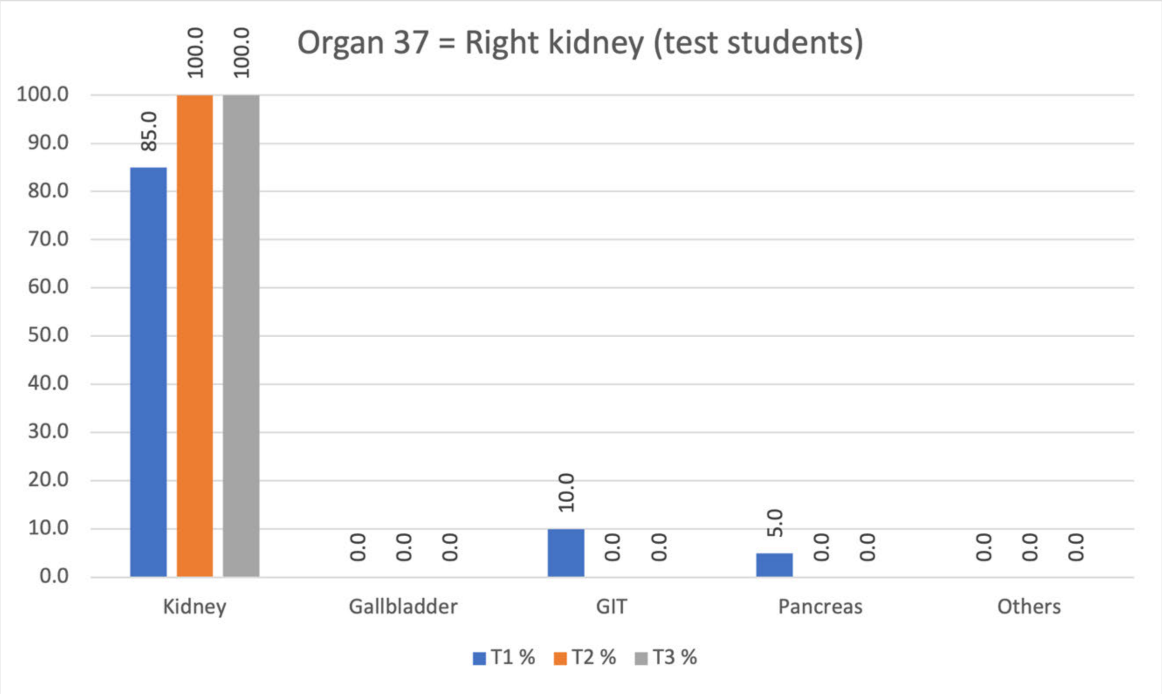


Figure 1 (3/5) Bar charts representing the relative frequencies of students' answers for identification of the kidneys (organs 1, 10, 31, 37, and 46). The X axis displays organ categories, including kidney, gallbladder, gastrointestinal tract (GIT), pancreas, and others, organised from left to right based on student responses. The Y axis represents the percentage of students giving a particular answer. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



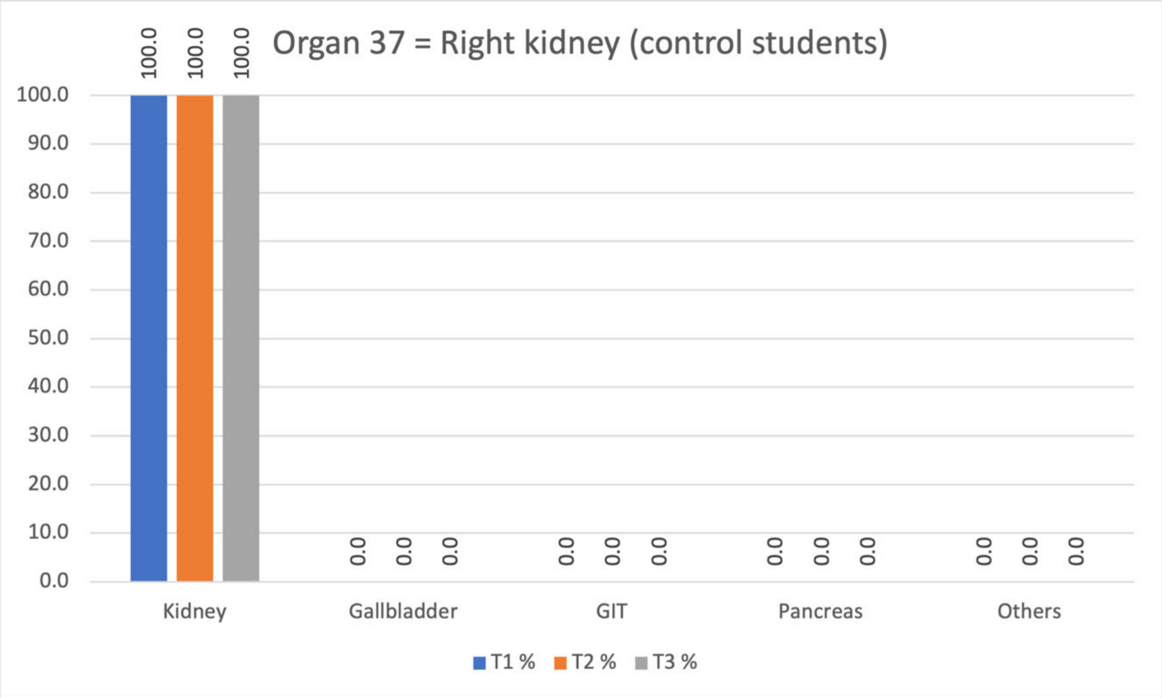
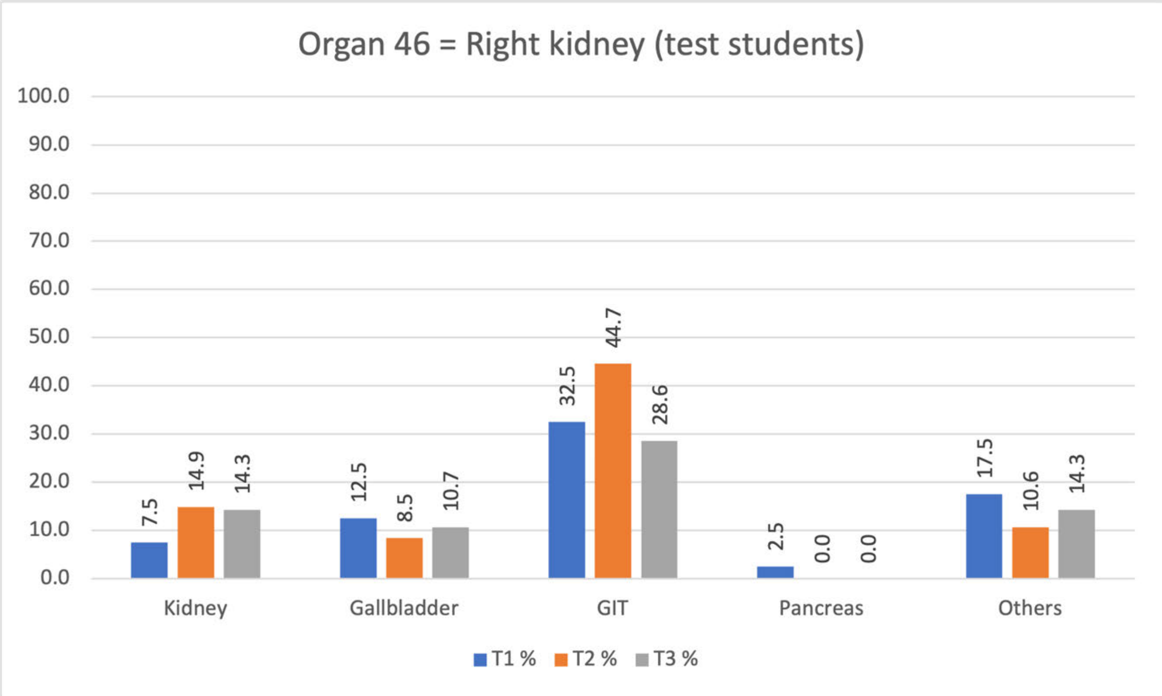


Figure 1 (4/5) Bar charts representing the relative frequencies of students' answers for identification of the kidneys (organs 1, 10, 31, 37, and 46). The X axis displays organ categories, including kidney, gallbladder, gastrointestinal tract (GIT), pancreas, and others, organised from left to right based on student responses. The Y axis represents the percentage of students giving a particular answer. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



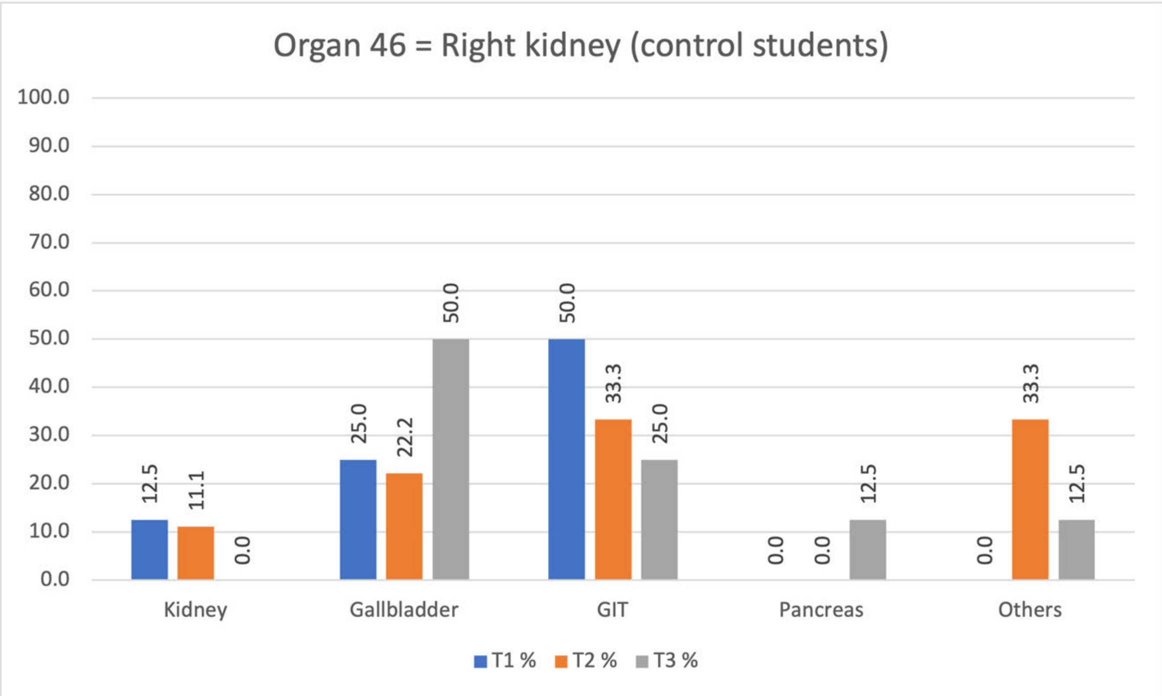


Figure 1 (5/5) Bar charts representing the relative frequencies of students' answers for identification of the kidneys (organs 1, 10, 31, 37, and 46). The X axis displays organ categories, including kidney, gallbladder, gastrointestinal tract (GIT), pancreas, and others, organised from left to right based on student responses. The Y axis represents the percentage of students giving a particular answer. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

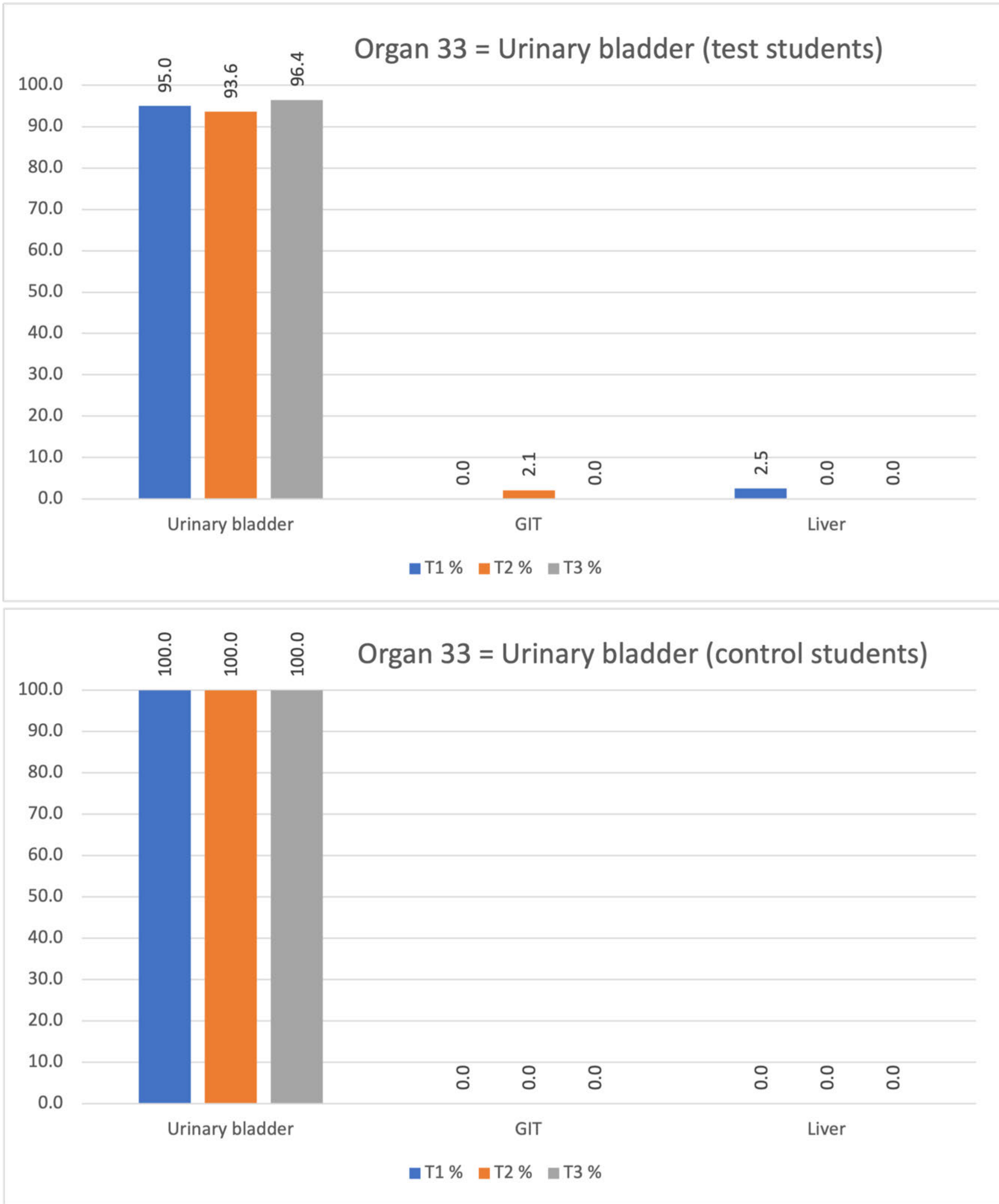


Figure 2 Bar charts representing the relative frequencies of students' answers for the urinary bladder (organ 33). The X axis displays organ categories including urinary bladder, gastrointestinal tract (GIT), and liver organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

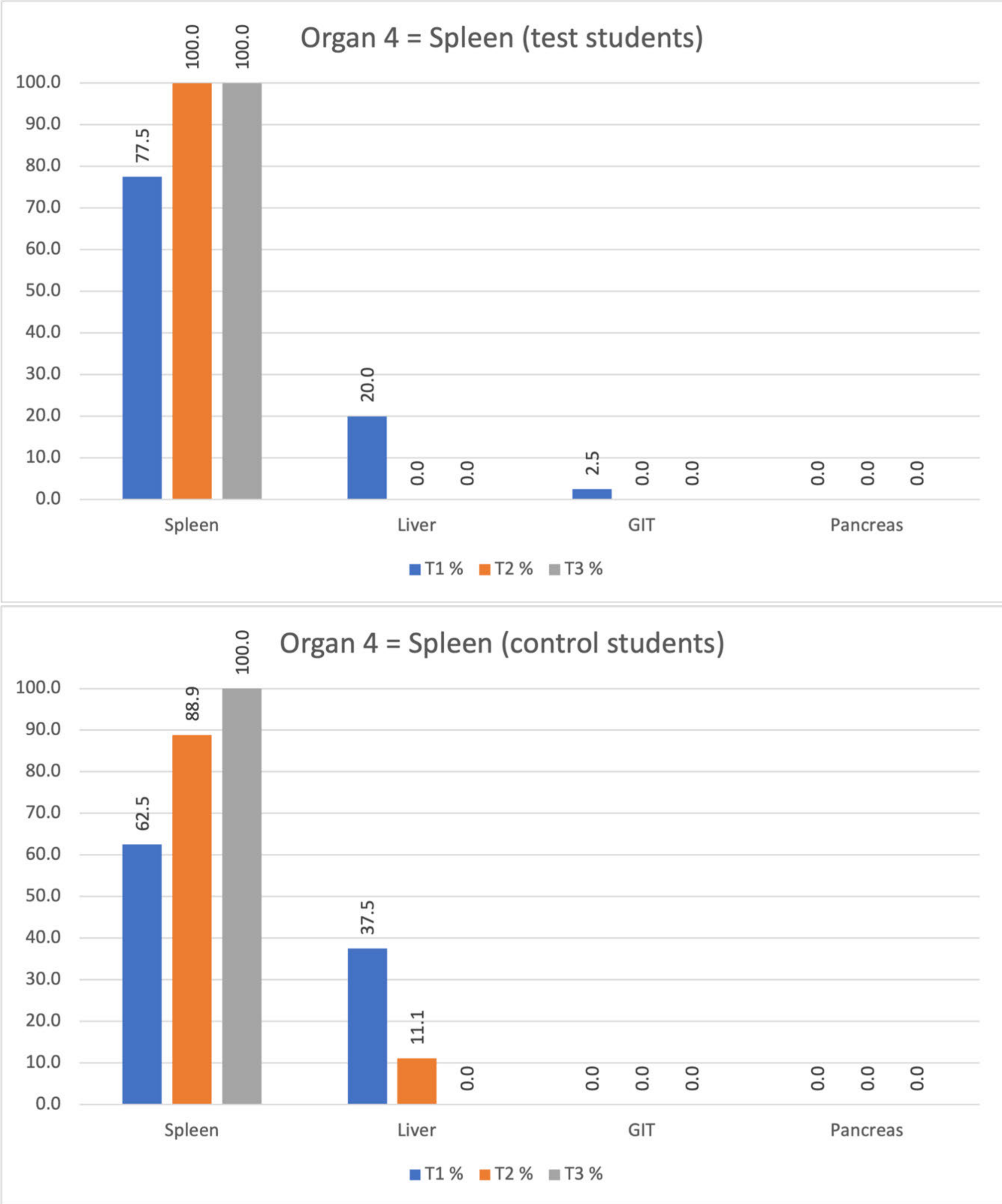
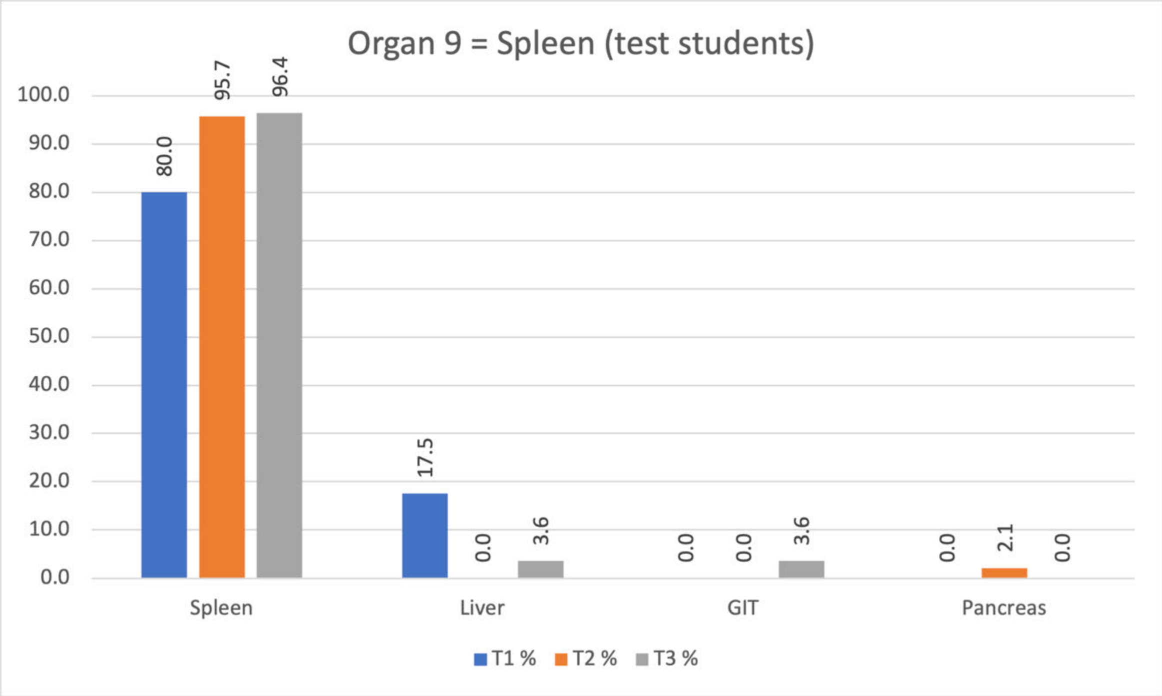


Figure 3 (1/3) Bar charts representing the relative frequencies of students' answers for the spleen (organs 4, 9 and 14). The X axis displays organ categories including spleen, liver, gastrointestinal tract (GIT) and pancreas organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



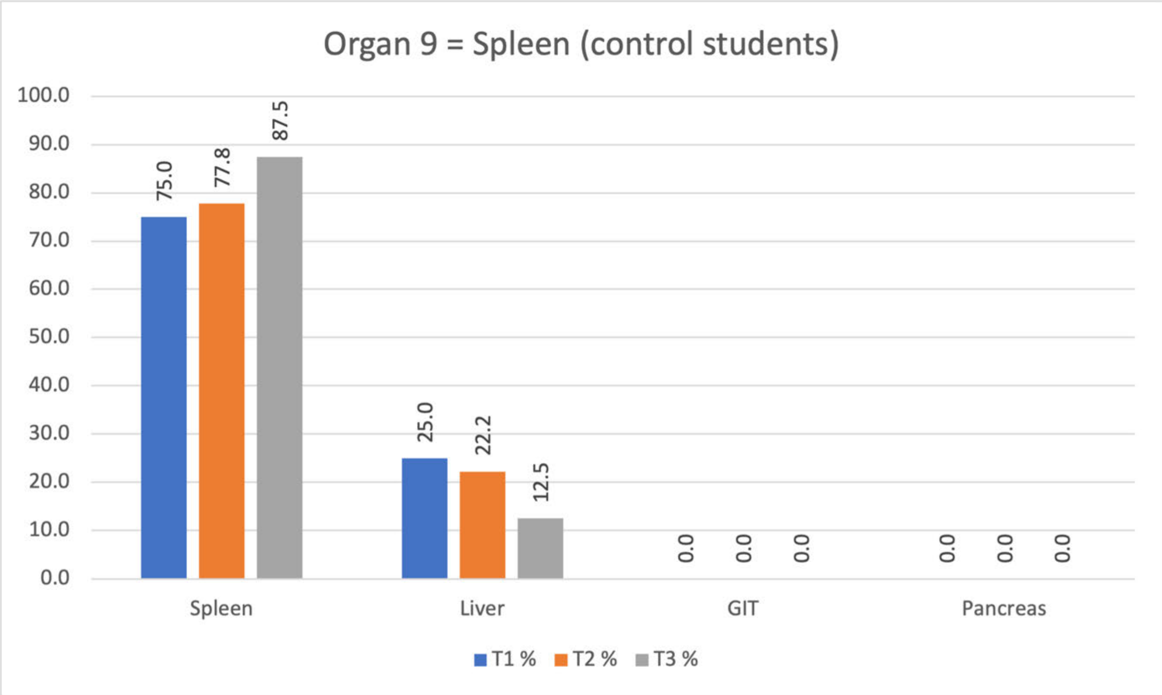
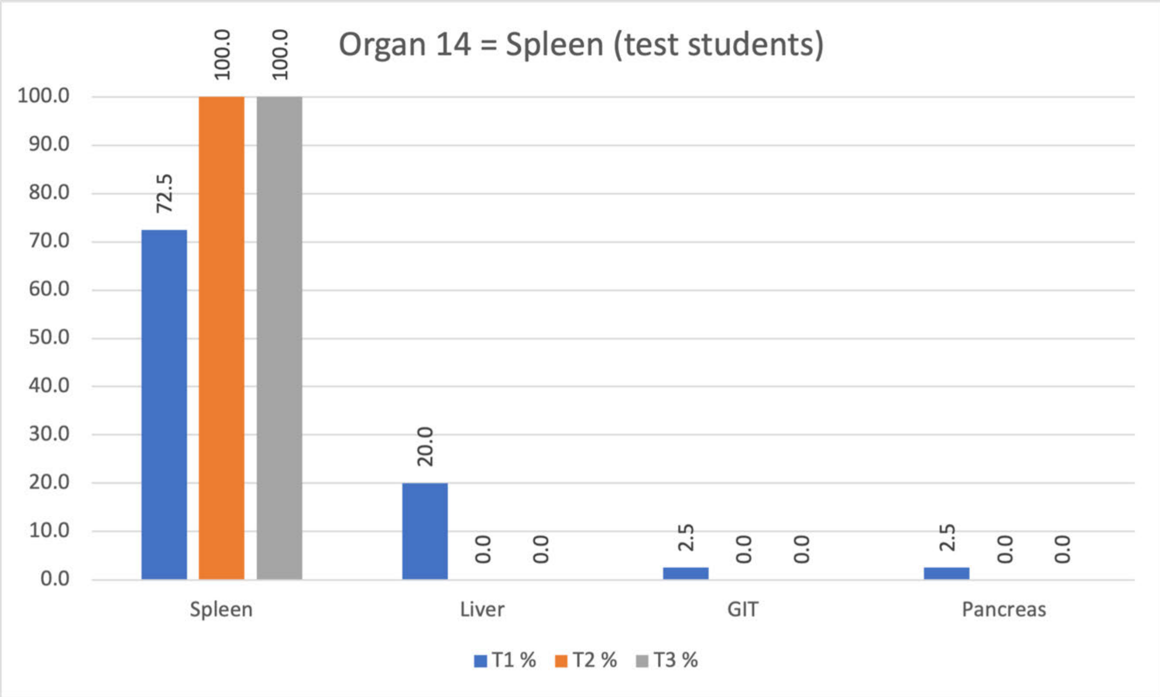


Figure 3 (2/3) Bar charts representing the relative frequencies of students' answers for the spleen (organs 4, 9 and 14). The X axis displays organ categories including spleen, liver, gastrointestinal tract (GIT) and pancreas organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



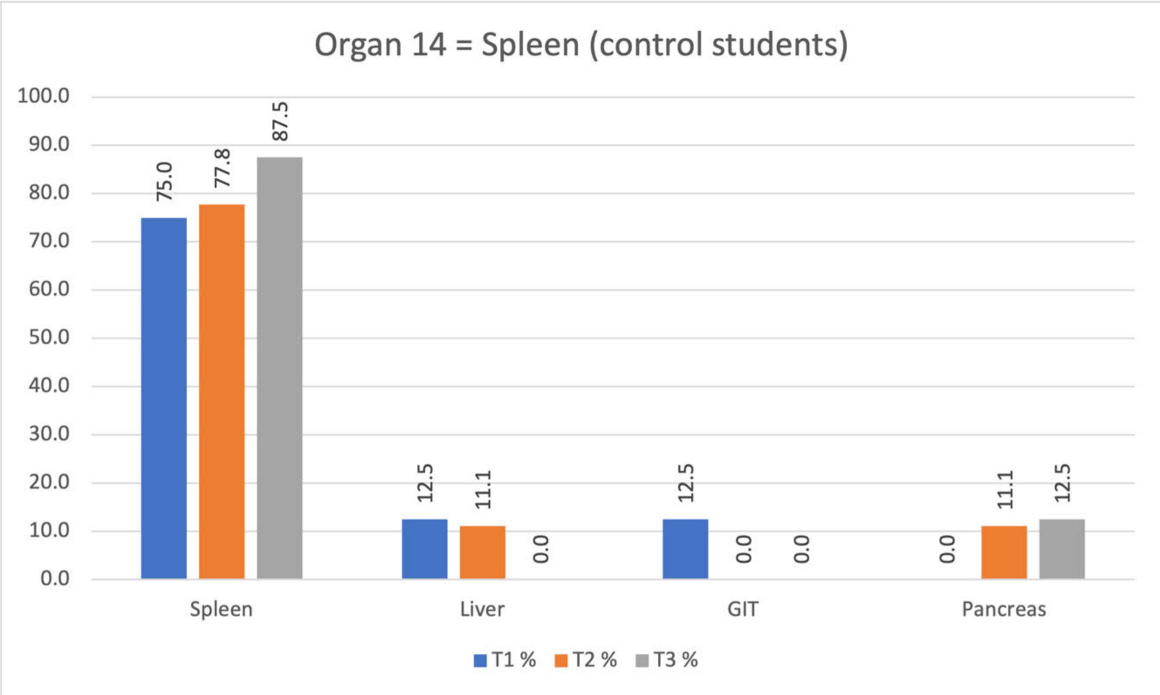


Figure 3 (3/3) Bar charts representing the relative frequencies of students' answers for the spleen (organs 4, 9 and 14). The X axis displays organ categories including spleen, liver, gastrointestinal tract (GIT) and pancreas organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

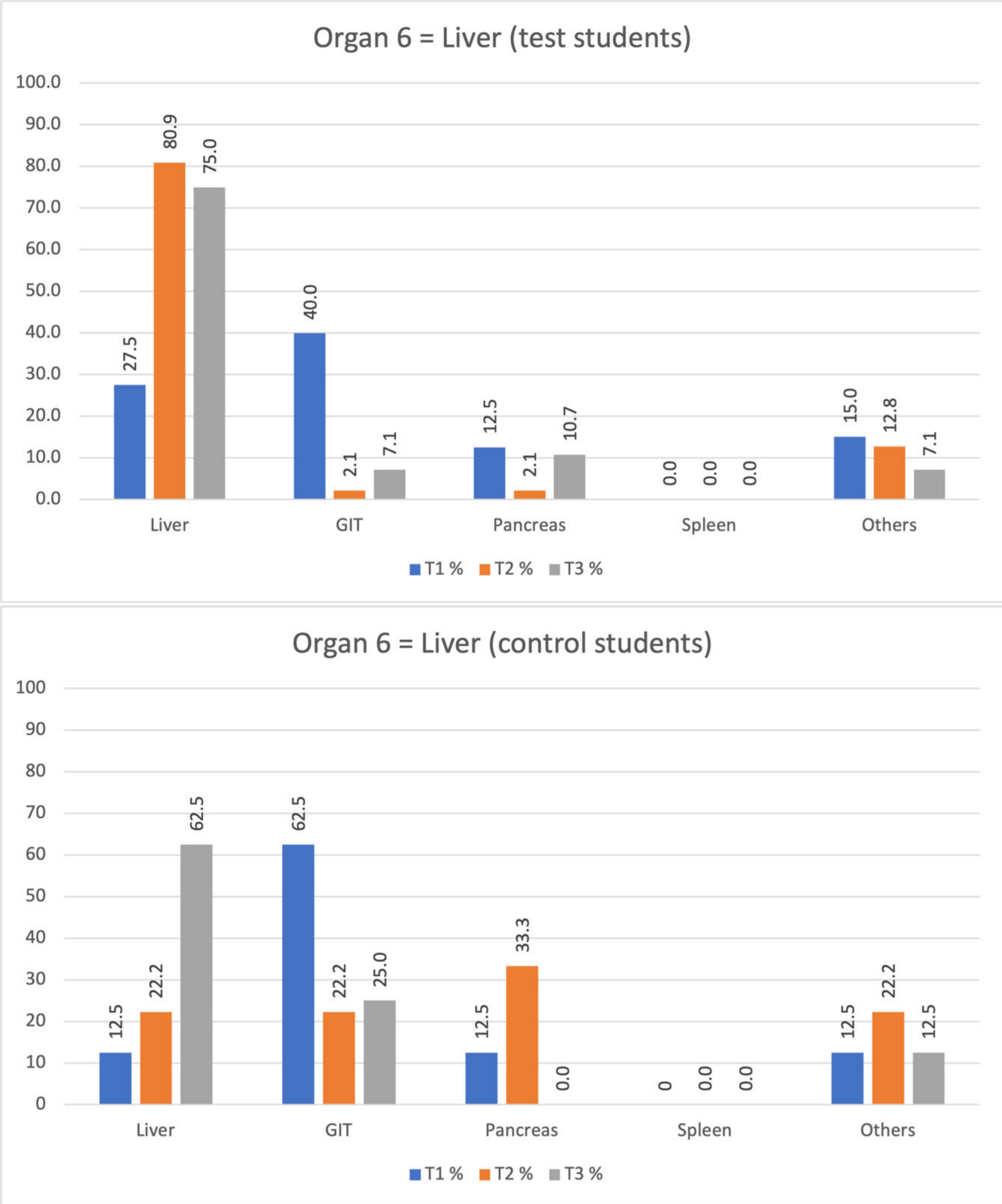
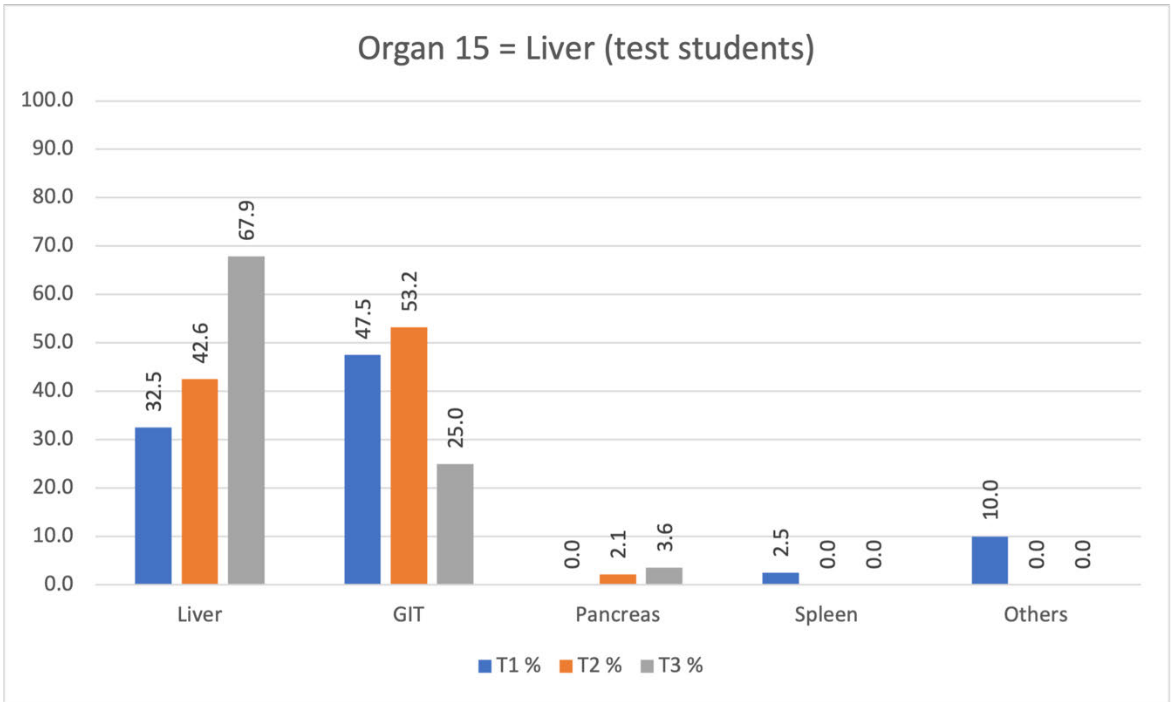


Figure 4 (1/4) Bar charts representing the relative frequencies of students' answers for the liver (organs 6, 15, 27 and 38). The X axis displays organ categories including liver, gastrointestinal tract (GIT), pancreas, spleen, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



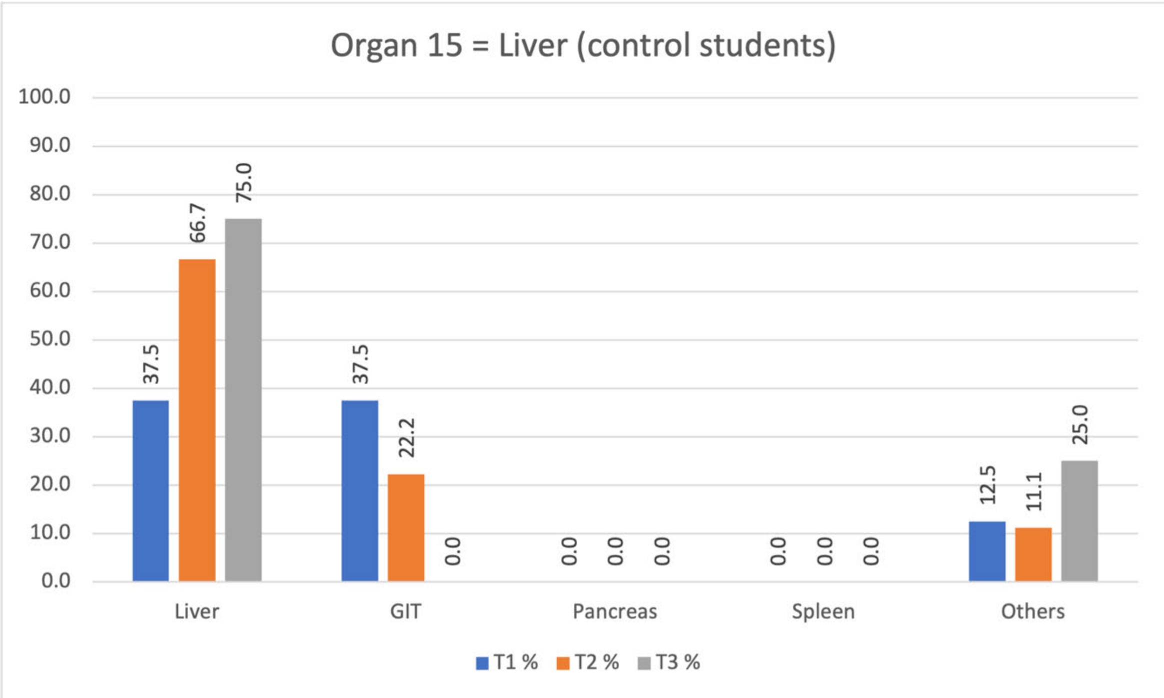
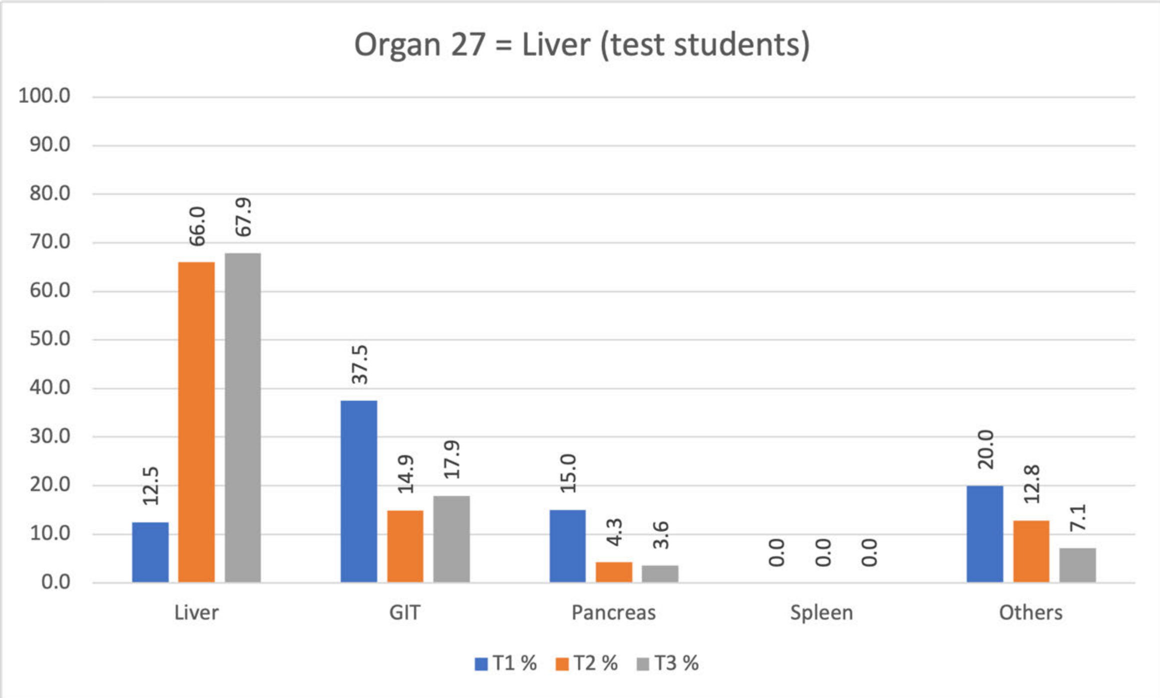


Figure 4 (2/4) Bar charts representing the relative frequencies of students' answers for the liver (organs 6, 15, 27 and 38). The X axis displays organ categories including liver, gastrointestinal tract (GIT), pancreas, spleen, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



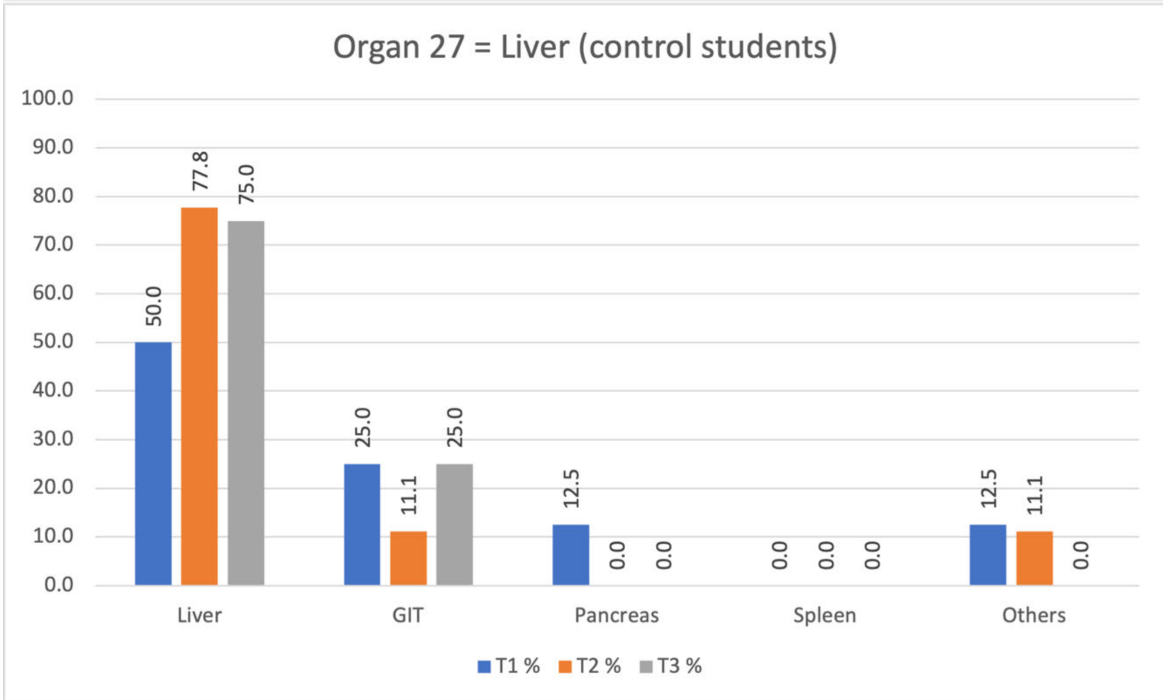
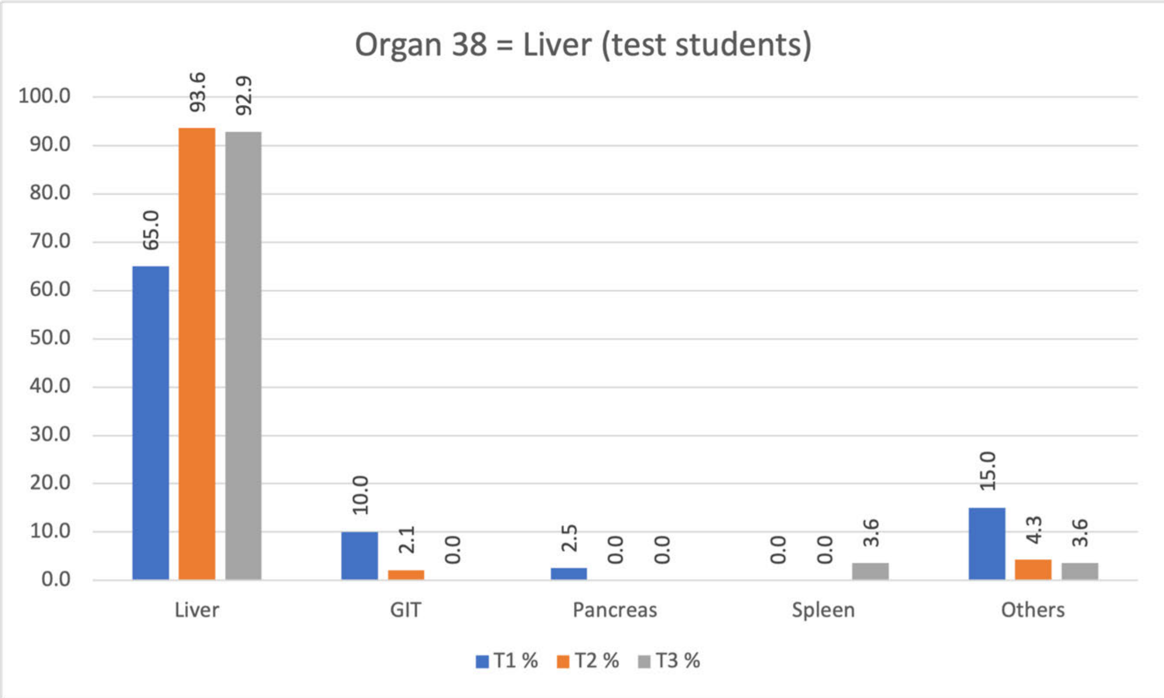


Figure 4 (3/4) Bar charts representing the relative frequencies of students' answers for the liver (organs 6, 15, 27 and 38). The X axis displays organ categories including liver, gastrointestinal tract (GIT), pancreas, spleen, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



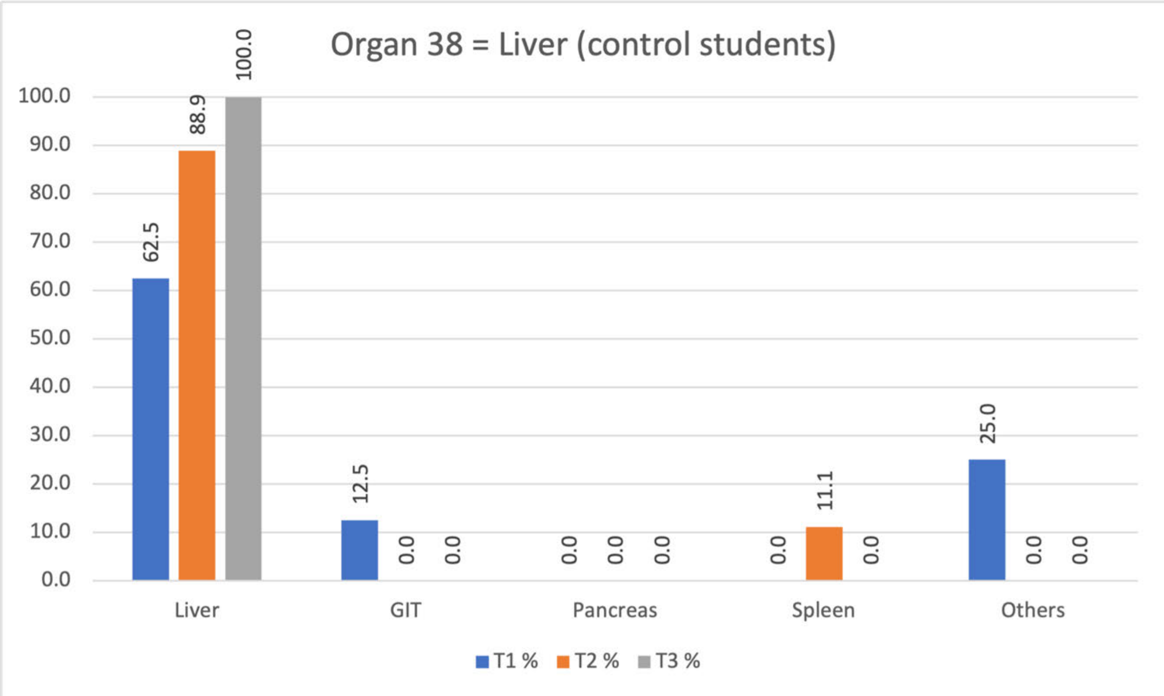


Figure 4 (4/4) Bar charts representing the relative frequencies of students' answers for the liver (organs 6, 15, 27 and 38). The X axis displays organ categories including liver, gastrointestinal tract (GIT), pancreas, spleen, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

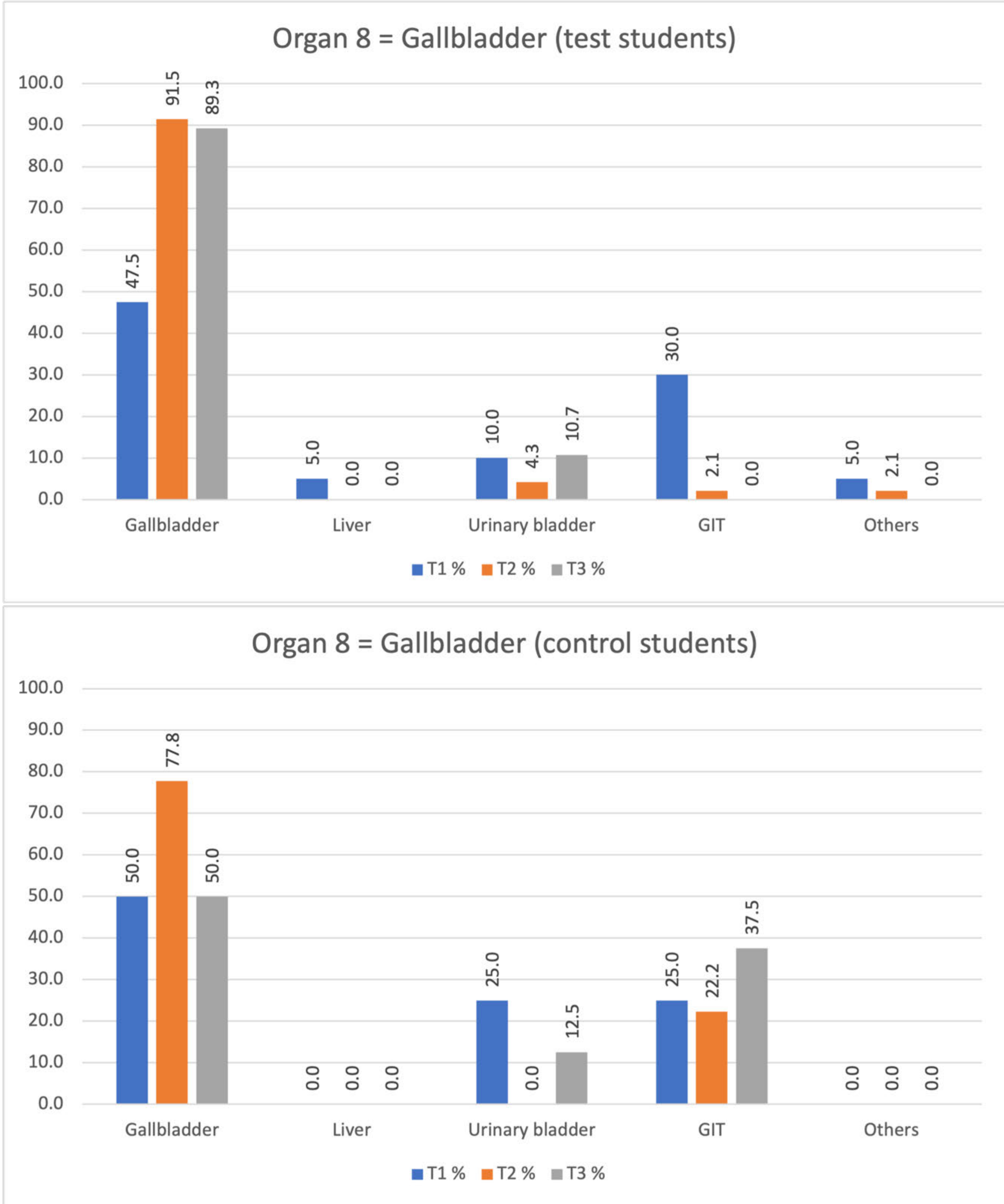
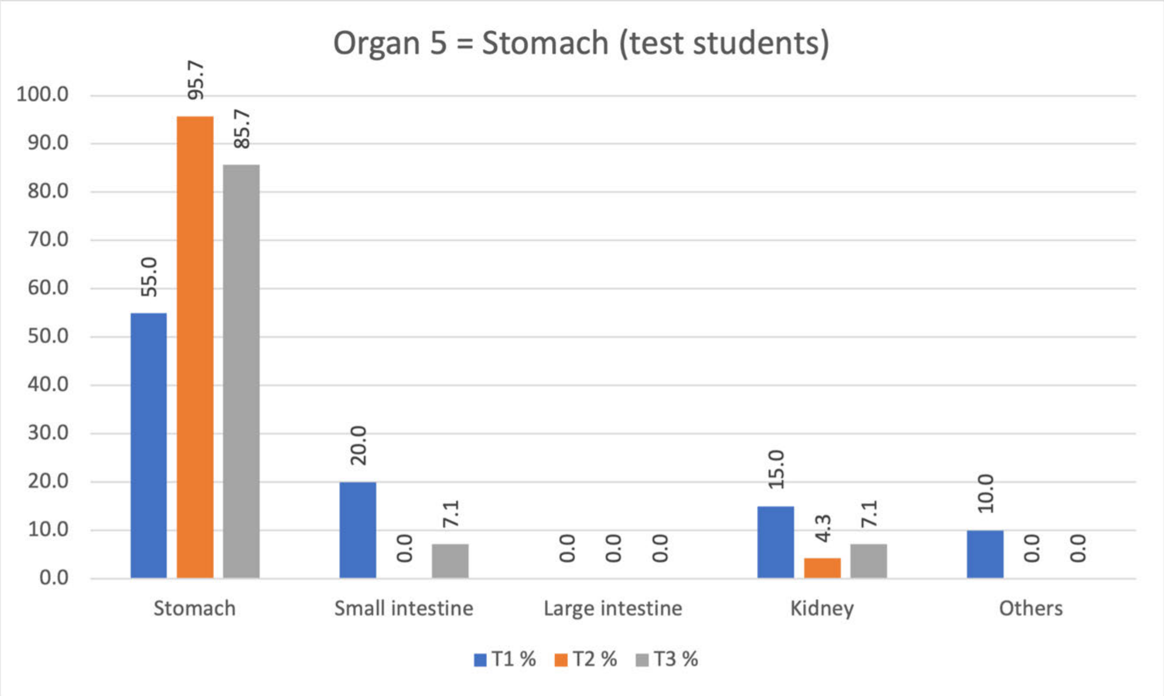


Figure 5 Bar charts representing the relative frequencies of students' answers for the gallbladder (organ 8). The X axis displays organ categories including gallbladder, liver, urinary bladder, gastrointestinal tract (GIT), and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



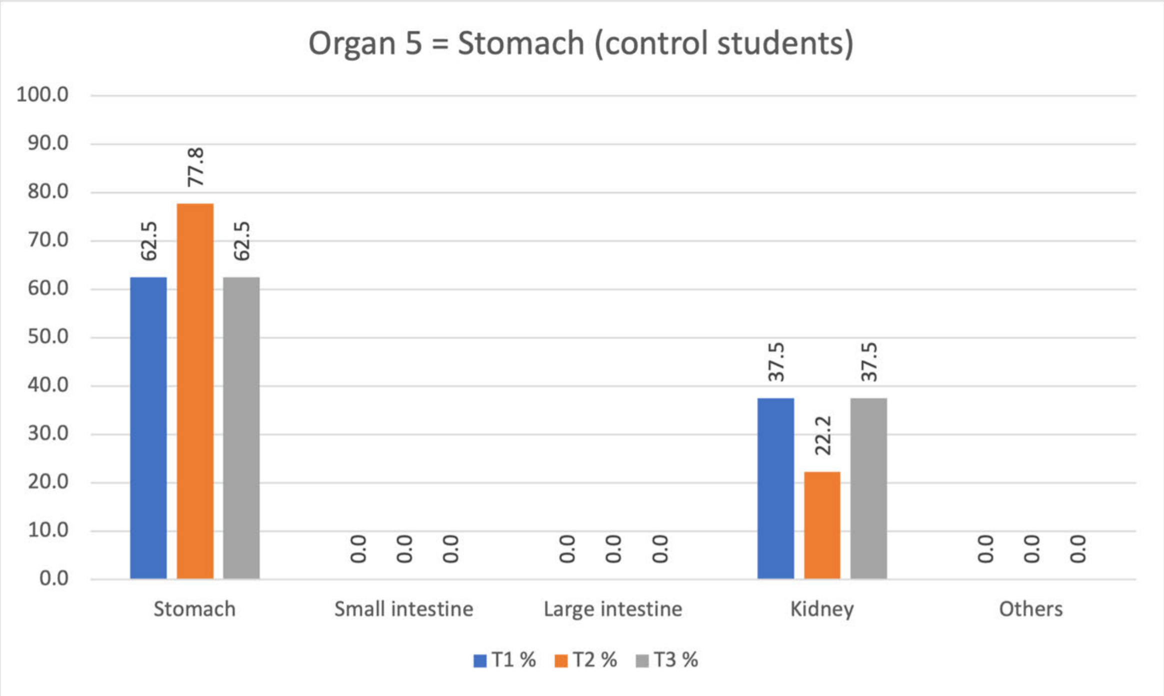
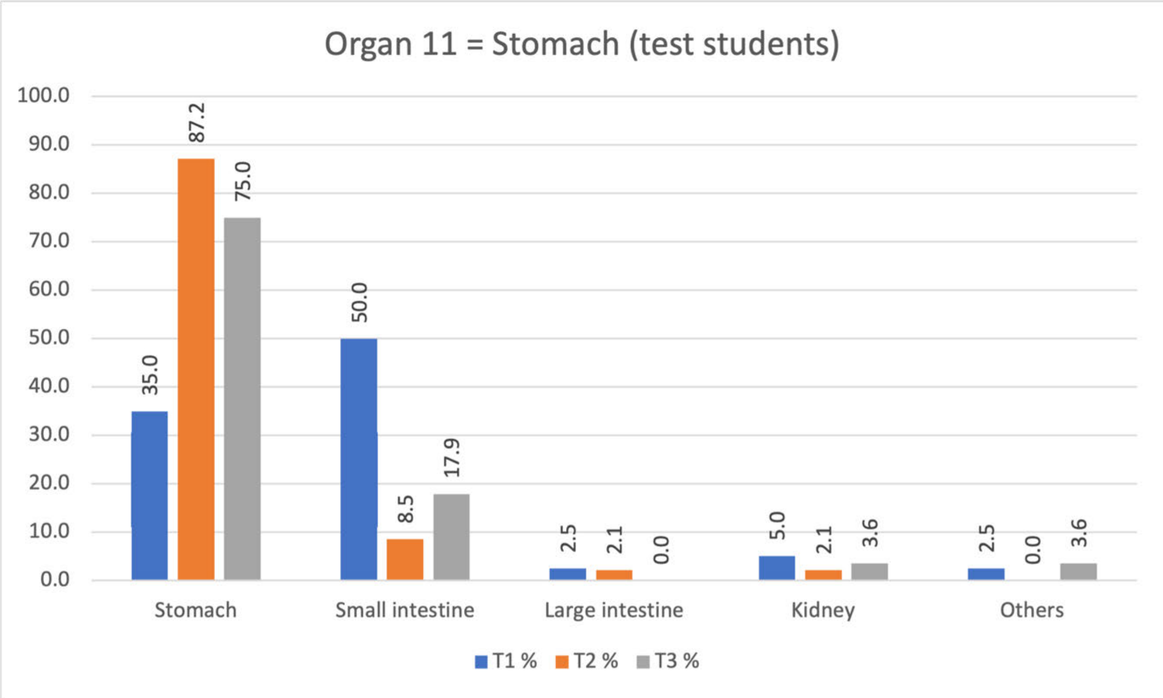


Figure 6 (1/3) Bar charts representing the relative frequencies of students' answers for the stomach (organs 5, 11 and 26). The X axis displays organ categories including stomach, small intestine, large intestine, kidney, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



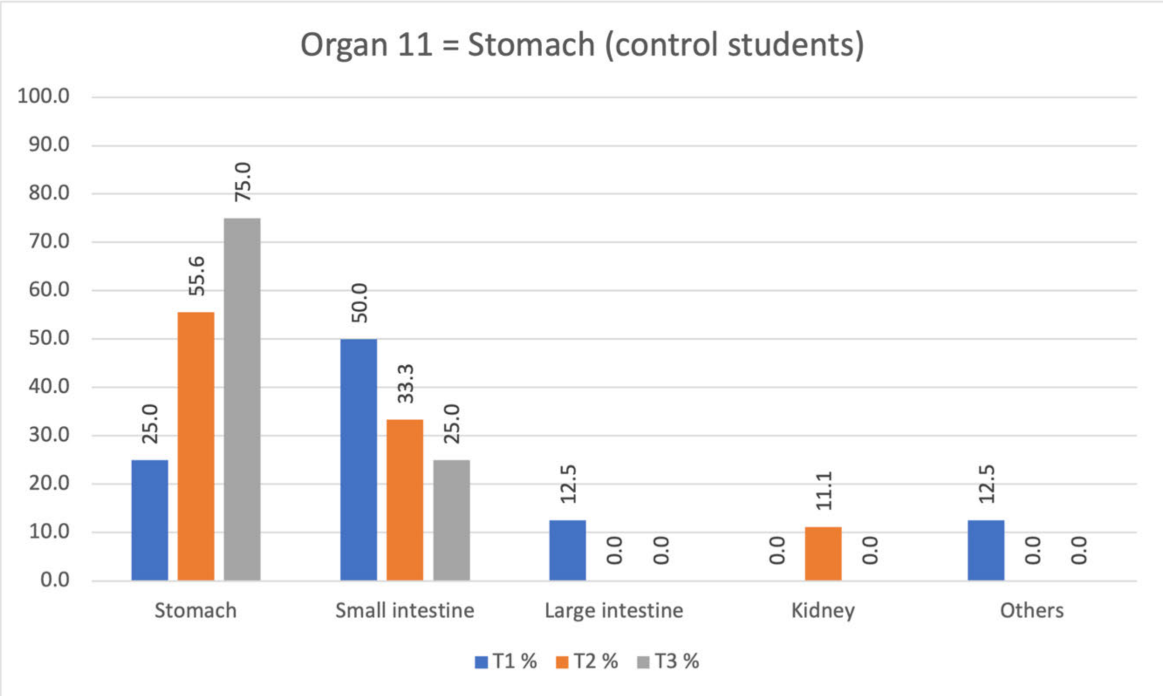
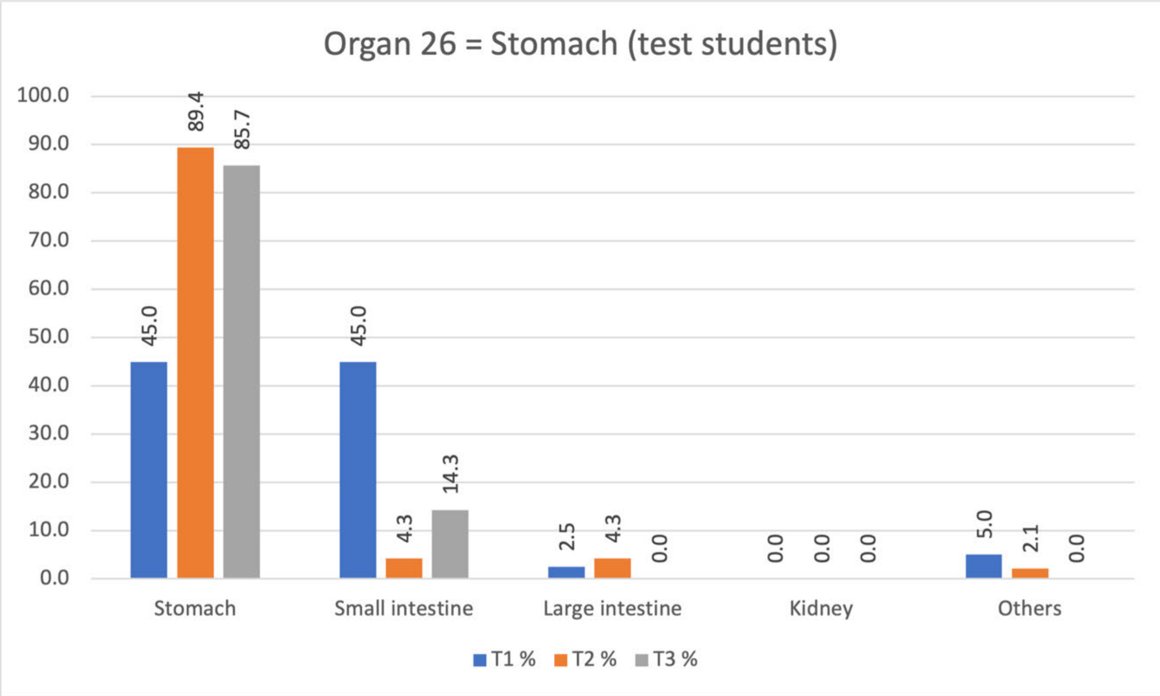


Figure 6 (2/3) Bar charts representing the relative frequencies of students' answers for the stomach (organs 5, 11 and 26). The X axis displays organ categories including stomach, small intestine, large intestine, kidney, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



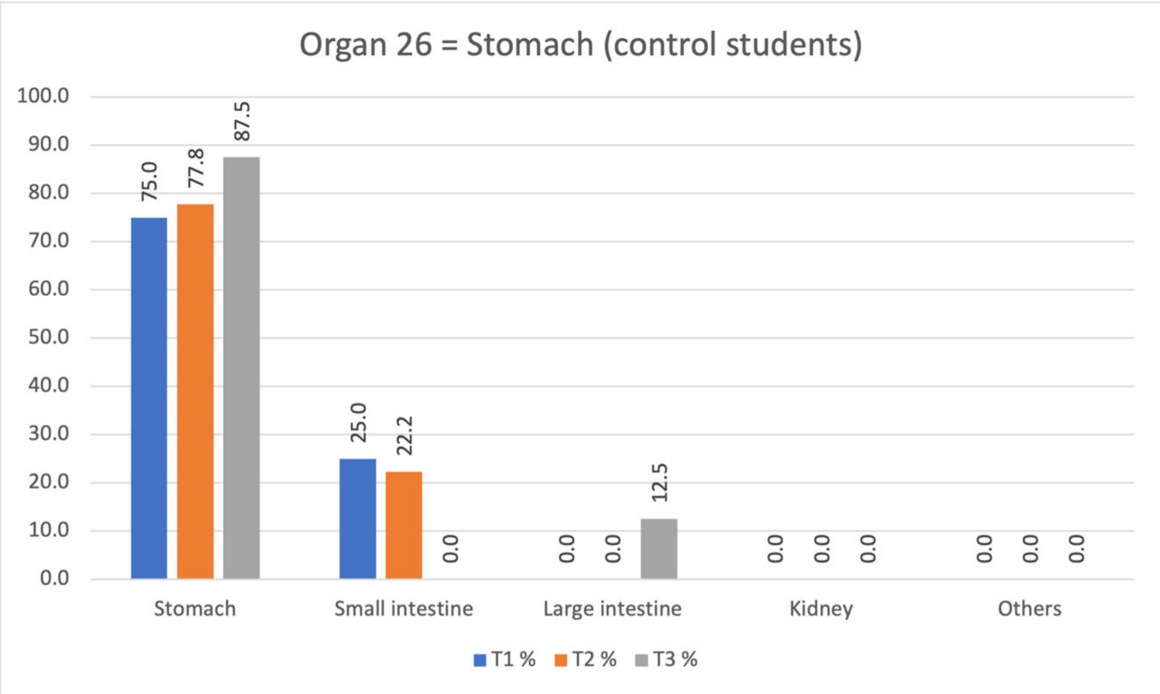


Figure 6 (3/3) Bar charts representing the relative frequencies of students' answers for the stomach (organs 5, 11 and 26). The X axis displays organ categories including stomach, small intestine, large intestine, kidney, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

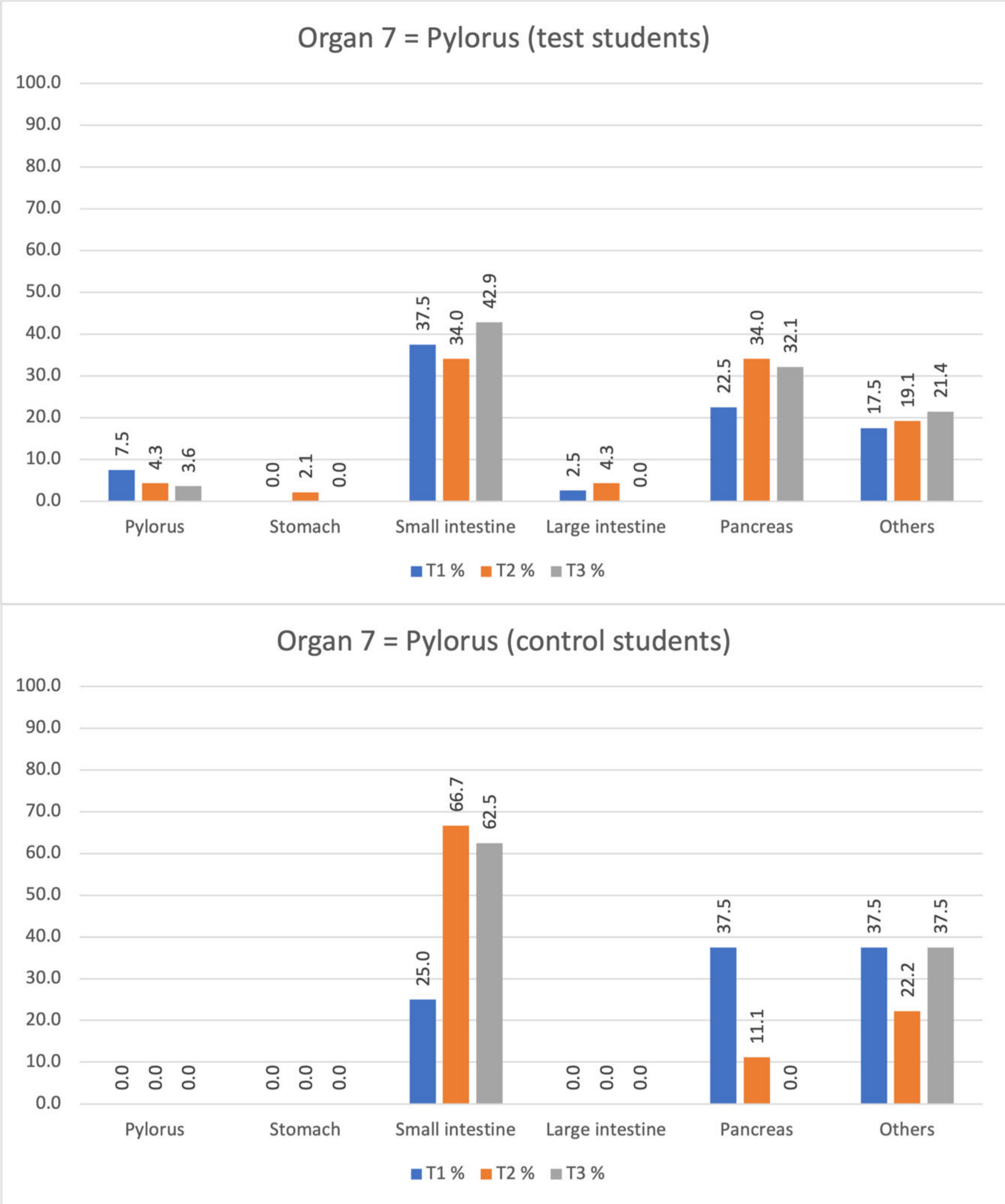
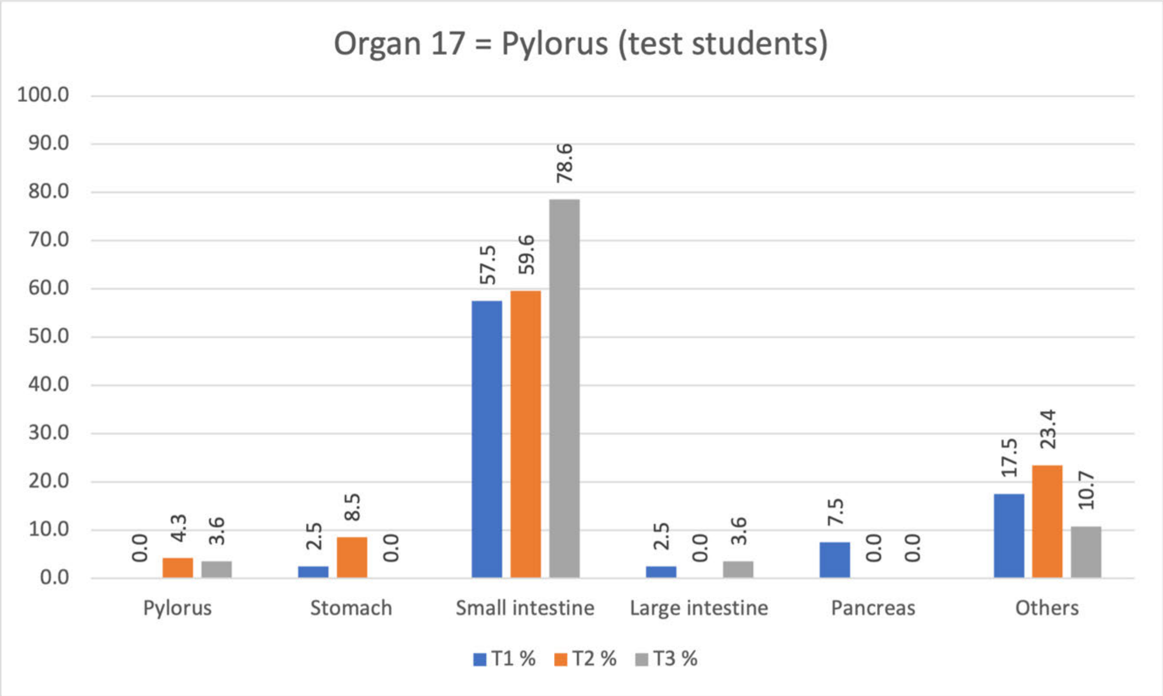


Figure 7 (1/3) Bar charts representing the relative frequencies of students' answers for the pylorus (organs 7, 17 and 29). The X axis displays organ categories including pylorus, stomach, small intestine, large intestine, pancreas, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



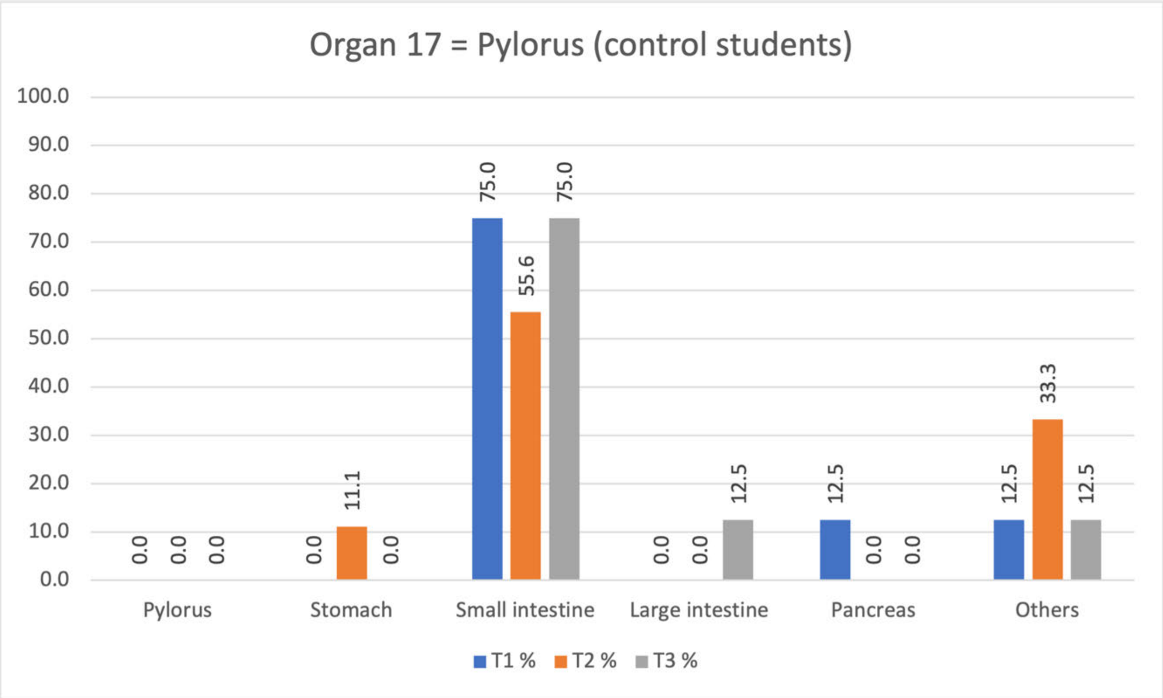


Figure 7 (2/3) Bar charts representing the relative frequencies of students' answers for the pylorus (organs 7, 17 and 29). The X axis displays organ categories including pylorus, stomach, small intestine, large intestine, pancreas, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

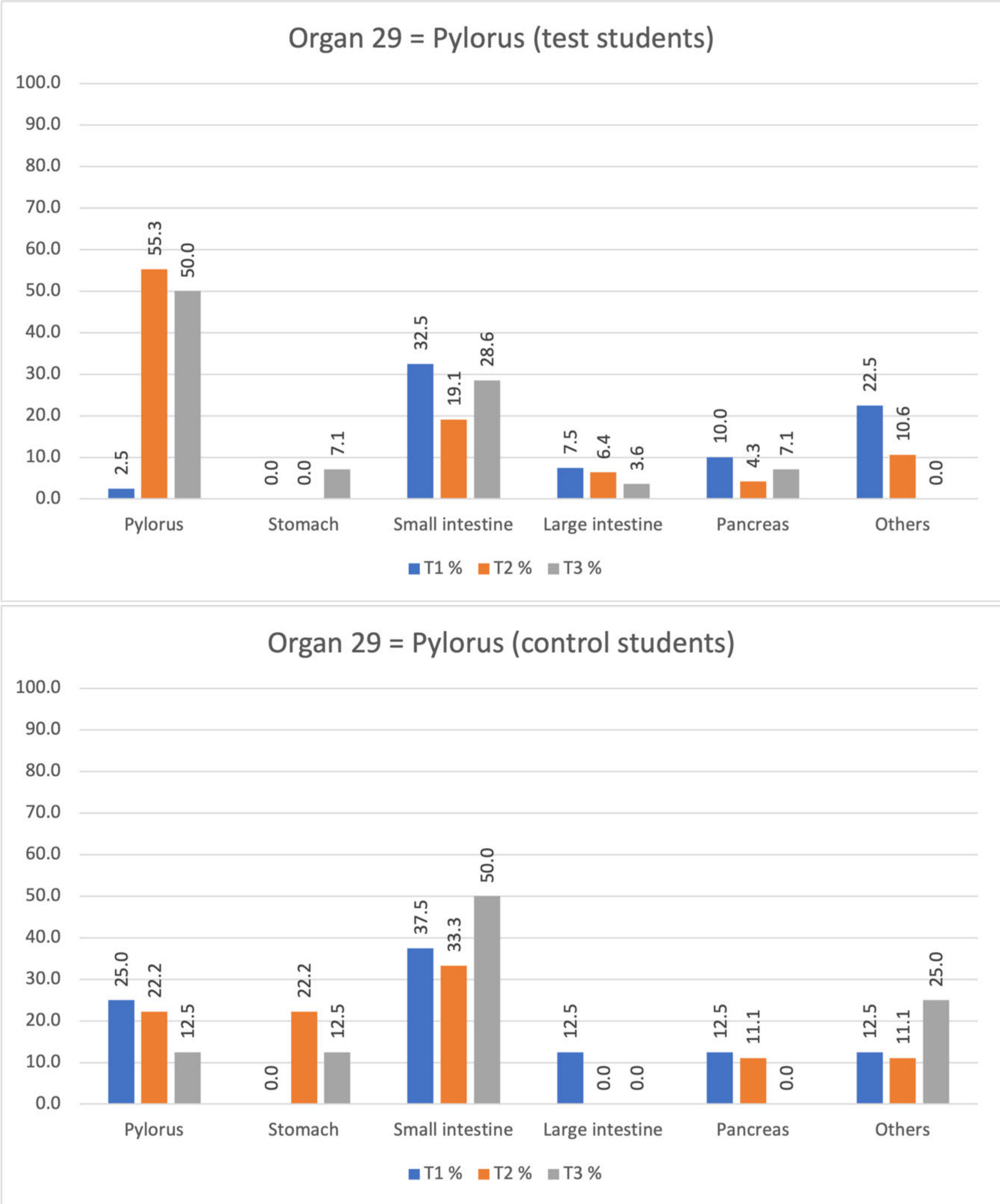


Figure 7 (3/3) Bar charts representing the relative frequencies of students' answers for the pylorus (organs 7, 17 and 29). The X axis displays organ categories including pylorus, stomach, small intestine, large intestine, pancreas, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

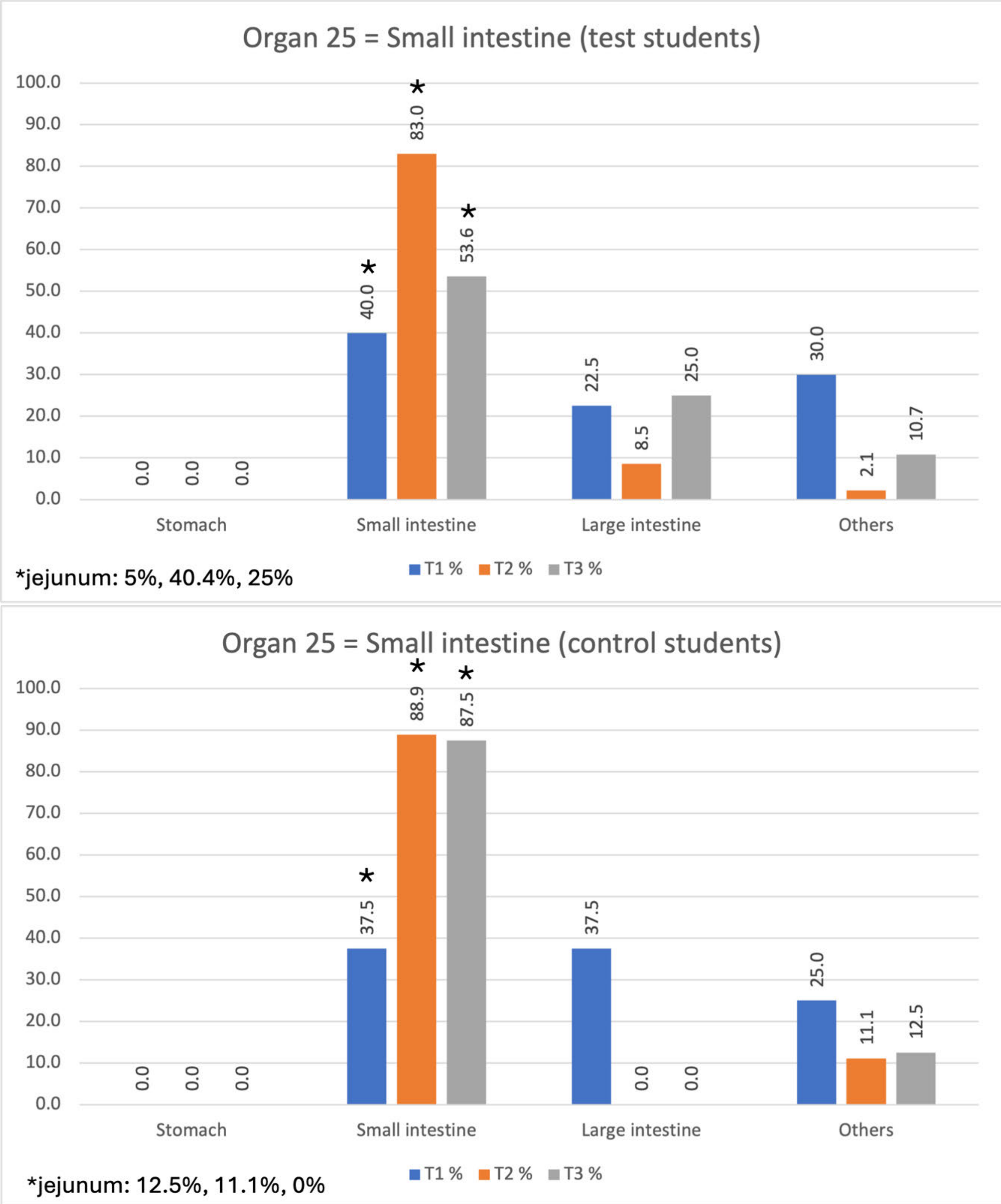
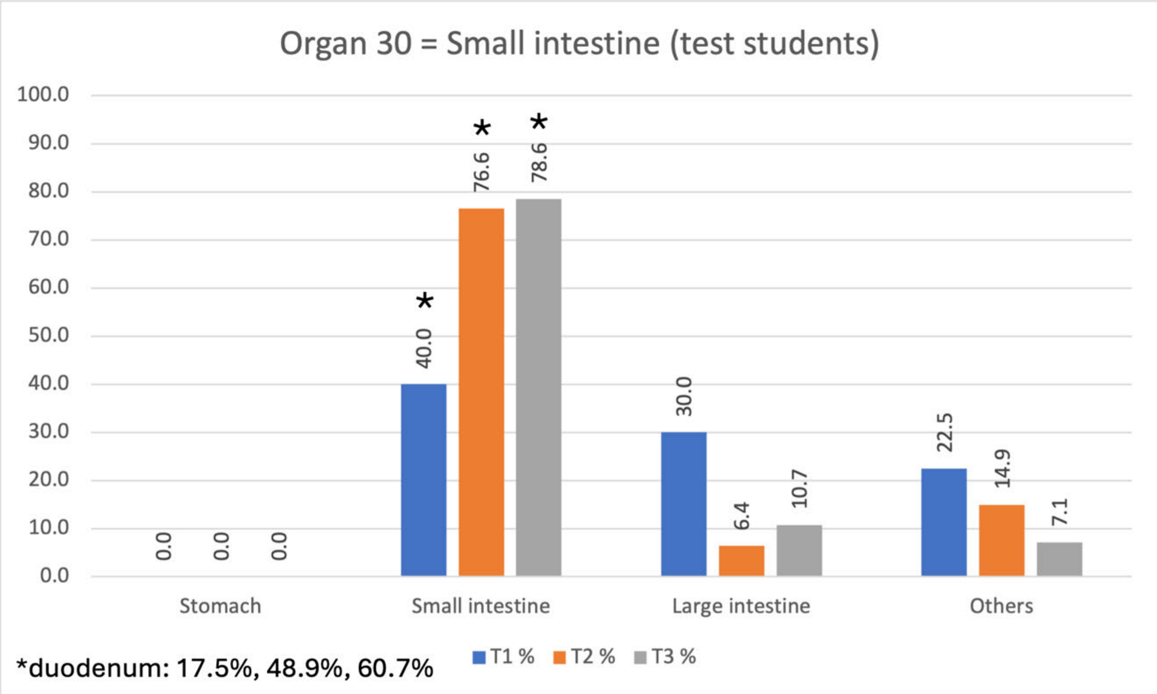


Figure 8 (1/6) Bar charts representing the relative frequencies of students' answers for the small intestine (organs 25, 30, 32, 36, 43 and 45). The X axis displays organ categories including stomach, small intestine, large intestine, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



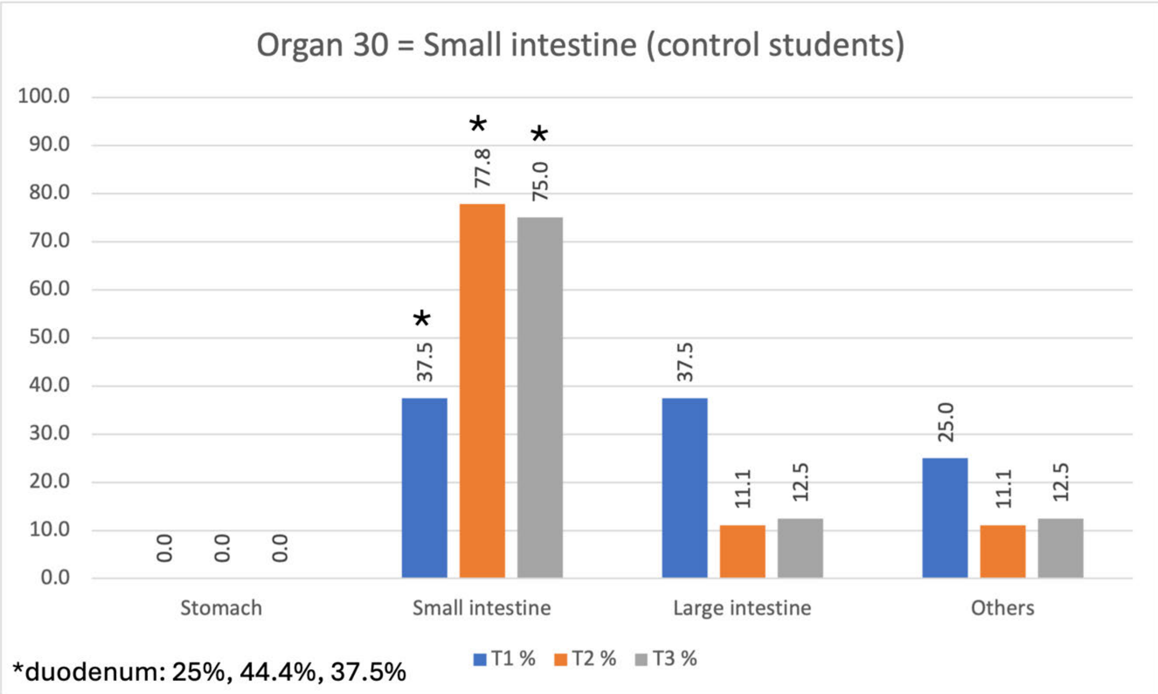


Figure 8 (2/6) Bar charts representing the relative frequencies of students' answers for the small intestine (organs 25, 30, 32, 36, 43 and 45). The X axis displays organ categories including stomach, small intestine, large intestine, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

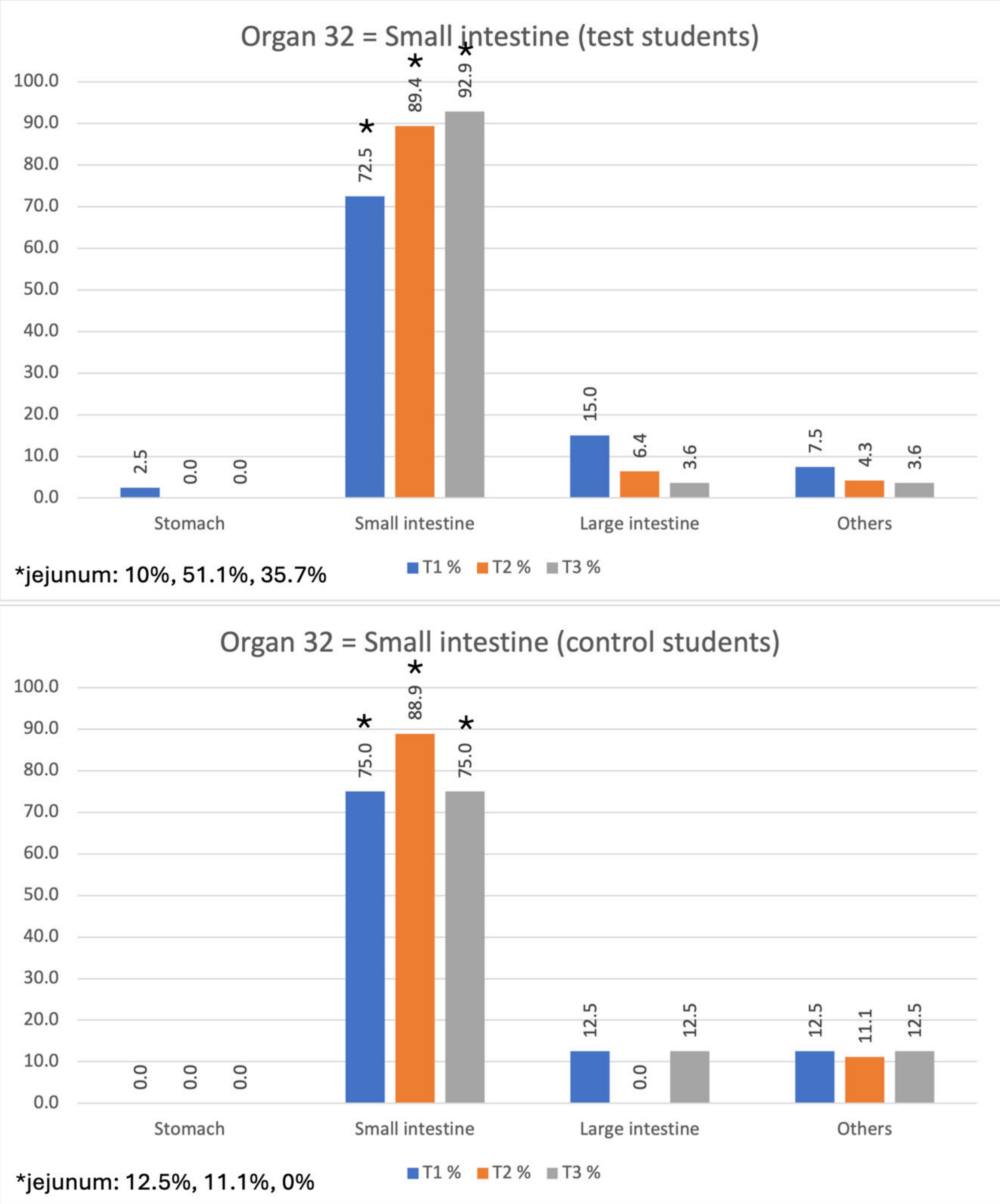
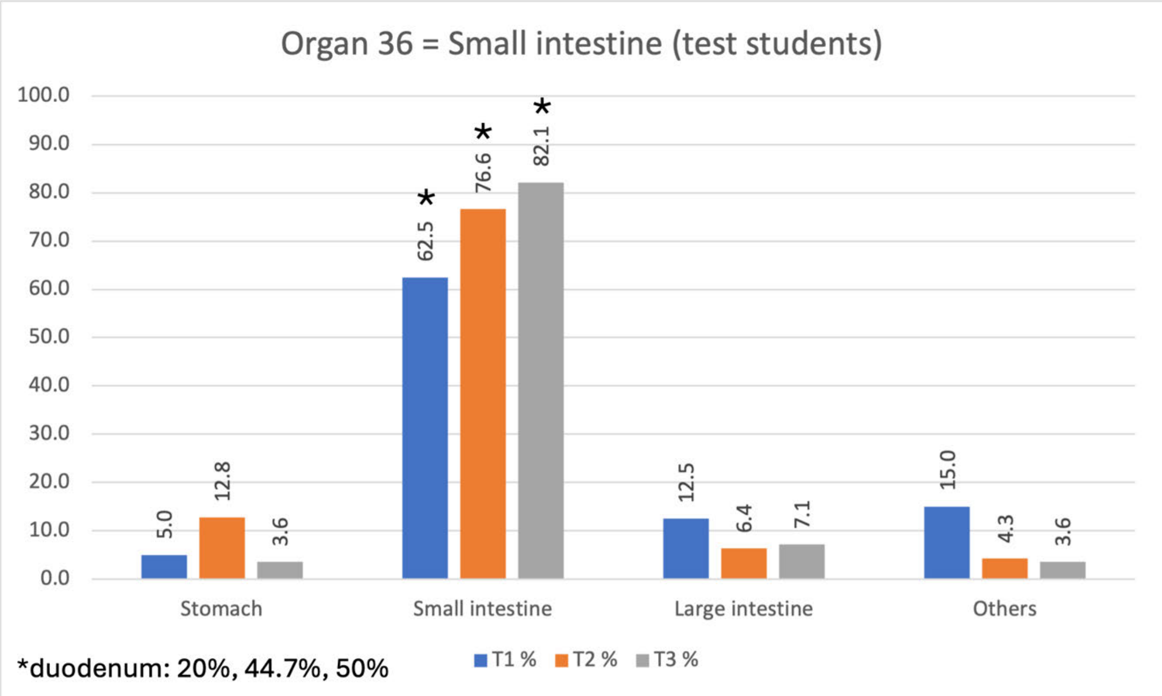


Figure 8 (3/6) Bar charts representing the relative frequencies of students' answers for the small intestine (organs 25, 30, 32, 36, 43 and 45). The X axis displays organ categories including stomach, small intestine, large intestine, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



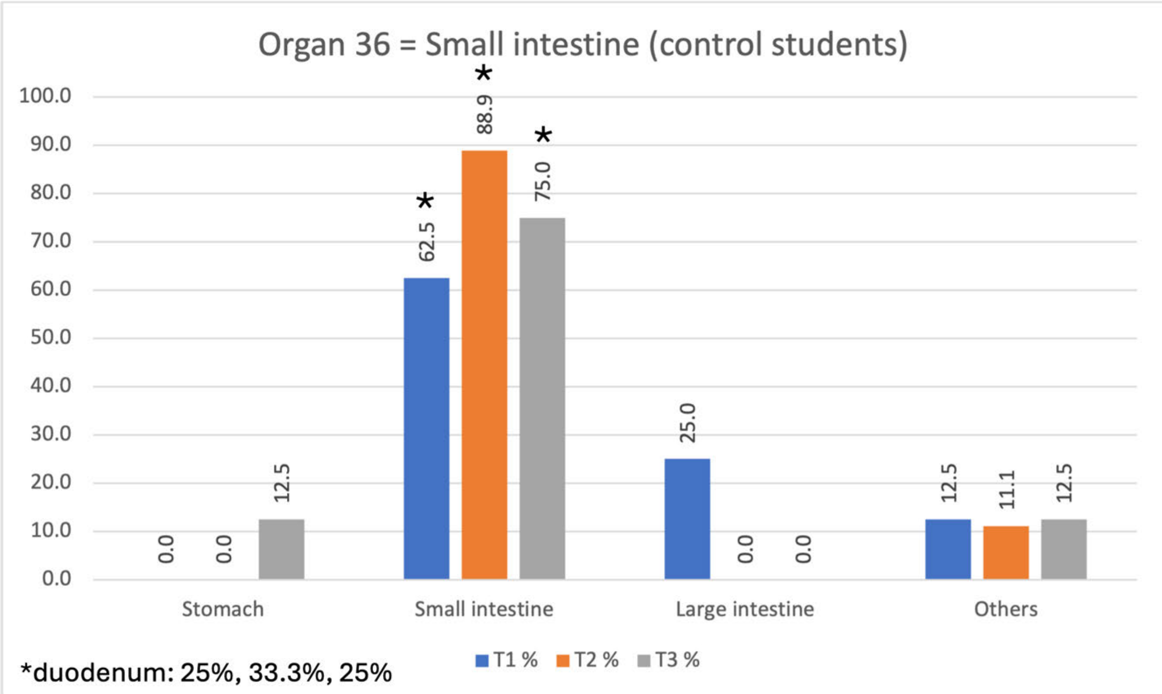
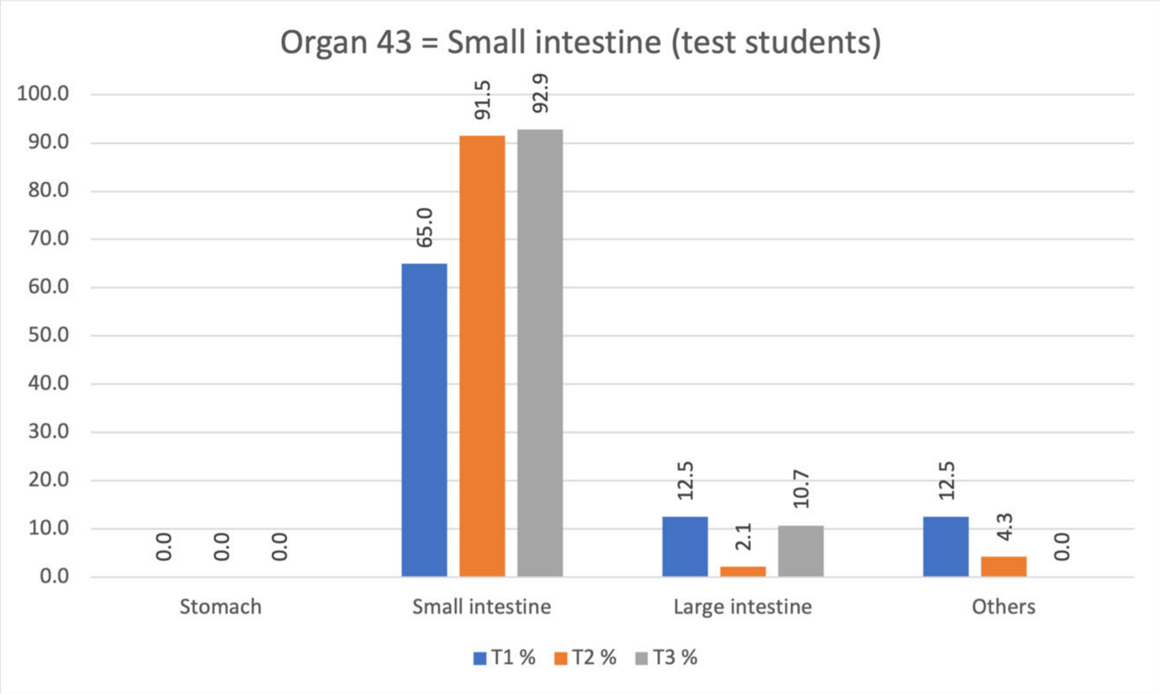


Figure 8 (4/6) Bar charts representing the relative frequencies of students' answers for the small intestine (organs 25, 30, 32, 36, 43 and 45). The X axis displays organ categories including stomach, small intestine, large intestine, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



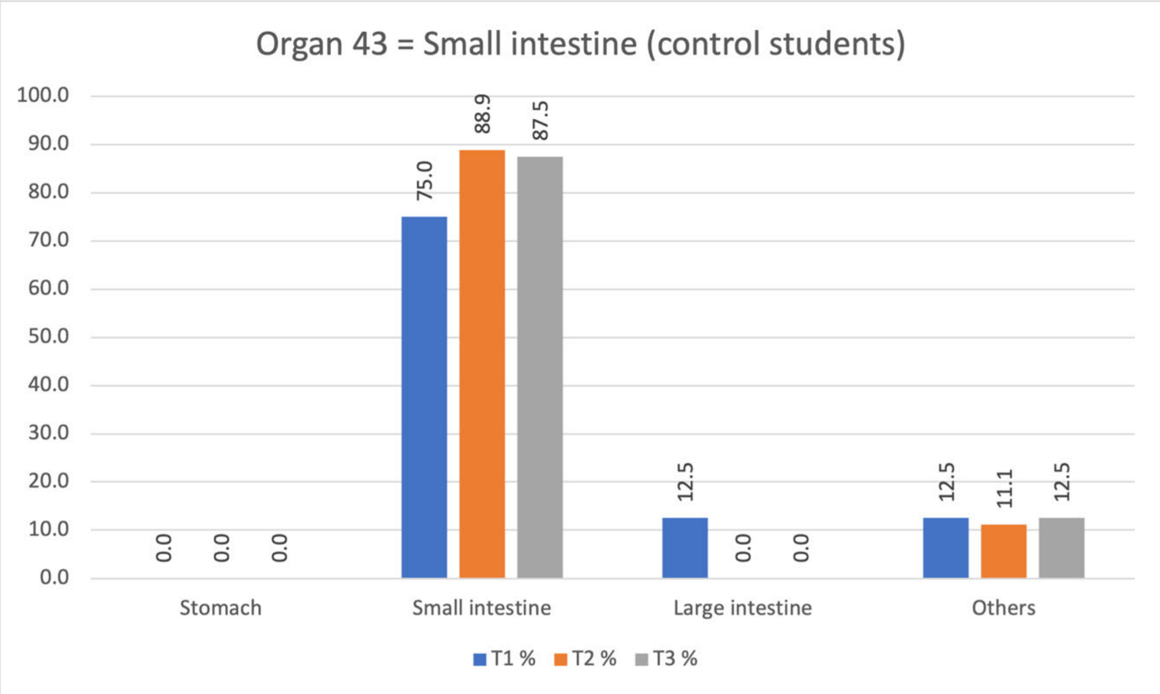
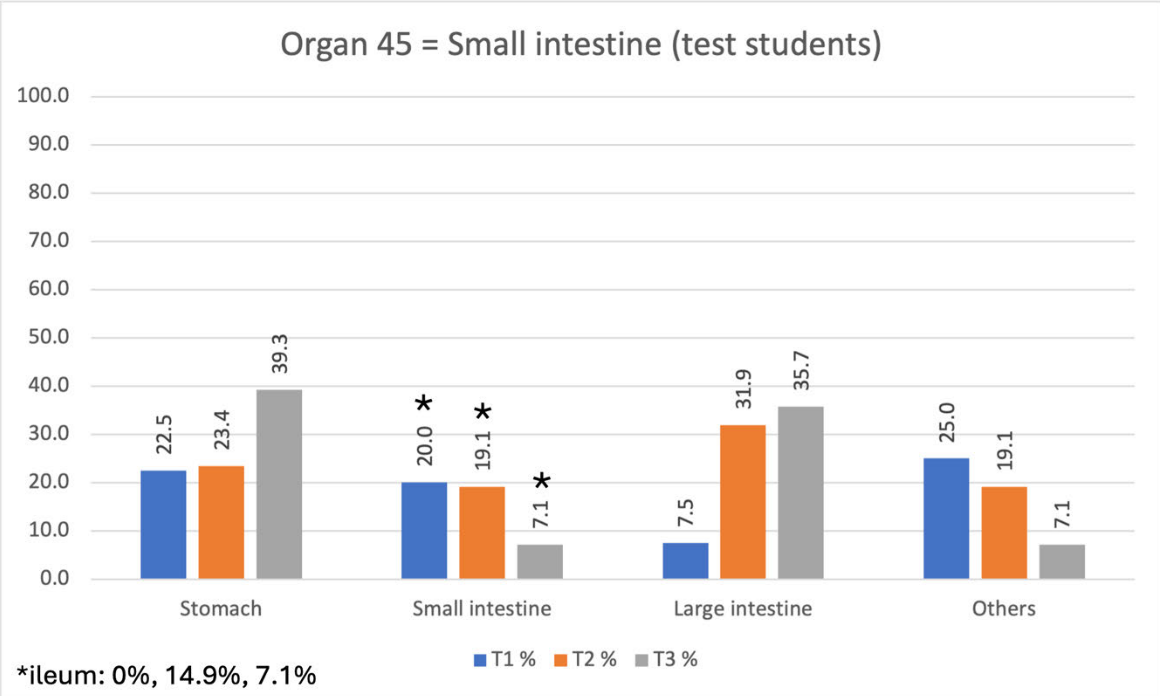


Figure 8 (5/6) Bar charts representing the relative frequencies of students' answers for the small intestine (organs 25, 30, 32, 36, 43 and 45). The X axis displays organ categories including stomach, small intestine, large intestine, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



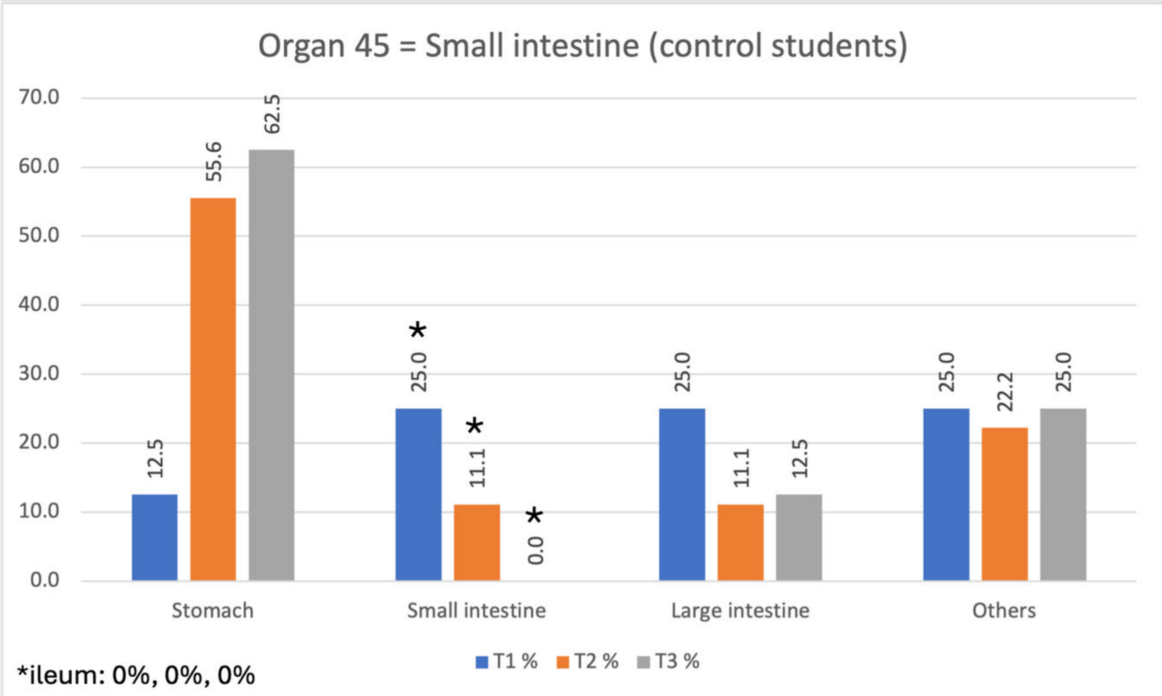


Figure 8 (6/6) Bar charts representing the relative frequencies of students' answers for the small intestine (organs 25, 30, 32, 36, 43 and 45). The X axis displays organ categories including stomach, small intestine, large intestine, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

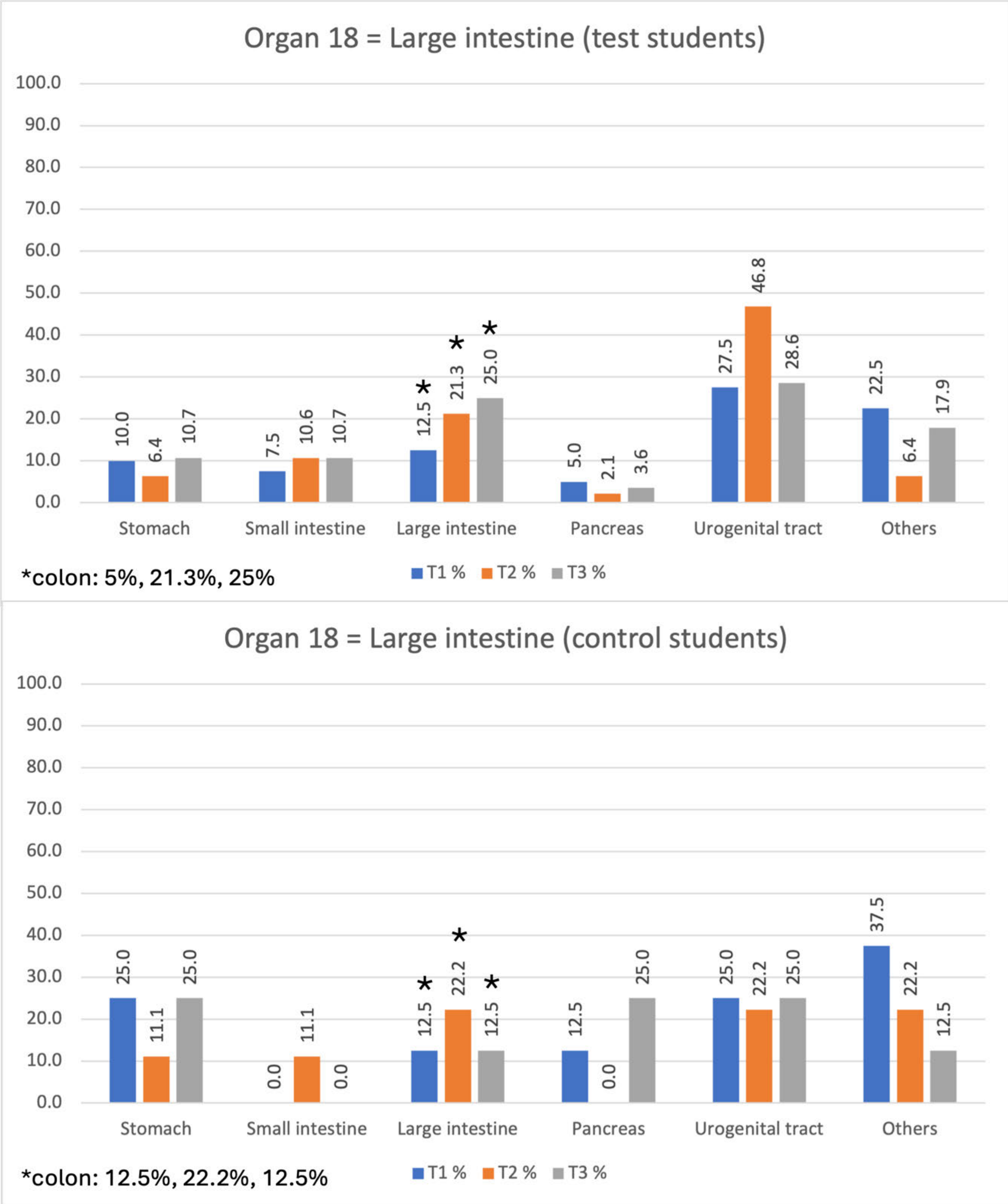


Figure 9 (1/5) Bar charts representing the relative frequencies of students' answers for the large intestine (organs 18, 22, 25, 42 and 44). The X axis displays organ categories including stomach, small intestine, large intestine, pancreas, urogenital tract and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

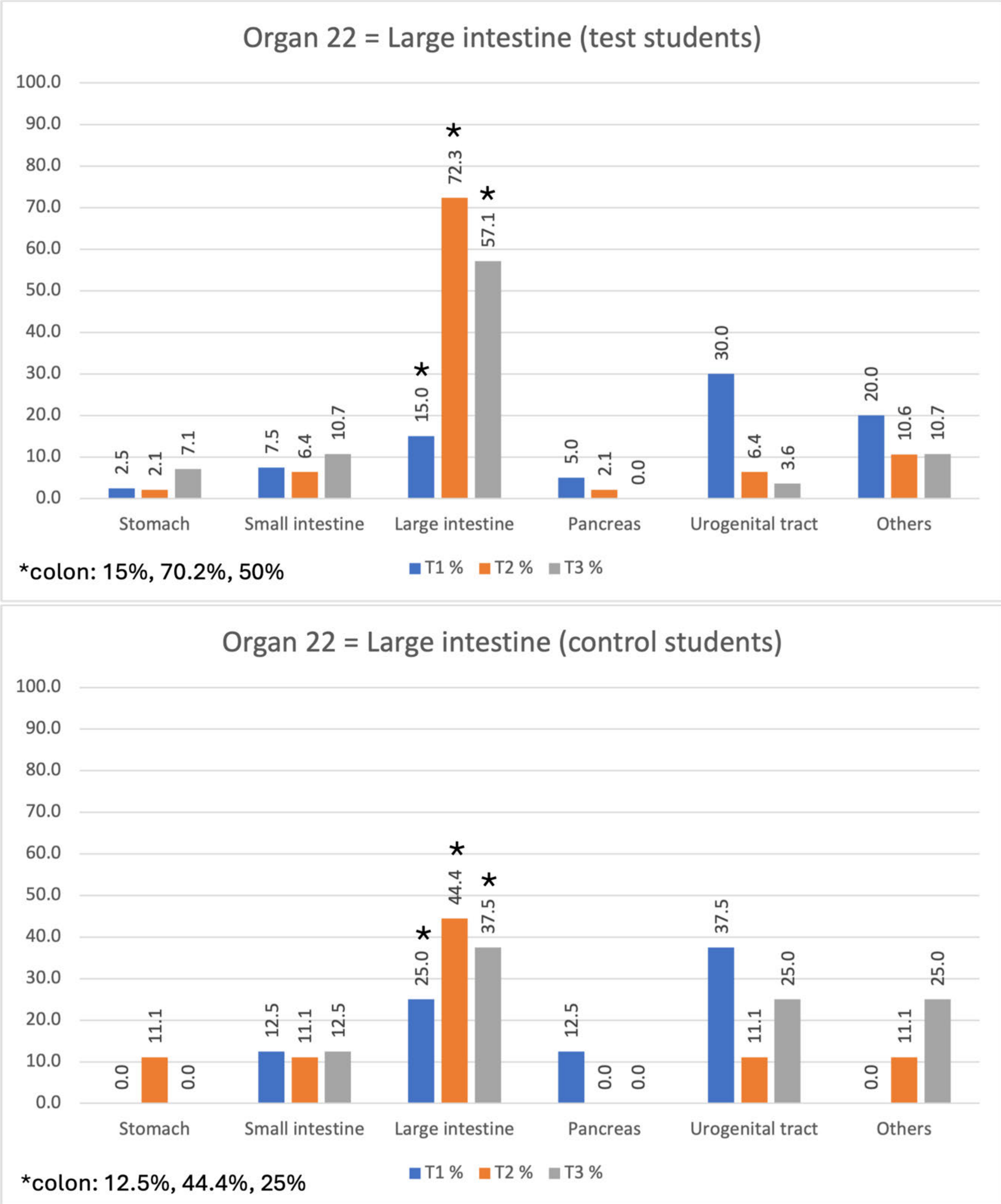


Figure 9 (2/5) Bar charts representing the relative frequencies of students' answers for the large intestine (organs 18, 22, 25, 42 and 44). The X axis displays organ categories including stomach, small intestine, large intestine, pancreas, urogenital tract and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

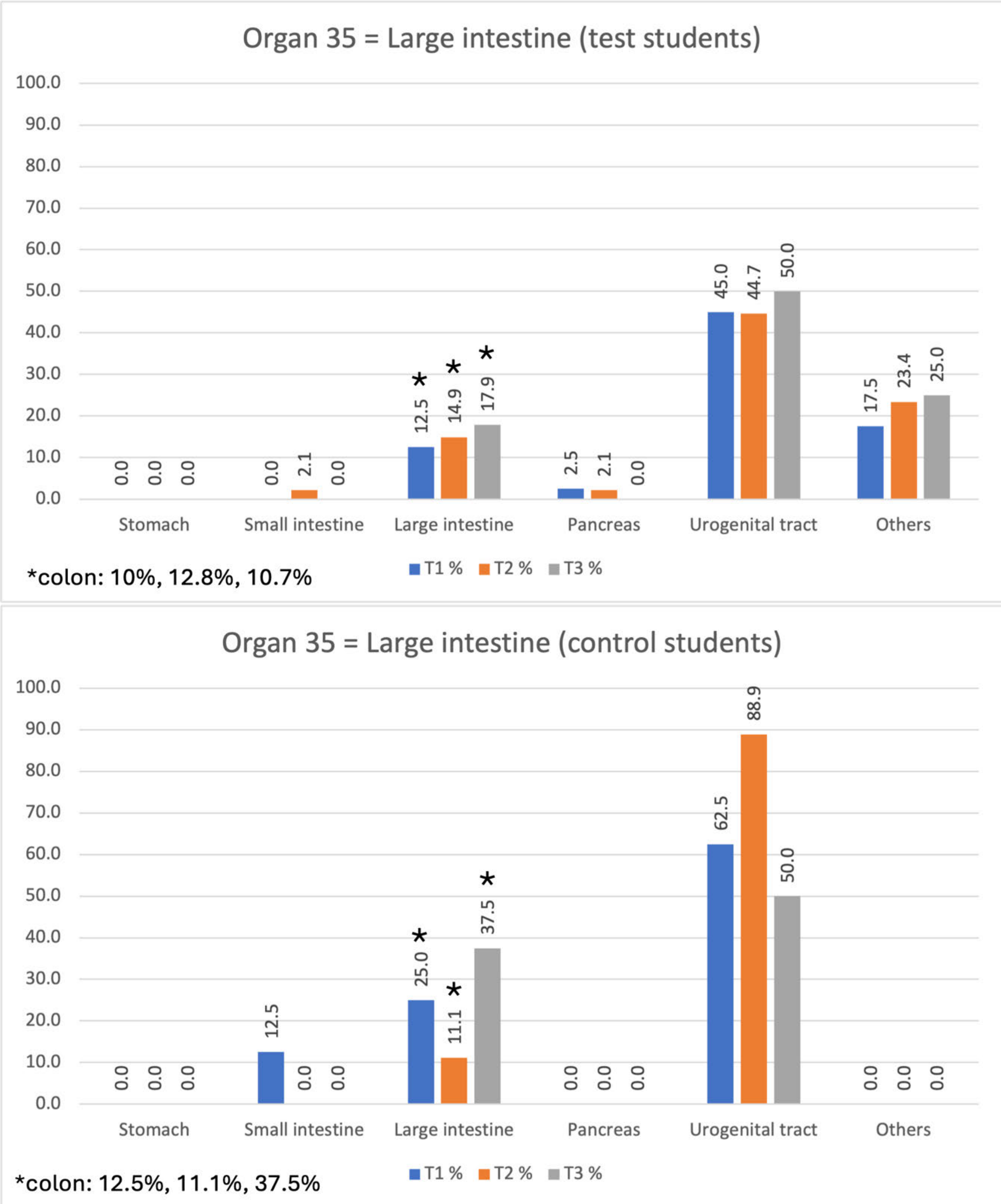


Figure 9 (3/5) Bar charts representing the relative frequencies of students' answers for the large intestine (organs 18, 22, 25, 42 and 44). The X axis displays organ categories including stomach, small intestine, large intestine, pancreas, urogenital tract and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

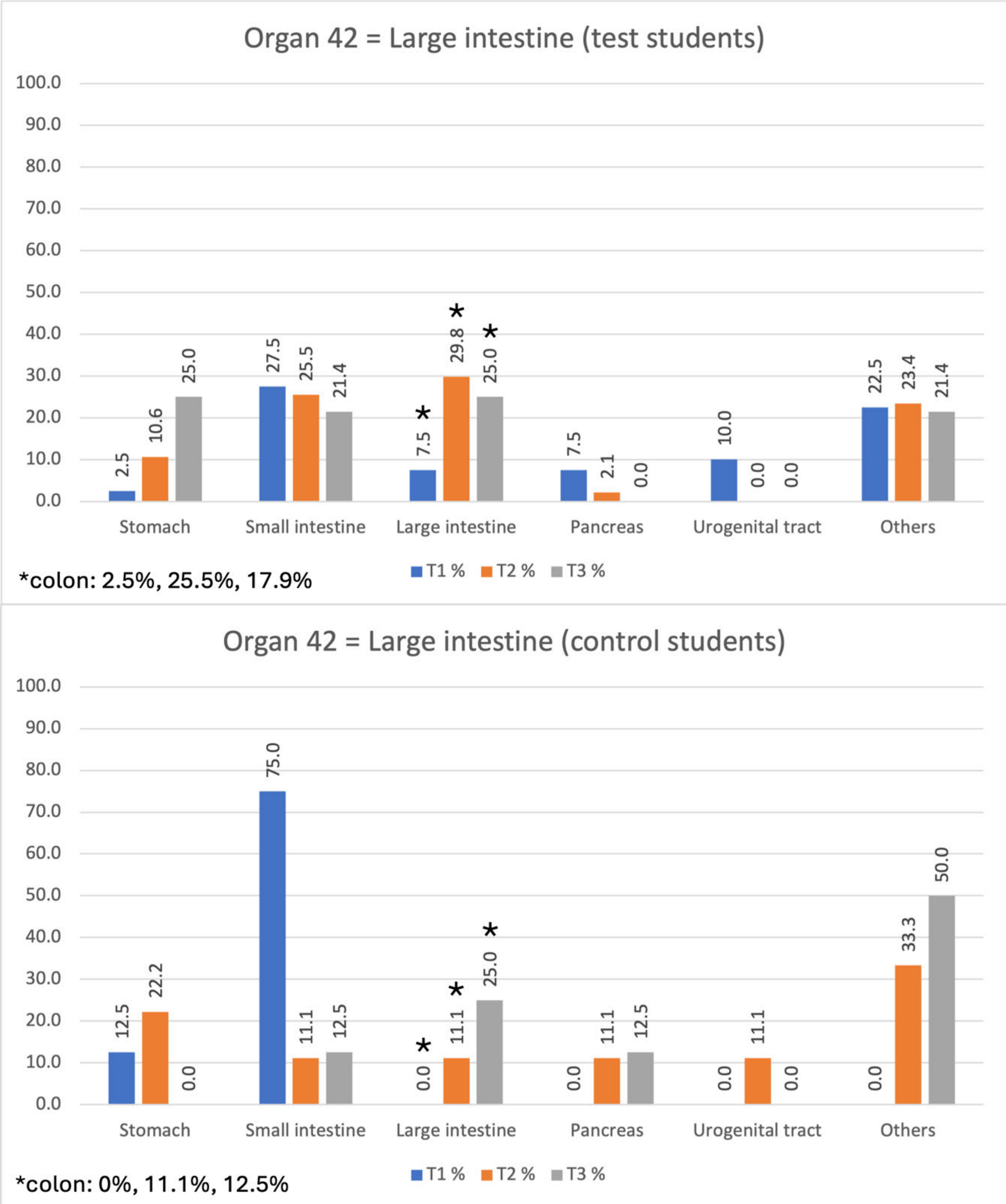


Figure 9 (4/5) Bar charts representing the relative frequencies of students' answers for the large intestine (organs 18, 22, 25, 42 and 44). The X axis displays organ categories including stomach, small intestine, large intestine, pancreas, urogenital tract and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

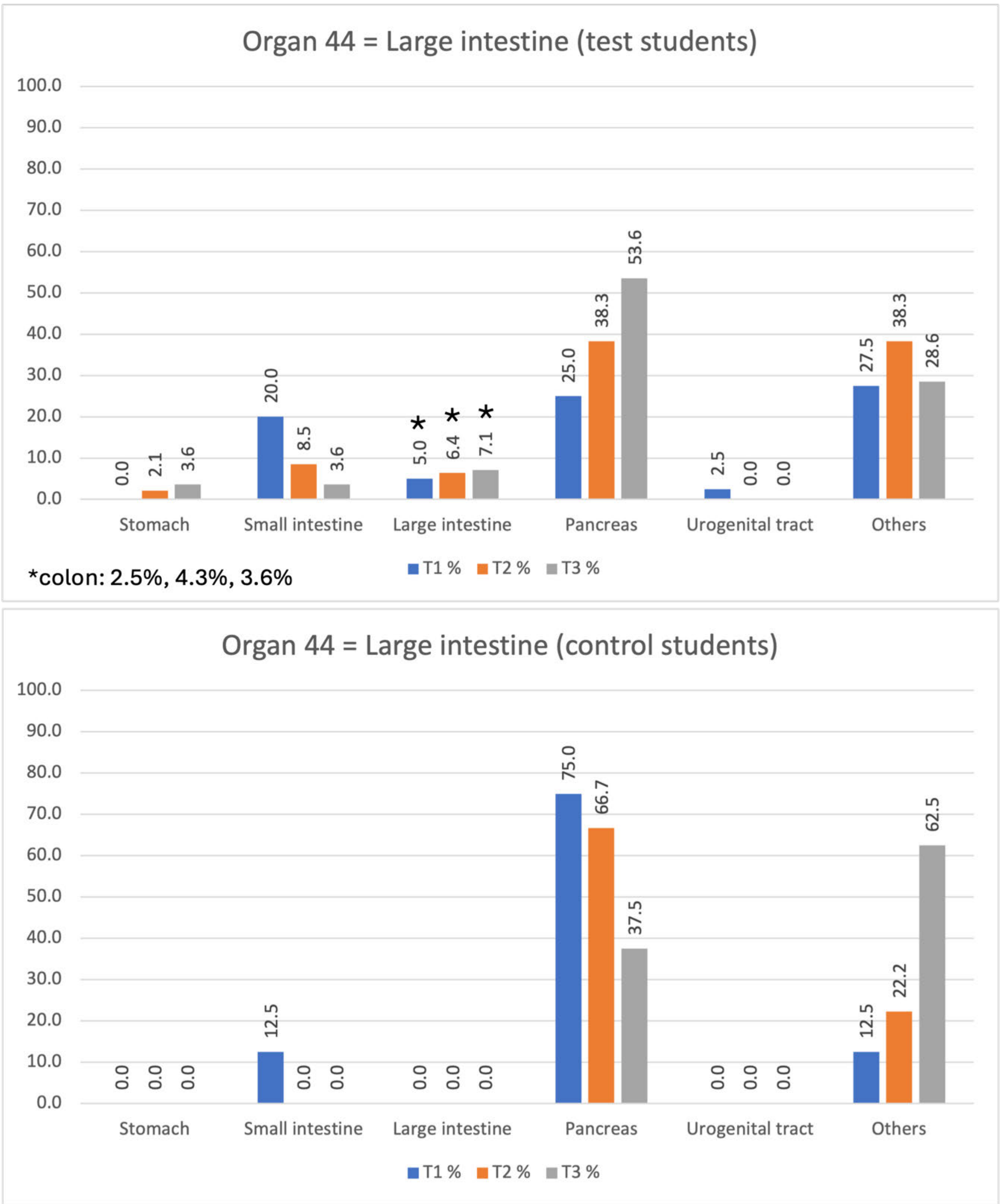
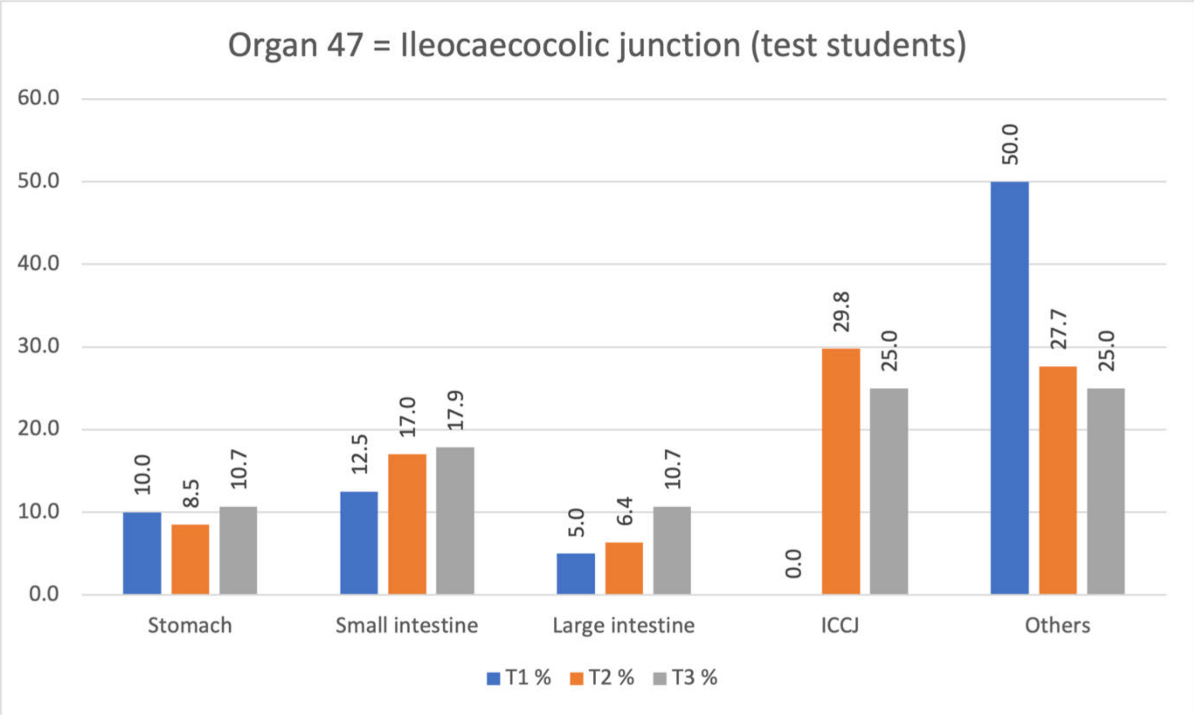


Figure 9 (5/5). Bar charts representing the relative frequencies of students' answers for the large intestine (organs 18, 22, 25, 42 and 44). The X axis displays organ categories including stomach, small intestine, large intestine, pancreas, urogenital tract and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



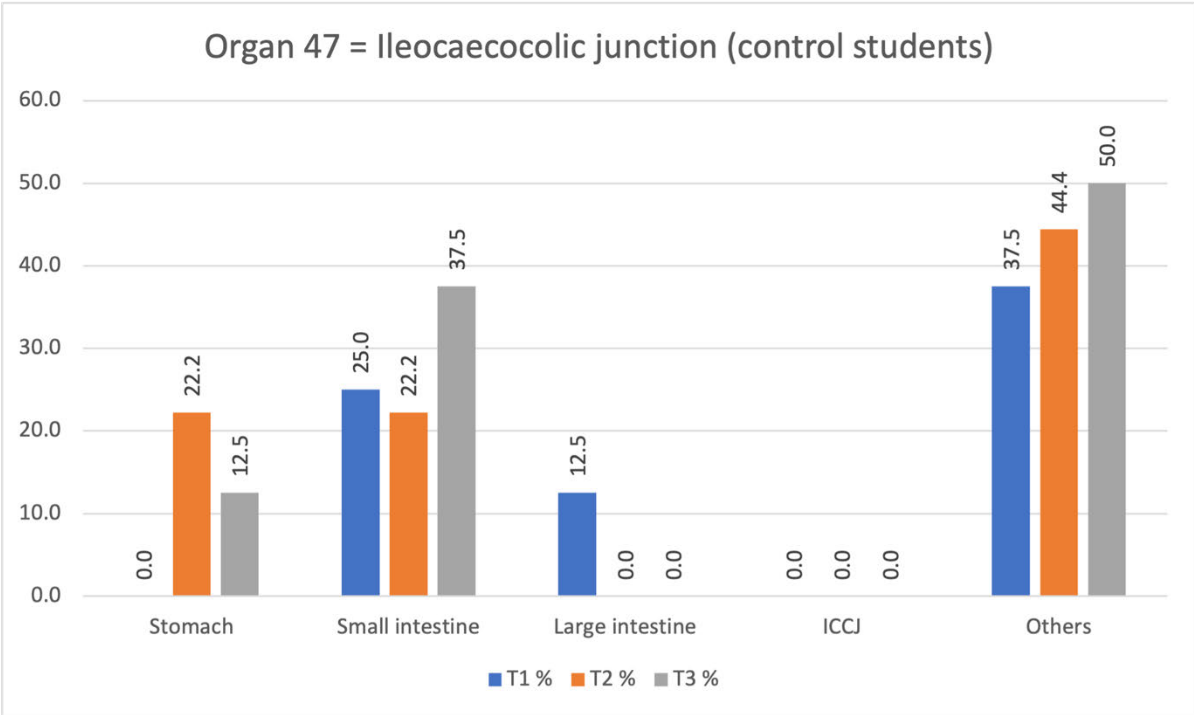
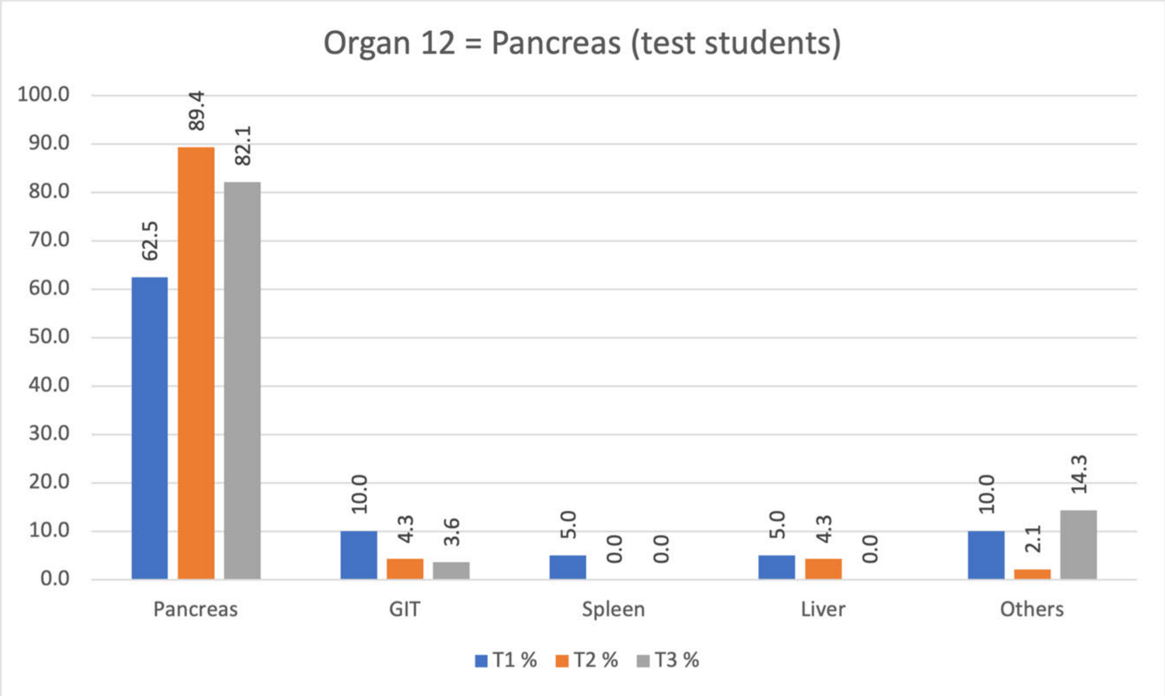


Figure 10 Bar charts representing the relative frequencies of students' answers for the ileocaecocolic junction (ICCJ, organ 47). The X axis displays organ categories including stomach, small intestine, large intestine, ICCJ, and others (including undifferentiated intestine) organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



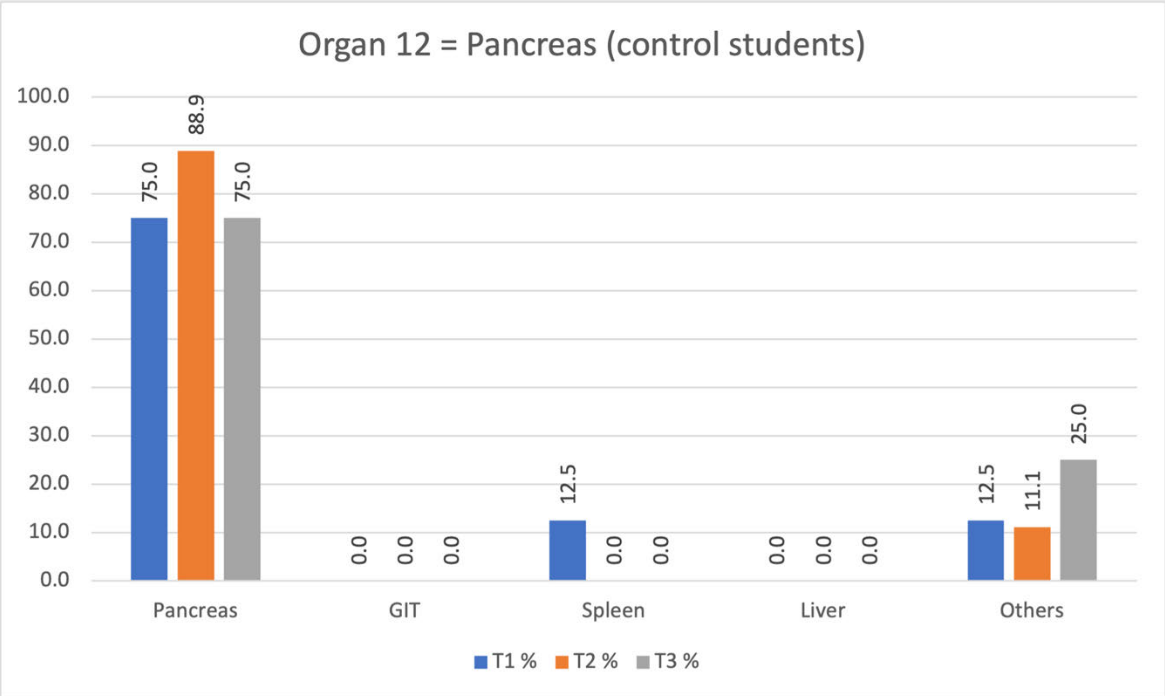


Figure 11 (1/4) Bar charts representing the relative frequencies of students' answers for the pancreas (organs 12, 13, 28, and 39). The X axis displays organ categories including pancreas, gastrointestinal tract (GIT), spleen, liver, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

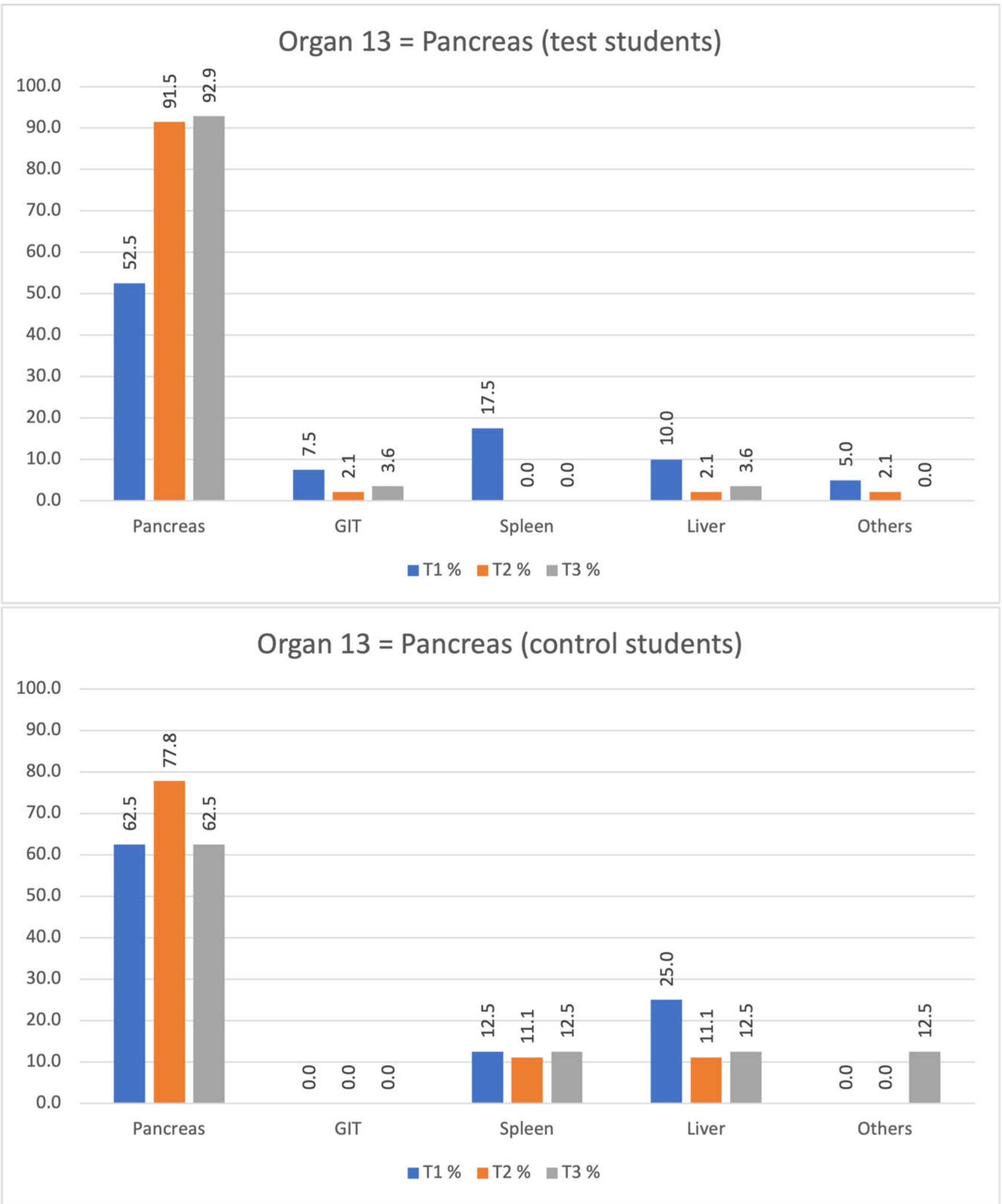
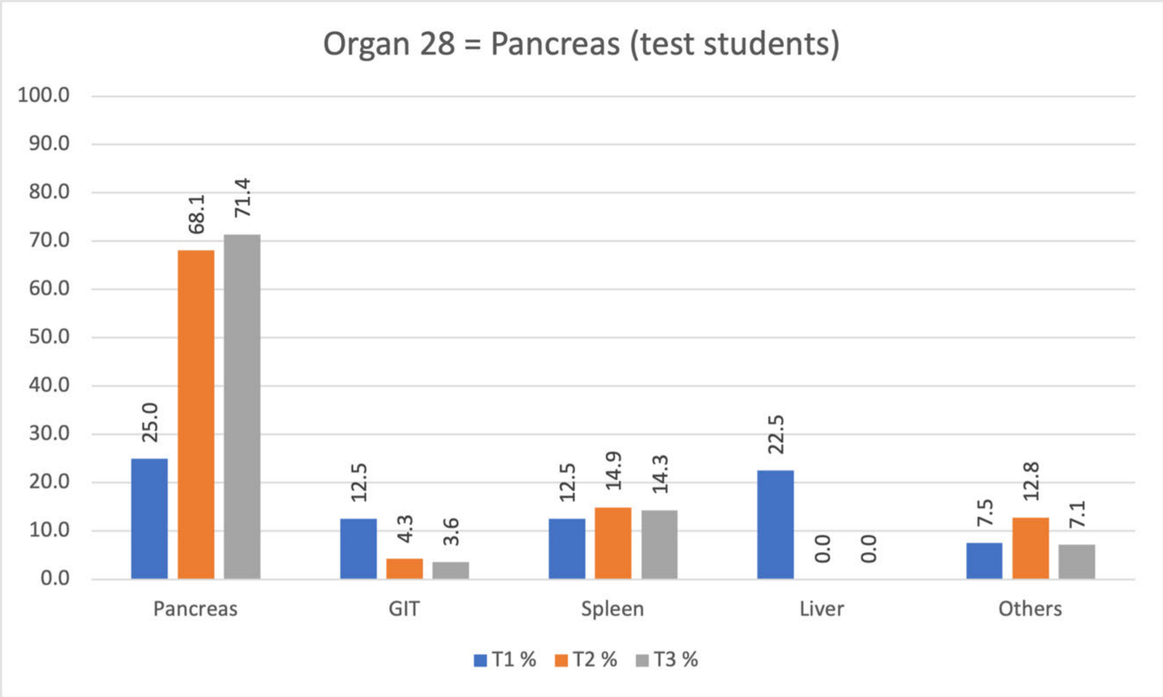


Figure 11 (2/4) Bar charts representing the relative frequencies of students' answers for the pancreas (organs 12, 13, 28, and 39). The X axis displays organ categories including pancreas, gastrointestinal tract (GIT), spleen, liver, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



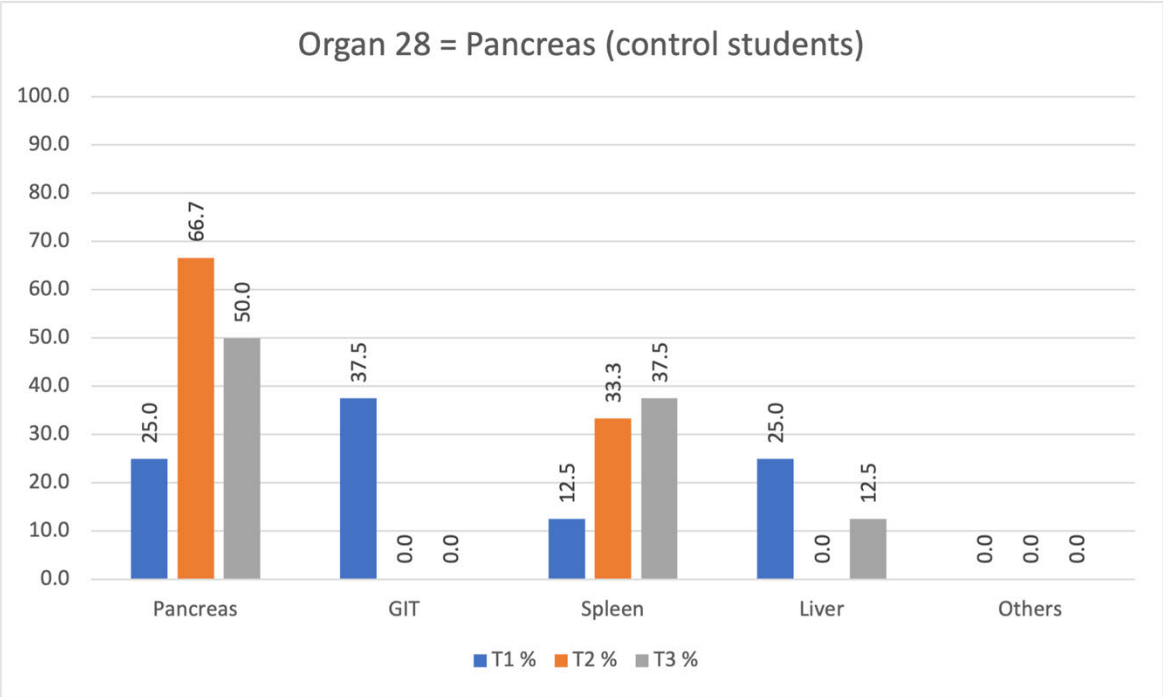


Figure 11 (3/4) Bar charts representing the relative frequencies of students' answers for the pancreas (organs 12, 13, 28, and 39). The X axis displays organ categories including pancreas, gastrointestinal tract (GIT), spleen, liver, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

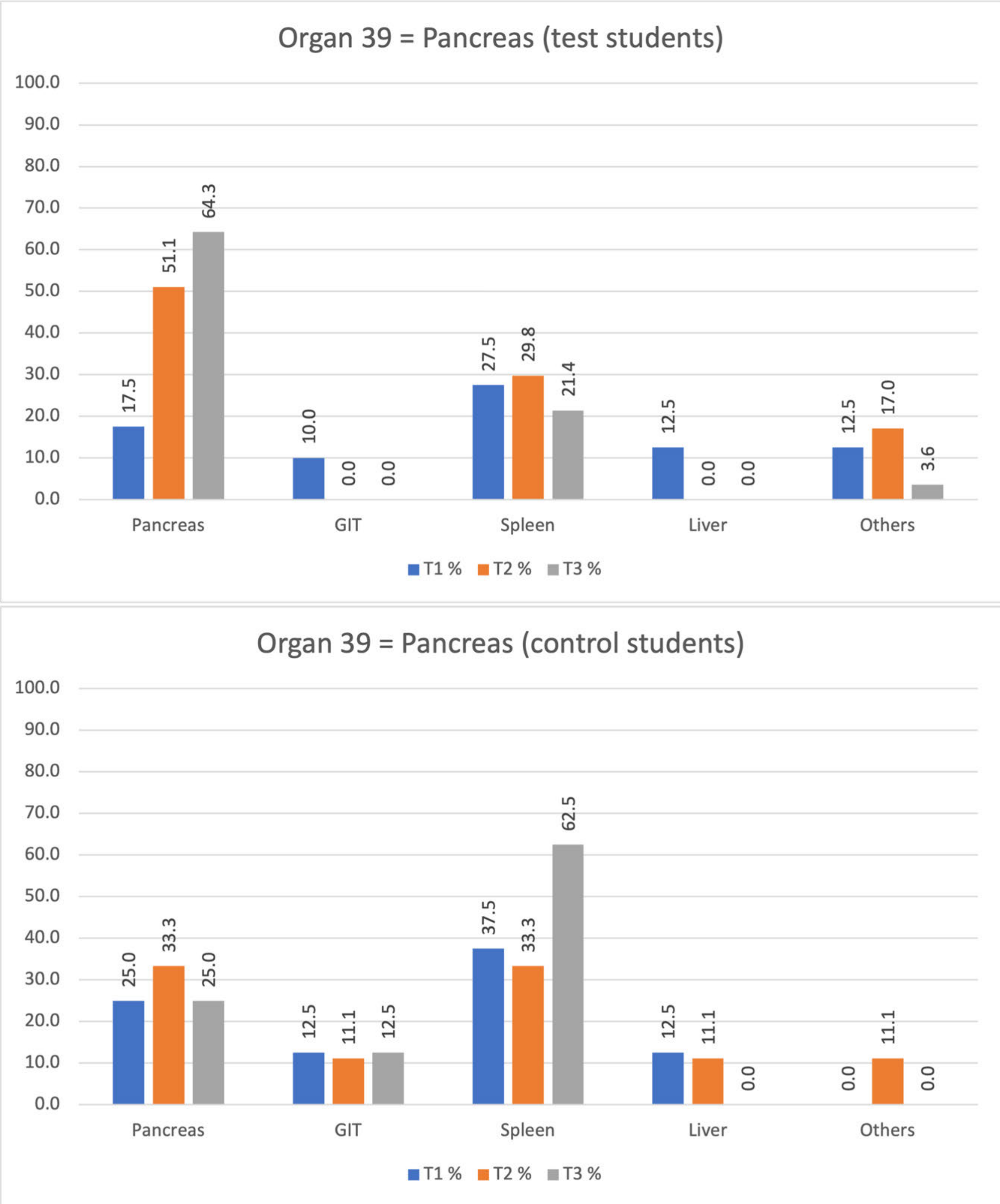
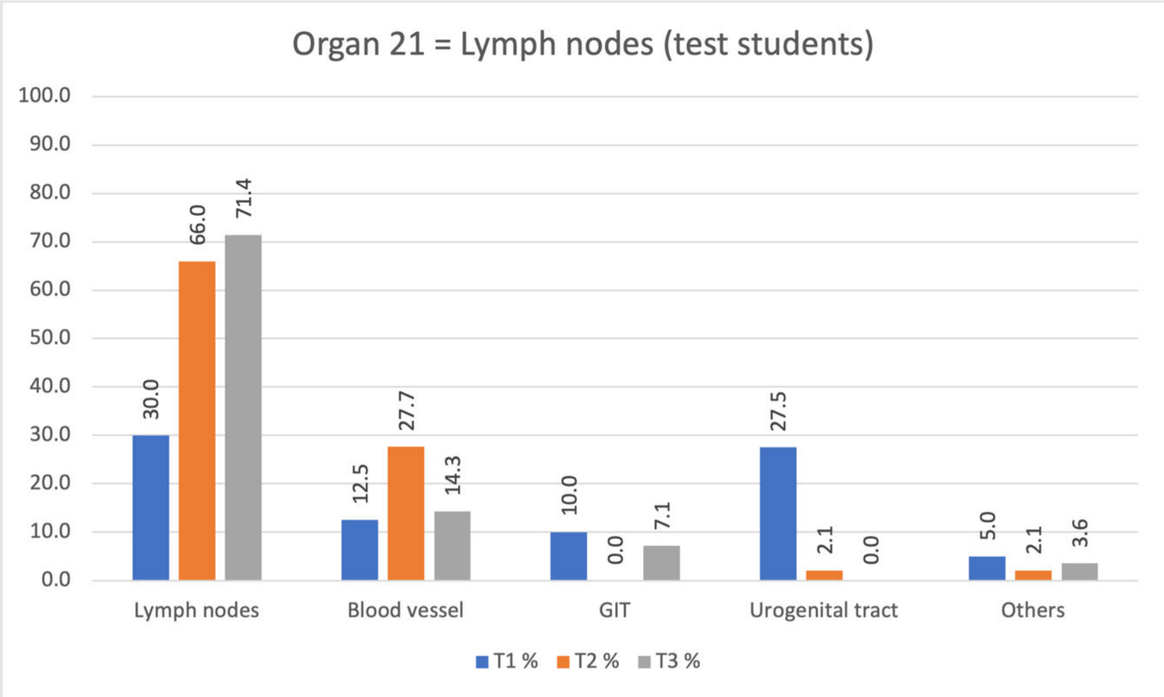


Figure 11 (4/4) Bar charts representing the relative frequencies of students' answers for the pancreas (organs 12, 13, 28, and 39). The X axis displays organ categories including pancreas, gastrointestinal tract (GIT), spleen, liver, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



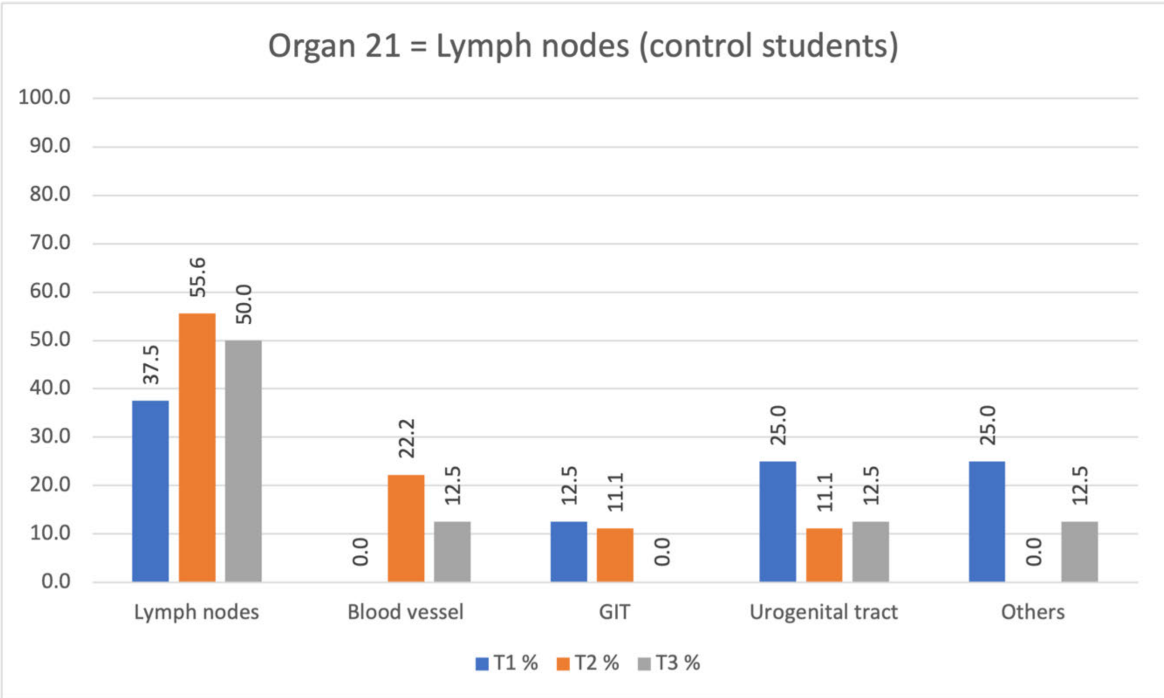
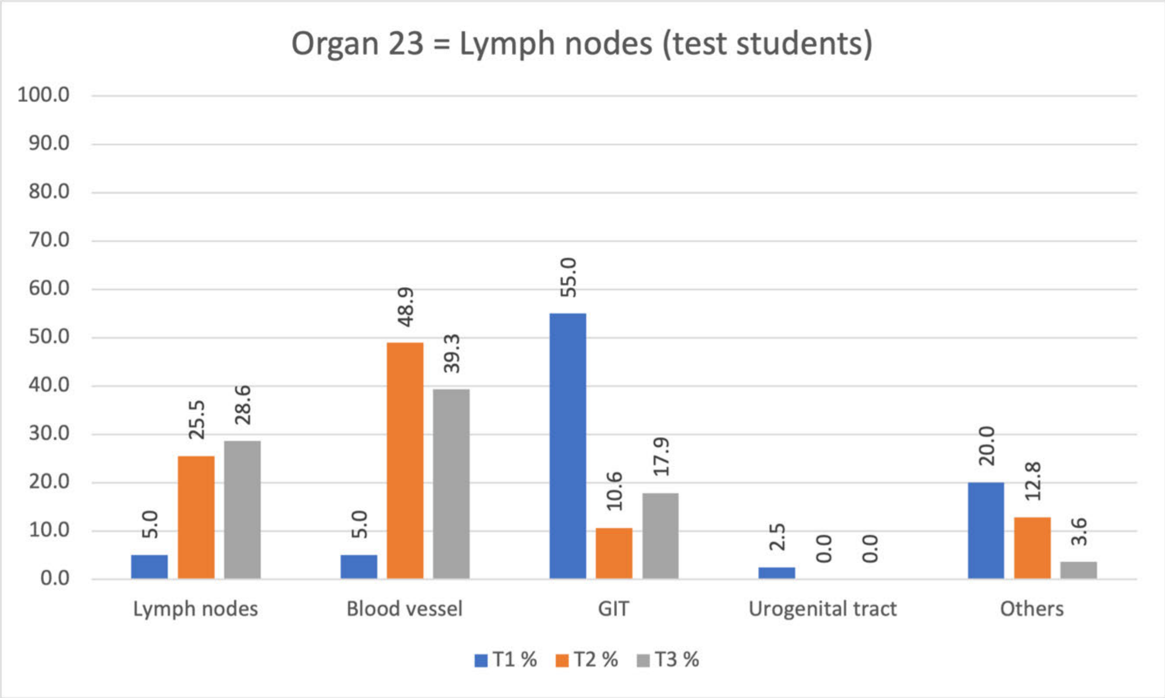


Figure 12 (1/2) Bar charts representing the relative frequencies of students' answers for the lymph nodes (organs 21 and 23). The X axis displays organ categories including lymph nodes, blood vessel, gastrointestinal tract (GIT), urogenital tract, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



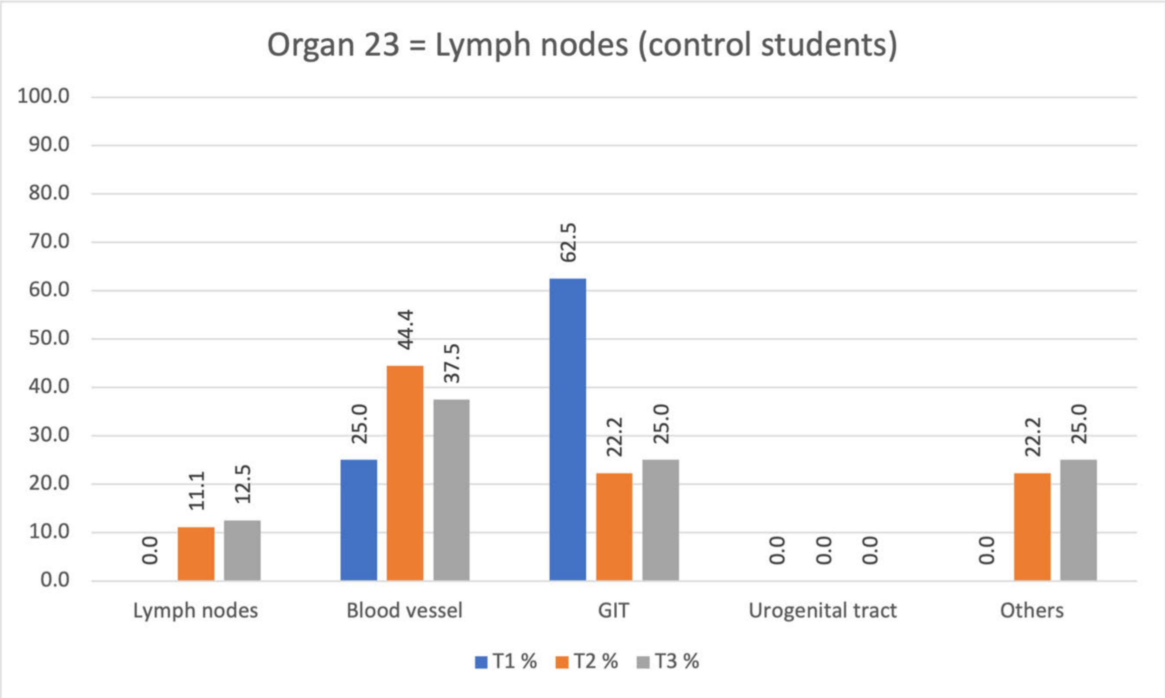


Figure 12 (2/2) Bar charts representing the relative frequencies of students' answers for the lymph nodes (organs 21 and 23). The X axis displays organ categories including lymph nodes, blood vessel, gastrointestinal tract (GIT), urogenital tract, and others organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

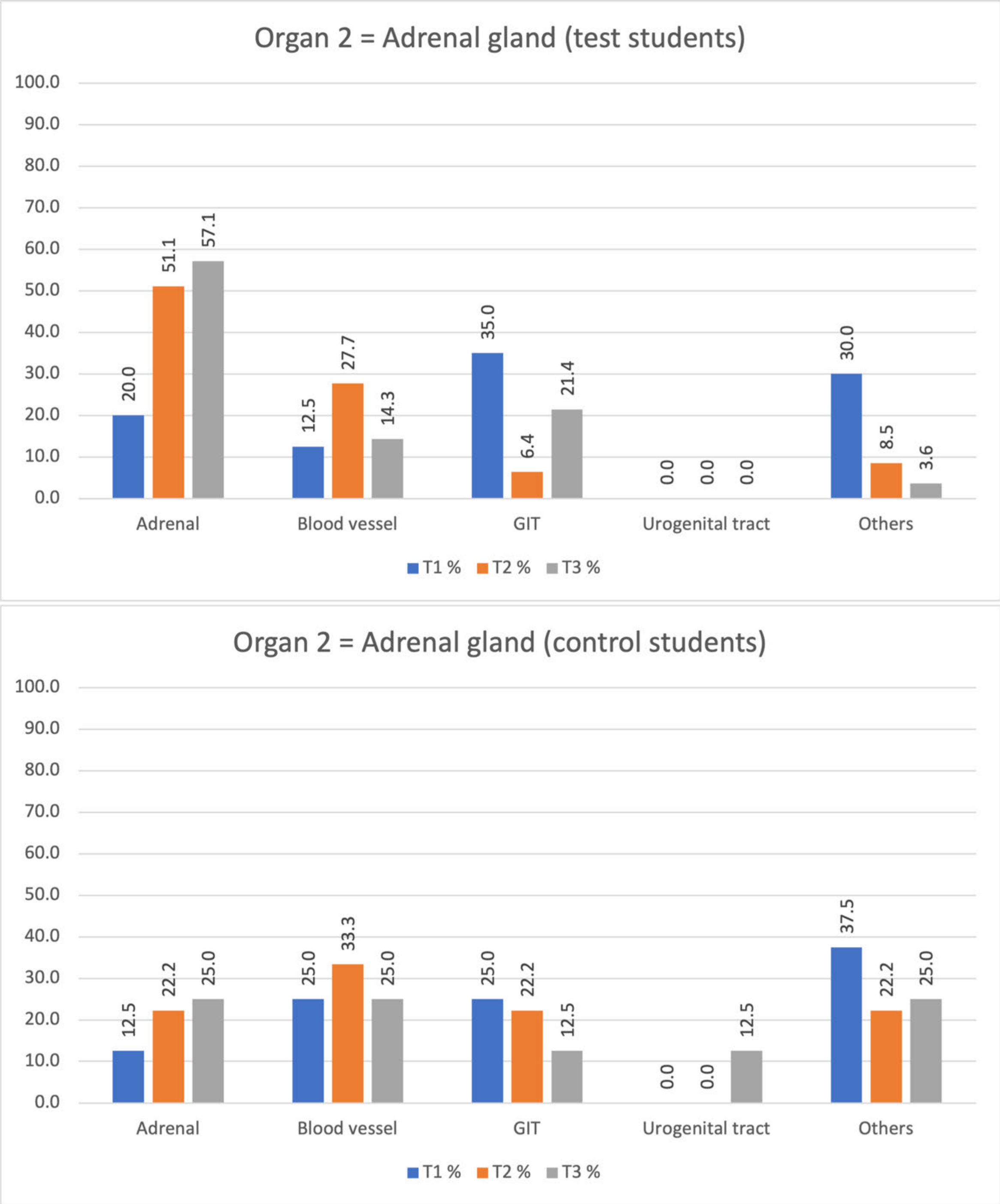
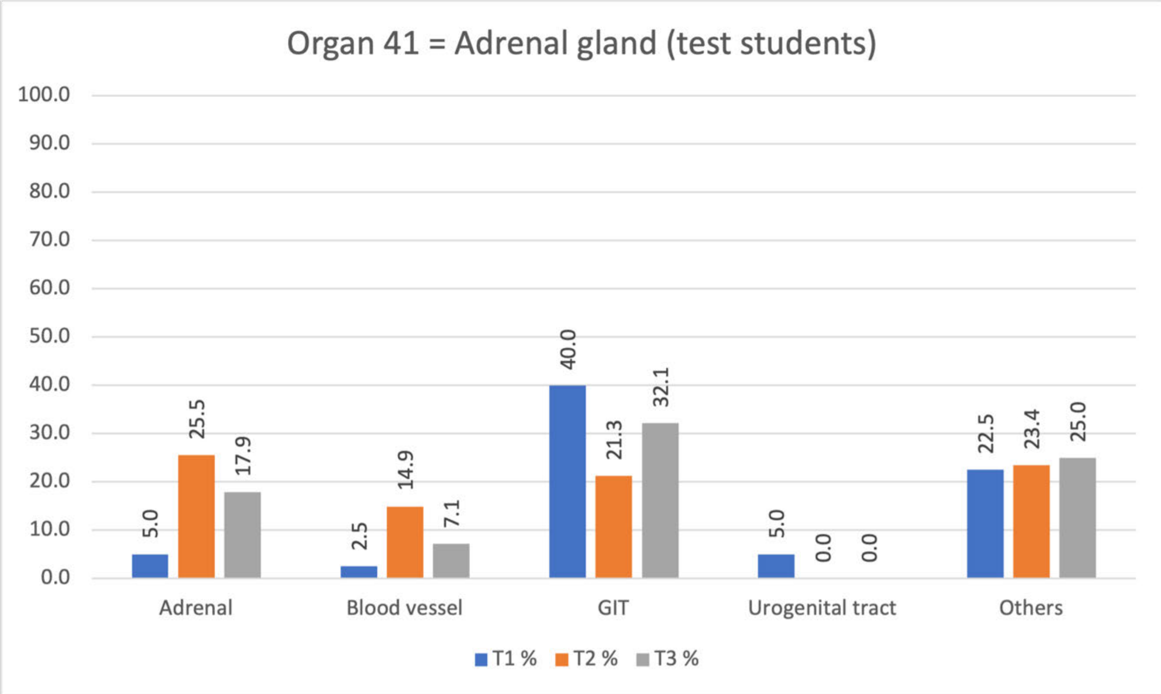


Figure 13 (1/2) Bar charts representing the relative frequencies of students' answers for the adrenal glands (organs 2 and 41). The X axis displays organ categories including adrenal, blood vessel, gastrointestinal tract (GIT), urogenital tract, and others. organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



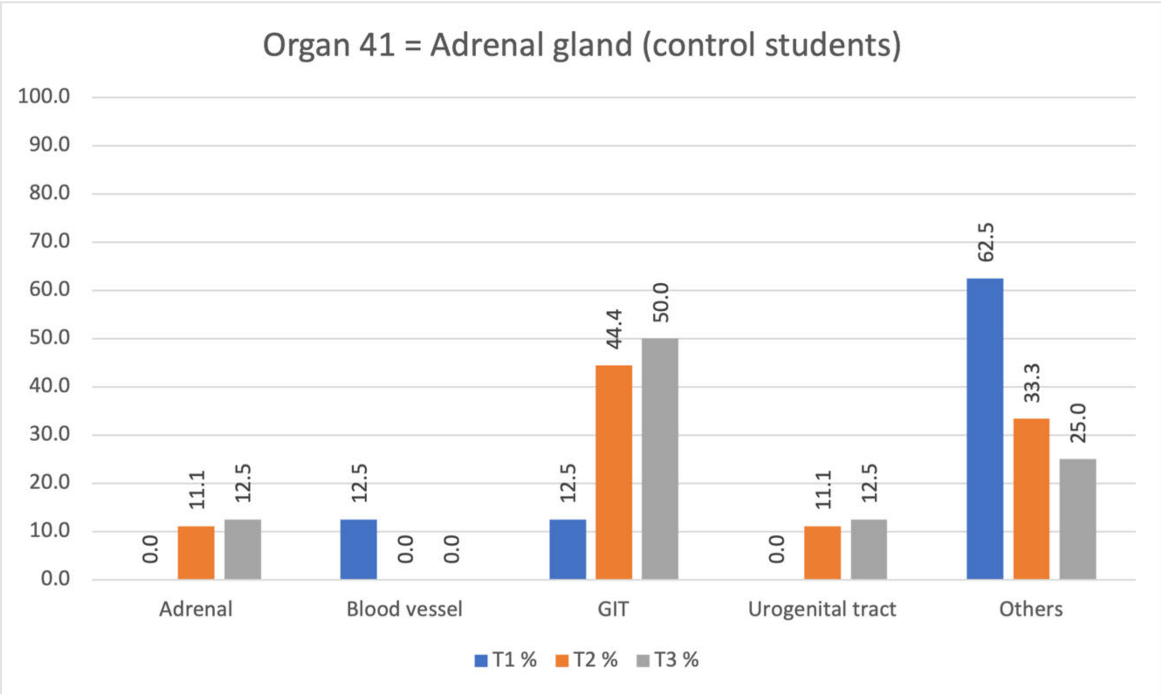
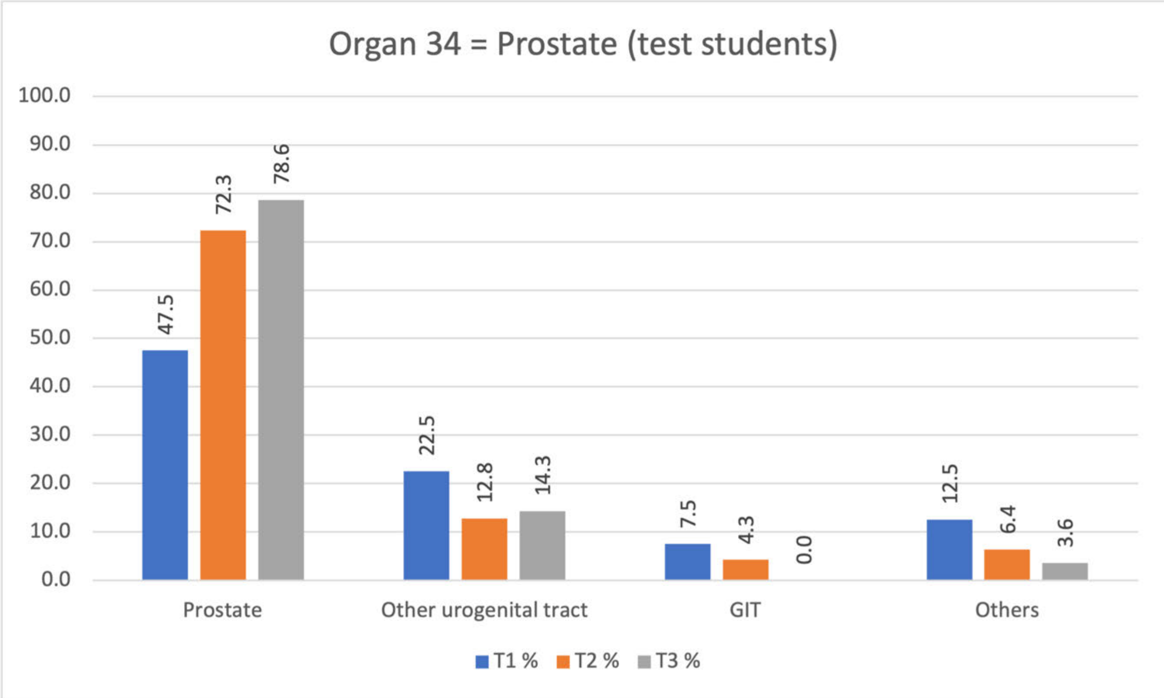


Figure 13 (2/2) Bar charts representing the relative frequencies of students' answers for the adrenal glands (organs 2 and 41). The X axis displays organ categories including adrenal, blood vessel, gastrointestinal tract (GIT), urogenital tract, and others. organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



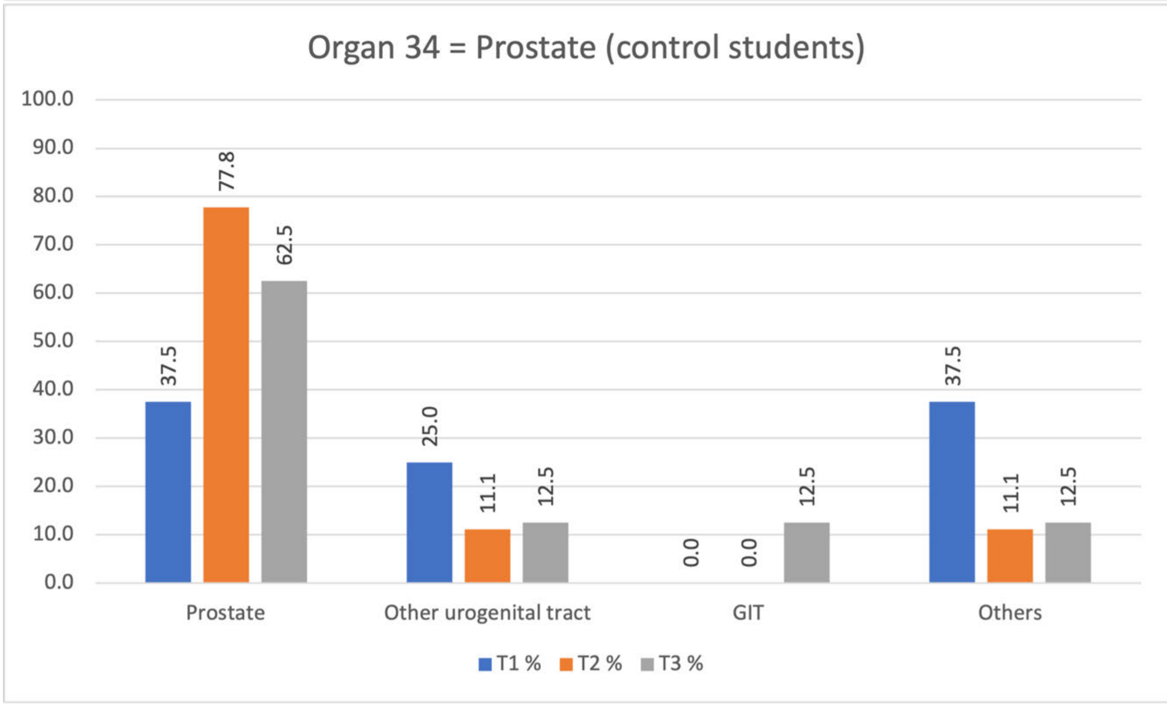


Figure 14 Bar charts representing the relative frequencies of students' answers for the prostate (organ 34). The X axis displays organ categories including prostate, other urogenital tract, gastrointestinal tract (GIT), and others. organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

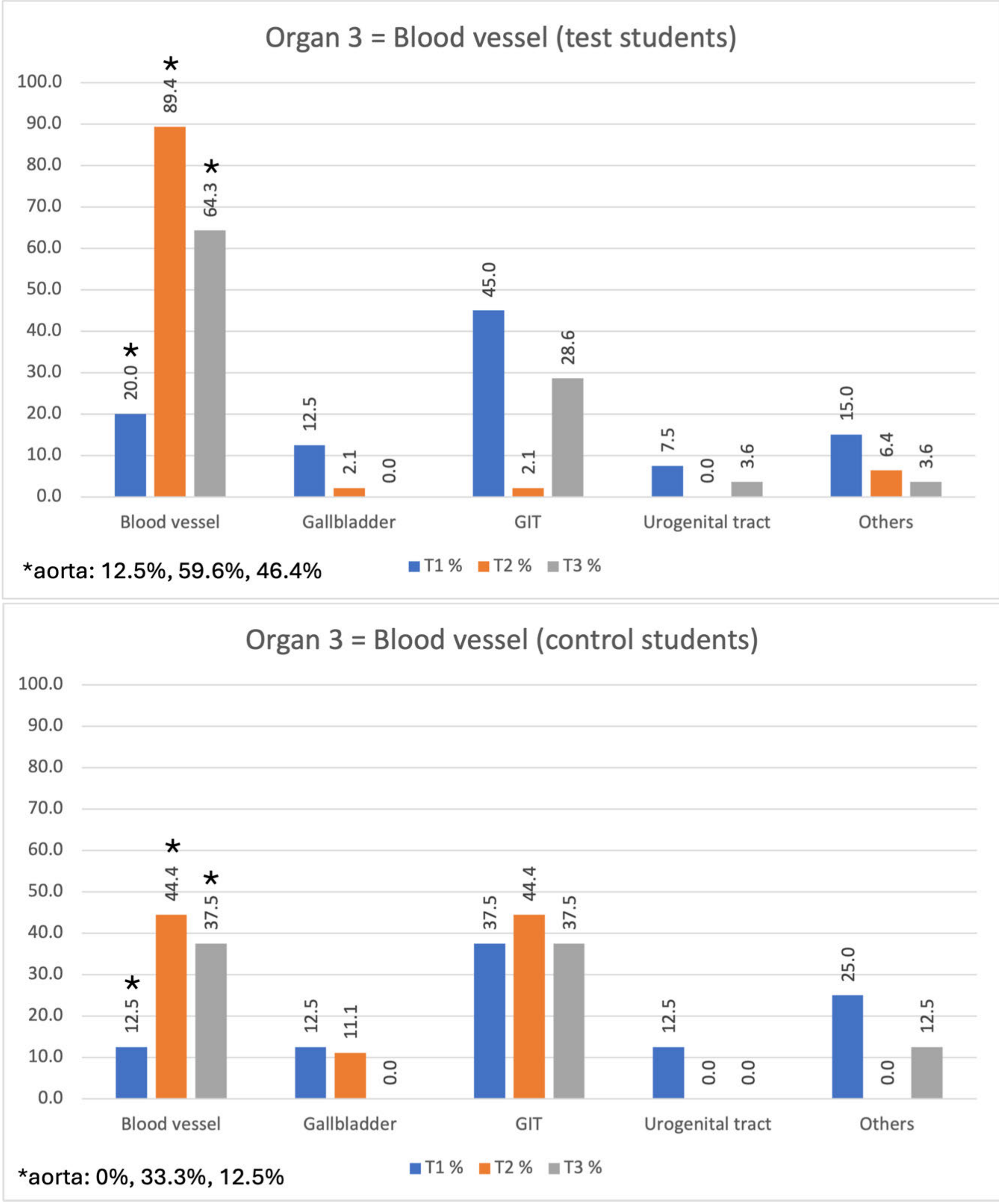


Figure 15 (1/6) Bar charts representing the relative frequencies of students' answers for the blood vessels (organs 3, 16, 19, 20, 24, and 40). The X axis displays organ categories including blood vessel, gallbladder, gastrointestinal tract (GIT), urogenital tract and others. organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

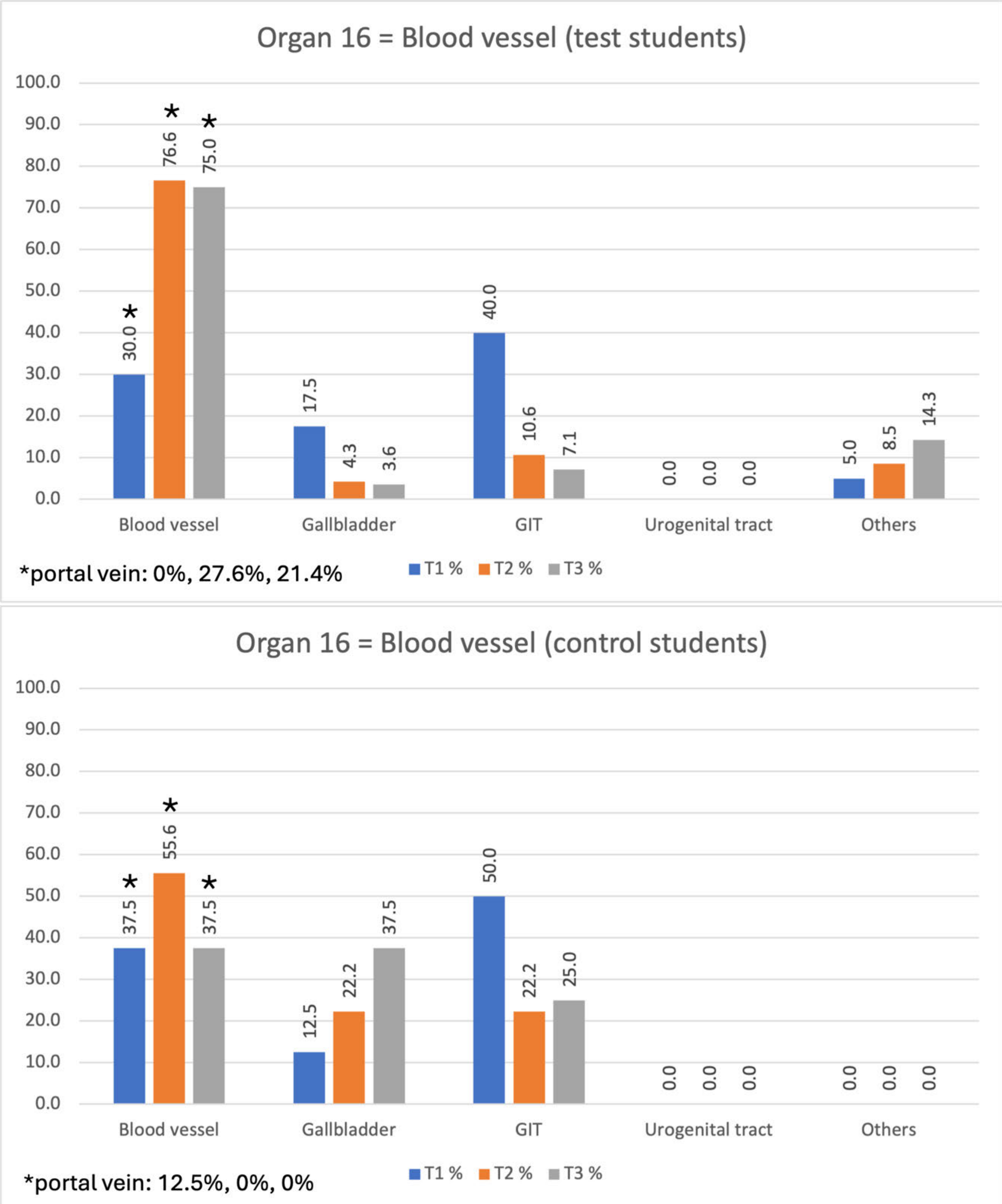
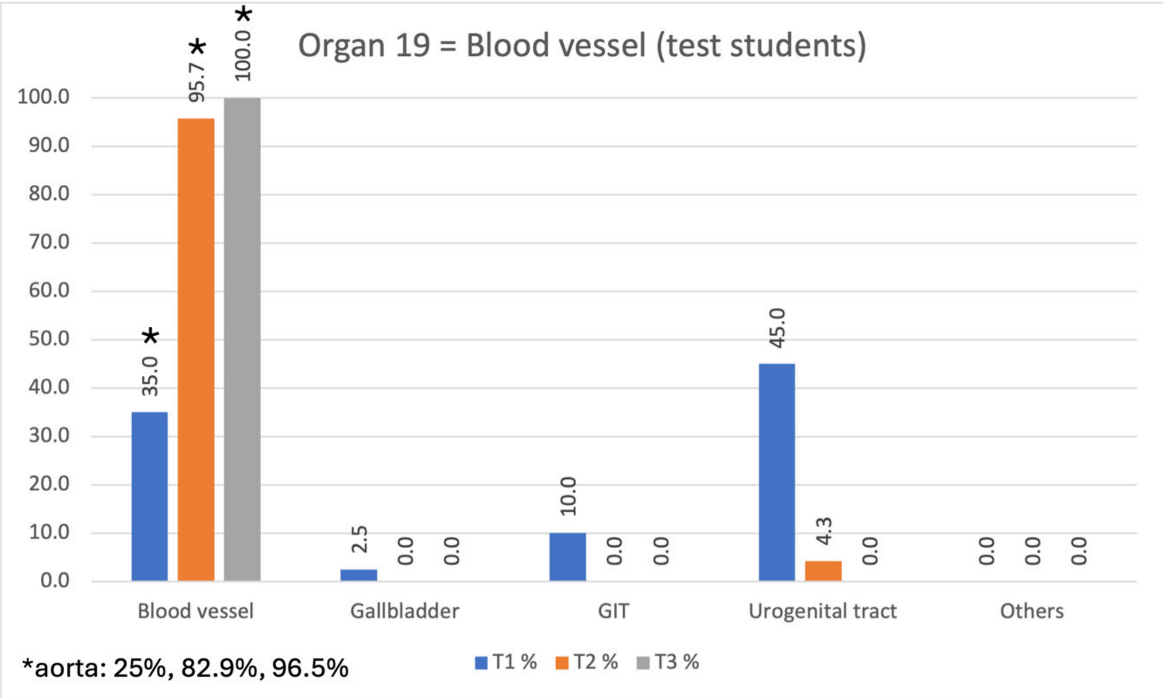


Figure 15 (2/6) Bar charts representing the relative frequencies of students' answers for the blood vessels (organs 3, 16, 19, 20, 24, and 40). The X axis displays organ categories including blood vessel, gallbladder, gastrointestinal tract (GIT), urogenital tract and others. organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



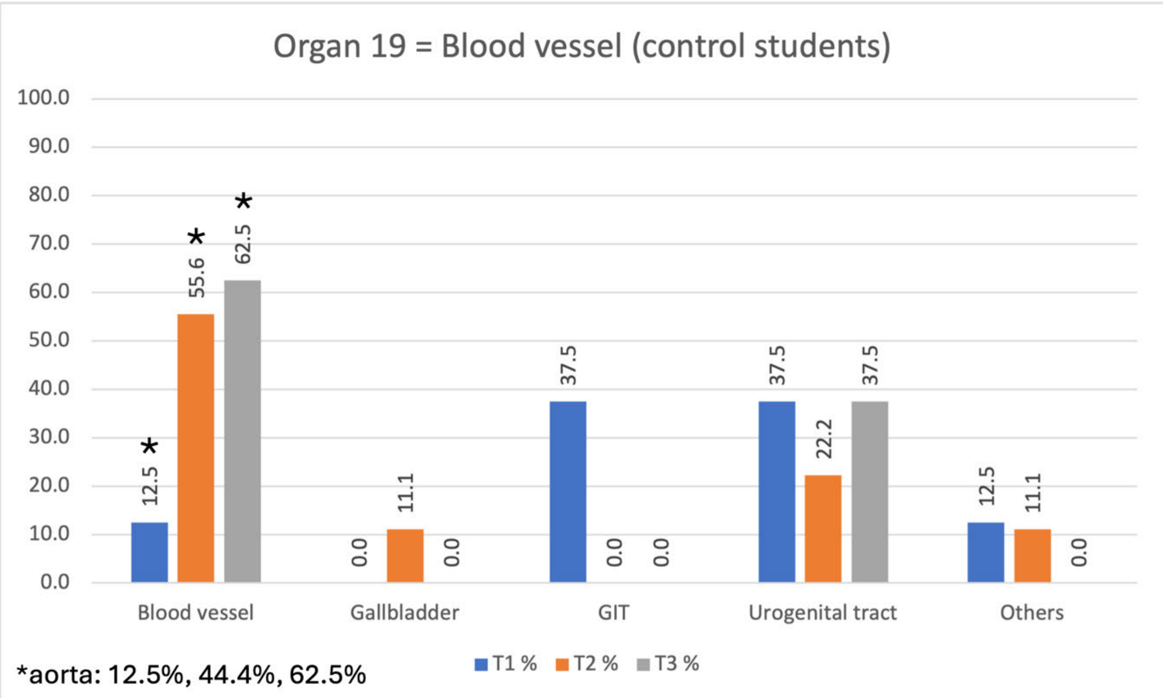
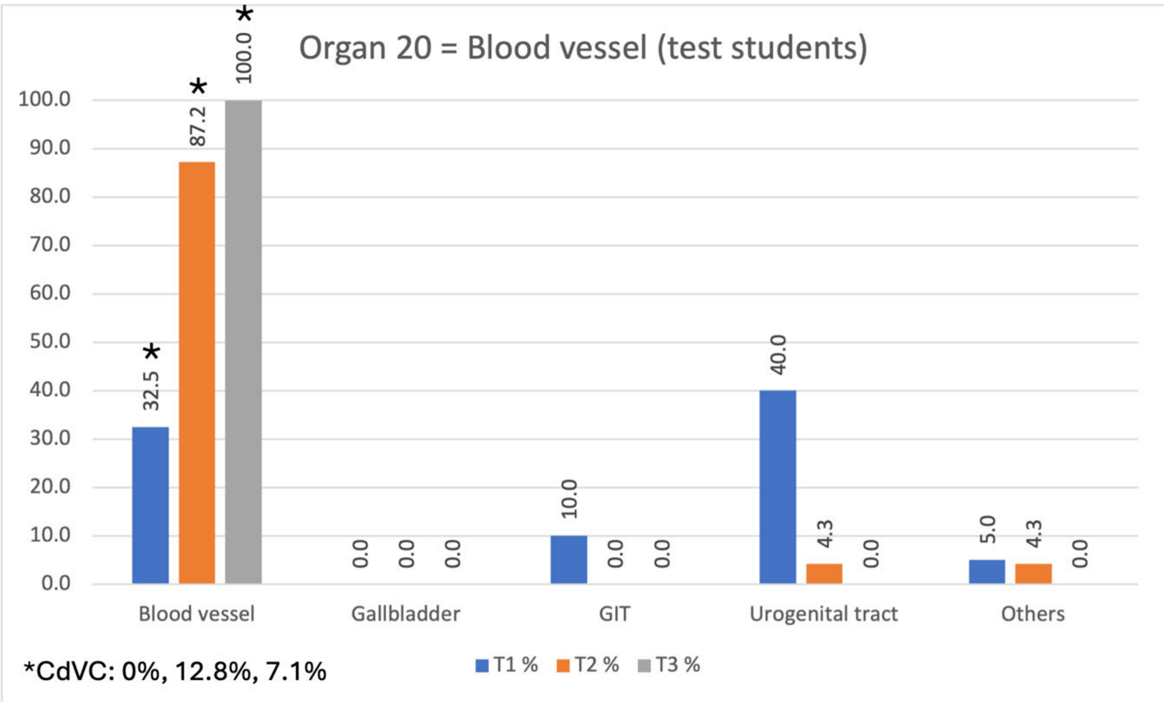


Figure 15 (3/6) Bar charts representing the relative frequencies of students' answers for the blood vessels (organs 3, 16, 19, 20, 24, and 40). The X axis displays organ categories including blood vessel, gallbladder, gastrointestinal tract (GIT), urogenital tract and others. organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



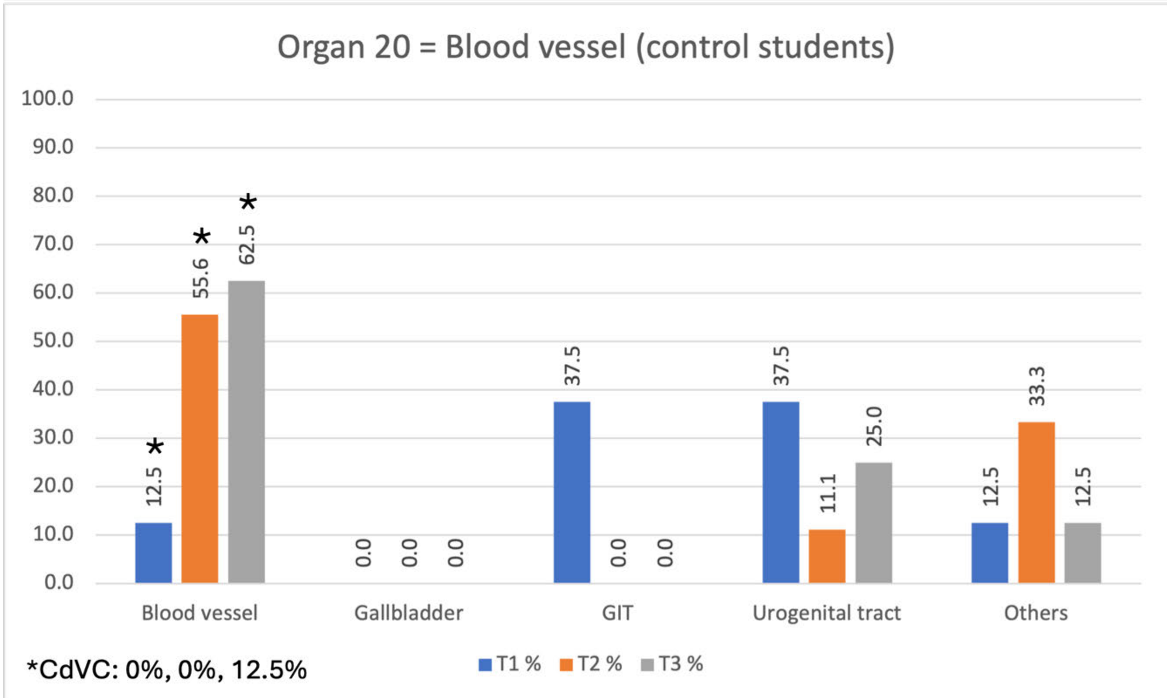
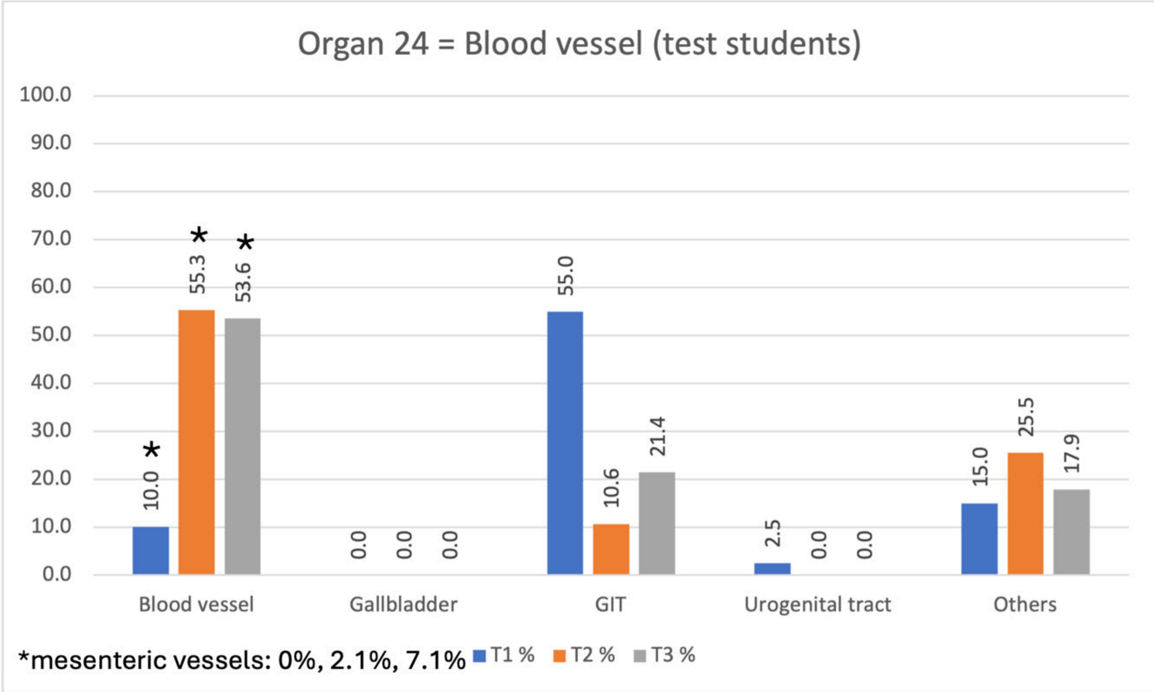


Figure 15 (4/6) Bar charts representing the relative frequencies of students' answers for the blood vessels (organs 3, 16, 19, 20, 24, and 40). The X axis displays organ categories including blood vessel, gallbladder, gastrointestinal tract (GIT), urogenital tract and others. organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



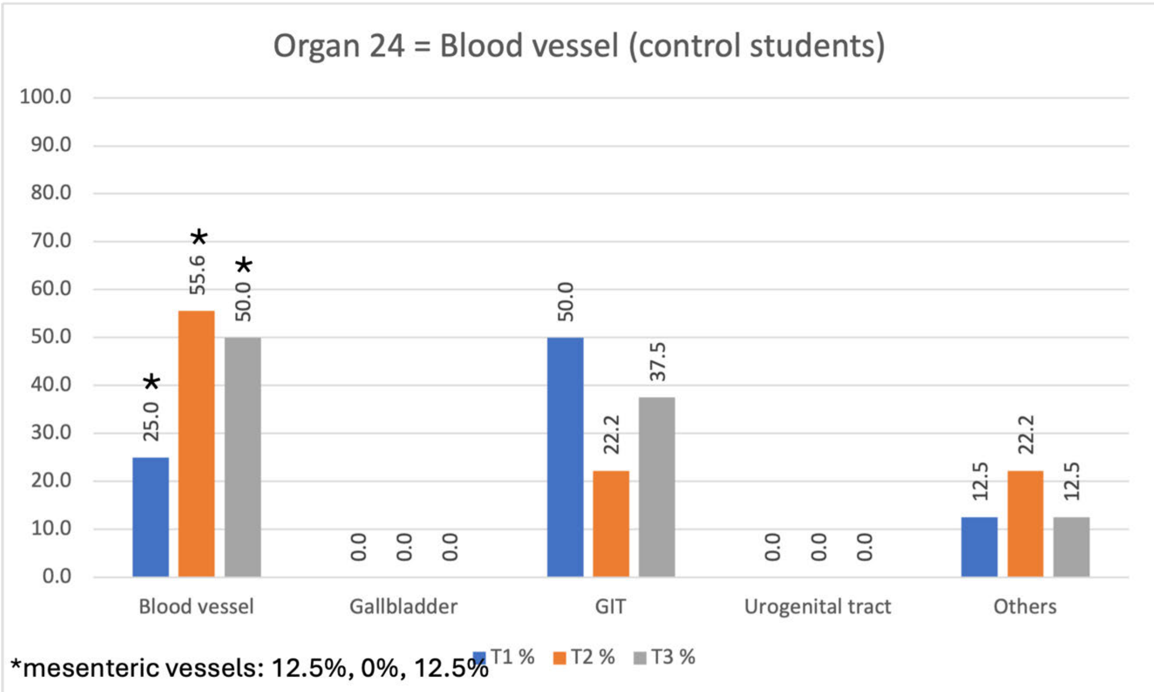
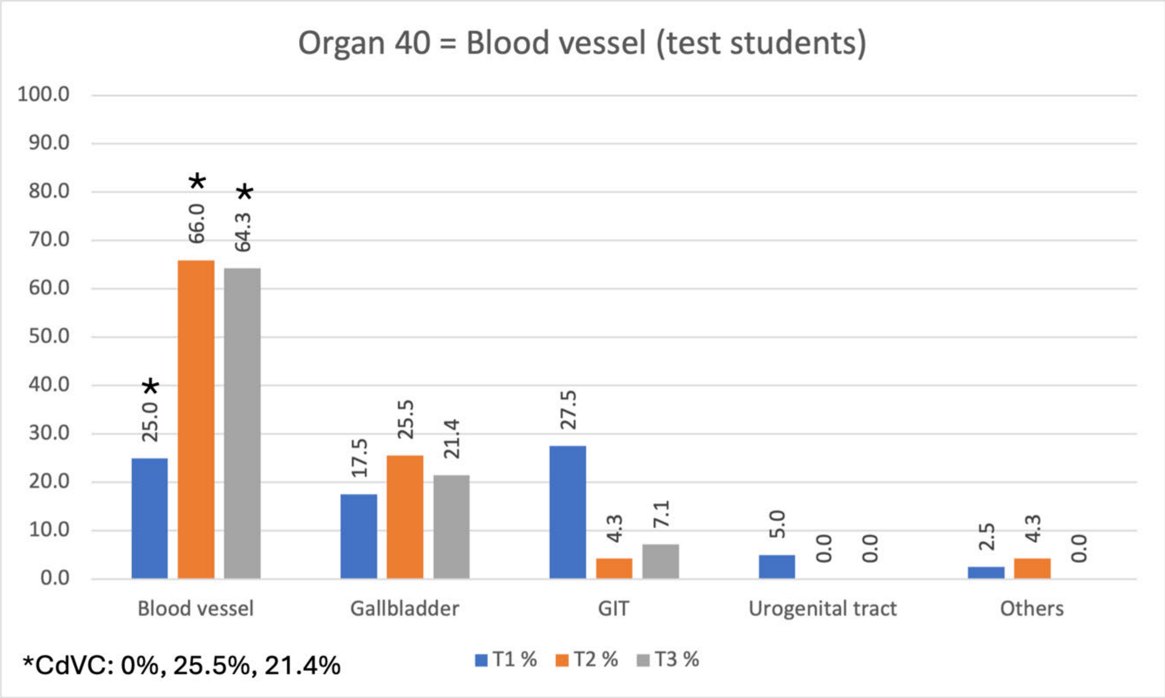


Figure 15 (5/6) Bar charts representing the relative frequencies of students' answers for the blood vessels (organs 3, 16, 19, 20, 24, and 40). The X axis displays organ categories including blood vessel, gallbladder, gastrointestinal tract (GIT), urogenital tract and others. organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).



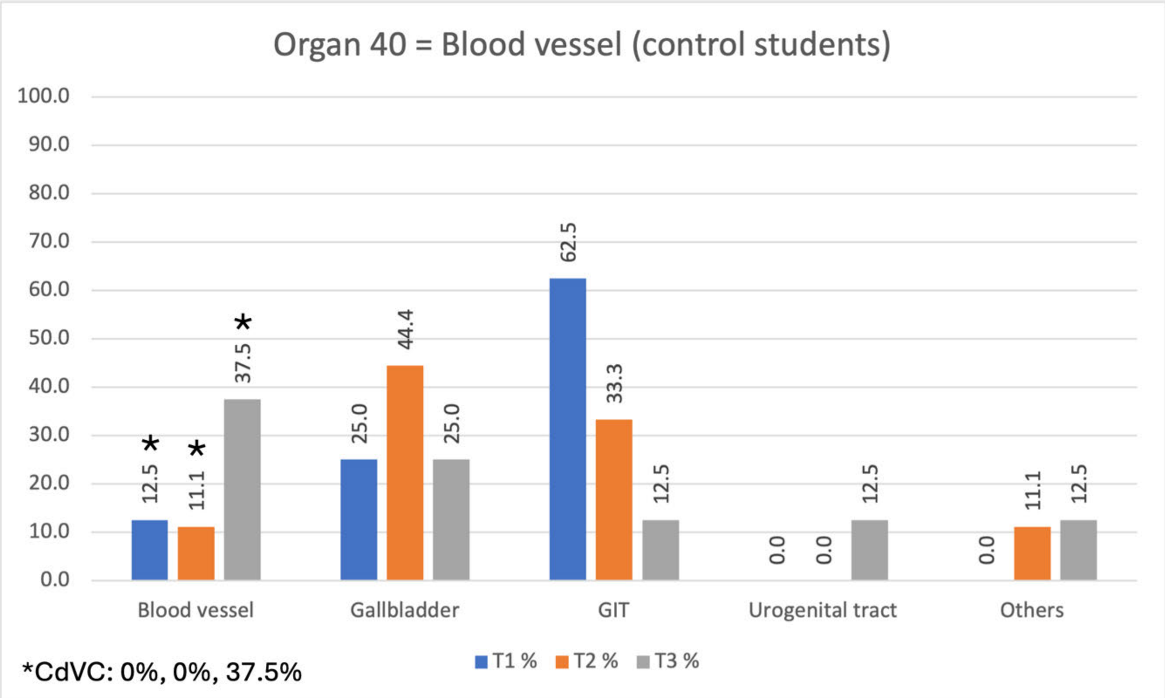


Figure 15 (6/6) Bar charts representing the relative frequencies of students' answers for the blood vessels (organs 3, 16, 19, 20, 24, and 40). The X axis displays organ categories including blood vessel, gallbladder, gastrointestinal tract (GIT), urogenital tract and others. organised from left to right based on student responses. The Y axis represents the percentage of students who gave a particular answer, with bars indicating the relative frequencies. Bars are coloured in blue for the pre-rotation test (T1), orange for post-rotation test 1 (T2), and grey for post-rotation test 2 (T3).

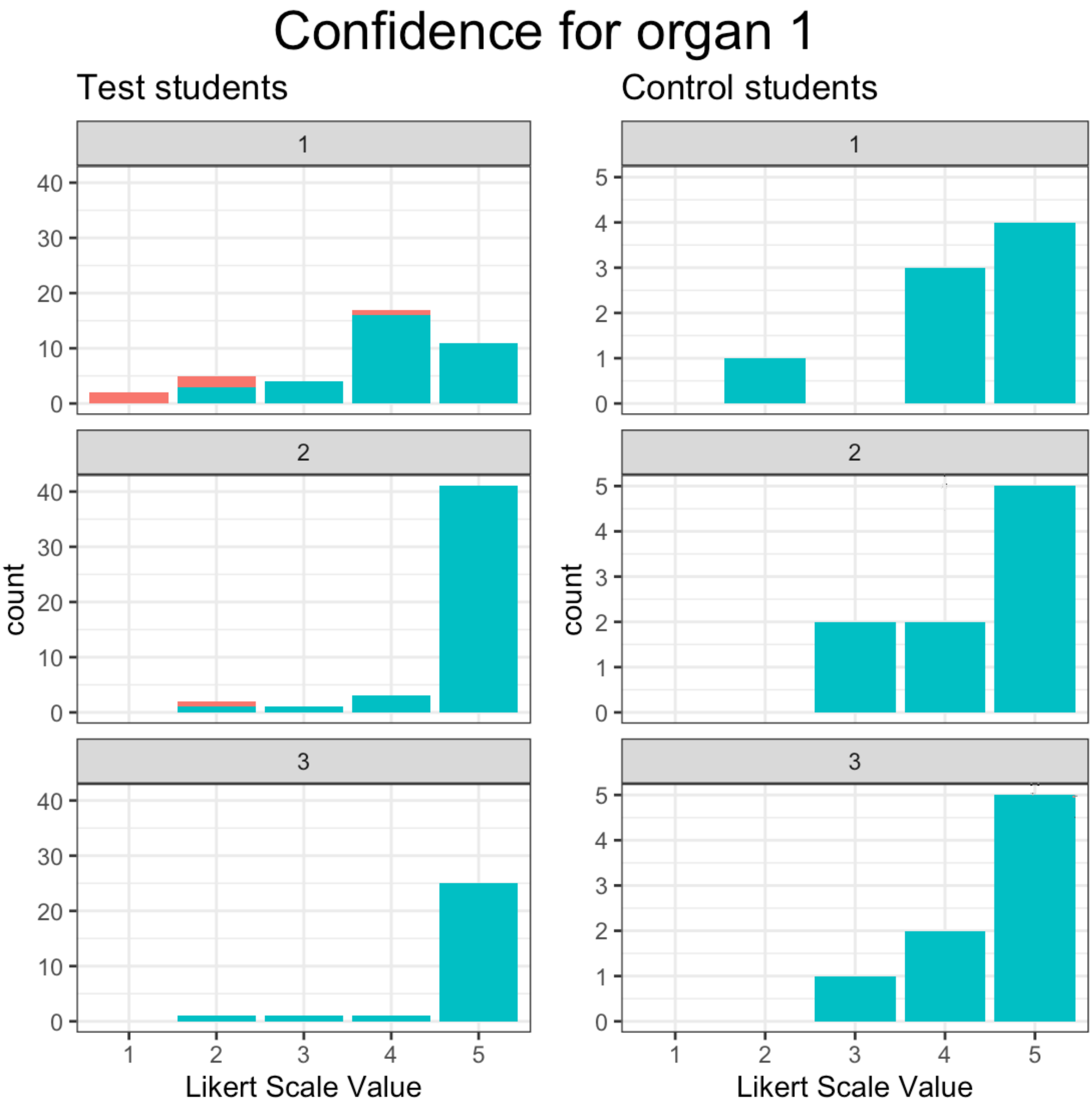


Figure 1 (1/5) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 1, 10, 31, 37 and 46 representing the kidneys.

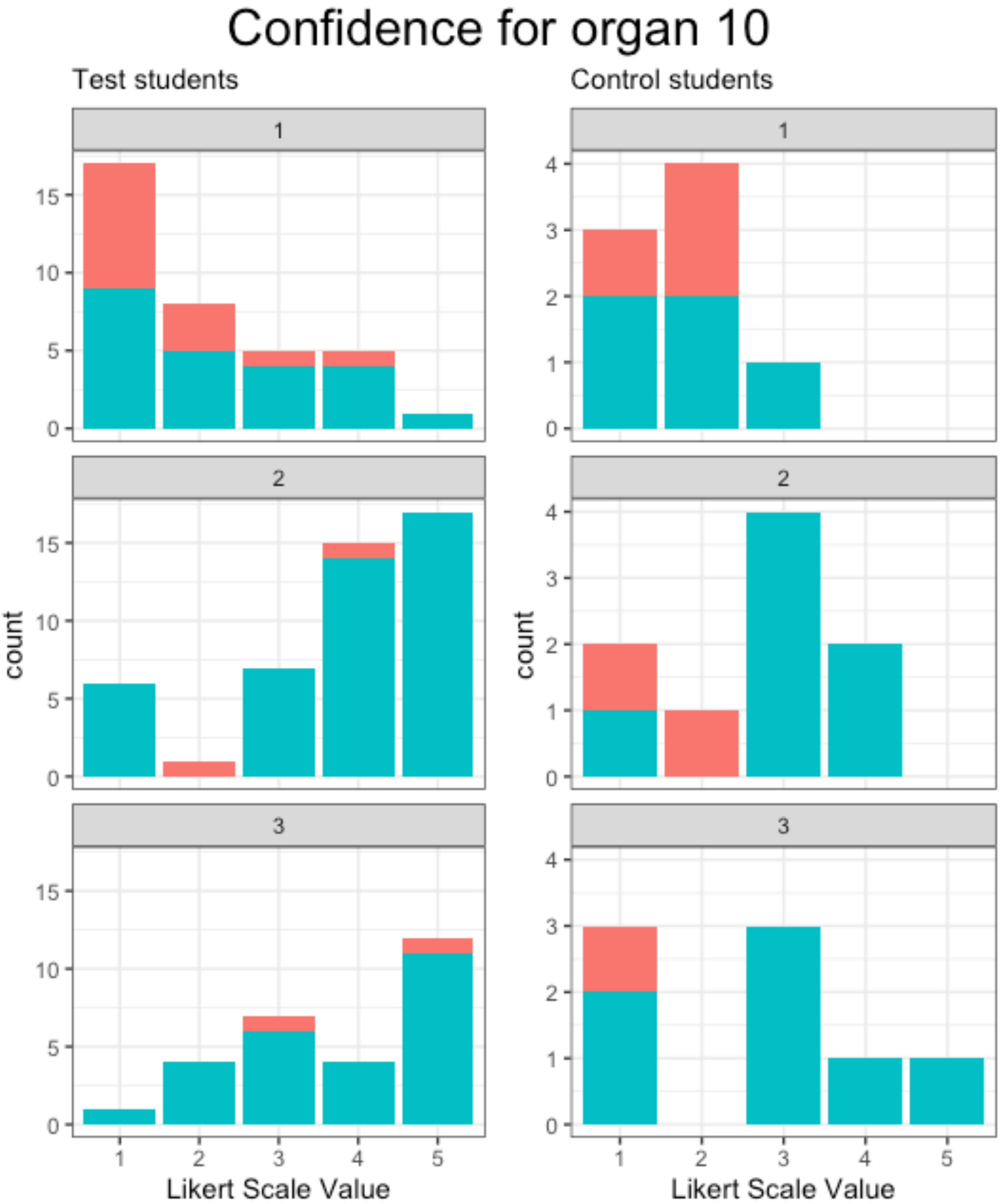


Figure 1 (2/5) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 1, 10, 31, 37 and 46 representing the kidneys.

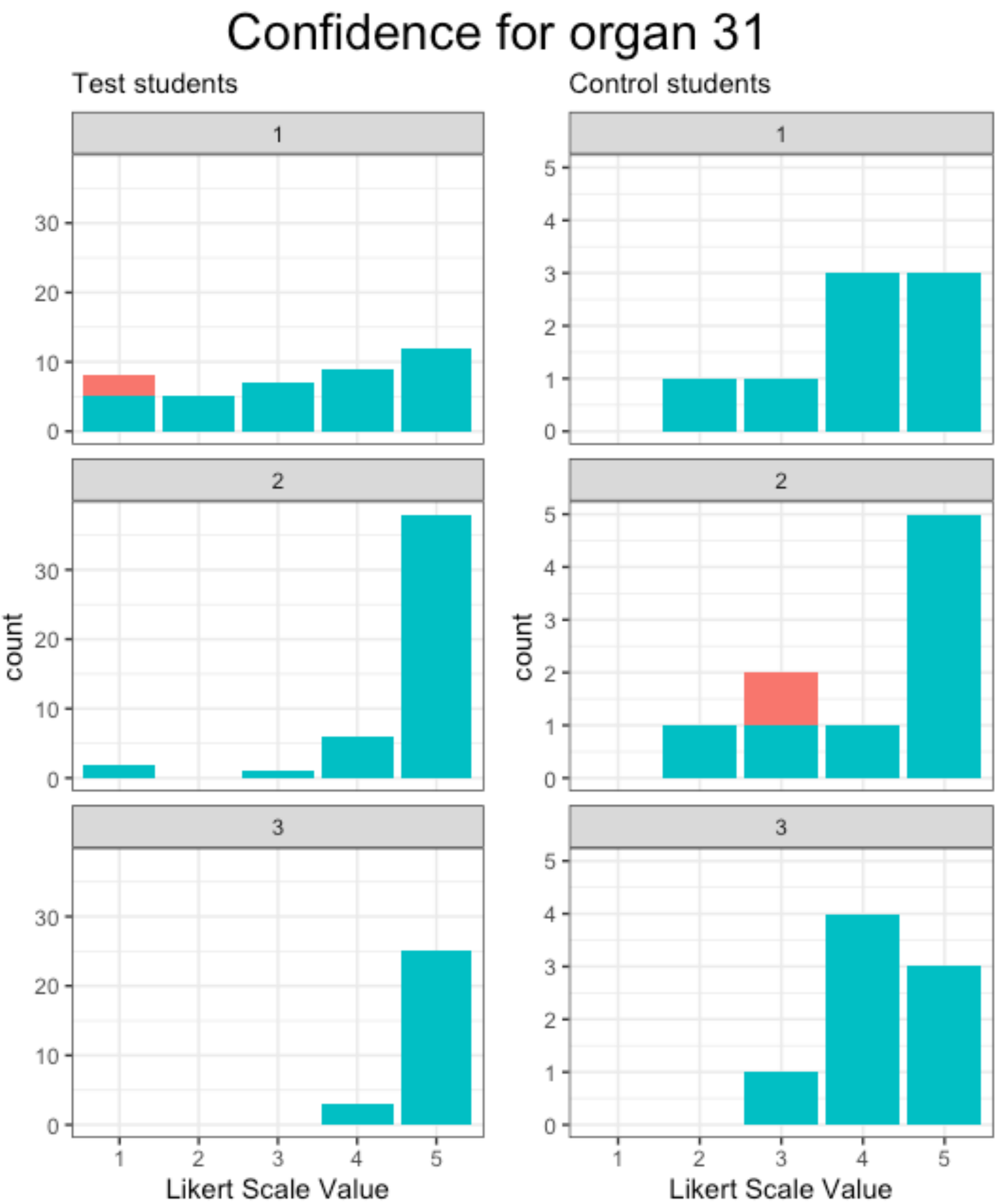


Figure 1 (3/5) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 1, 10, 31, 37 and 46 representing the kidneys.

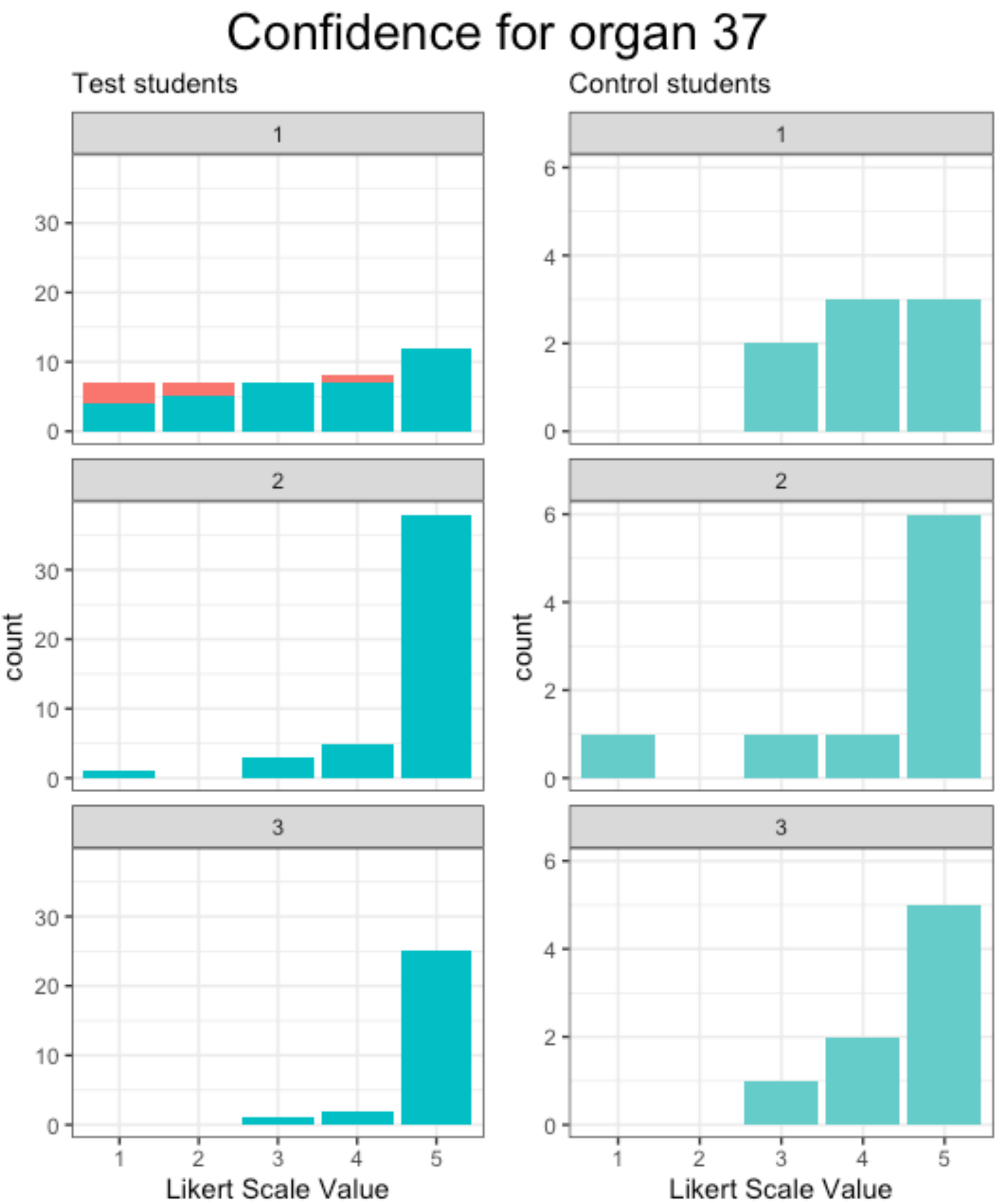


Figure 1 (4/5) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 1, 10, 31, 37 and 46 representing the kidneys.

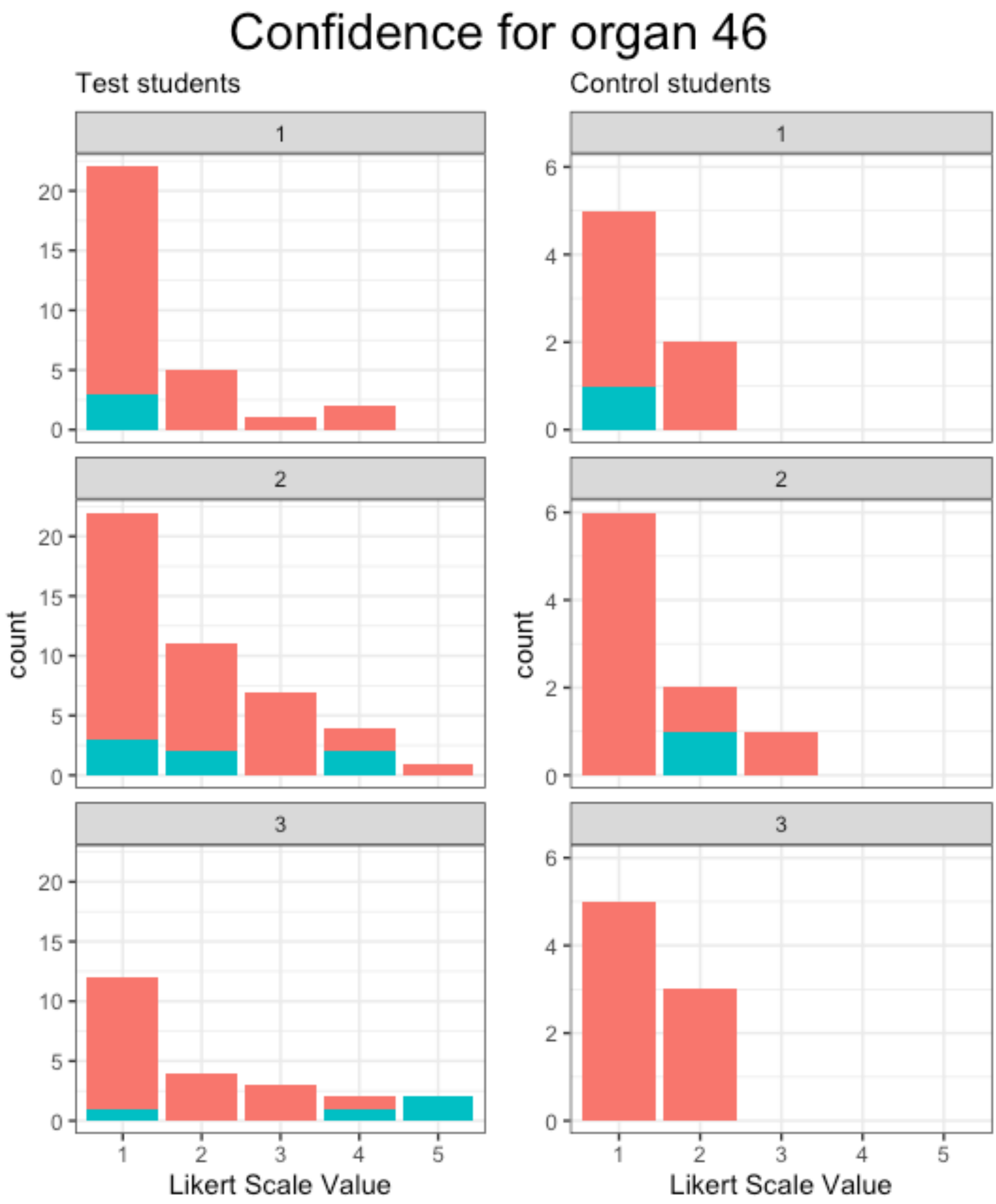


Figure 1 (5/5) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 1, 10, 31, 37 and 46 representing the kidneys.

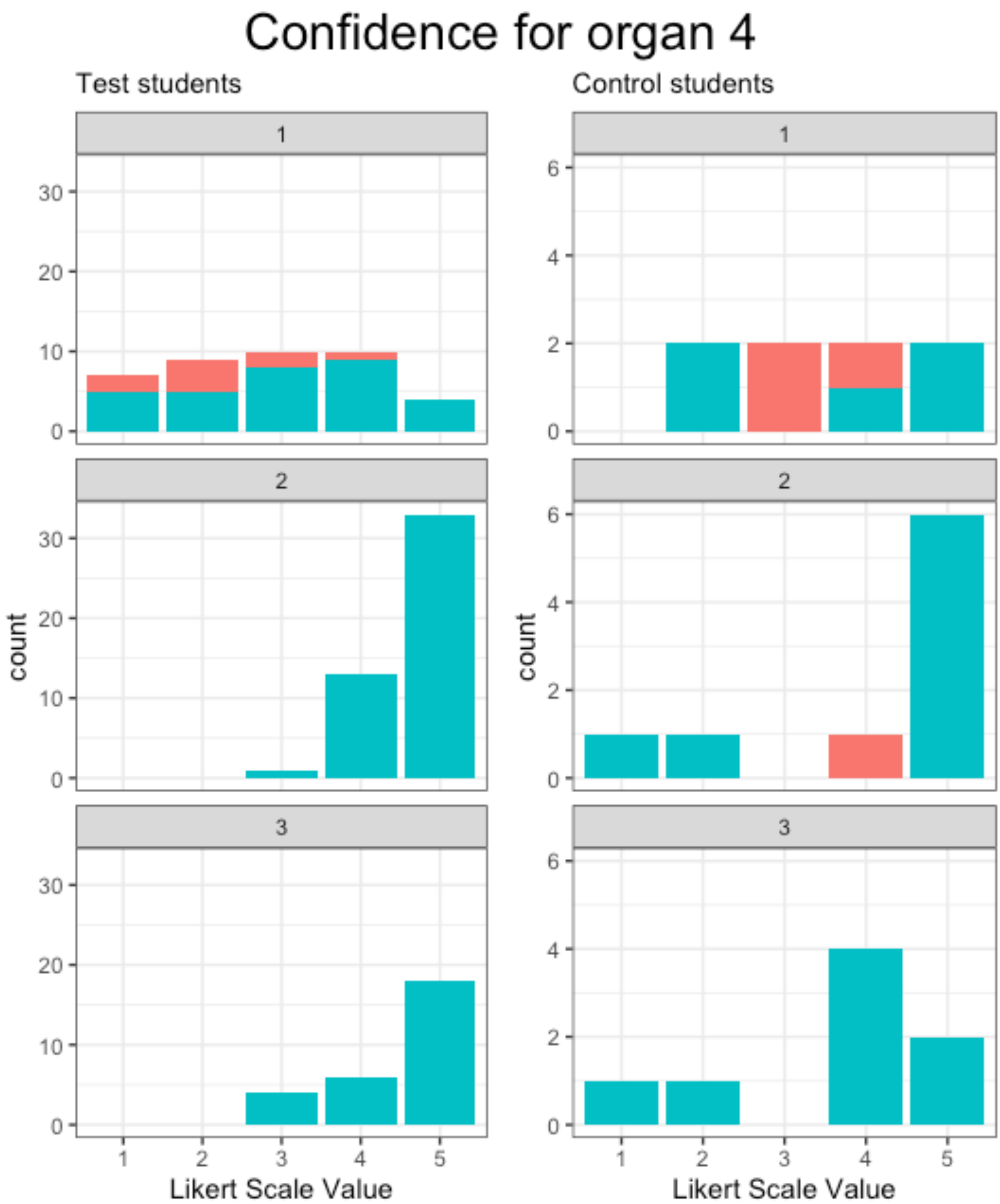


Figure 2 (1/3) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 4, 9 and 14 representing the spleen.

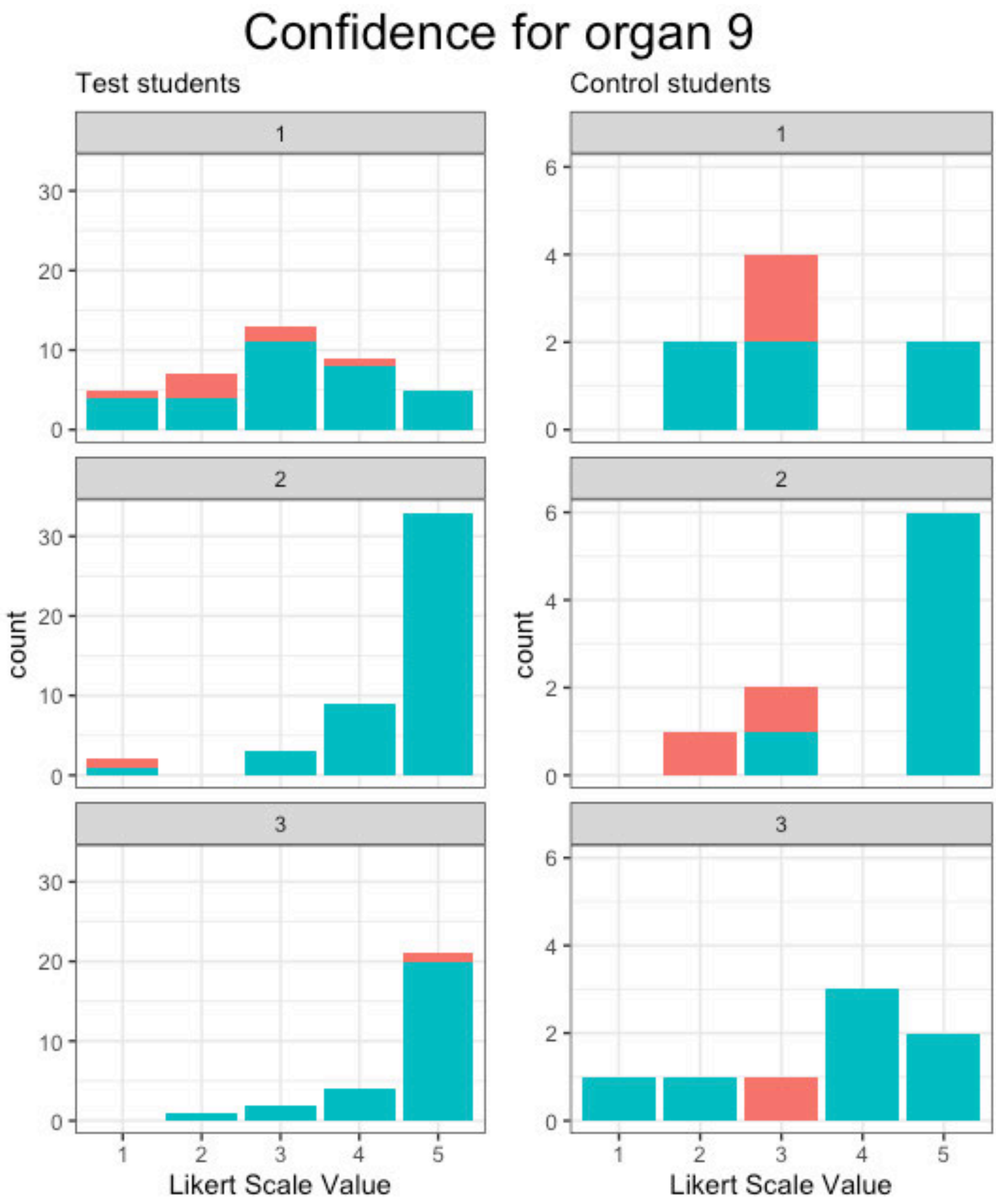


Figure 2 (2/3) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 4, 9 and 14 representing the spleen.

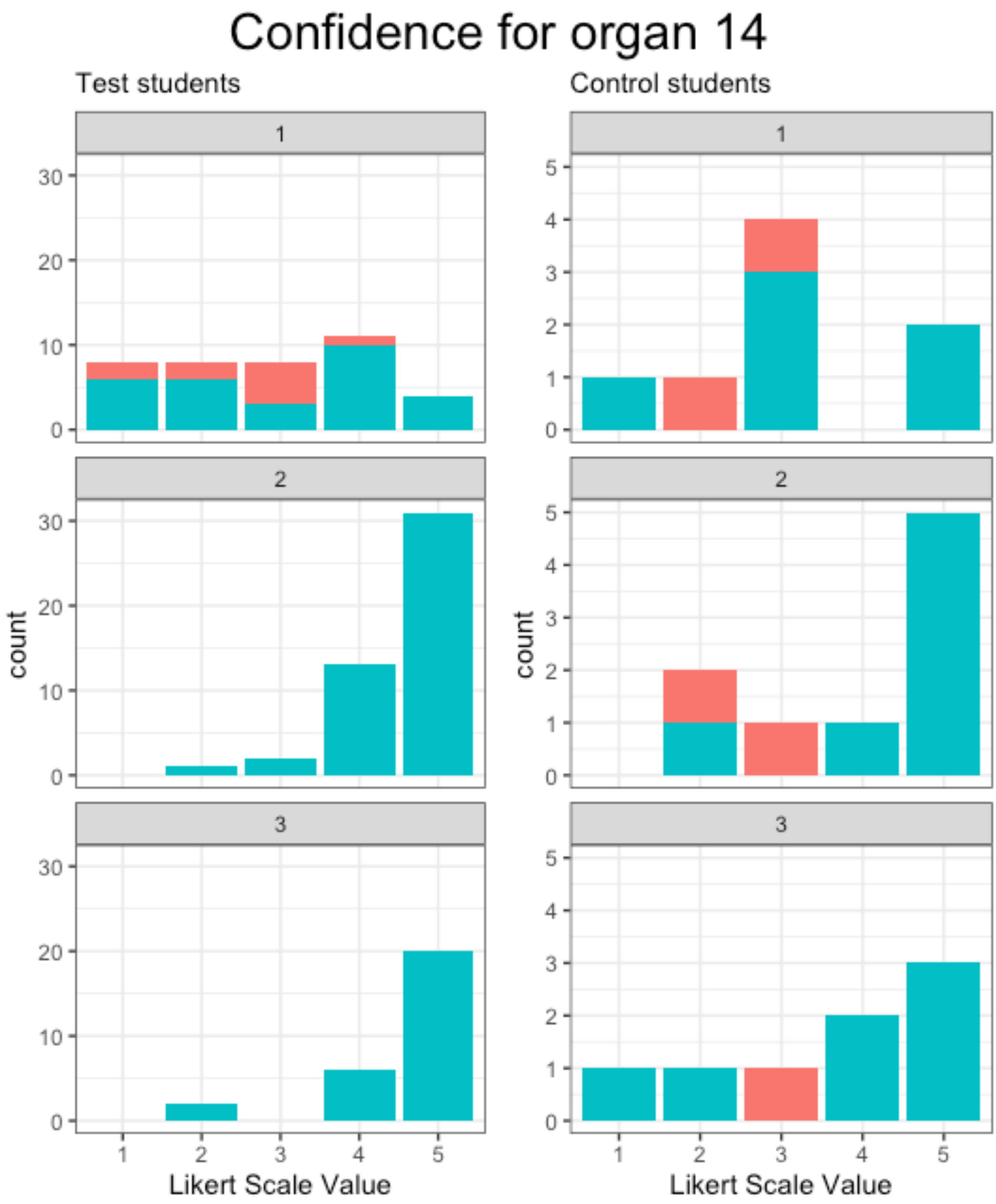


Figure 2 (3/3) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 4, 9 and 14 representing the spleen.

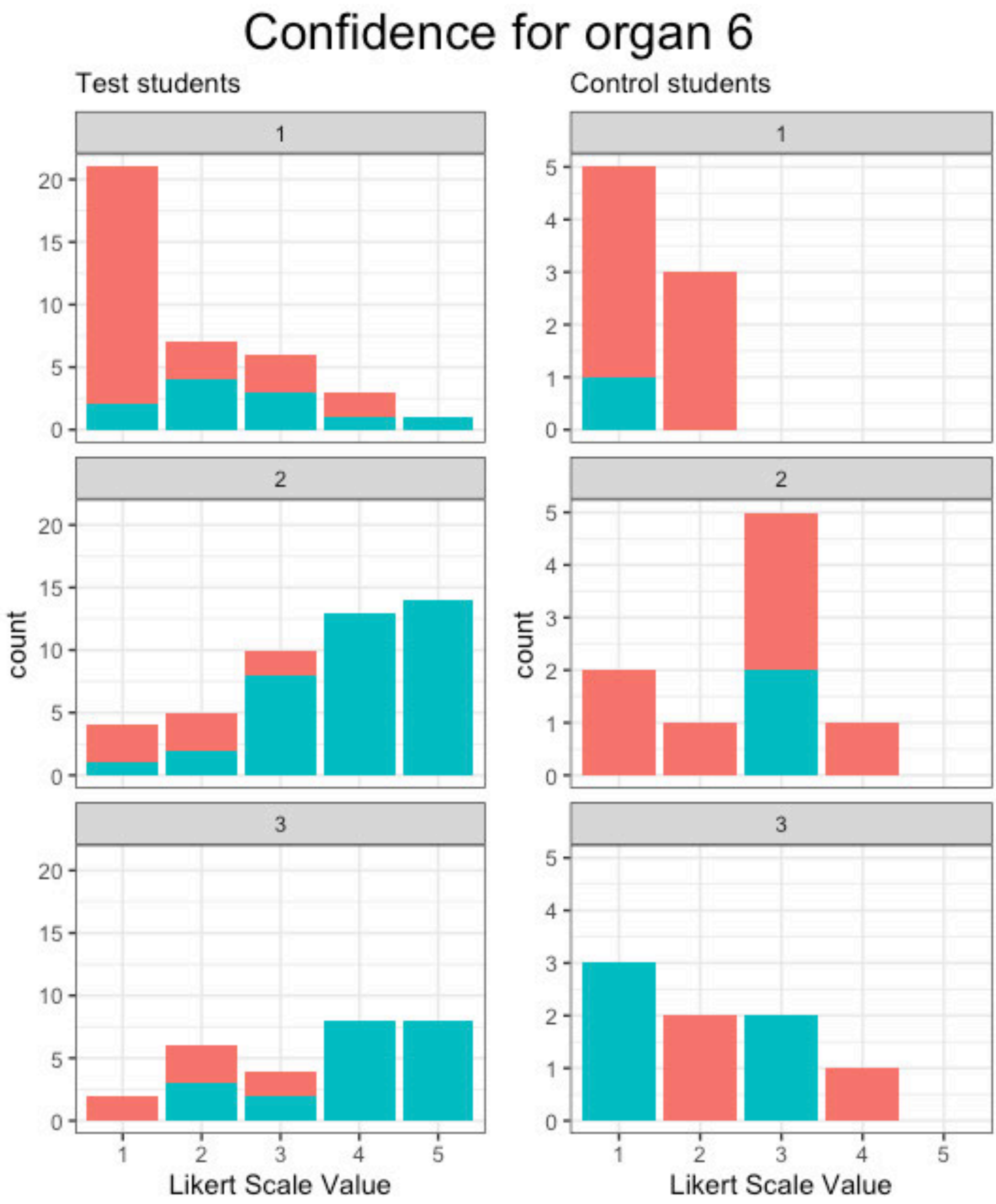


Figure 3 (1/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 6, 15, 27 and 38 representing the liver.

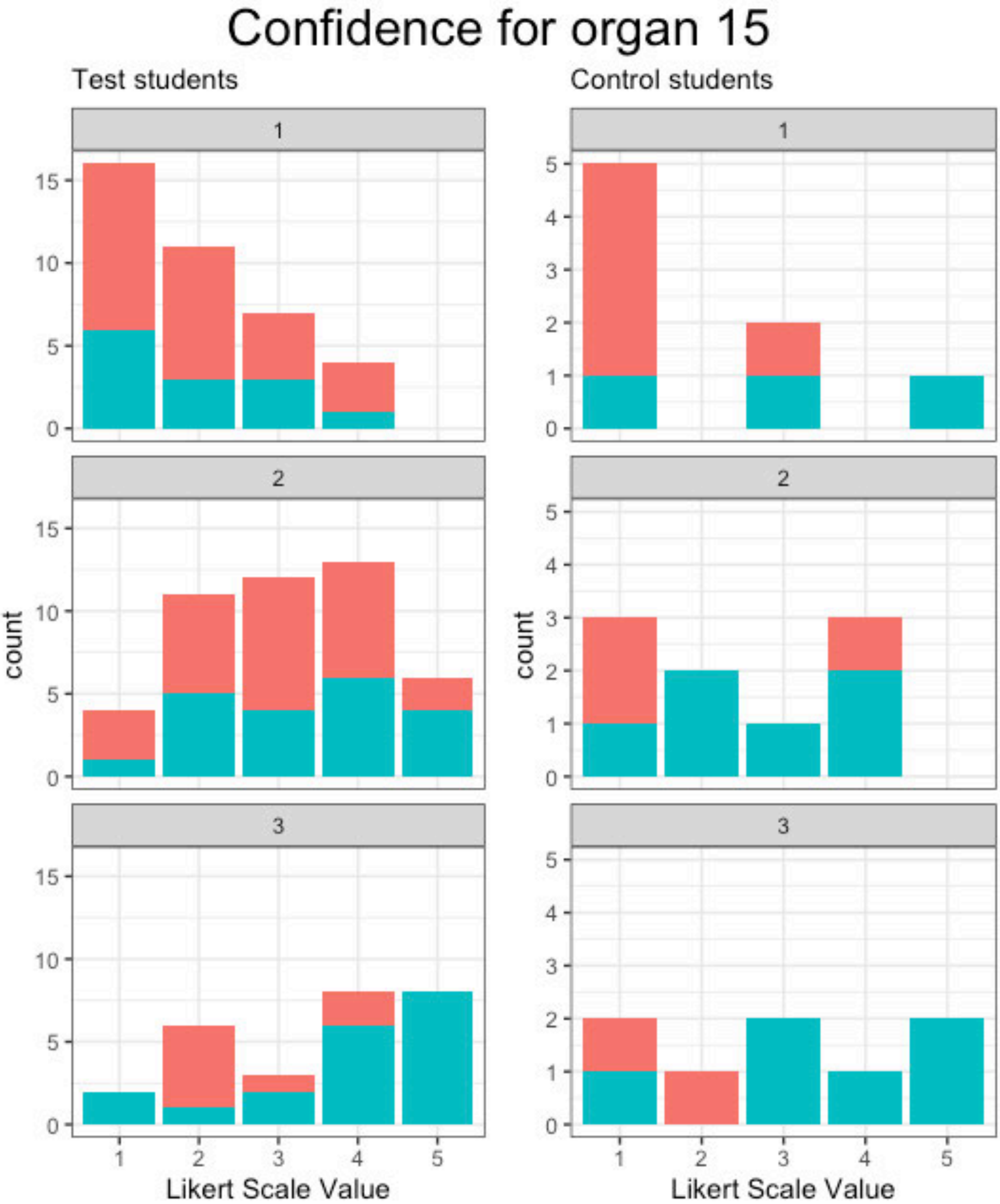


Figure 3 (2/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 6, 15, 27 and 38 representing the liver.

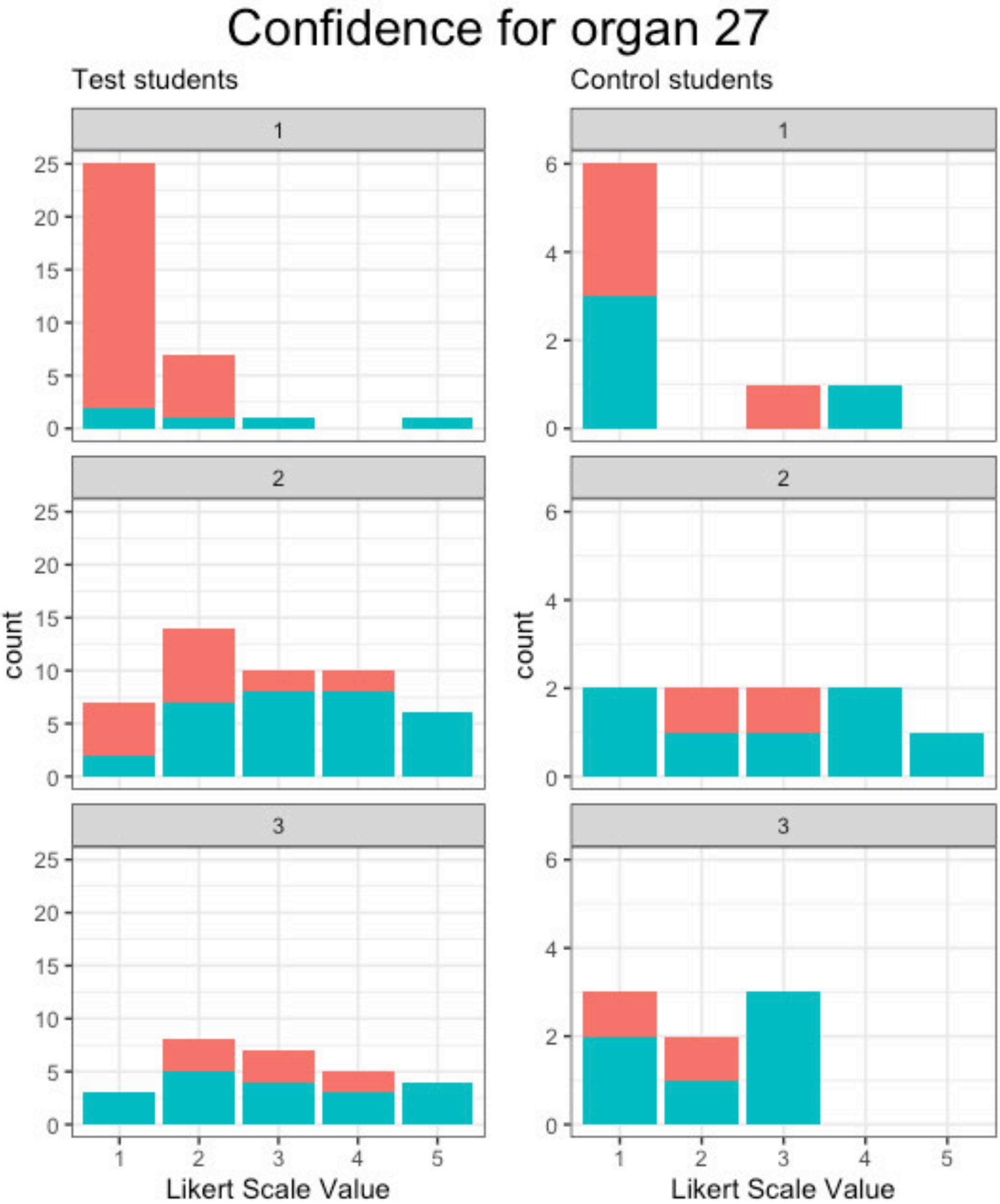


Figure 3 (3/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 6, 15, 27 and 38 representing the liver.

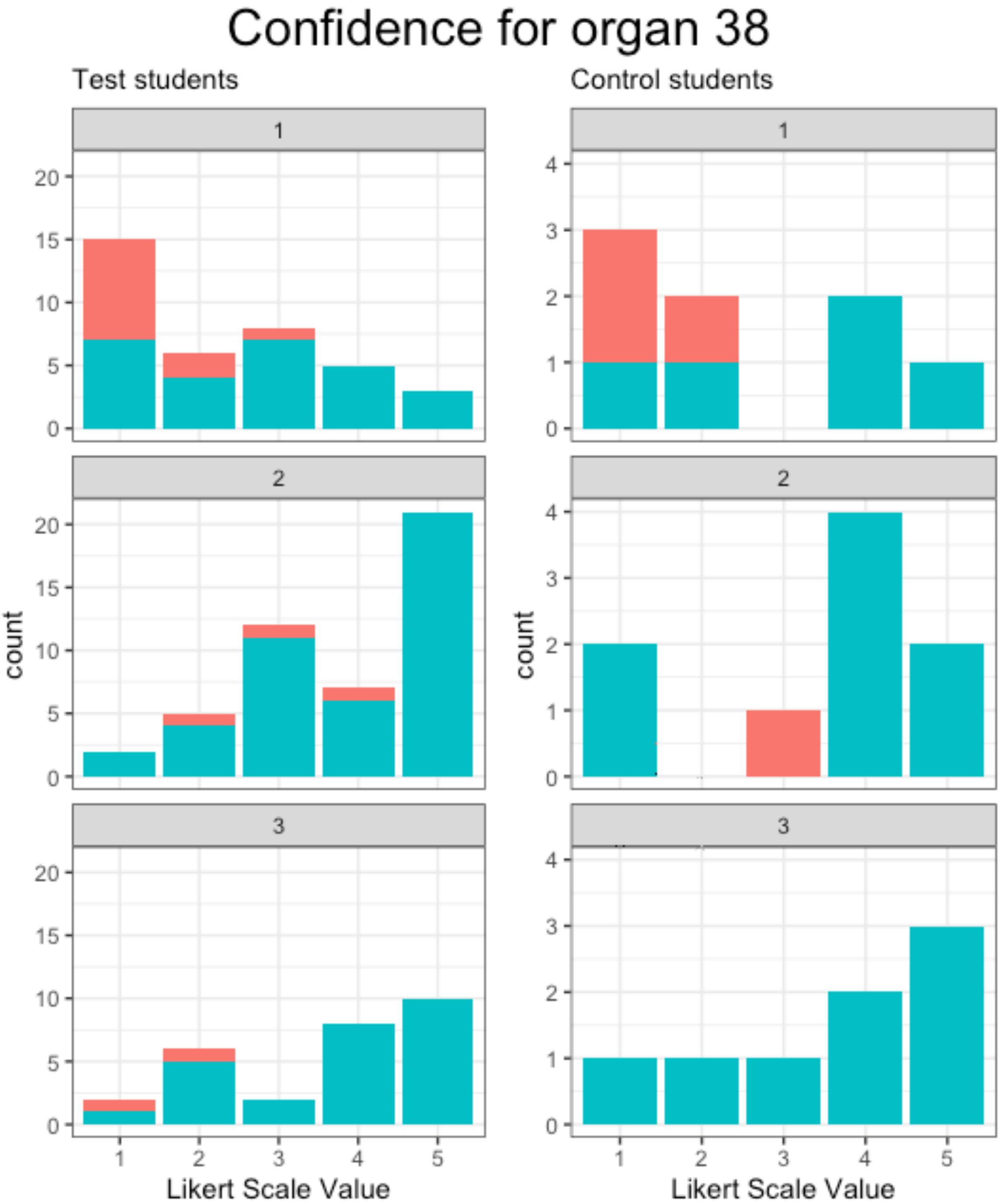


Figure 3 (4/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 6, 15, 27 and 38 representing the liver.

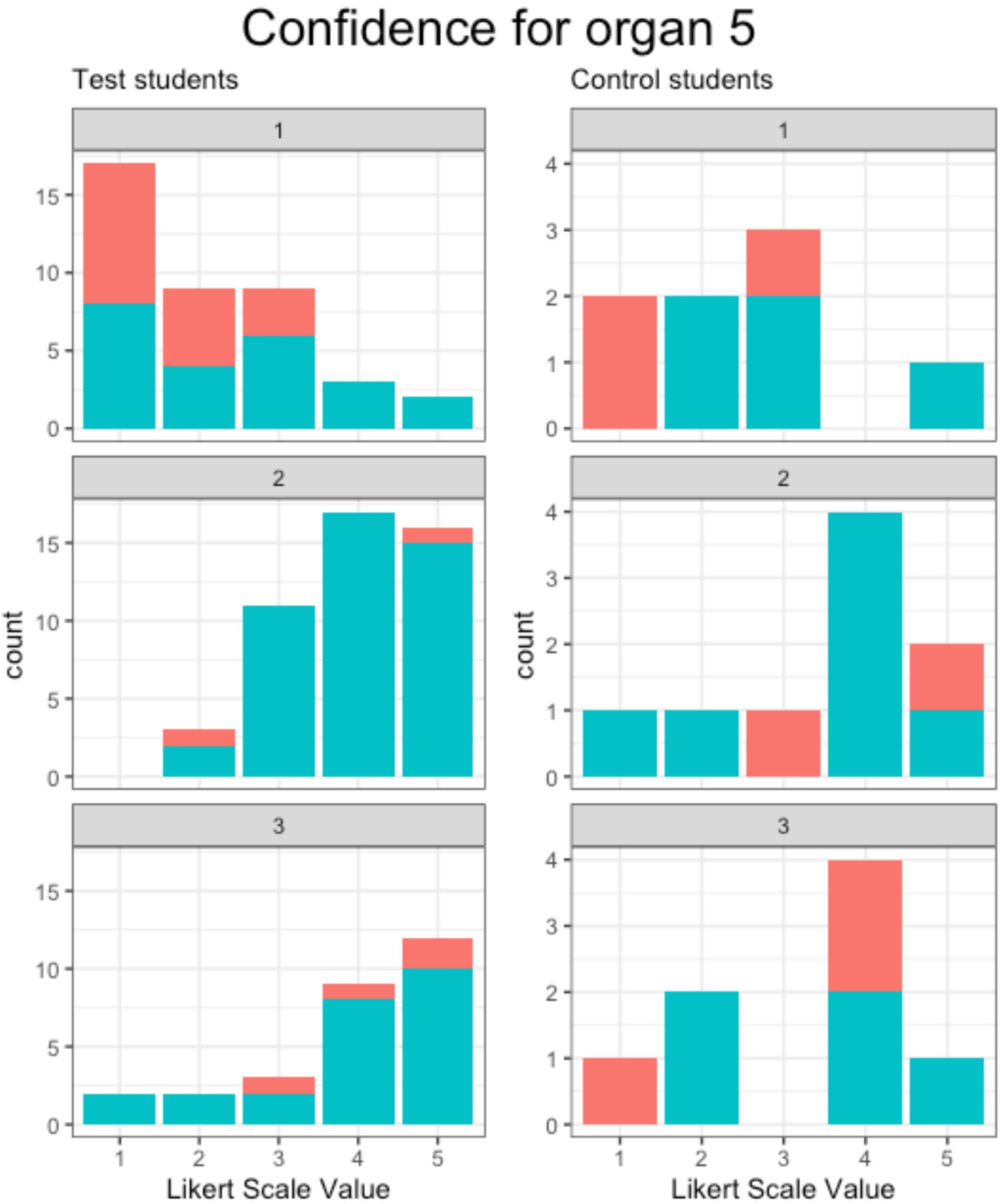


Figure 4 (1/3) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 5, 11 and 26 representing the stomach.

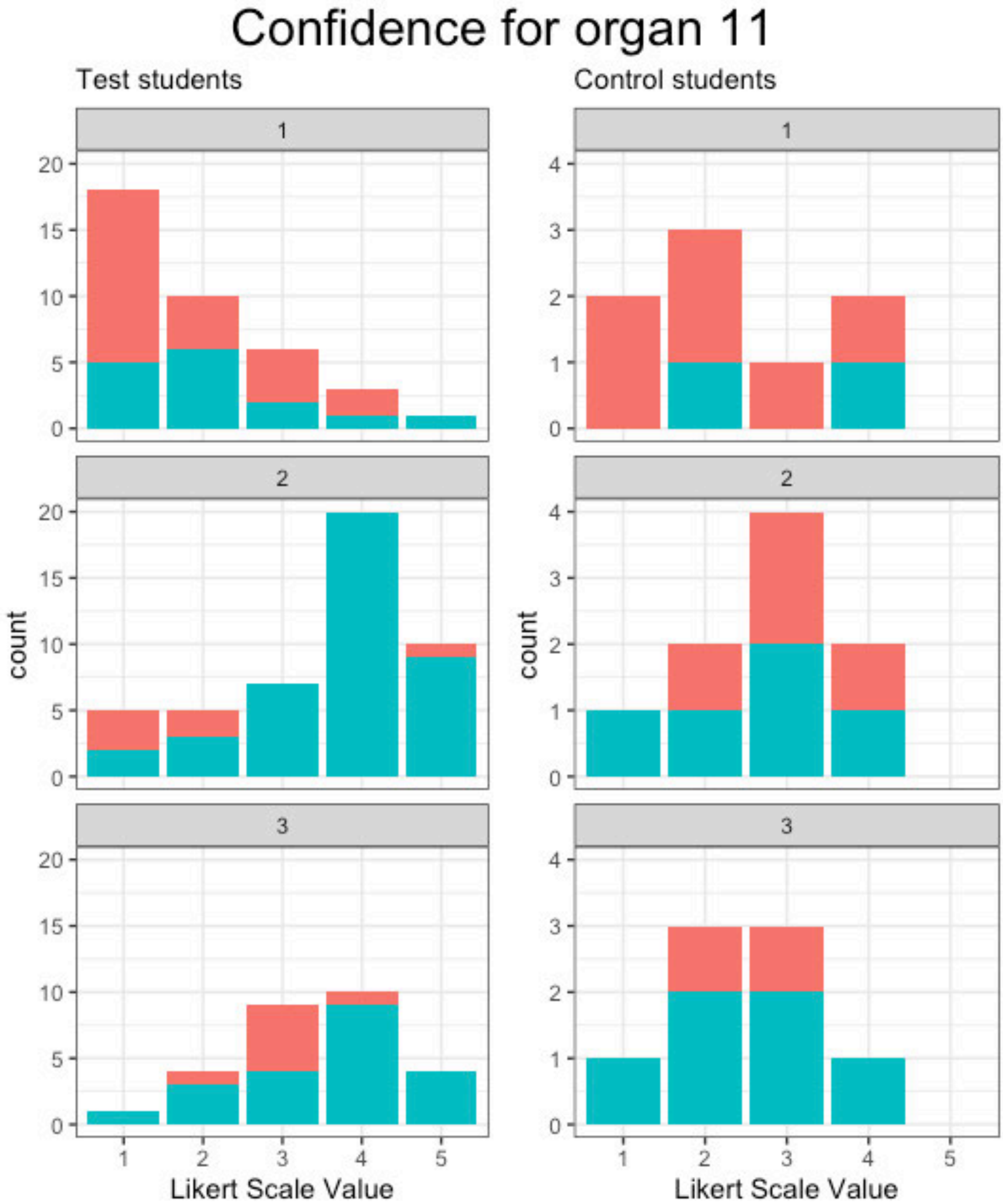


Figure 4 (2/3) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 5, 11 and 26 representing the stomach.

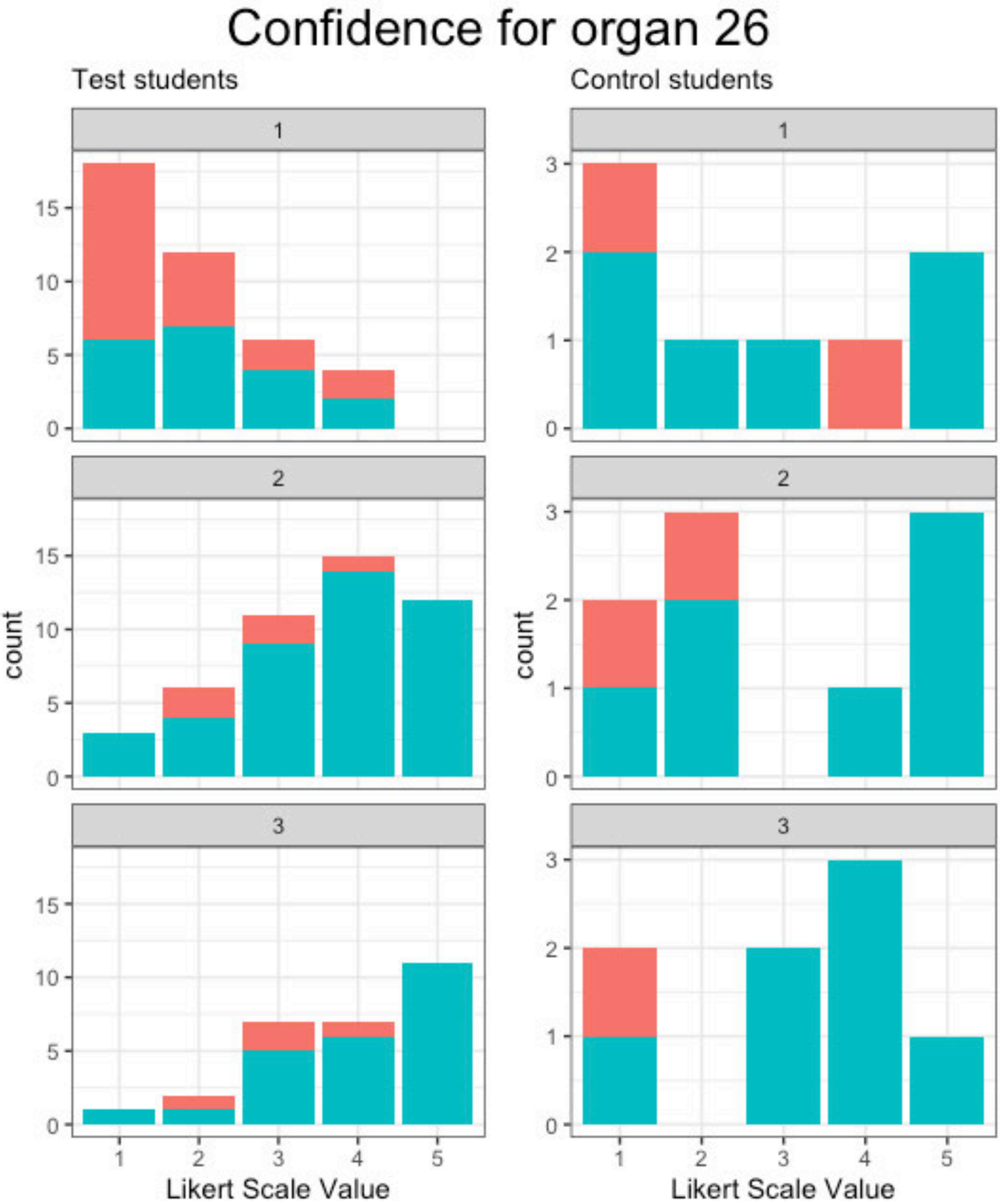


Figure 4 (3/3) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 5, 11 and 26 representing the stomach.

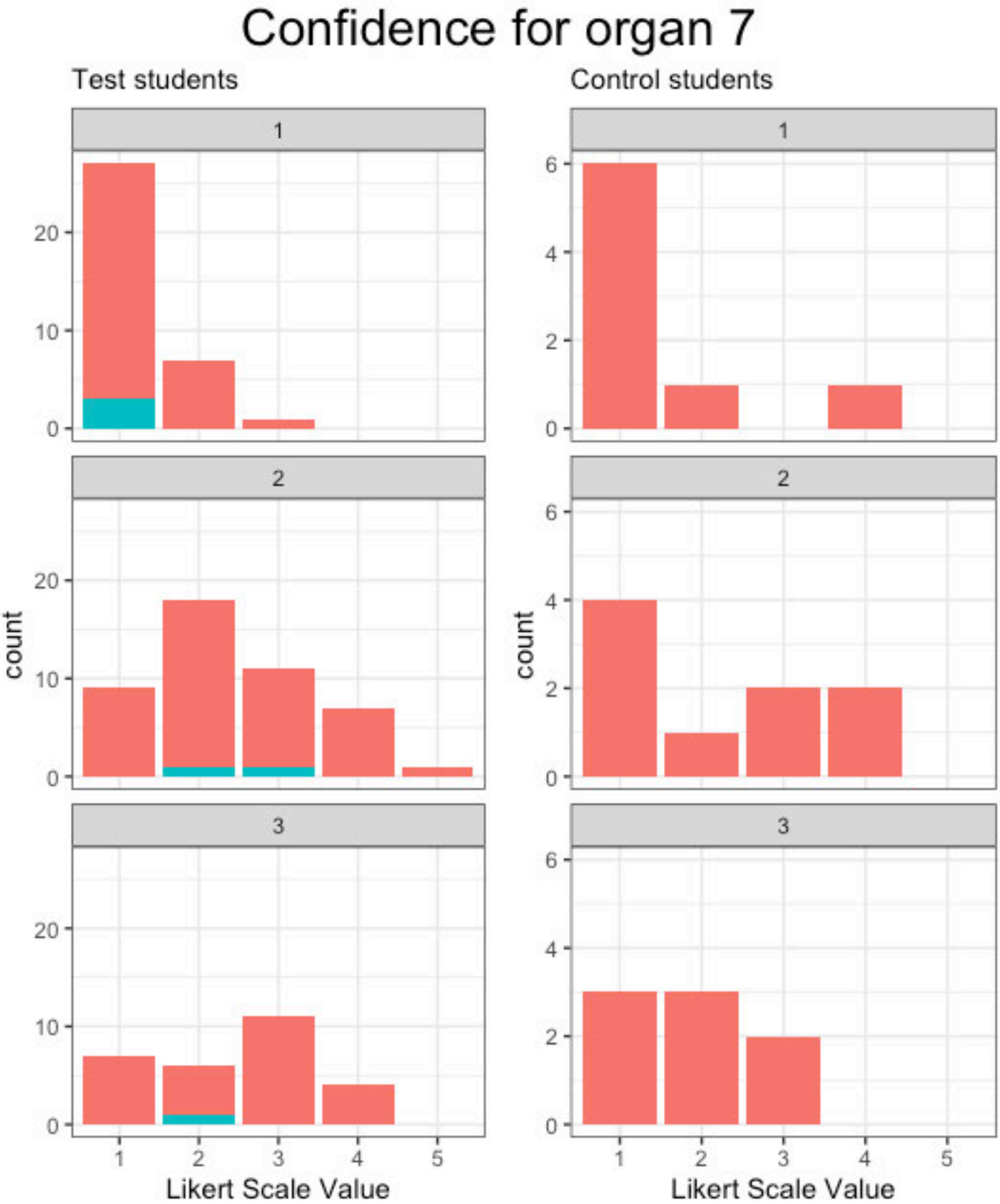


Figure 5 (1/3) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 7, 17 and 29 representing the pylorus.

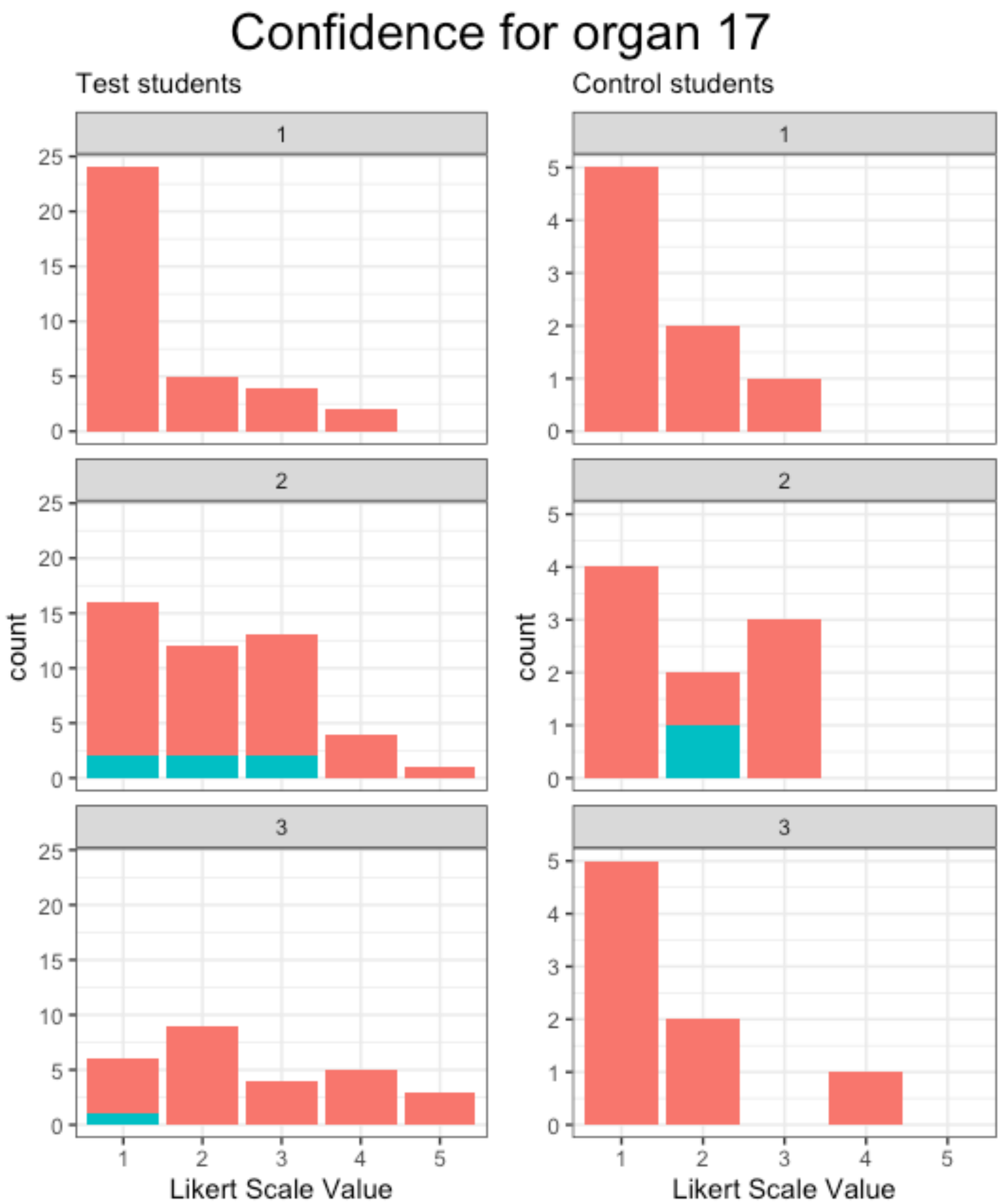


Figure 5 (2/3) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 7, 17 and 29 representing the pylorus.

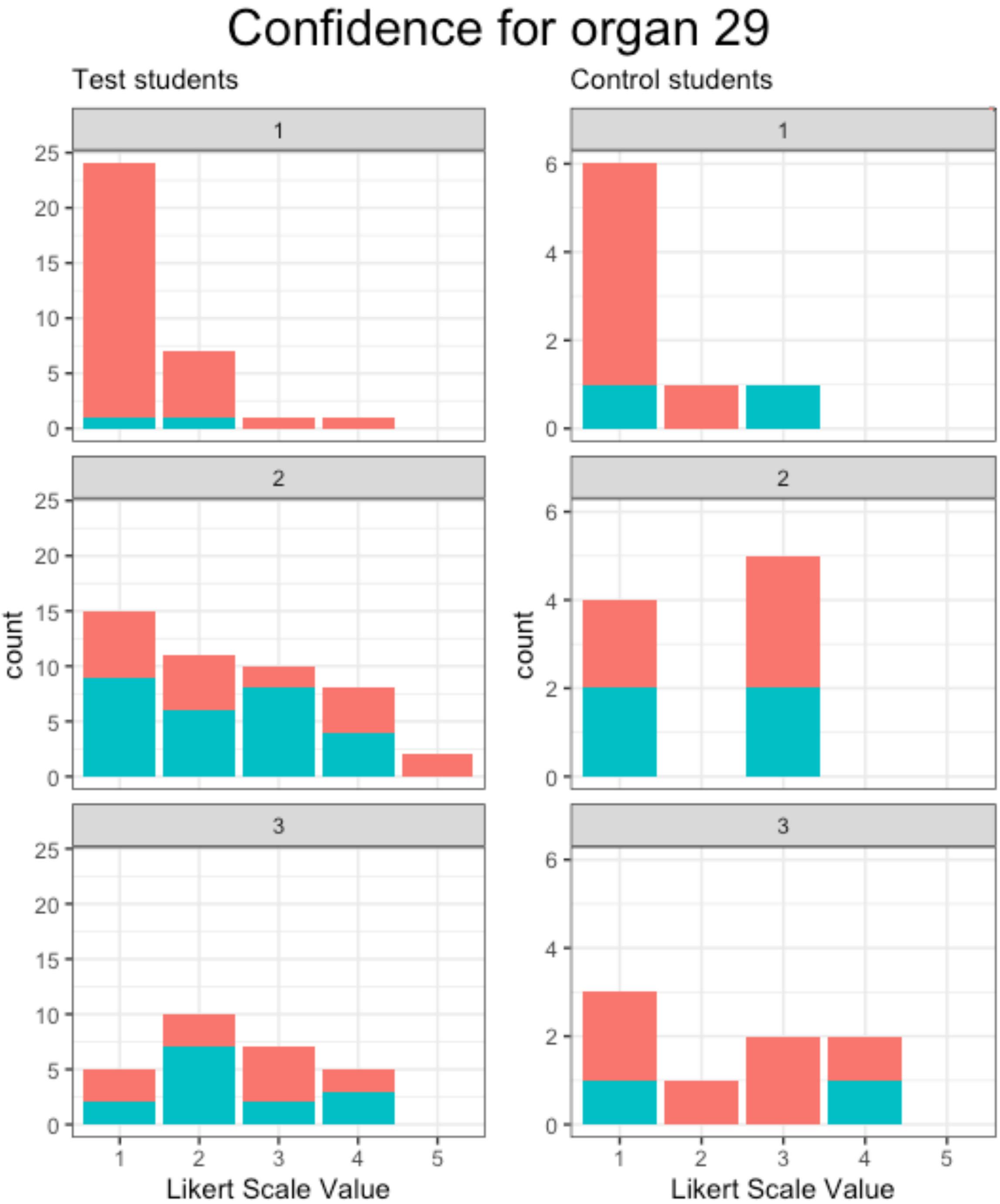


Figure 5 (3/3) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 7, 17 and 29 representing the pylorus.

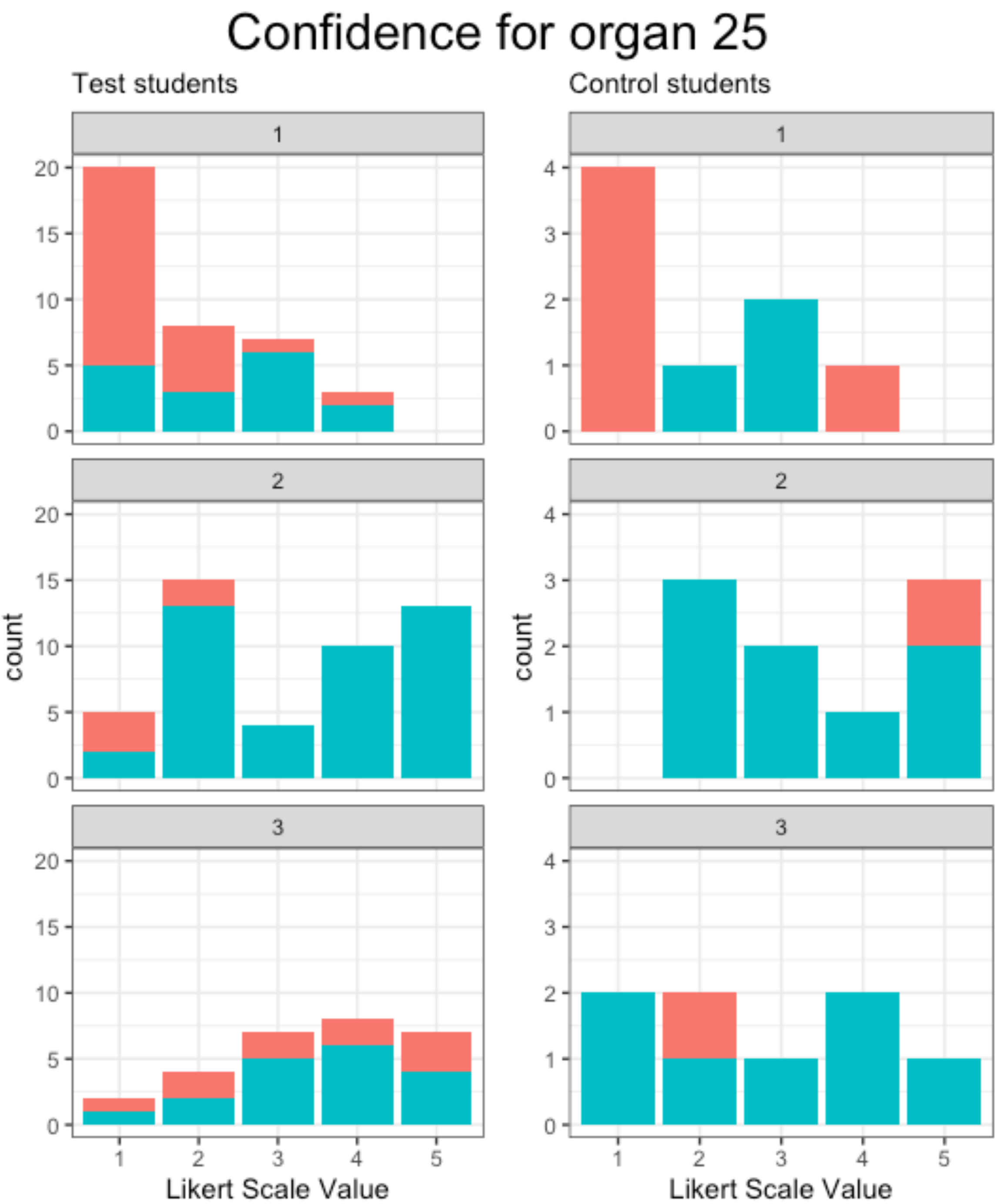


Figure 6 (1/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 25, 30, 32, 36, 43 and 45 representing the small intestine.

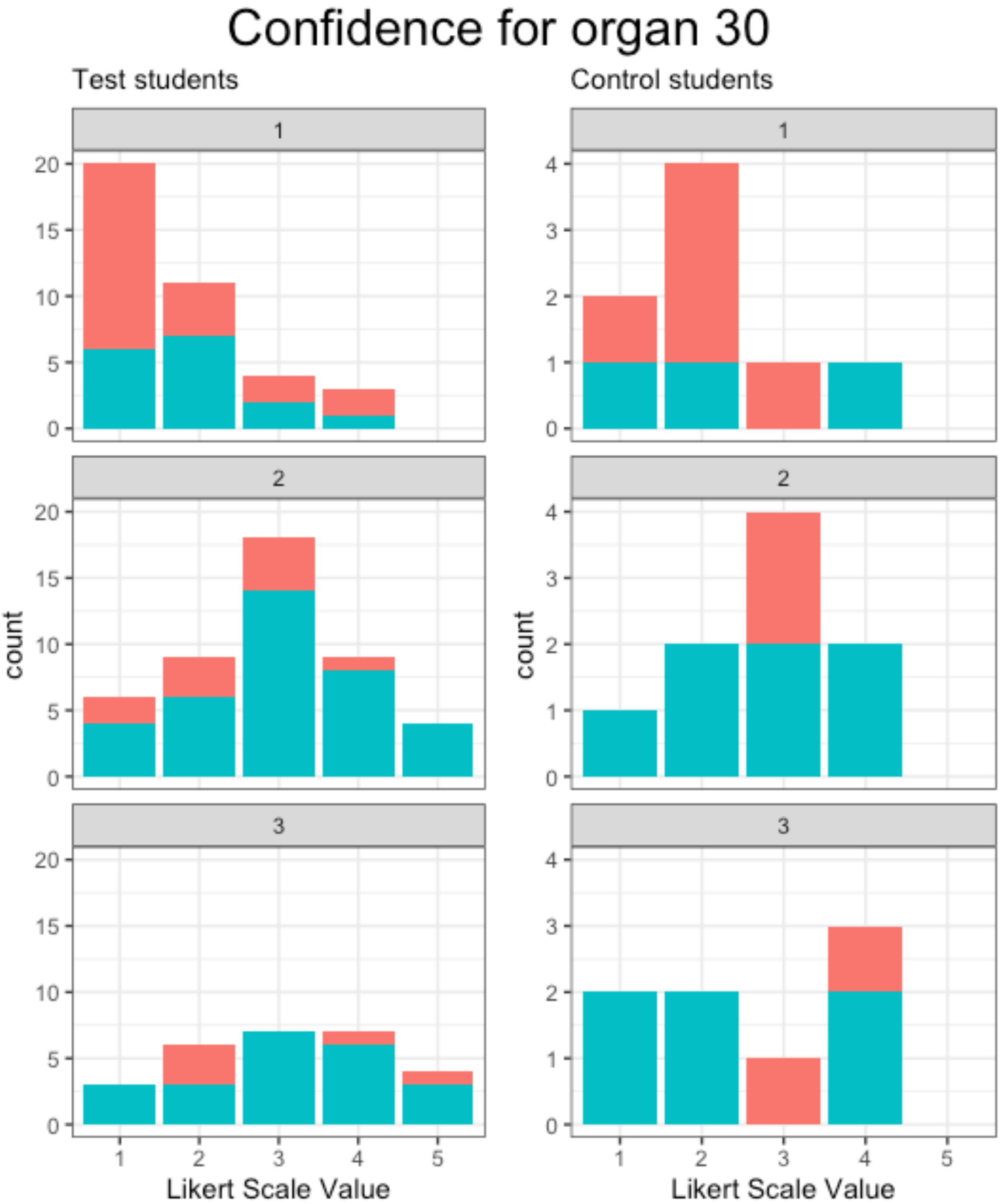


Figure 6 (2/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 25, 30, 32, 36, 43 and 45 representing the small intestine.

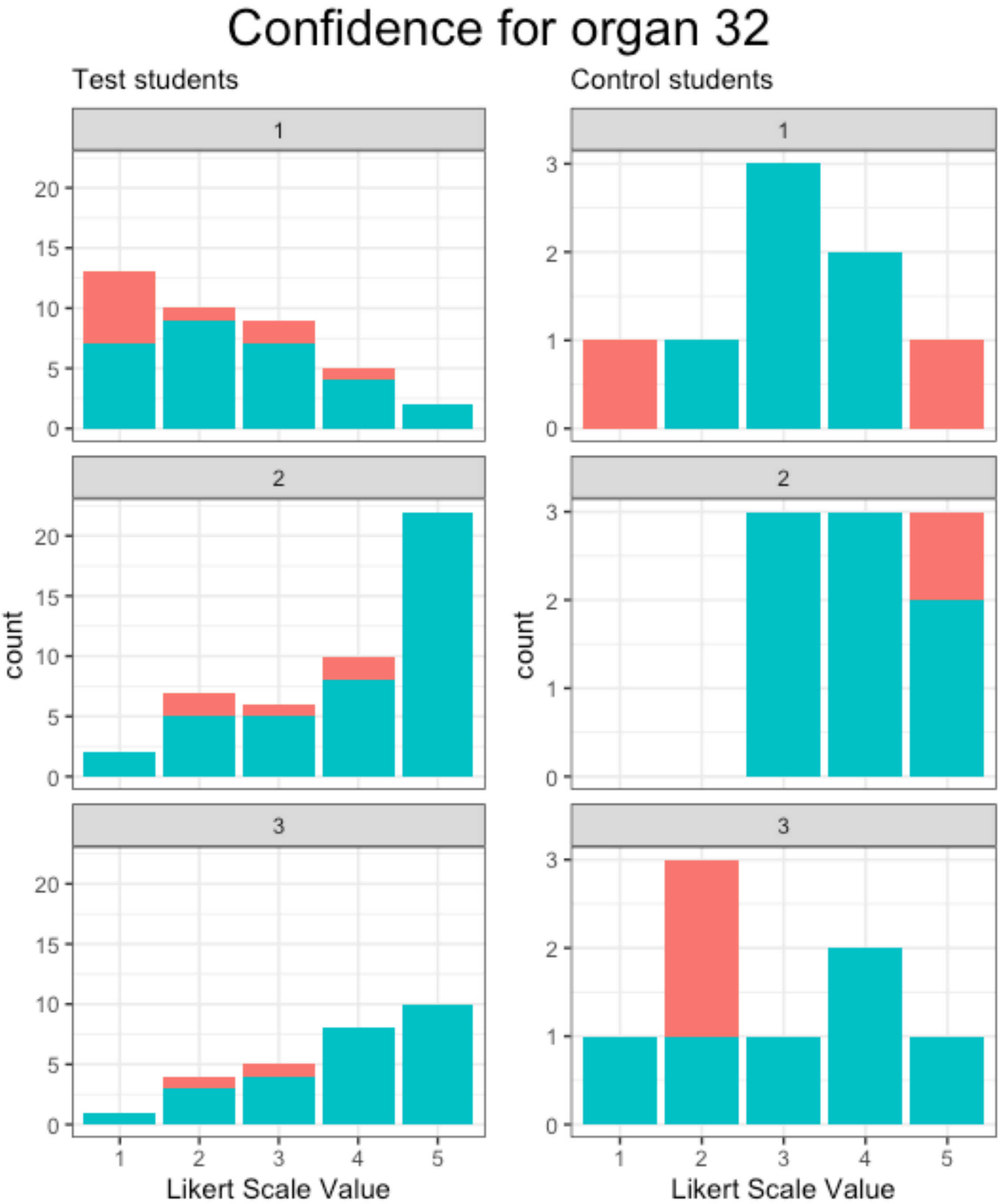


Figure 6 (3/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 25, 30, 32, 36, 43 and 45 representing the small intestine.

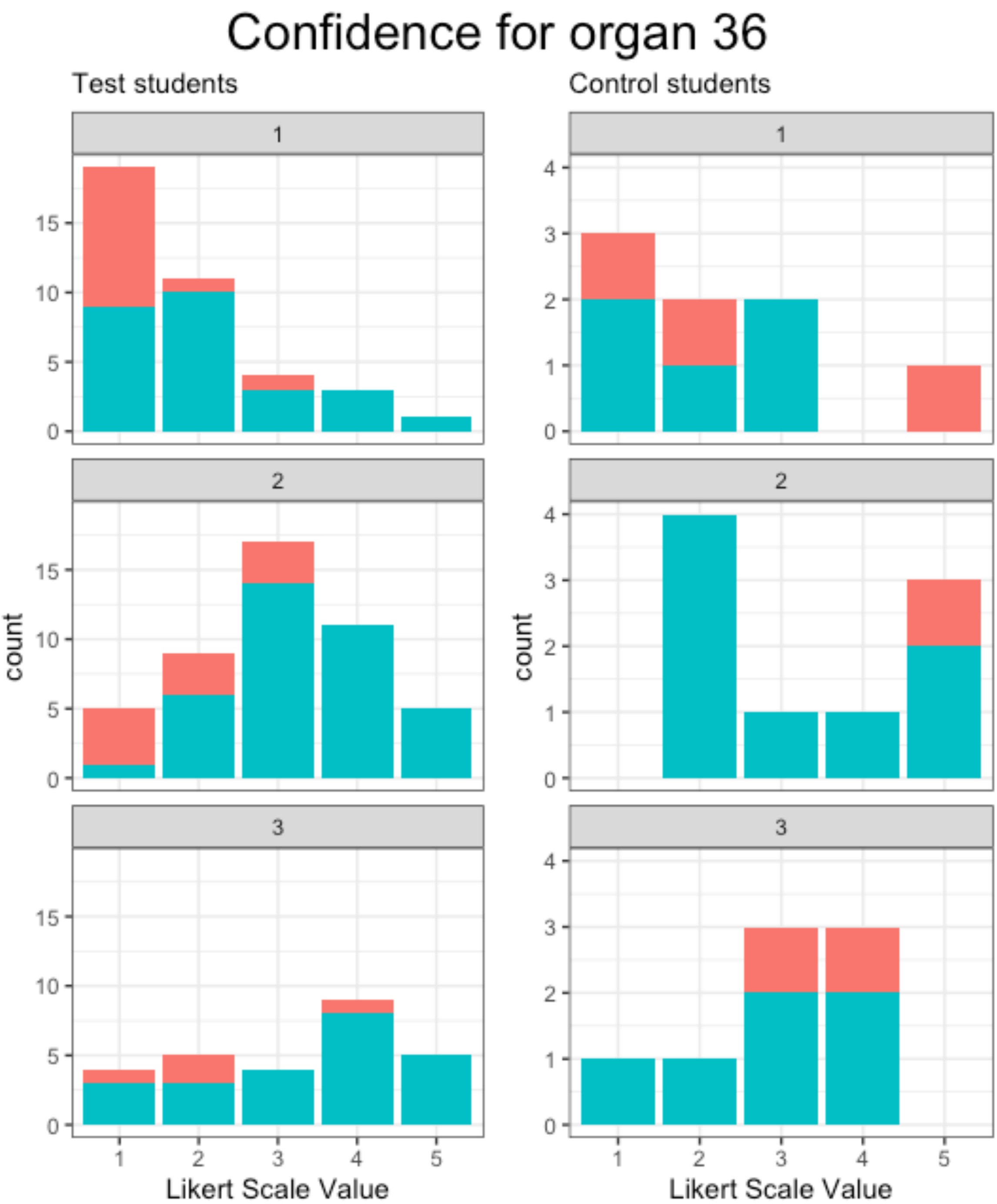


Figure 6 (4/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 25, 30, 32, 36, 43 and 45 representing the small intestine.

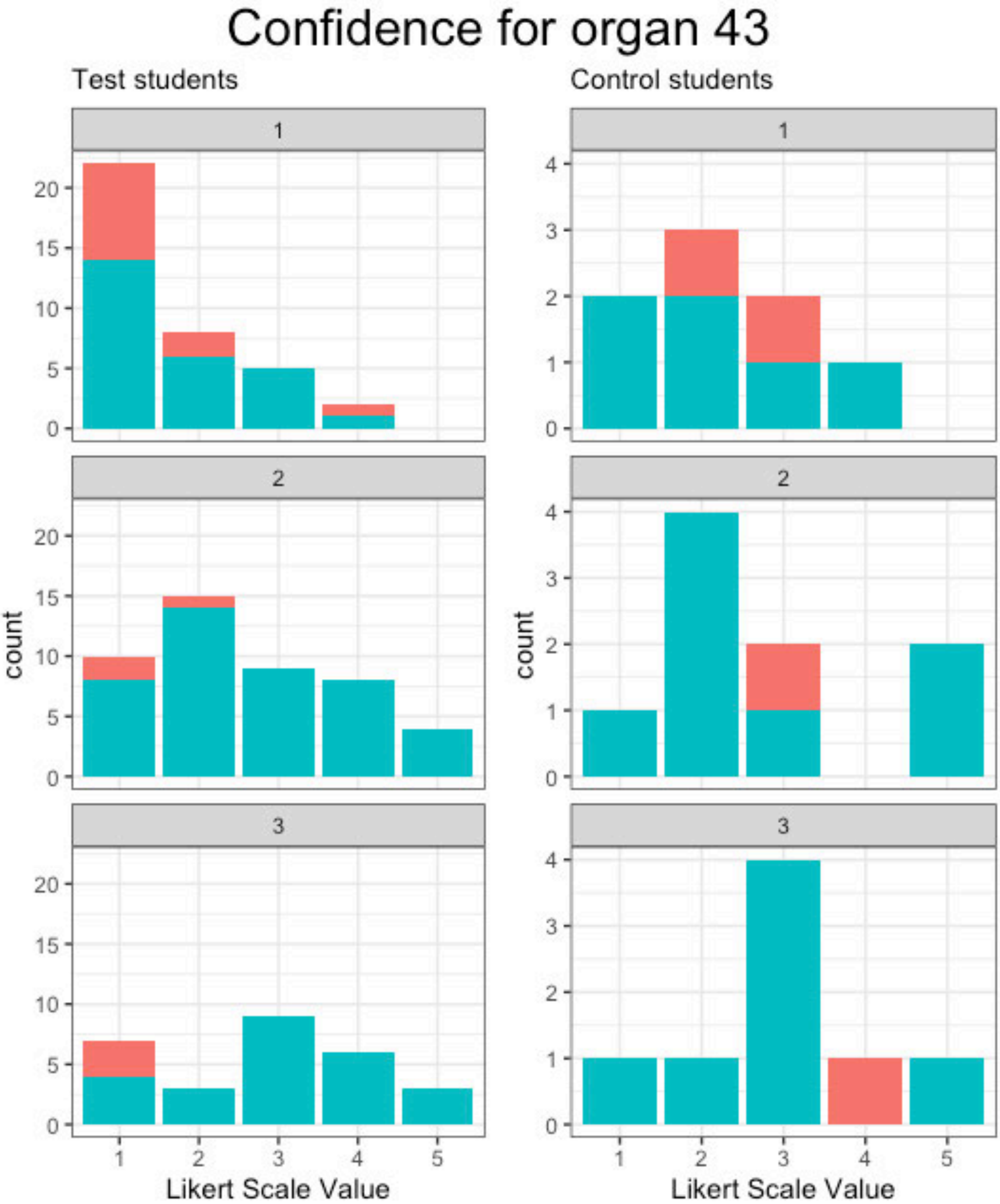


Figure 6 (5/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 25, 30, 32, 36, 43 and 45 representing the small intestine.

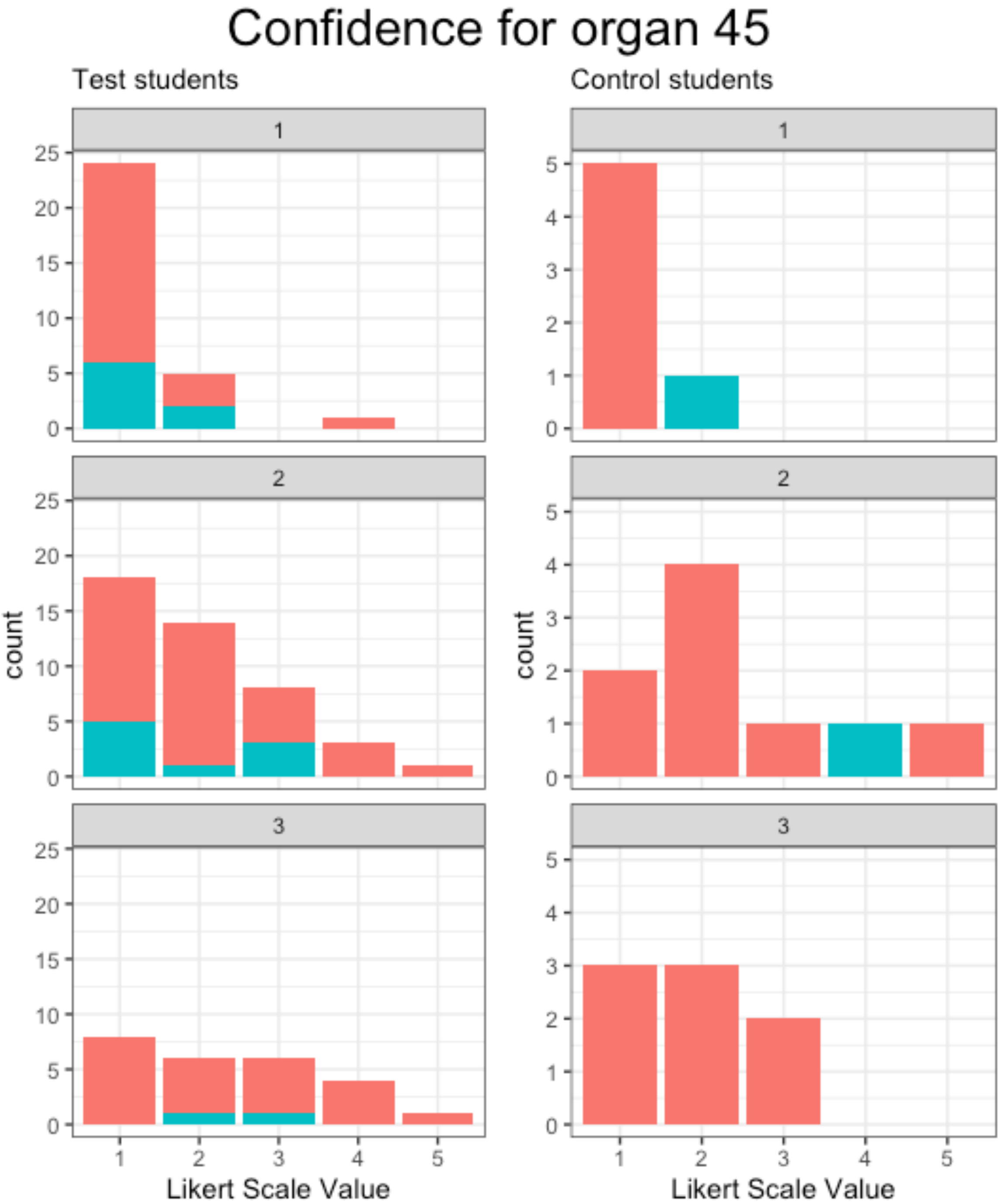


Figure 6 (6/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 25, 30, 32, 36, 43 and 45 representing the small intestine.

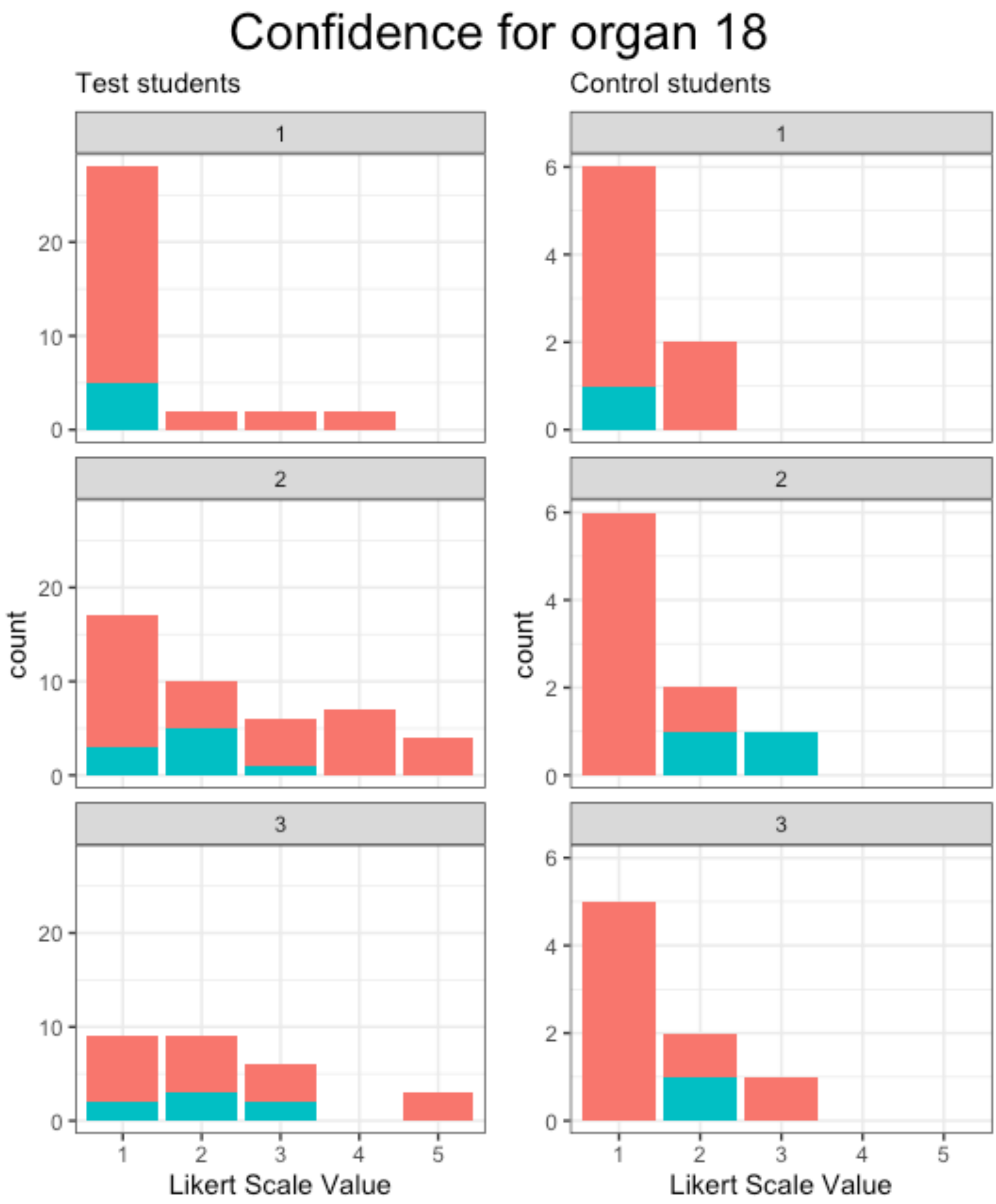


Figure 7 (1/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 18, 22, 35 and 42 representing the large intestine.

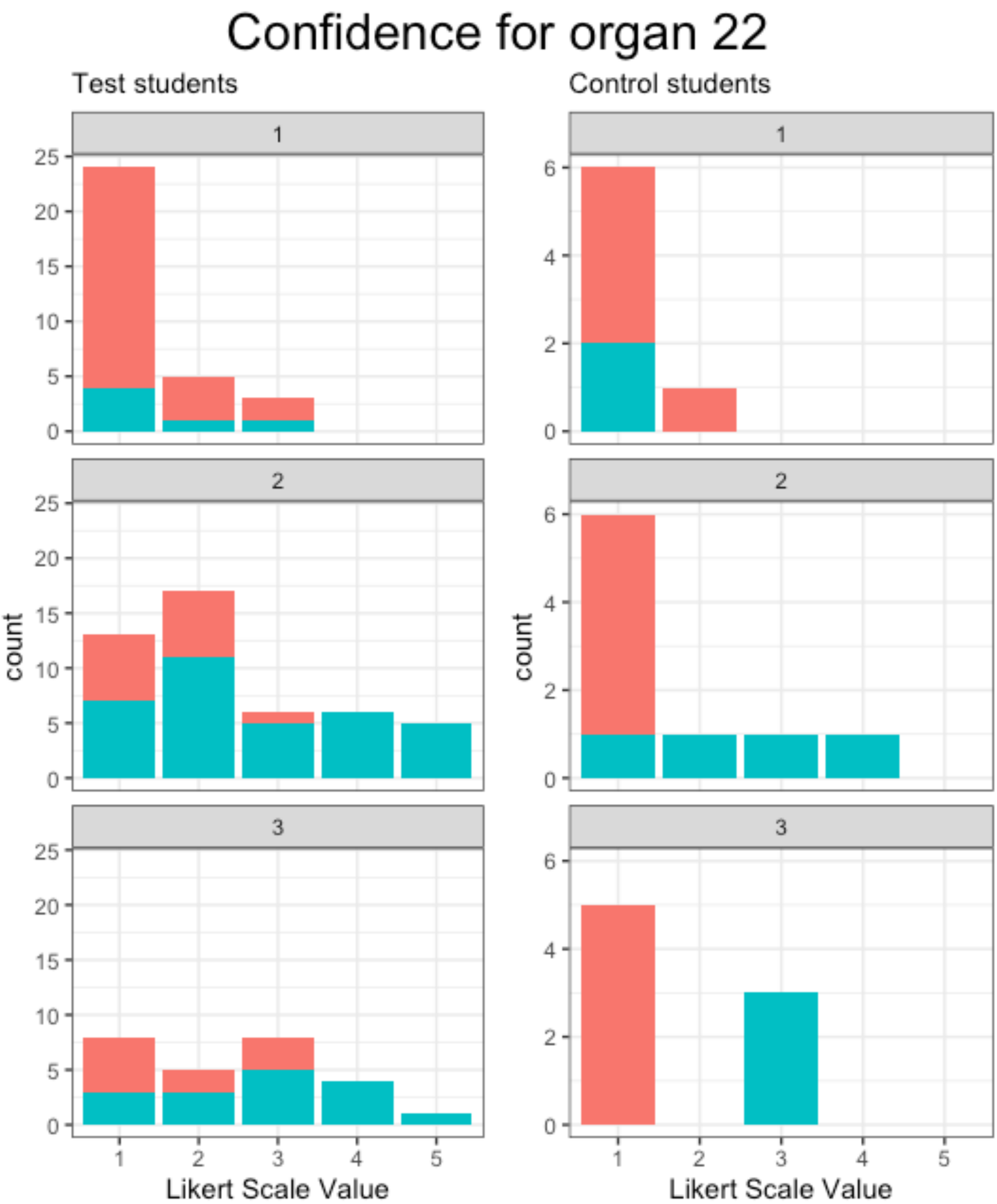


Figure 7 (2/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 18, 22, 35 and 42 representing the large intestine.

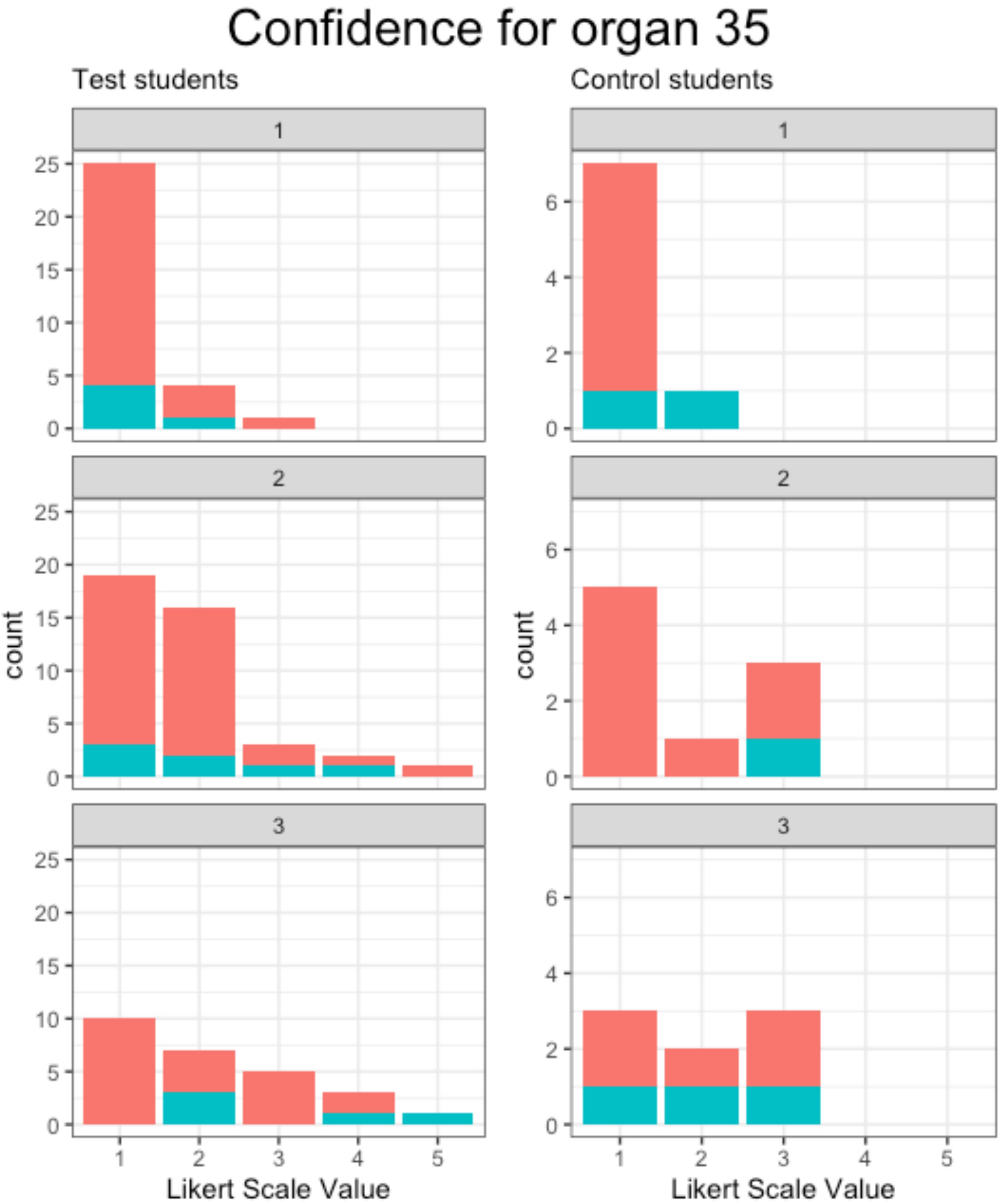


Figure 7 (3/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 18, 22, 35 and 42 representing the large intestine.

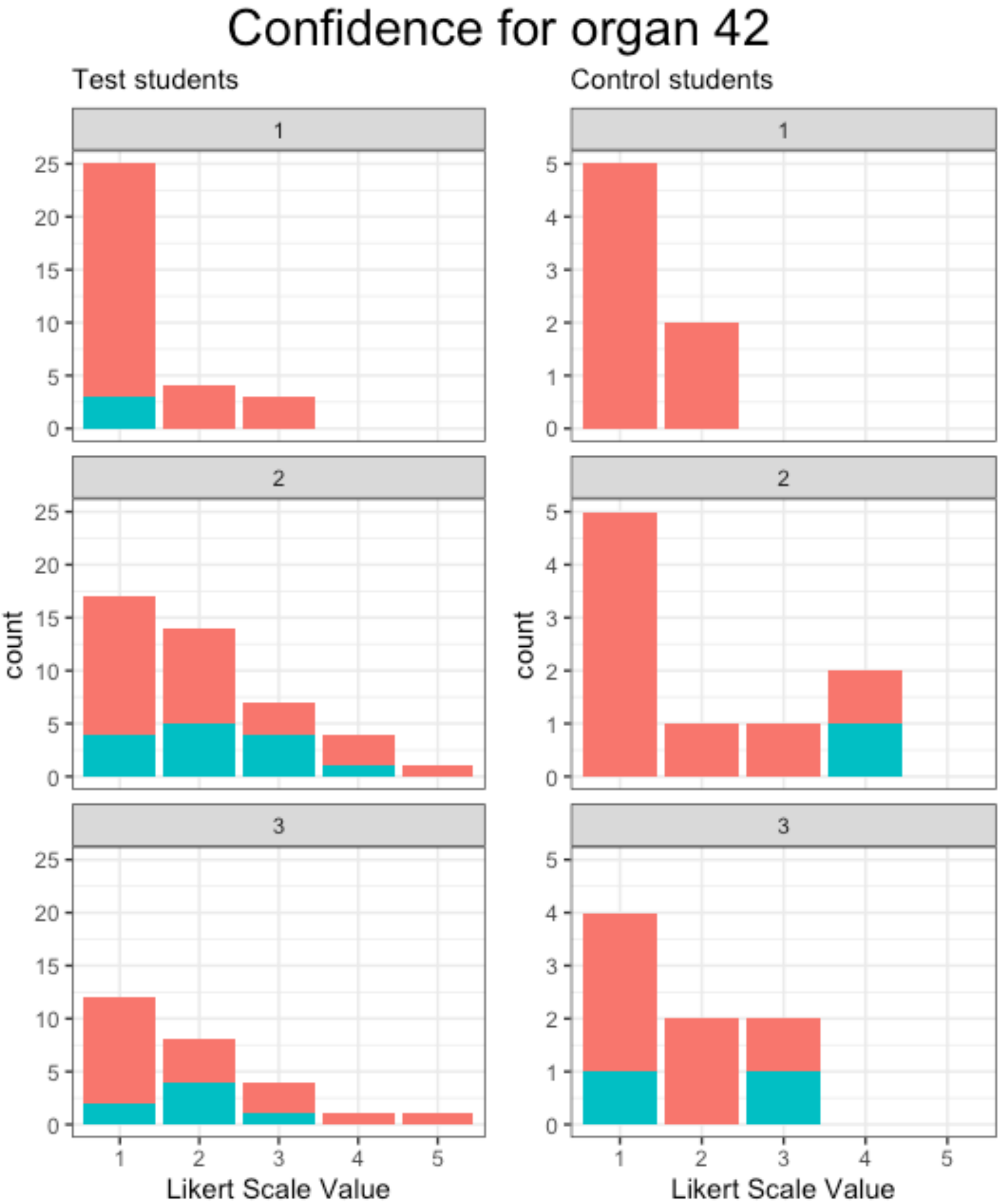


Figure 7 (4/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 18, 22, 35 and 42 representing the large intestine.

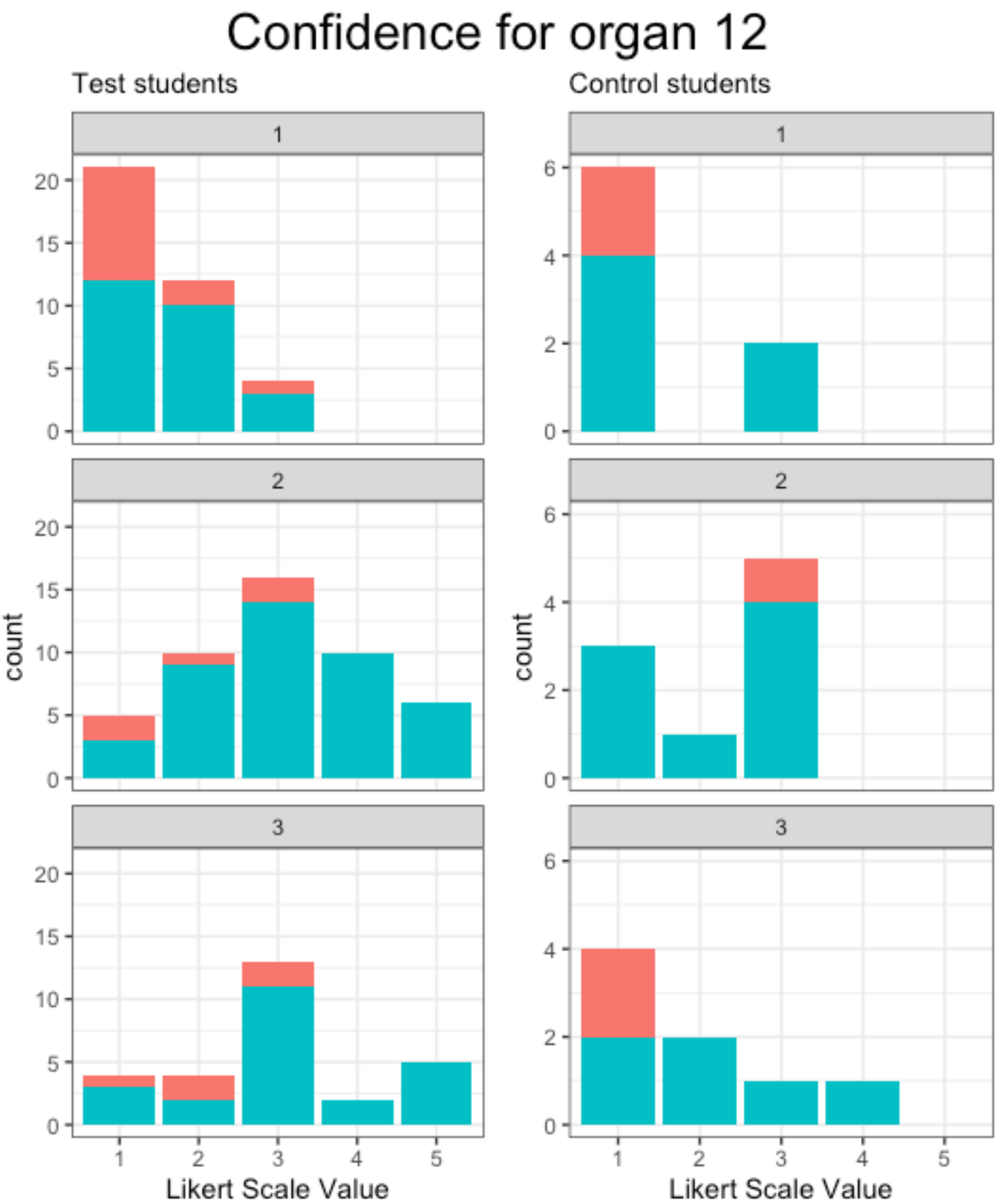


Figure 8 (1/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 12, 13, 28 and 39 representing the pancreas.

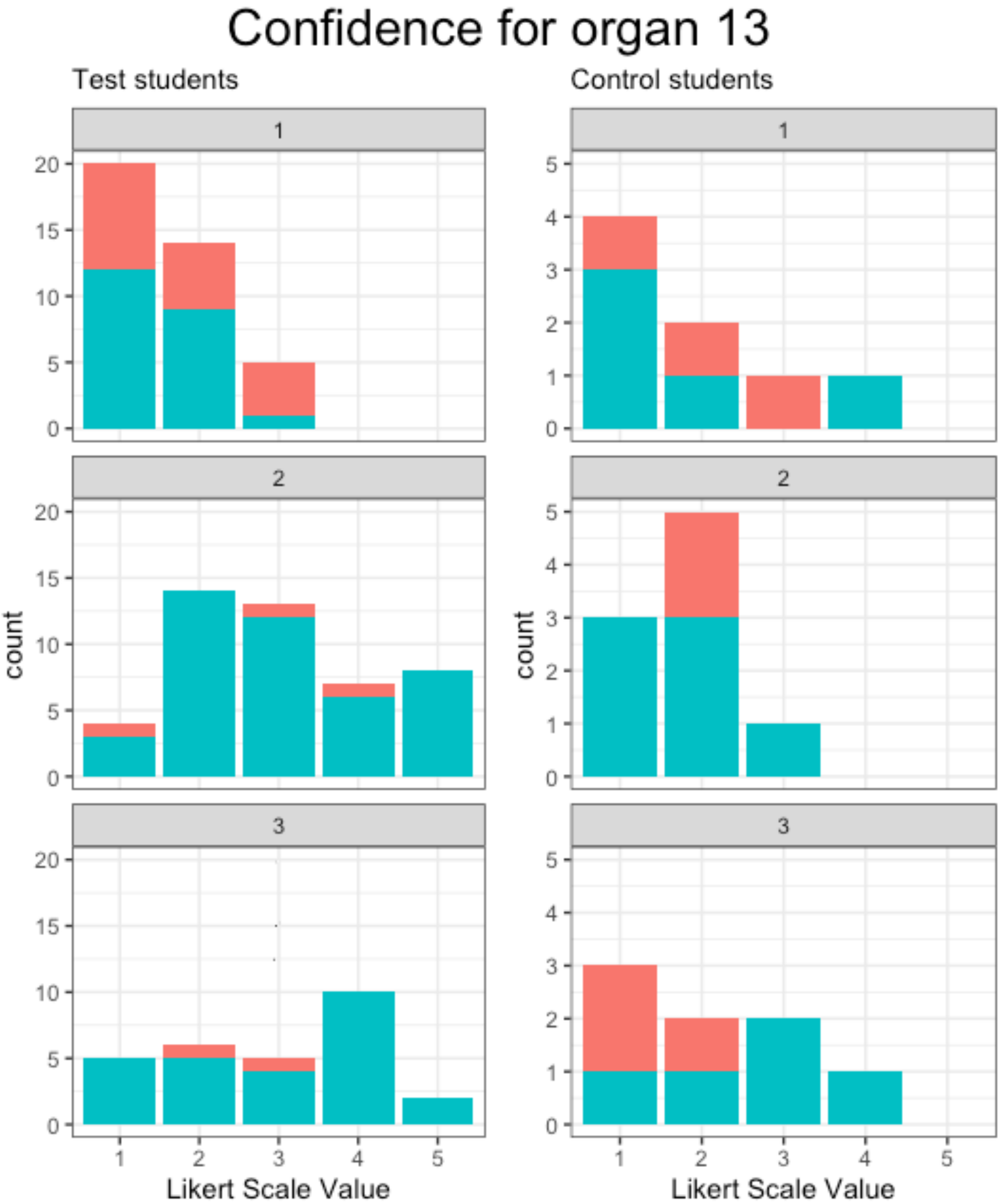


Figure 8 (2/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 12, 13, 28 and 39 representing the pancreas.

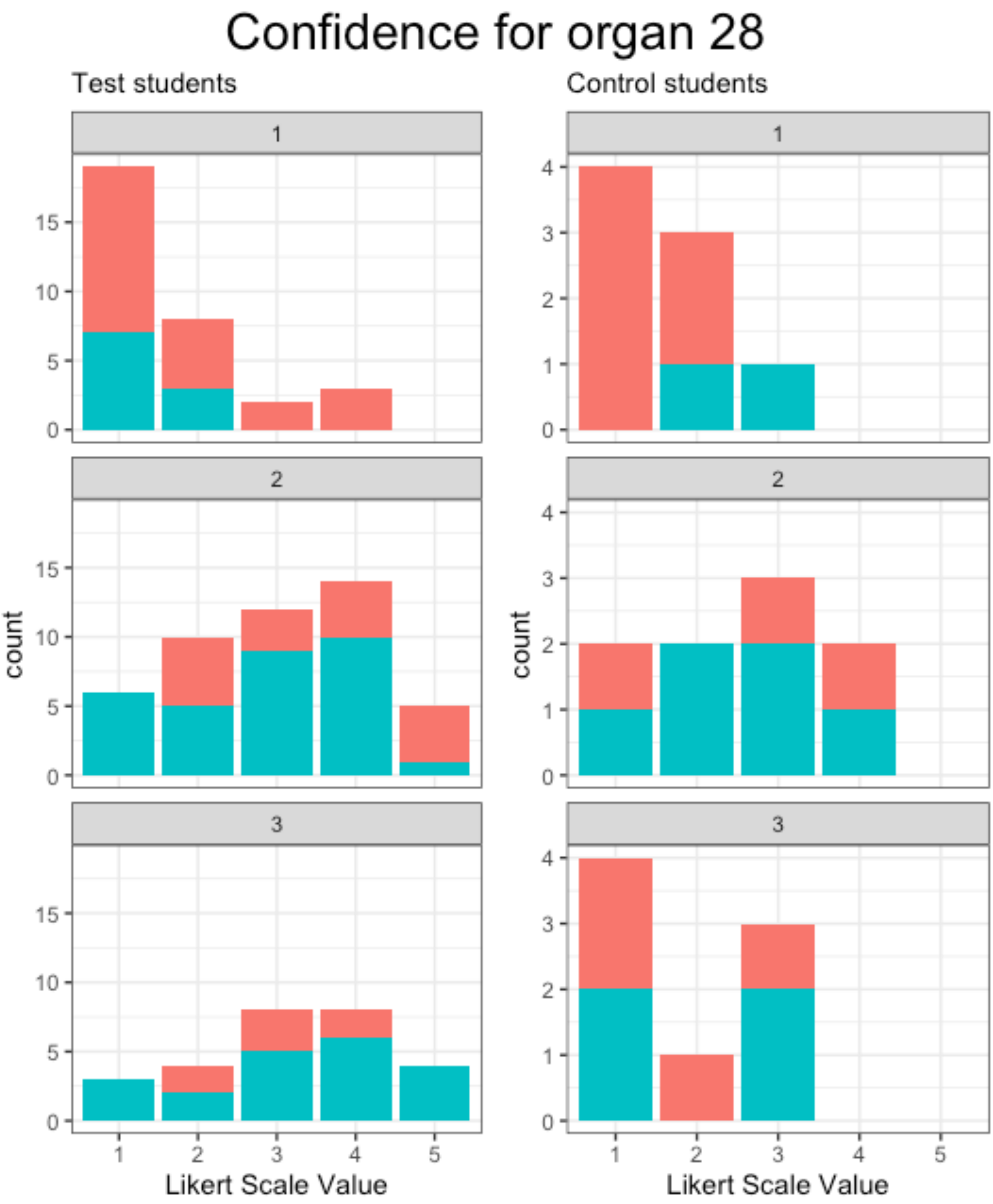


Figure 8 (3/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 12, 13, 28 and 39 representing the pancreas.

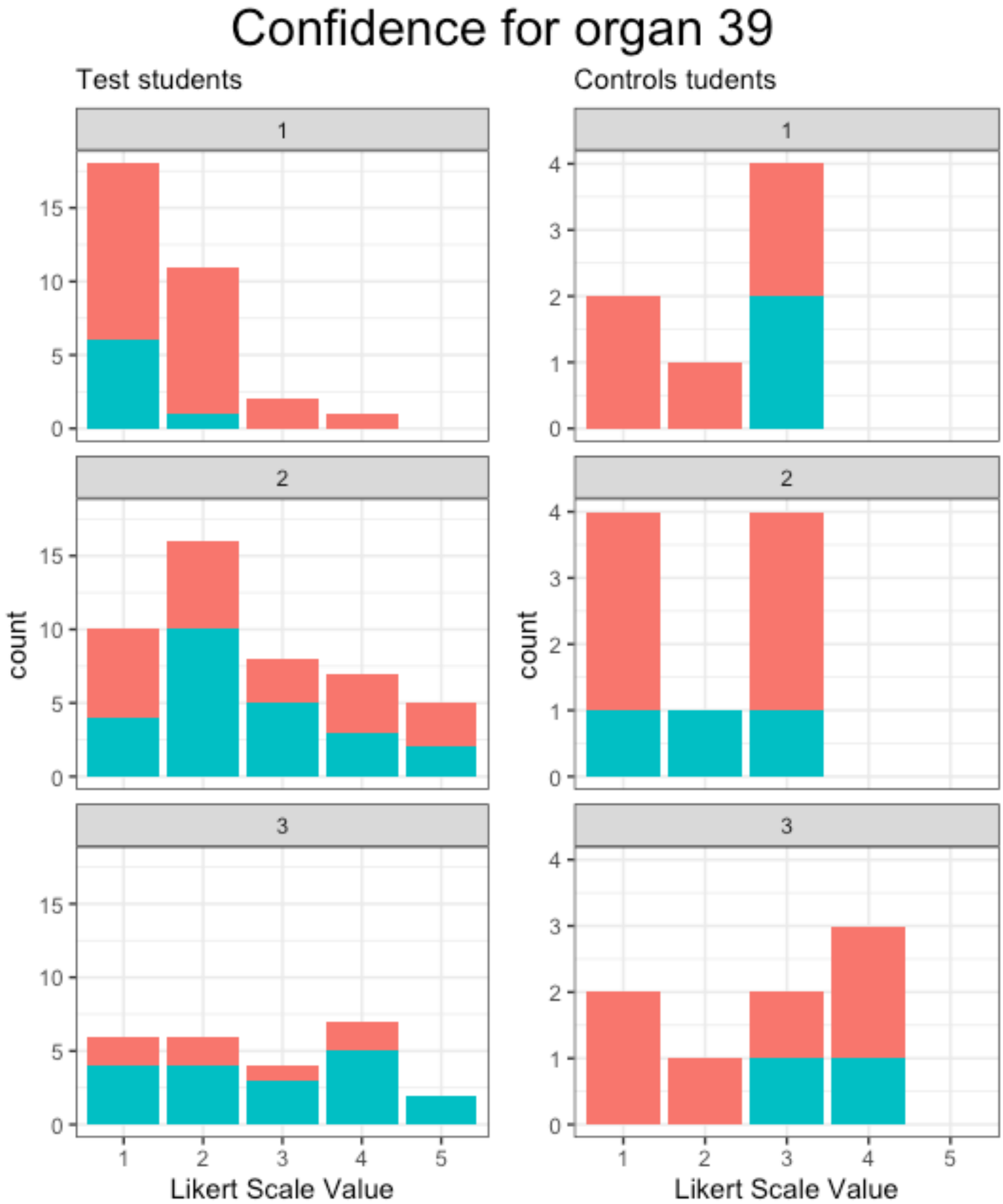


Figure 8 (4/4) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 12, 13, 28 and 39 representing the pancreas.

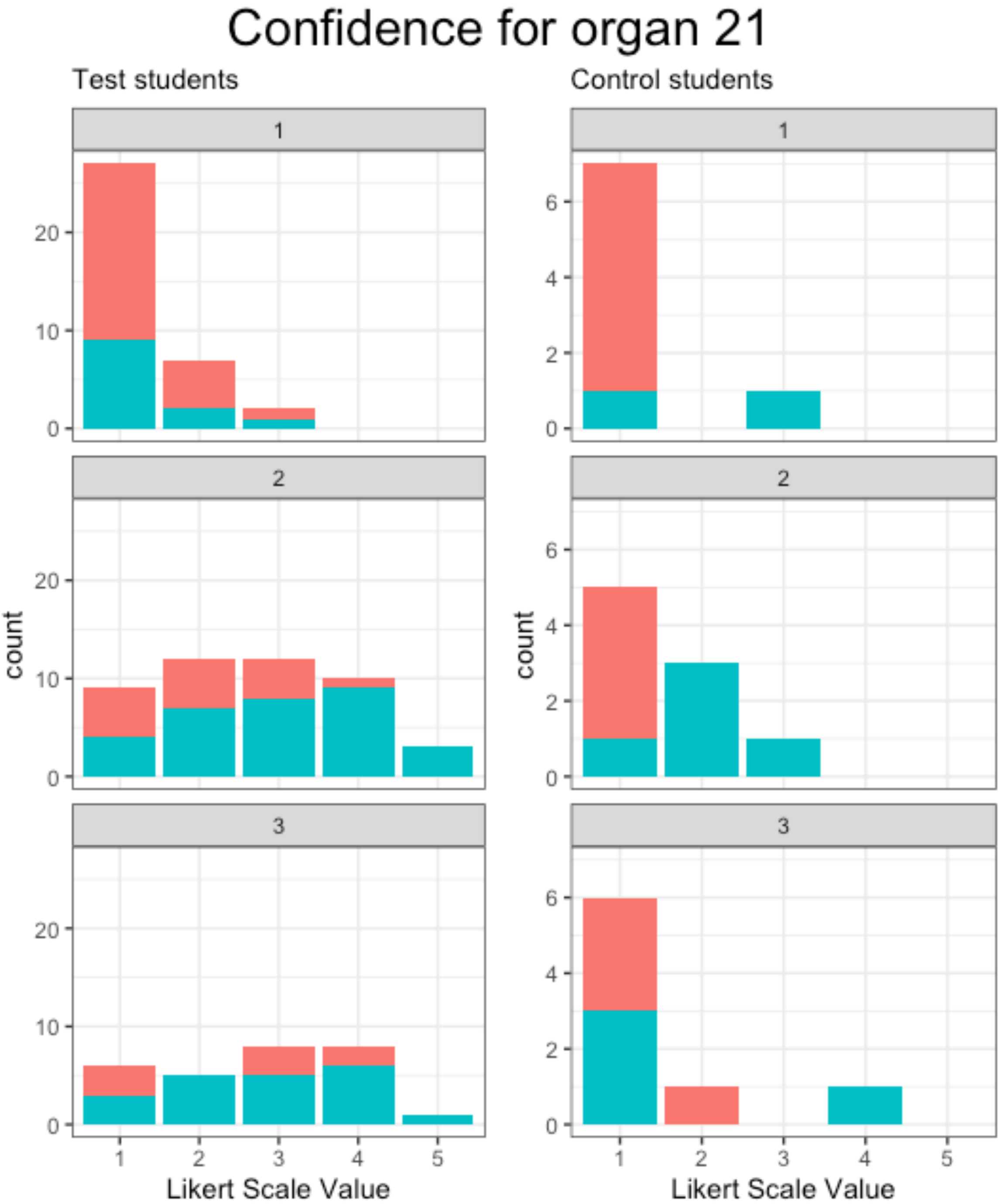


Figure 9 (1/2) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 21 and 23 representing the lymph nodes.

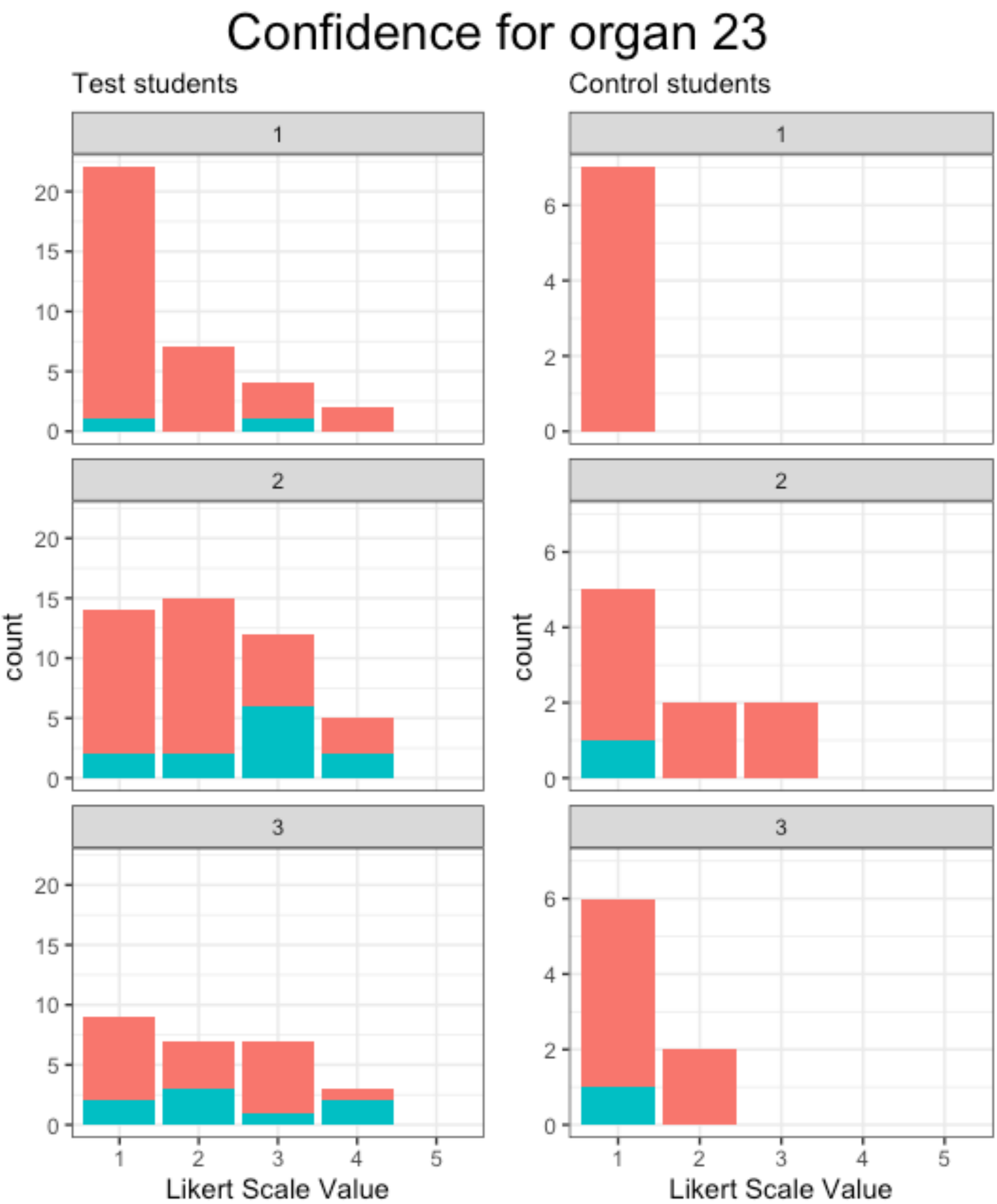


Figure 9 (2/2) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 21 and 23 representing the lymph nodes.

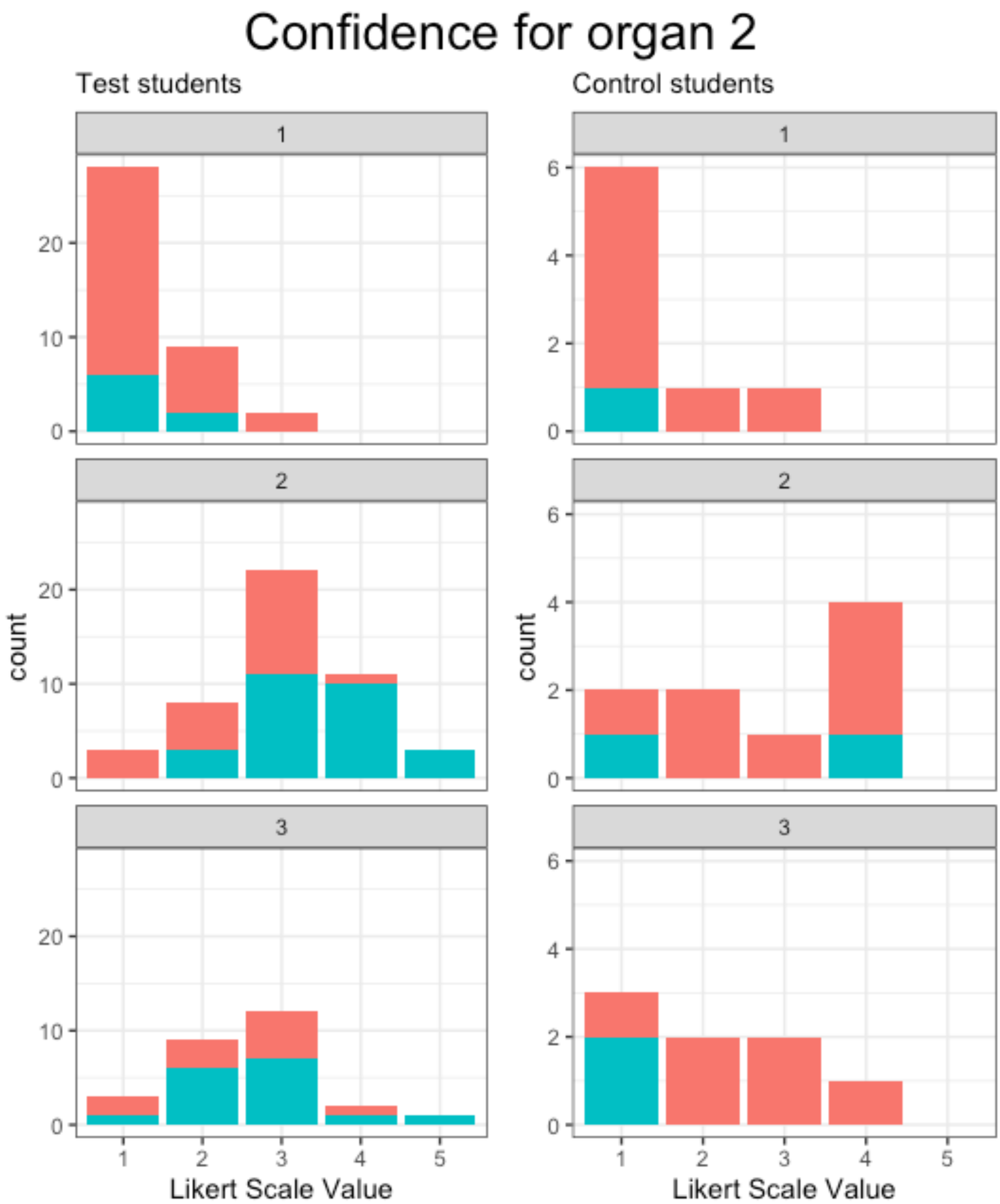


Figure 10 (1/2) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 2 and 41 representing the adrenal glands.

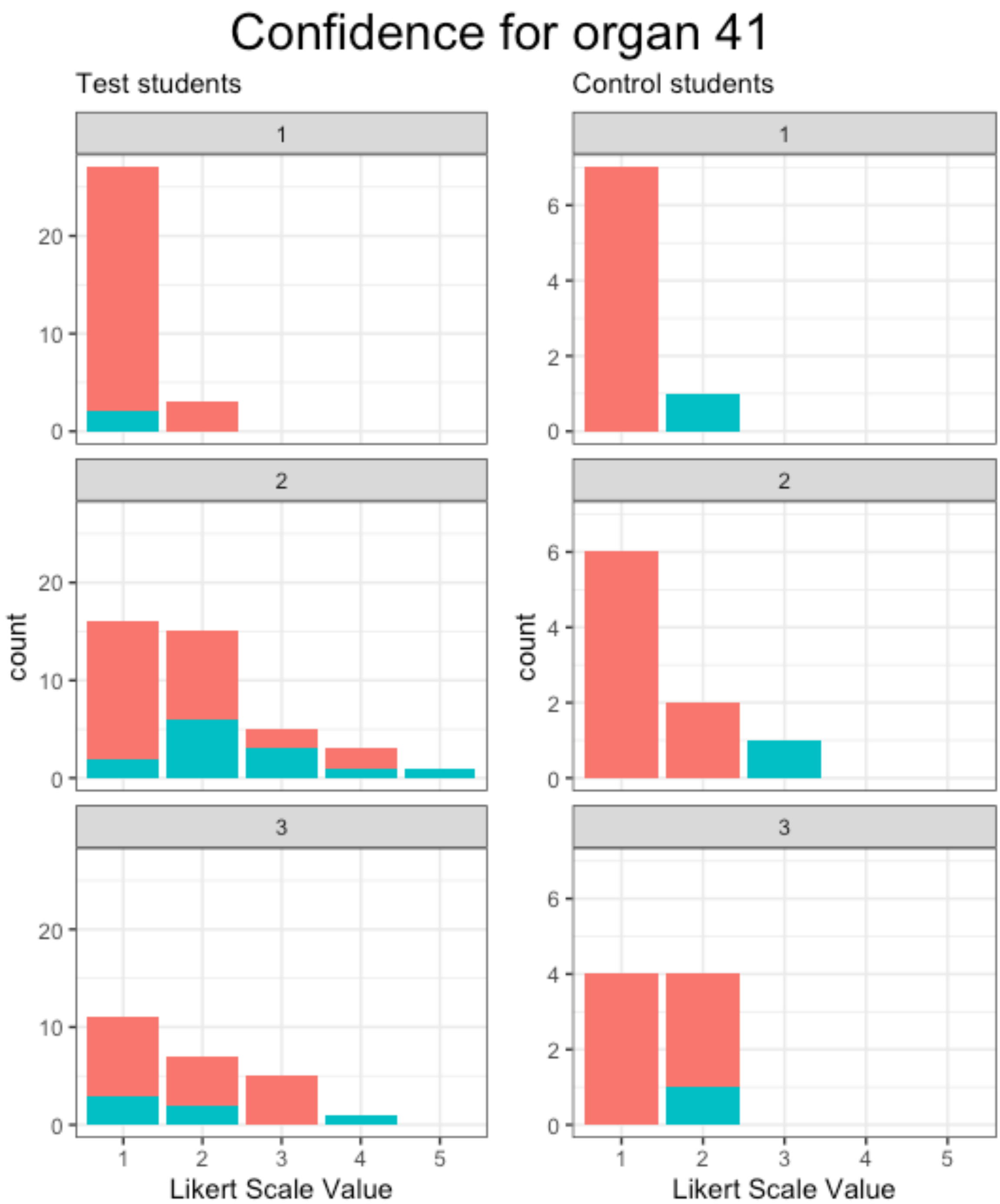


Figure 10 (2/2) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 2 and 41 representing the adrenal glands.

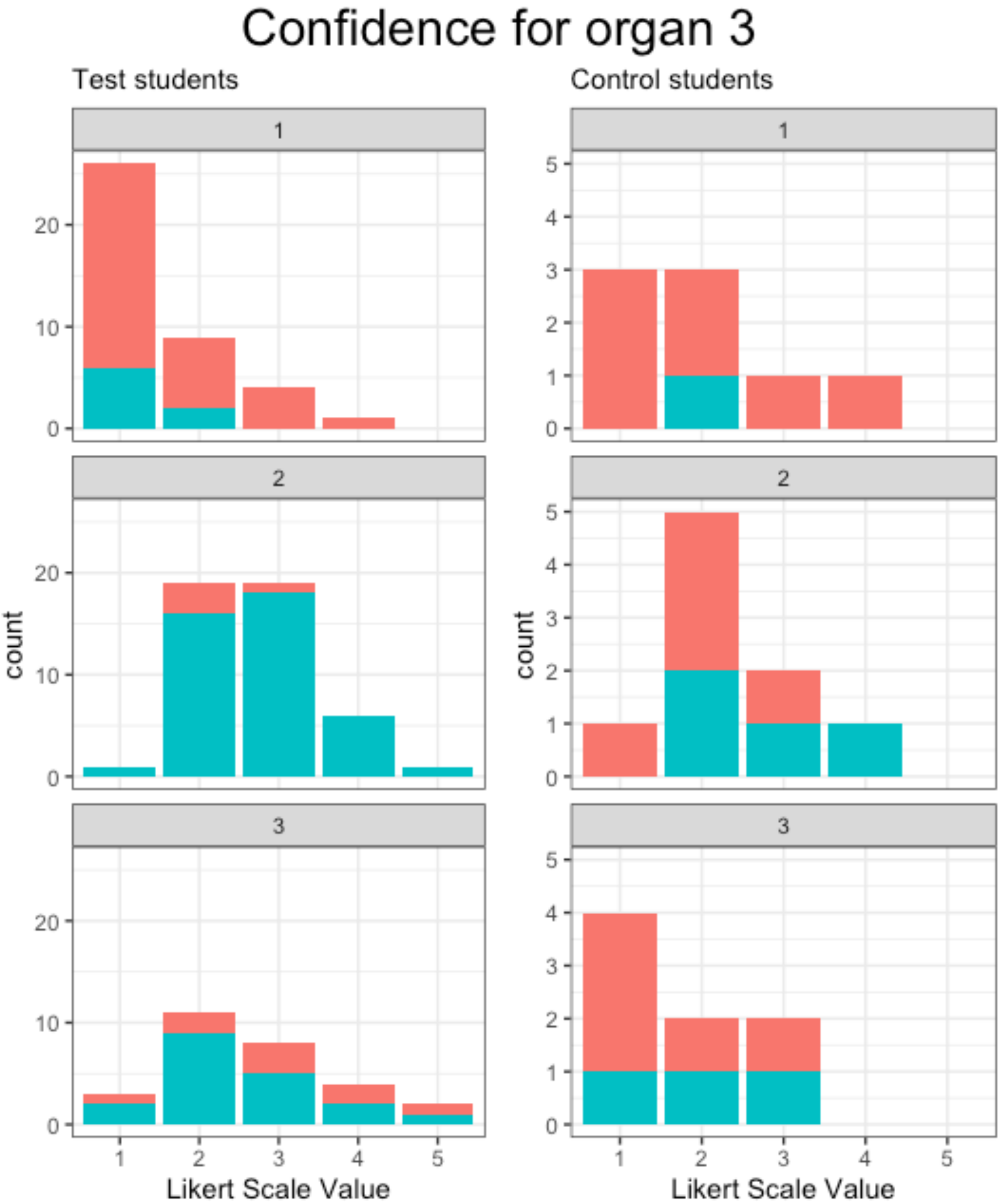


Figure 11 (1/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 3, 16, 19, 20, 24 and 40 representing the blood vessels.

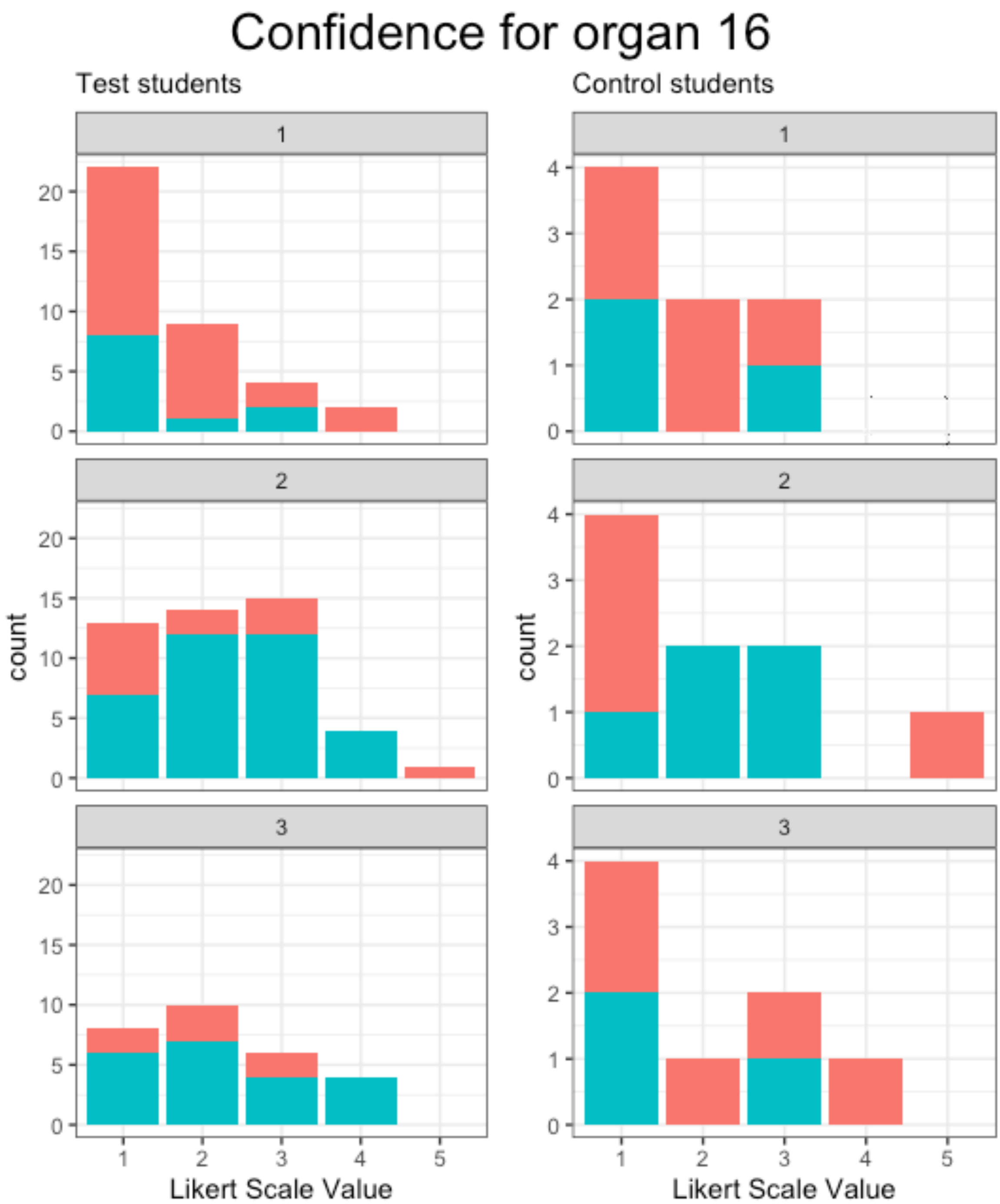


Figure 11 (2/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 3, 16, 19, 20, 24 and 40 representing the blood vessels.

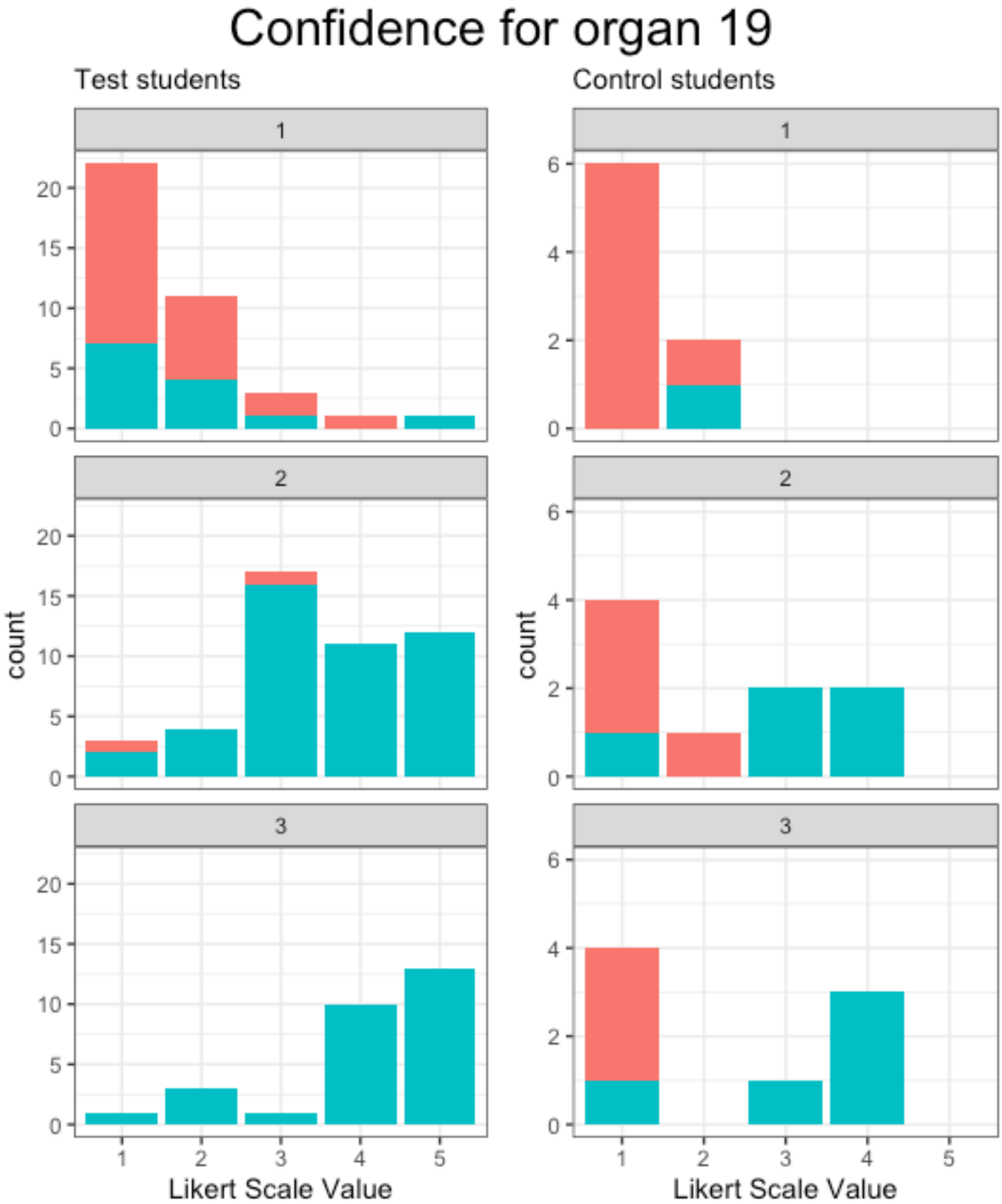


Figure 11 (3/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 3, 16, 19, 20, 24 and 40 representing the blood vessels.

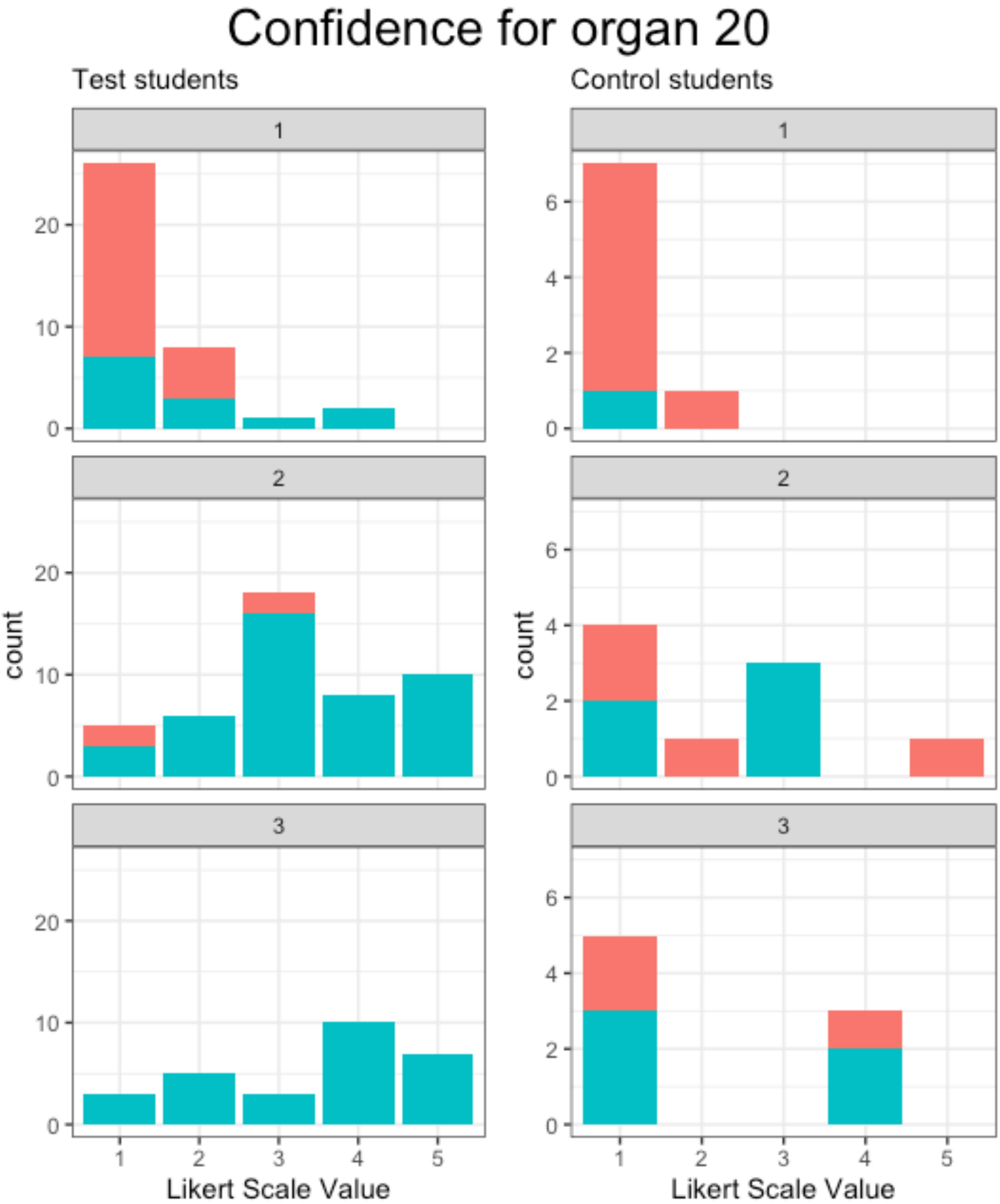


Figure 11 (4/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 3, 16, 19, 20, 24 and 40 representing the blood vessels.

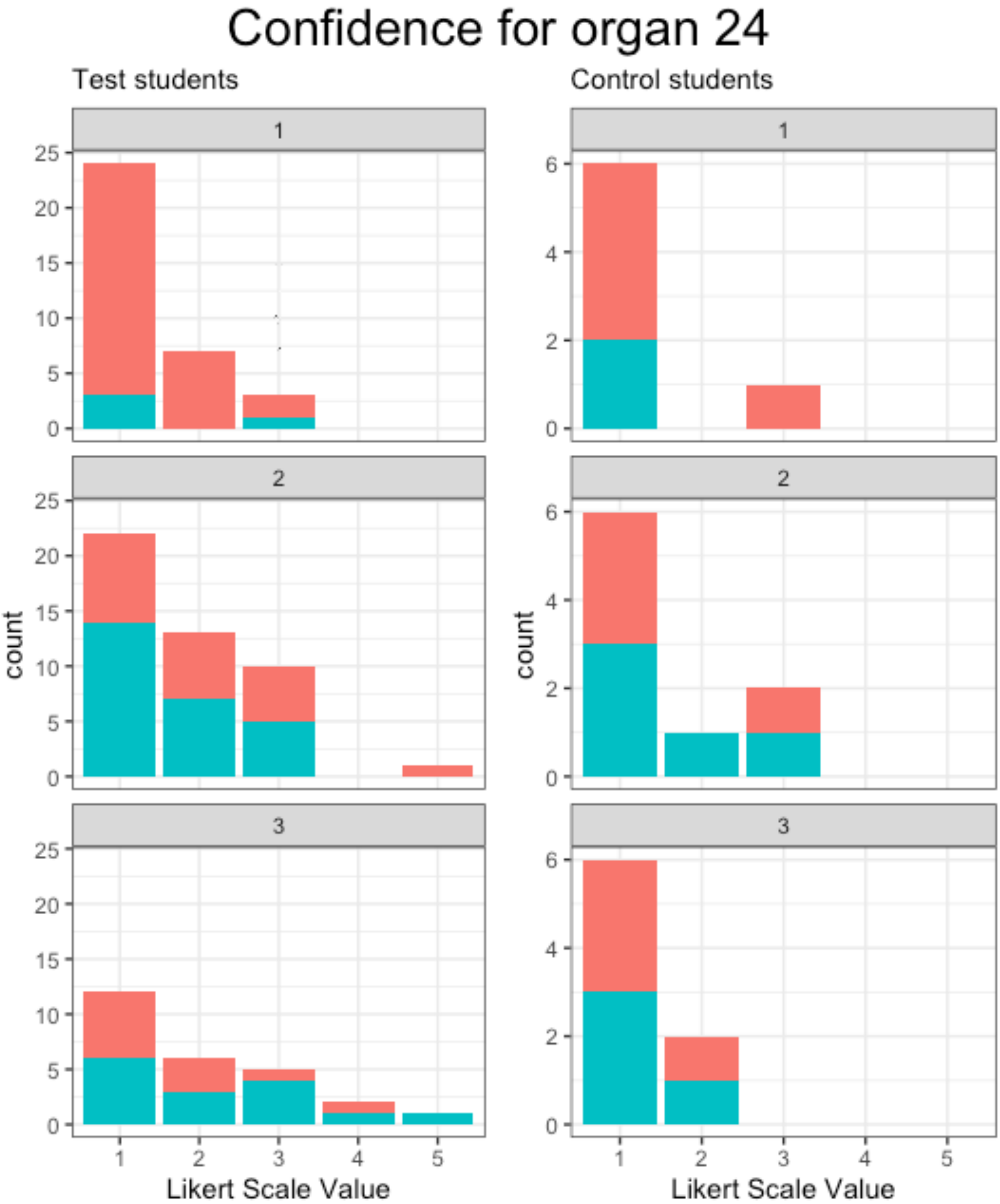


Figure 11 (5/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 3, 16, 19, 20, 24 and 40 representing the blood vessels.

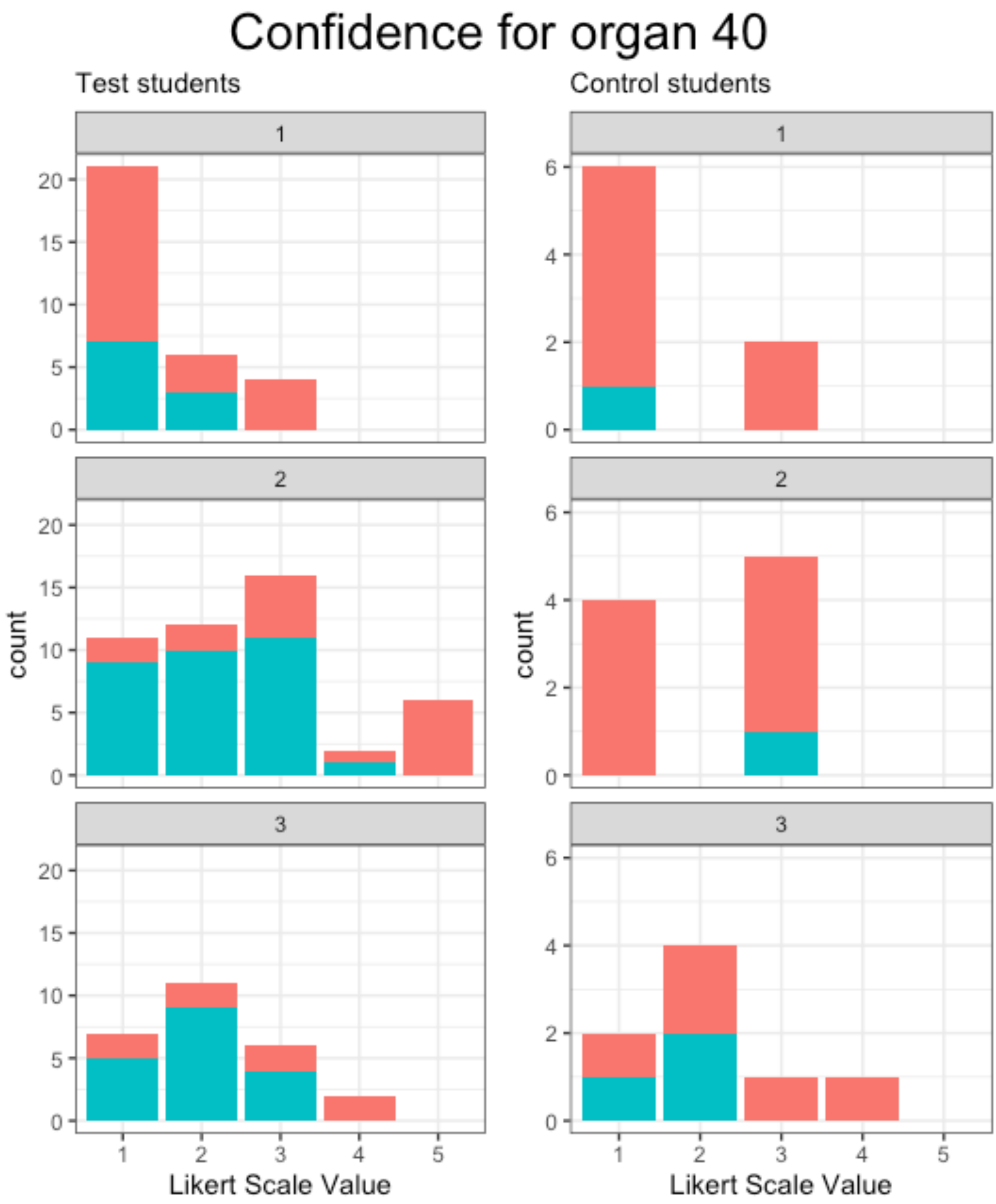


Figure 11 (6/6) Bar charts illustrating the confidence levels of both test and control students, differentiated by correct answers (in blue) and incorrect answers (in red), across three assessment points: the pre-rotation test (1), post-rotation test 1 (2), and post-rotation test 2 (3) for the identification of organs 3, 16, 19, 20, 24 and 40 representing the blood vessels.

Appendix 13: Results from the statistical tests

Table 1 Comparison of the answers between the test and control students at the pre-rotation test (T1), post-rotation test 1 (T2) and post-rotation test 2 (T3): results of the Fisher's exact test.

Abdominal systems	T1 (p-value)	T2 (p-value)	T3 (p-value)
Kidneys	0.5902	0.3919	0.4326
Urinary bladder	1.0000	1.0000	1.0000
Spleen	0.6248	0.0004*	0.1235
Liver	0.8902	0.4740	1.0000
Gallbladder	1.0000	0.2441	0.0301
Stomach	0.7644	0.0077	0.5586
Pylorus	0.6160	0.0138	0.3525
Small intestine	0.9484	0.9664	0.6751
Large intestine	1.0000	0.1239	0.6253
Ileocaecocolic junction	0.3385	0.0211	0.0715
Pancreas	0.9434	0.3853	<0.0001*
Lymph nodes	0.7276	0.4311	0.2441
Adrenal glands	1.0000	0.0452	0.1433
Prostate	0.6981	1.0000	0.3460
Blood vessels	0.3377	<0.0001*	<0.0001*

* represents p-values <0.001.

Table 2 Comparison of the answers between the tests for the test students: results of the McNemar paired test. Pre-rotation test is T1, post-rotation test 1 is T2 and post-rotation test 2 is T3. Unpaired answers were excluded from analysis.

Abdominal systems	T1 compared to T2 (p-value)	T2 compared to T3 (p-value)	T1 compared to T3 (p-value)
Kidneys	<0.0001*	0.6171	0.0015
Urinary bladder	1.0000	NA	NA
Spleen	NA	NA	NA
Liver	<0.0001*	0.8445	<0.0001*
Gallbladder	0.0003*	0.4795	0.0412
Stomach	<0.0001*	0.0098	<0.0001*
Pylorus	0.0002*	0.0801	0.0098
Small intestine	<0.0001*	0.0633	0.0087
Large intestine	0.0003*	0.1904	0.0005*
Ileocaecocolic junction	0.0044	1.0000	0.0133
Pancreas	<0.0001*	0.8026	0.0001*
Lymph nodes	0.0022	0.7728	0.0026
Adrenal glands	0.0085	0.1814	0.0033
Prostate	0.0133	0.6171	0.2482
Blood vessels	<0.0001*	0.1508	<0.0001*

* represents p-values <0.001.

NA: not applicable.

Table 3 Comparison of the answers between the tests for the control students: results of the McNemar paired test. Pre-rotation test is T1, post-rotation test 1 is T2 and post-rotation test 2 is T3. Unpaired answers were excluded from analysis.

Abdominal systems	T1 compared to T2 (p-value)	T2 compared to T3 (p-value)	T1 compared to T3 (p-value)
Kidneys	1.0000	NA	NA
Urinary bladder	NA	NA	NA
Spleen	1.0000	0.2482	0.1336
Liver	0.0771	0.0771	0.0233
Gallbladder	0.4795	0.4795	1.0000
Stomach	0.0736	0.6171	0.1336
Pylorus	0.0233	0.6171	0.0736
Small intestine	0.019	0.6831	0.0433
Large intestine	0.7518	1.0000	0.7237
Ileocaecocolic junction	NA	NA	NA
Pancreas	0.0077	0.1336	0.0412
Lymph nodes	0.0736	1.0000	0.2482
Adrenal glands	1.0000	1.0000	1.0000
Prostate	0.2482	1.0000	1.0000
Blood vessels	0.0265	1.0000	0.1824

* represents p-values <0.001.

NA: not applicable.

Table 4 Comparison of the confidence level over time for the test students. The results of the Friedman test evaluate the overall difference of confidence level over time. Unpaired answers were excluded from analysis. The comparison between the three time points was performed using a Wilcoxon signed-rank test.

Abdominal systems	Friedman test p-value	T1 vs T2 (p-value)	T1 vs T3 (p-value)	T2 vs T3 (p-value)
Kidneys	<0.0001*	<0.0001**	<0.0001**	0.44
Urinary bladder	0.0002*	0.0096	0.0111	1.0000
Spleen	<0.0001*	<0.0001**	<0.0001**	0.1200
Liver	<0.0001*	<0.0001**	<0.0001**	0.0630
Gallbladder	0.0013*	0.0080	0.0410	0.1790
Stomach	<0.0001*	<0.0001**	<0.0001**	0.2400
Pylorus	<0.0001*	<0.0001**	<0.0001**	0.6500
Small intestine	<0.0001*	<0.0001**	<0.0001**	0.6500
Large intestine	<0.0001*	<0.0001**	<0.0001**	0.1900
Ileocaecocolic junction	0.0353	NA	NA	NA
Pancreas	<0.0001*	<0.0001**	<0.0001**	0.7300
Lymph nodes	0.0002*	0.0006**	0.0098	0.1839
Adrenal glands	<0.0001*	<0.0001**	0.0032	0.0007**
Prostate	0.0008*	0.0025	0.0398	0.0549
Blood vessels	<0.0001*	<0.0001**	<0.0001**	0.0630

*significant p-values (p<0.003)

**significant p-values (p<0.001)

Table 5 Comparison of the confidence and correct/incorrect answers for the test students: results from the Mann Whitney U test.

Abdominal systems	T1 (p-value)	T2 (p-value)	T3 (p-value)
Kidneys	<0.0001*	<0.0001*	<0.0001*
Urinary bladder	0.9301	0.0022	NA
Spleen	0.0094	0.0368	0.5381
Liver	<0.0001*	<0.0001*	<0.0001*
Gallbladder	0.6134	0.3979	0.3210
Stomach	0.0103	0.0012	0.0407
Pylorus	0.6578	0.7076	0.4646
Small intestine	<0.0001*	<0.0001*	0.0004*
Large intestine	0.6778	0.0306	0.0274
Ileocaecocolic junction	0.7268	0.9888	0.3953
Pancreas	0.3309	0.5940	0.0891
Lymph nodes	0.8941	0.0002*	0.1096
Adrenal glands	0.9514	<0.0001*	0.2359
Prostate	0.3728	0.0225	0.1493
Blood vessels	0.8179	0.0249	0.0173

*significant p-values (p<0.001)

Table 6 Comparison of the confidence level over time for the control students. The results of the Friedman test evaluate the overall difference of confidence level over time. Unpaired answers were excluded from analysis. The comparison between the three time points was performed using a Wilcoxon signed-rank test.

Abdominal systems	Friedman test p-value	T1 vs T2 (p-value)	T1 vs T3 (p-value)	T2 vs T3 (p-value)
Kidneys	0.0008*	0.0045	0.0092	1.0000
Urinary bladder	0.0231	NA	NA	NA
Spleen	0.0450	NA	NA	NA
Liver	0.0009*	0.0056	0.0162	0.0975
Gallbladder	0.4200	NA	NA	NA
Stomach	0.0095	NA	NA	NA
Pylorus	0.0020*	0.0140	0.0430	0.1870
Small intestine	0.0001*	0.0002**	0.0071	0.0247
Large intestine	<0.0001 *	0.0025	0.0064	0.0953
Ileocaecocolic junction	0.7170	NA	NA	NA
Pancreas	0.2550	NA	NA	NA
Lymph nodes	0.1290	NA	NA	NA
Adrenal glands	0.0302	NA	NA	NA
Prostate	0.2100	NA	NA	NA
Blood vessels	0.0026*	0.0150	0.0220	0.3510

*significant p-values (p<0.003)

**significant p-values (p<0.001)

Table 7 Comparison of the confidence and correct/incorrect answers for the control students: results from the Mann Whitney U test.

Abdominal systems	T1 (p-value)	T2 (p-value)	T3 (p-value)
Kidneys	0.0003*	<0.0001 *	<0.0001 *
Urinary bladder	NA	NA	NA
Spleen	0.5931	0.0048	0.3008
Liver	0.0627	0.1360	0.1678
Gallbladder	0.8809	1.0000	0.8831
Stomach	0.1533	0.5505	0.3536
Pylorus	0.4336	0.9196	0.6973
Small intestine	0.0414	0.6617	0.3454
Large intestine	0.9756	0.0033	0.0400
Ileocaecocolic junction	0.1190	NA	NA
Pancreas	0.3535	0.6458	0.1715
Lymph nodes	0.0186	0.3213	1.0000
Adrenal glands	0.3507	0.4902	0.3470
Prostate	0.6084	0.5333	0.7524
Blood vessels	1.0000	0.0502	0.4455

*significant p-values (p<0.001)

Table 8 Comparison of the confidence between the test and control students at the pre-rotation test (T1), post-rotation test 1 (T2) and post-rotation test 2 (T3): results from the Mann Whitney U test.

Abdominal systems	T1 (p-value)	T2 (p-value)	T3 (p-value)
Kidneys	0.2678	0.0047*	0.0014
Urinary bladder	0.5645	0.0076	0.0076
Spleen	0.2701	0.1920	0.0001*
Liver	0.6697	0.0254	0.0114
Gallbladder	0.6523	0.0024	0.1018
Stomach	0.0568	0.0371	0.0061
Pylorus	0.7862	0.3326	0.0355
Small intestine	0.0187	0.3799	0.0322
Large intestine	0.8509	0.0642	0.1024
Ileocaecocolic junction	0.4685	0.7227	0.9266
Pancreas	0.3031	0.0007*	0.0019
Lymph nodes	0.0712	0.0040	0.0008*
Adrenal glands	0.9484	0.1371	0.1197
Prostate	0.2713	1.0000	0.6440
Blood vessels	0.8509	0.0009*	<0.0001 *

*significant p-values (p<0.001)

Appendix 14: Figshare repository links

List and links of the webinars:

Webinars	Duration	DOI Link
Presentation	3’26	10.6084/m9.figshare.26830624
Liver Gallbladder	4’40	10.6084/m9.figshare.26830711
Spleen	5’41	10.6084/m9.figshare.26830780
Gastrointestinal tract (stomach and small intestine)	7’40	10.6084/m9.figshare.26830783
Gastrointestinal tract (large intestine)	6’27	10.6084/m9.figshare.26830789
Pancreas	10’57	10.6084/m9.figshare.26830792
Kidneys	4’12	10.6084/m9.figshare.26830795
Adrenal glands	6’34	10.6084/m9.figshare.26830807
Urinary bladder	3’58	10.6084/m9.figshare.26830810
Large abdominal vessels	11’44	10.6084/m9.figshare.26830813
Abdominal lymph nodes	7’27	10.6084/m9.figshare.26830819

Ultrasound video test ppt: 10.6084/m9.figshare.26830840

Excel spreadsheet: 10.6084/m9.figshare.26840239

Csv and R code files: 10.6084/m9.figshare.26840263