NON-INVASIVE METHODS FOR THE INVESTIGATION OF SOFT TISSUE INJURY IN THE EQUINE LIMB: DIAGNOSTIC ULTRASONOGRAPHY AND MICROWAVE THERMOGRAPHY.

VOLUME ONE.

A Thesis submitted for the

Degree of Doctor of Philosophy,

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GLOSSARY OF TERMS AND ABBREVIATIONS.

A number of abbreviations is utilised in the tables, figures and appendices and the meaning of these is given at the appropriate points in the text.

Acoustic impedance = the resistance to the passage of sound waves

Aerial = that part of a microwave thermographic unit which is held against the skin to receive emitted microwaves

Air tendinogram = a radiograph of the tendons in which air was used as a negative contrast agent

Anechoic, anechogenic = adjectives which describe an area on an ultrasonogram in which there are no echoes producing a black region

Attenuation = the progressive loss of energy which occurs as a sound wave or microwave travels further from its source

Desmotomy = the surgical transection of a ligament

Echoes = the reflections of sound energy which are produced when a sound wave passes from a medium of one acoustic impedance to a medium of another acoustic impedance

Echogenicity = the level of brightness of echoes on an ultrasonogram

Echogenic, echoic = adjectives which describe a structure which produces echoes on an ultrasonogram producing a white or grey area

Echolucent = an adjective which describes a material which contains no acoustic interfaces and consequently does not produce any echoes on a ultrasonogram

Firing, bar, line and pin = techniques of thermocautery which involve the application of hot irons to the skin in a bar or line pattern or with pins into the subcutaneous tissues

Grey Scale = the adjective which describes the form of ultrasonographic imaging which utilises a range of shades of brightness of white dots to denote the amplitude of the returning echoes

Hyperechoic, hyperechogenic = adjectives which describes an area on an ultrasonogram in which there is a high level of echo production producing a white region

Hypoechoic, hypoechogenic = adjectives which describe an area on an ultrasonogram in which there is a low level of echoes producing a grey area

H & E = haematoxylin and eosin (a histological staining technique)

Inferior check ligament = the accessory ligament of the deep digital flexor tendon

Interface = a boundary between tissue of one acoustic impedance and tissue of another acoustic impedance at which an echo is produced

MBVG = methyl blue van Gieson (a histological staining technique)

Masson's = Masson's Trichrome (a histological staining technique)

MSB = Martius Scarlet Blue (a histological staining technique)

Non-specular echoes = the form of echoes produced by small structures within the body which have low amplitudes and are scattered in numerous directions

Off-normal incidence = used to describe both the situation where and artifacts which are a result of the ultrasound beam being orientated in a direction which is not perpendicular to the structure under investigation

Piezoelectric = an adjective which describes a material which can convert pressure to electrical energy and vice versa

p = probability

Radiopaque = an adjective to describe a material which does not allow the passage of X rays

Real-time image = a continuously updated, moving image

Reverberation = used to describe both the situation where and the artifacts which are a result of ultrasound bouncing repeatedly between two structures

Specular echoes = the form of echoes which are produced by large interfaces within the body which have large amplitudes and travel in a direction such that the angle of reflection of sound equals the angle of incidence

Suspensory ligament = the interosseous muscle

Superior check ligament = the accessory ligament of the superficial digital flexor tendon

Tendon splitting = a percutaneous surgical procedure which involves placing several longitudinal incisions along the long axis of the superficial digital flexor tendon

Time gain compensation = a control on the ultrasonographic unit which determines the amount of amplification which is applied to overcome the attenuating effects of distance

Thermograph = a plot of the absolute temperatures recorded during a thermographic examination

Transducer = that part of an ultrasonographic unit which emits and receives ultrasound

Ultrasonogram = an image produced by ultrasonographic means

EQUIPMENT

The ultrasonographic unit used in Part 2.1 and in some cases included in Chapter 5 was a "Concept 1", Dynamic Imaging Ltd., Livingston, Scotland, and for the remainder of the ultrasonographic studies a "Concept 2", Dynamic Imaging Ltd., Livingston, Scotland, was used. The echolucent stand-off blocks were "Kitecho", 3M Health Care Ltd., Loughborough, England and "Sonokit", Vertnebs GMBH, Idstein, West Germany. The microwave thermographic unit was built by Dr. D. Land, Department of Physics, University of Glasgow.

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DECLARATION

The work included in this thesis has been performed by myself with the exceptions of the colour photomicrographs in Figs. 3.3, 3.6, 3.15, 3.17, 3.23, 3.29, 3.39, 3.49 and 3.50 which were taken by Professor Norman Wright.

ABSTRACT.

A technique was established for the examination of the soft tissue structures of the palmar aspect of the distal equine limb using an ultrasonographic unit equipped with a 7.5 MHz linear array transducer and a separate echolucent stand-off block by performing examinations in six cadaver limbs and in twenty-five adult Thoroughbred horses. The flexor tendons had shapes on ultrasonograms which corresponded with their expected anatomy and their size varied along their length. The lateral to medial and dorsal to palmar dimensions of the flexor tendon were correlated with each other and with the age, weight and height of the horse, the limb circumference and metacarpal bone diameter but consistent relationships between pairs of variables were not evident although the correlation between a variety of individual pairs was significant ($p < 0.05$).

The ultrasonographic findings in fourteen horses with bilateral superficial digital flexor tendon injuries were compared with the macroscopic and microscopic pathological findings. Well-defined anechoic and hypoechoic areas represented haemorrhage, collagenolysis, oedema and inflammation in the earliest stages but also corresponded to areas of granulation tissue in slightly older lesions. Chronic lesions were typified by heterogeneous hypoechoic areas with varying degrees of linear echo formation apparent on the longitudinal images and in these cases immature tendon,

fibroplasia and fibrosis was present. Hyperechoic foci were associated with scar formation. Extensive proliferation of the subcutaneous tissue and the paratenon could be readily identified on the ultrasonograms.

It was concluded that the ultrasonographic findings appeared to be representative of the tissue type which was present although similar appearances could represent different processes depending on the age of the lesion. A grading system was developed using the ultrasonograms from these horses which could be used to describe the various appearances of the echogenicity, the linear echo formation and the distinctness of the lesion border.

The ultrasonographic findings in ten normal horses and eight horses with superficial digital flexor tendon injury were compared with negative contrast radiographic findings. Ultrasonography was more effective in assessing the presence and extent of superficial digital flexor tendon injury as the internal morphology of the tendon was examined. Peritendinous lesions were observed in both ultrasonograms and air tendinograms but neither technique was considered definitive for the diagnosis of intertendinous adhesion. Measurements of the tendon dimensions by ultrasonographic and radiographic means were not accurate diagnostic criteria if they were used in isolation. However, the radiographic and ultrasonographic dimensions correlated well ($p < 0.05$) when they were compared with the gross post mortem findings in thirteen limbs. The non-invasive nature of ultrasonographic imaging was a major advantage when it was compared to air tendinography.

Ninety horses with 127 superficial digital flexor tendon injuries were examined for varying periods of up to 110 weeks. Only horses which had sustained the injury greater than nine months prior to completion of the study were included. The mean number of examinations per horse was five with a range of one to thirteen. 433 ultrasonograms were used to establish the relative frequency of observation of each grade of echogenicity, linear echo formation and lesion border distinctness in examinations performed at less than four weeks and at approximately eight, twelve, sixteen, twenty-six, thirty-six, fifty-two, seventy-two and greater than seventy-two weeks' duration. Three distinct ultrasonographic patterns were associated with acute flexor tendon injury in these horses namely discrete areas of reduced echogenicity within the tendon; complex lesions with anechoic and hypoechoic areas which comprised the majority of the cross-sectional area and length of the tendon and a generalised reduction in echogenicity. Specific patterns of progression were assessed in ninety-two lesions and these could be related to the initial appearance. Small hypoechoic lesions disappeared most quickly with the shortest time to ultrasonographic resolution being sixteen weeks. In complex lesions, the echogenicity gradually increased with time and anechoic areas were not usually observed at greater than twenty-six weeks' duration and at this stage heterogeneous hypoechoic lesions were most frequently observed in this group. This pattern continued to dominate throughout the remainder of the study. The linear echo formation continued to increase and the lesion border clarity to decrease after twenty-six weeks and, therefore, these factors were helpful in assessing the stage of healing. Very few exceptions (four) to these general trend were noted.

A history of previous tendon injury was the only factor which significantly influenced the severity of tendon injury in these horses.

The work versus retiral rate, the rate of recurrence of superficial digital flexor tendon injury and the duration of the lay-off period between the initial injury were known in sixty-nine horses. The rate of return to work for the whole group was 42% with a recurrence rate in those animals of 35% and a mean lay-off period of 13.5 with a range of six to twenty-six months. Mares had a significantly higher retiral rate but those that did return to work showed no difference in the recurrence rate or the duration of the lay-off period. Three treatment regimens were employed in these horses and these were conservative management, polysulphated glycosaminoglycan administration and laser therapy but there were no significant differences in the eventual outcome associated with the treatment regimen.

The initial lesions were assessed by ultrasonographic examination and the animals were divided into mild, moderate and severe subgroups based on the severity of the most severe lesion if the injuries were bilateral. There was no difference in outcome between horses with bilateral and unilateral injuries in the same severity category but the severity of the most severe injury was the only factor which influenced both the retiral rate and the duration of the lay-off period. However, the severity did not significantly influence the recurrence rate.

The potential role of microwave thermography as a diagnostic aid in equine superficial digital flexor tendon injury was investigated. 154 normal thermographs were used to determine the normal temperature profiles of the palmar metacarpal region and their frequency and the normal ranges for mean temperature ($25.04^{o}C$ - $37.4^{o}C$), the maximum temperature difference between symmetrical points ($0^{o}C$ - $5.33^{o}C$) and the difference in mean temperatures between contralateral limbs (0 - $2.89^{o}C$). Clipping the hair did not influence the results significantly. 420 thermographs from horses with superficial digital flexor tendon injury were examined. Horses with acute superficial digital flexor tendon injury frequently displayed abnormalities in the above parameters but these findings did not reflect the severity of the injury. Use of these parameters in combination as diagnostic criteria produced the best sensitivity and specificity but these were only 80% and 86% respectively. In chronic tendon injuries the sensitivity and specificity were reduced further and it was concluded that the technique had little potential for the diagnosis or evaluation of clinical superficial digital flexor tendon injuries.

The microwave thermographic findings in thirty-four horses in training were monitored weekly for thirteen weeks and the thermographs were assessed using the criteria defined above. Thermographic abnormalities were noted two weeks prior to the onset of clinical signs of flexor tendon injury in both of the two horses which sustained superficial digital flexor tendon injury during the study. However, abnormalities were also noted in a further sixteen animals resulting in poor specificity. Nevertheless, microwave thermography was considered to have potential as a screening tool for the diagnosis of superficial digital flexor tendon injury.

CHAPTER 1.

LITERATURE REVIEW.

SECTION 1.1. ULTRASONOGRAPHIC IMAGING:

PHYSICAL PRINCIPLES AND DEVELOPMENT OF THE TECHNOLOGY.

The term ultrasound refers to high frequency sound, outwith the audible range, and the frequency of sound utilised in ultrasonographic imaging ranges in frequency from 1 to 10 MHz (Shirley, Blackwell, Cusick, Farman and Vicary, 1978). Ultrasound energy travels in a longitudinal or compressional waveform which is propagated through a medium by the vibration of molecules, backwards and forwards, along the direction in which the sound energy is travelling, producing transient increases and decreases of pressure within the medium (Fig. 1.1). The ability of any medium to conduct sound energy is referred to as its acoustic impedance and can be described by the following equation:

$$Z = C.D$$

where Z is acoustic impedance, C is the velocity of sound in that medium, and D is the density of the medium. Thus, the acoustic impedance is dependent on the density of any medium.

As a sound wave travels from one medium to another of different acoustic impedance, a proportion of the sound wave is reflected. If it can be assumed that the speed of the sound through the media under investigation is constant, then, by recording the time taken for the sound to travel to the interface between one medium and another, and subsequently, the time taken for the echo to return to the origin of the sound then the distance

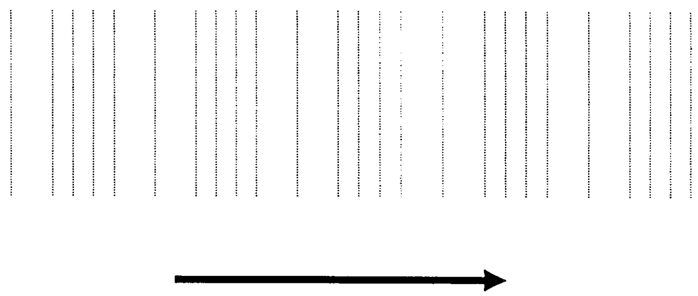


FIG. 1.1. THE ULTRASOUND WAVE: ENERGY TRAVELS IN A LONGITUDINAL OR COMPRESSIONAL WAVEFORM AND IT IS PROPAGATED THROUGH A MEDIUM BY VIBRATION OF MOLECULES ALONG THE DIRECTION OF THE WAVE.

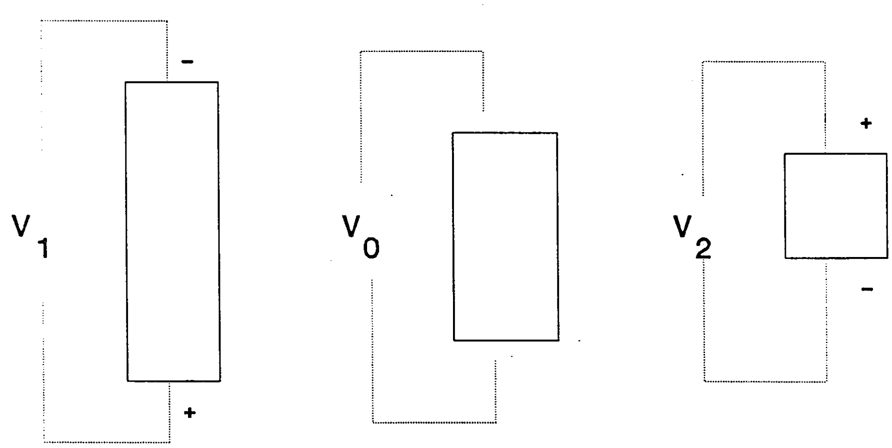


FIG. 1.2. THE PIEZOELECTRIC EFFECT: AN ELECTRIC CURRENT PASSING THROUGH A PIEZOELECTRIC MATERIAL DEFORMS IT SUCH THAT A PRESSURE CHANGE IS INDUCED. CONVERSELY, A PRESSURE CHANGE IN A PIEZOELECTRIC MATERIAL INDUCES AN ELECTRIC CURRENT.

of the interface from the origin of the sound can be calculated by applying the following formula:

$$D = \frac{v.t}{2}$$

where D is distance, v is velocity and is known for any given combination of media, and t is time.

The production of ultrasound by electronic means is based on the piezoelectric effect, so called because it refers to the transformation of pressure to electricity (piezo, Greek for pressure). A material which has piezoelectric properties can both transform sound energy to electricity and vice versa and an electrical current passing through a piezoelectric material deforms the internal structure of that material in such a way that a pressure change is induced (Fig. 1.2). This pressure change can be transmitted across a medium such that the molecules composing that medium vibrate to propagate a wave. Similarly, distortion and production of pressure changes in a piezoelectric material, by bombarding it with sound waves, will result in a change in electrical potential difference. Further, the amplitude of the sound produced by a piezoelectric material is directly proportional to the voltage applied to stimulate the material and conversely, the voltage produced is directly proportional to the amplitude of the sound which stimulates it. Consequently, piezoelectric materials have the ability to distinguish and describe different voltages and amplitudes (Shirley and others, 1978;

Bartrum and Crow, 1983; Powis and Powis, 1984). This effect was first described by the Curie brothers in 1880 and their discovery was fundamental to the development of the science of ultrasonics (Curie and Curie, 1880).

Ultrasound, like any other form of sound energy, will also be partly reflected as a sound wave travels from one medium to another, thereby producing echoes. If ultrasound is emitted from the piezoelectric material in pulses then, while the material is not producing sound, it is able to receive the returning reflections or echoes and produce electrical currents (Fig. 1.3; Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984). The first practical application of this pulse-echo production of ultrasound was patented in 1912 when Richardson devised apparatuses to detect submerged objects and potential hazards for fogbound ships (1912a and b). Further development of this concept led to the invention of a device for the detection of submarines (Langevin, 1924) and, during the Second World War, Langevin's system was improved and named SONAR (sound navigation and ranging).

The body is composed of tissues of a variety of densities and acoustic impedances and, therefore, echoes are produced when sound is directed through the tissues. Sound has been found to travel at approximately the same speed throughout the body (1540 ms^{-1}) and, therefore, the distance that an echo has travelled from its source within the body can be calculated by recording the time

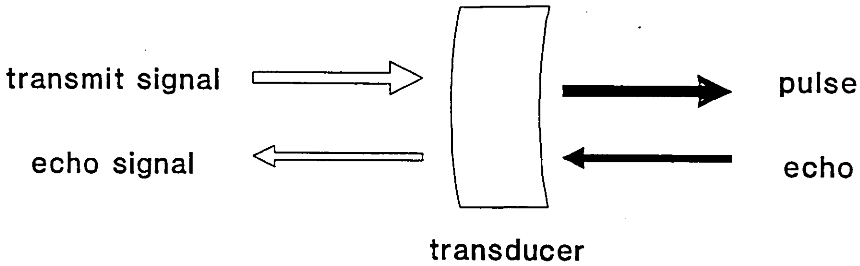


FIG. 1.3. THE PULSE-ECHO PRINCIPLE: THE PIEZOELECTRIC MATERIAL WITHIN THE TRANSDUCER ALTERNATELY EMITS AND RECEIVES SOUND.

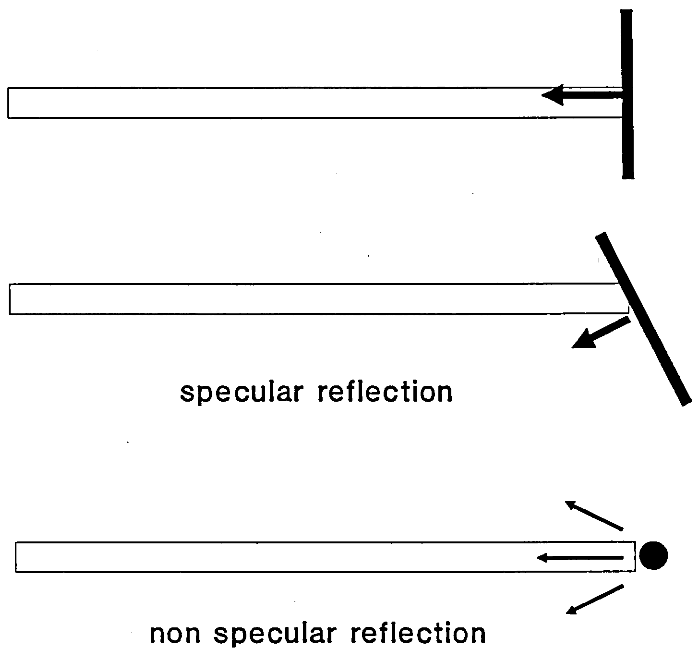


FIG. 1.4. SPECULAR REFLECTIONS ARE ANGLE DEPENDENT AND ARE PRODUCED BY STRUCTURES LARGER THAN THE BEAM WIDTH. NON-SPECULAR ECHOES ARE PRODUCED BY SMALL STRUCTURES AND TRAVEL IN NUMEROUS DIRECTIONS.

taken for the sound to return to its origin at the surface of the body (Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984).

These principles are the basis of the use of ultrasound for medical imaging. However, the development of medical ultrasound technology has been slow. In 1942, the use of ultrasound as a diagnostic aid was proposed (Dussik, 1942) and, in 1947, "hyperphonograms" of the head were produced (Dussik, Dussik and Wyt, 1947). Next, ultrasound was used to identify gallstones and foreign bodies by the acoustic shadows which they produced (Ludwig and Struthers, 1949), and throughout the 1950's, reports of the identification of intracranial masses appeared (Ballantine, Bolt, Heuter and Ludwig, 1950; Wild, French and Neal, 1950; Miyajima, Wagai, Uchid and Hagiwara, 1952; Leskell, 1956). The use of ultrasonography to image the heart was proposed in 1955 (Edler, 1955; Edler and Hertz, 1955) and, the following year, it was used to demonstrate the structure of the eye (Henry, Mundt and Hughes, 1956). In animals, the first application of ultrasound was a technique for assessing carcass quality in pigs by the measurement of back fat (Hazel and Kline, 1959).

All these techniques utilised a system which is now known as A mode. A single beam of sound was directed at the tissues and thus the body was interrogated along one dimension. The location and amplitude of the returning echoes was displayed as a graph of amplitude against location relative to the origin (Dussik, Dussik and Wyt, 1947; Ludwig and Struthers, 1949; Ballantine, Bolt, Heuter and Ludwig, 1950; Wild, French and Neal, 1950; Miyajima, Wagai, Uchid and Hagiwara, 1952; Leskell, 1956; Edler, 1955; Edler and Hertz, 1955; Henry, Mundt and Hughes, 1956; Hazel and Kline, 1959).

The first compound waterbath scanner which produced two-dimensional images was described in 1958 (Howry, 1958). This system was based on the sequential analysis of an area with multiple sound beams. The location of each interface producing an echo was calculated and displayed on a visual display unit as a series of dots to describe a two-dimensional area of the body. The system required the total submersion of the subject in water and, therefore, its use was limited to experimental situations (Shirley and others, 1978). Subsequent refinement of the technique in Glasgow led to the production of the first contact scanner (Brown, 1960). A piezoelectric material was housed within a mobile transducer, so called because it could convert energy from one form to another. This transducer was mounted on an arm and it was moved across the subject's body to form a complete scan (Brown, 1960). This apparatus was used by gynaecologists to distinguish between cystic and solid lesions within the female reproductive tract, using the full urinary bladder to create an acoustic window into the lower abdominal and pelvic areas (Donald and Brown, 1961). Ultrasonography was particularly appropriate for differentiating between solid and cystic structures because cystic structures produce no echoes due to the absence of interfaces between areas of acoustic impedance within a fluid area (Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984).

The reflections of ultrasound produced within the body can be divided into two types: specular and non-specular (Fig. 1.4). Specular echoes are produced by structures or interfaces which are larger than the ultrasound beam where a large amount of sound is reflected and the angle of reflection is dependent on the angle of incidence of the original sound beam. If the sound beam is directed at right angles to the structure, then, and only then, the reflected echo will return to the transducer so that it can be detected. Non-specular echoes are produced by smaller structures which are less than the width of the sound beam. These interfaces produce a scatter effect, with small amounts of sound being reflected in numerous directions and thus, non-specular reflection is not dependent on the angle of incidence of the sound beam. A small proportion of the non-specular reflection will be orientated such that it returns to the transducer and can be detected (Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984).

The earliest two-dimensional ultrasonographic units utilised the specular form of reflection only and they were able to demonstrate only large interfaces such as the borders of organs (Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984). Analysis of small echoes arising within organs to produce an image had originally been proposed in 1950 (Wild, 1950), but the early ultrasonographic units had utilised analogue conversion systems and, therefore, amplitude and brightness of the display had to have a linear relationship in these units, and small echoes could not be enhanced or displayed (Fig. 1.5; Wells and Ross, 1969). A major advance in the development of ultrasound technology followed the introduction of digital conversion systems which enhanced the display of small echoes and led to the production of grey-scale units (Kossoff, Fry and Eggleton, 1971; Milan, 1972). The input signal amplitudes were grouped into several categories and each group was allocated one shade of brightness and, therefore, non-specular echoes arising from within an organ could be demonstrated (Figs. 1.6 and 1.7; Shirley and others, 1978). Reports of imaging of the breast and thyroid gland marked the beginning of the clinical application of grey-scale technology (Kossoff, 1974; Crocker, McLaughlin and Kossoff, and Jellins, 1974). One of the earliest successful applications of this technique was in distinguishing between the ultrasonographic characteristics of normal and diseased livers (Joseph, Dewbury and McGuire, 1979).

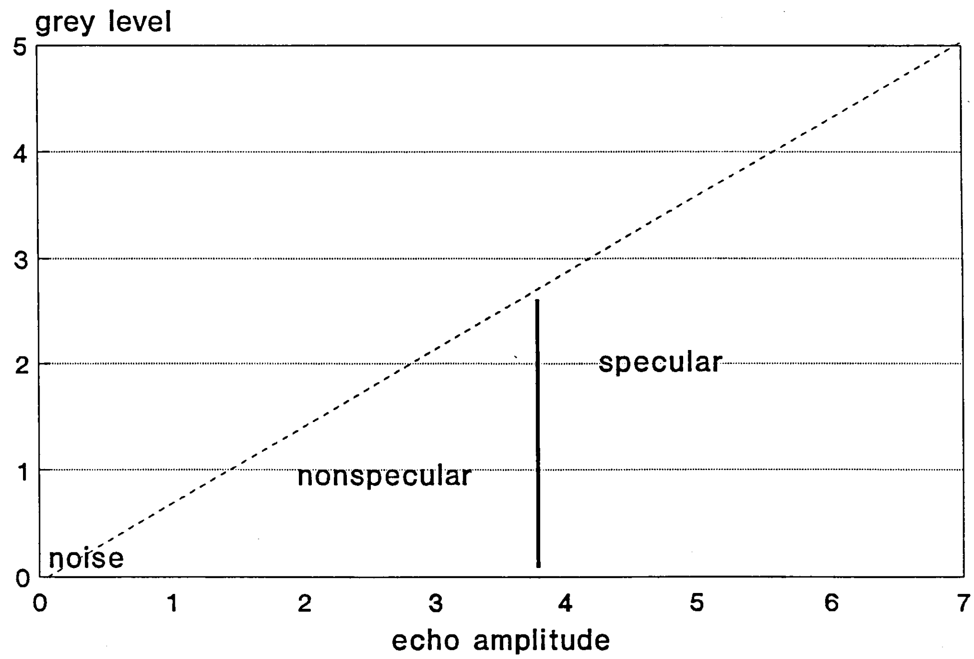


FIG. 1.5. LINEAR GREY SCALE ALLOCATION: EARLY ULTRASONOGRAPHIC UNITS UTILISED ANALOGUE CONVERSION SYSTEMS AND THE AMPLITUDES OF THE ECHOES AND BRIGHTNESS OF THE DISPLAY HAD A LINEAR RELATIONSHIP.

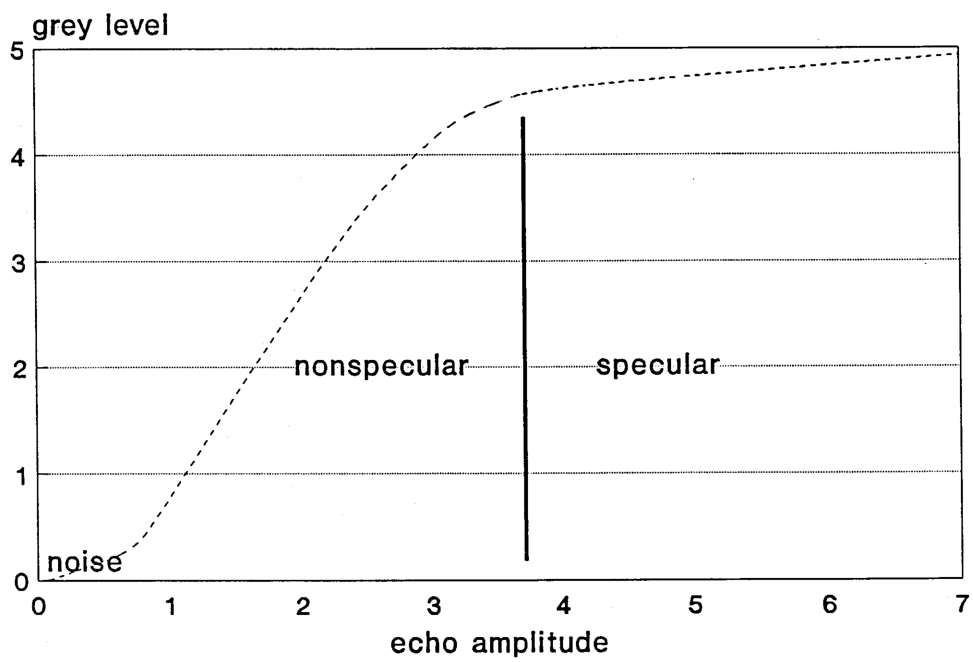


FIG. 1.6. NON-LINEAR GREY SCALE ALLOCATION: ECHOES ARE GROUPED INTO CATEGORIES TO DESCRIBE A RANGE OF AMPLITUDES. EACH GROUP IS ALLOCATED ONE SHADE OF GREY IN A NON-LINEAR WAY WHICH ALLOWS SMALL DIFFERENCES IN THE AMPLITUDE OF NON-SPECULAR ECHOES TO BE ENHANCED.

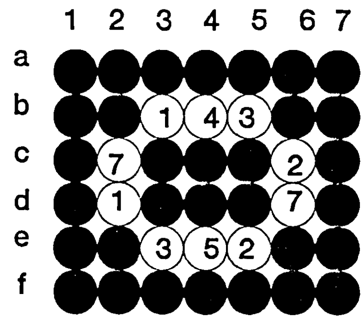


FIG. 1.7. DIGITAL PROCESSING: THE LOCATION OF THE ORIGIN OF AN ECHO IS DESCRIBED ON A MATRIX IN TWO DIMENSIONS AND A GREY SCALE IS ALLOCATED TO DESCRIBE ITS AMPLITUDE.

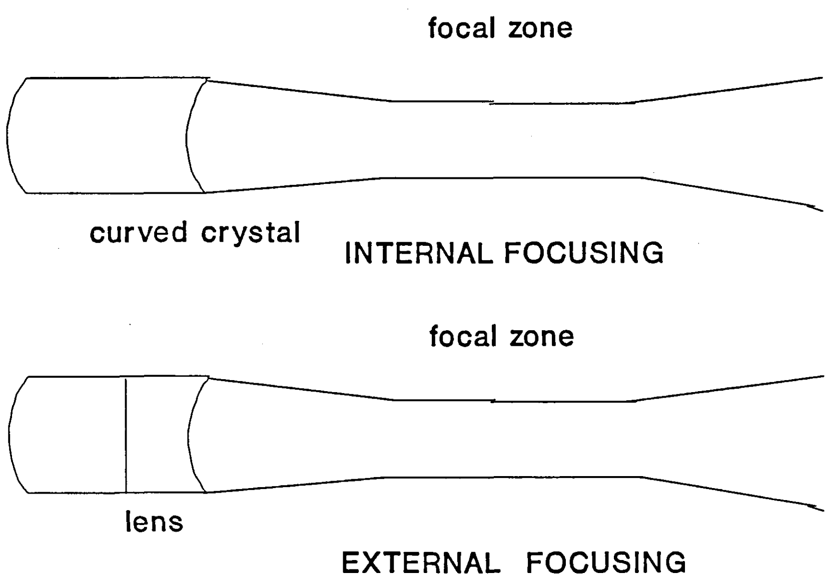


FIG. 1.8. ULTRASOUND CAN BE FOCUSED USING A CURVED CRYSTAL (INTERNAL FOCUSING) OR BY PLACEMENT OF A LENS IN FRONT OF THE SOUND-EMITTING MATERIAL (EXTERNAL FOCUSING).

Further advances in computer technology throughout the last twenty years have permitted ultrasonographic technology to follow suit. The data collection methods were improved so that information could be analysed by the system and constantly updated many times per second to produce a moving image (Bartrum and Crow, 1983).

During recent years, dramatic improvements have been made in the quality of the display screens and focusing of the transducers producing the sound beams and each development has produced equipment with superior resolving powers. Sound waves can be focused in the same way as light, using either internal or external lens systems (Fig. 1.8; Bartrum and Crow, 1983). However, the axial resolution of any ultrasonographic unit is limited to some extent by the frequency of sound that it utilises. Distinct, separate echoes can only be produced by interfaces that are more than one pulse width apart. The shortest pulse width which can be achieved is one wavelength in length (Fig. 1.9). Therefore, equipment which utilises ultrasound with higher frequencies has inherently superior resolution (Bartrum and Crow, 1983; Powis and Powis, 1984). Lateral resolution is dependent on the width of the beam as two structures which are less than the beam width apart will be perceived as one (Fig. 1.10).

As an ultrasound wave travels through the body, it has been found that its energy is progressively lost or attenuated (Fig. 1.11). This attenuation is due to

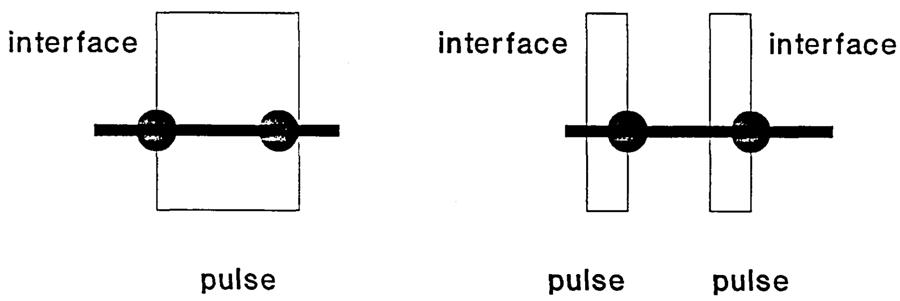


FIG. 1.9. AXIAL RESOLUTION: STRUCTURES LESS THAN THE BEAM WIDTH APART CANNOT BE DISTINGUISHED.

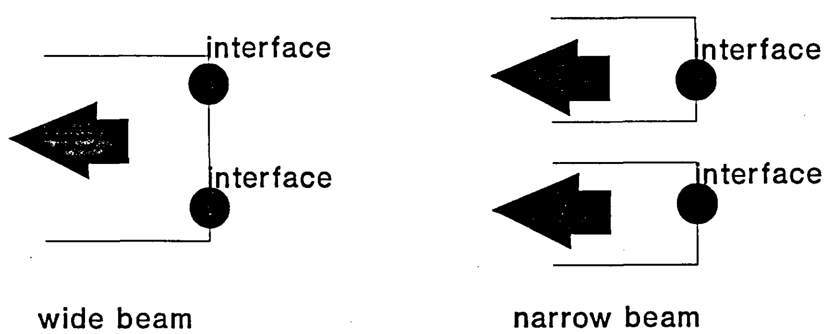


FIG. 1.10. LATERAL RESOLUTION: STRUCTURES LESS THAN ONE PULSE LENGTH APART CANNOT BE DISTINGUISHED.

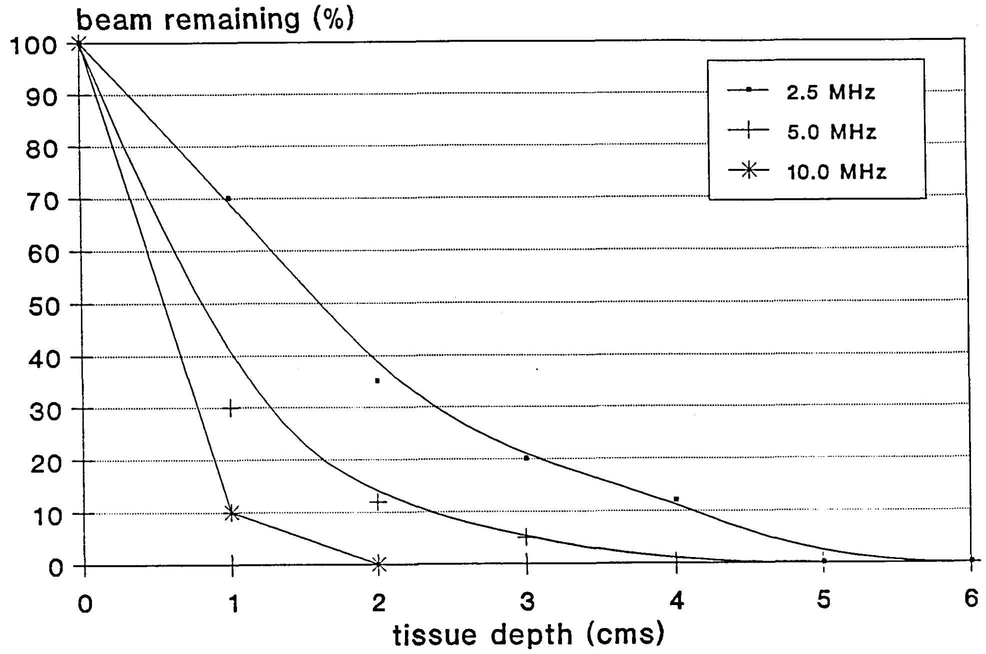


FIG. 1.11. ATTENUATION OF ULTRASOUND: AS SOUND TRAVELS THROUGH TISSUES ITS ENERGY IS PROGRESSIVELY LOST. HIGH FREQUENCY SOUND IS ATTENUATED MORE RAPIDLY THAN LOW FREQUENCY SOUND.

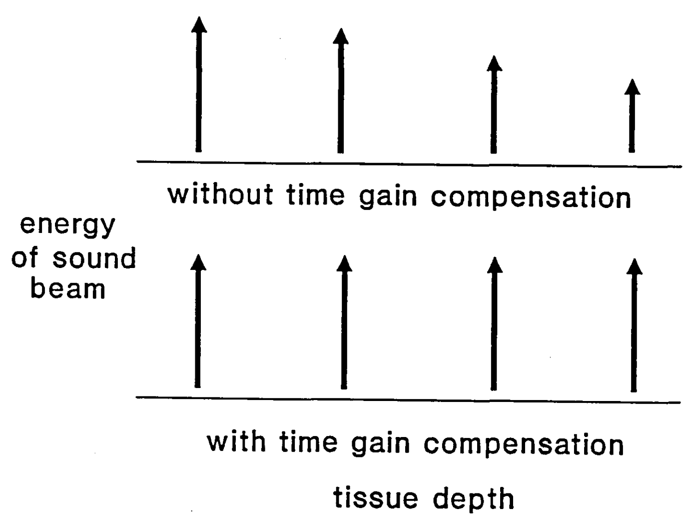


FIG. 1.12. TIME GAIN COMPENSATION: IN THE ABSENCE OF T.G.C. THE ECHOES DECREASE IN AMPLITUDE RELATIVE TO THE DISTANCE OF THEIR ORIGIN FROM THE SOURCE. T.G.C. COMPENSATES FOR THIS BY PROGRESSIVELY INCREASING THE AMPLITUDE OF THE ECHOES IN PROPORTION TO THE DISTANCE BETWEEN THEIR ORIGIN AND THE TRANSDUCER.

adsorption, reflection and scattering of sound energy (Hill, 1977; Shirley and others, 1978). The attenuation rate is directly proportional to the frequency of the sound wave. Thus, high frequency sound is attenuated more rapidly than low frequency sound and to provide a large field of imaging, low frequency transducers are required. In contrast, to produce superior resolution of superficial structures, high frequency transducers are more appropriate (Shirley and others, 1978).

Ultrasonographic units are fitted with amplification systems to overcome the effects of attenuation due to tissue depth. In order to overcome the progressive decrease in the intensity of the sound wave, and so that tissues at varying depths could be compared, the depth or time gain compensation function was developed. Echoes are amplified in proportion to their distance from the source and the degree of amplification can be controlled by the operator to suit each individual subject (Fig. 1.12; Powis and Powis, 1984).

There are two types of beam shape which are most widely used in ultrasonographic imaging at present: sector and linear array (Bartrum and Crow, 1983; Powis and Powis, 1984). In a linear array transducer, the piezoelectric crystals are arranged such that a rectangular sound beam is produced. This equipment has the advantage that it is less expensive to produce and maintain. However, the point of contact of these transducers with the body is large. The initial design of sector scanners utilised several piezoelectric crystals mounted on a rotating wheel which produced a pie-shaped image and this is described as a mechanical sector scanner. This system is more delicate and expensive but it has the advantage that only a small area of contact with the body is required to image a large area internally (Bartrum and Crow, 1983; Powis and Powis, 1984). This design was then followed by phased array transducers in which crystals are stimulated electronically in sequence to produce a similar effect (Bartrum and Crow, 1983; Powis and Powis, 1984).

SECTION 1.2. THE INTERACTION OF ULTRASOUND WITH TISSUES.

Ultrasound is an ideal energy form on which to base a medical imaging system because, at the power outputs that are required to produce images, there are no adverse effects on the tissues. At higher power outputs, heat may be produced within the tissues and this is the basis of therapeutic ultrasound. In part, the safety of ultrasonographic imaging is due to the pulse-echo principle which allows for brief bursts of sound (1 microsecond) followed by a much longer period of echo retrieval (1 millisecond) and, therefore, the actual exposure time of the tissues to ultrasound is extremely small (Herring and Bjornton, 1985).

In 1975, the following statement was issued by the American Institute of Ultrasound in Medicine: "In the low megahertz frequency range there have been (as of this date) no demonstrated significant biological effects in mammalian tissues exposed to intensities below 100 $mWcm^{-2}$. Furthermore, for ultrasonic exposure times less than 500 seconds and greater than one second, such effects have not been demonstrated even at higher intensities when the product of intensity and exposure time is less than 50 joules cm^{-1} (American Institute of Ultrasound in Medicine, 1975).

This non-invasive quality of diagnostic ultrasonography has undoubtedly contributed to the versatility of the technique.

The interaction of sound with the body tissues also defines those areas in which the technique has clinical applications. In general terms, any soft tissue in the body can be imaged providing that the sound wave can reach it unimpeded. Tissues which produce echoes are described as echogenic or echoic while those that do not are anechogenic or anechoic. The terms hypoechoic and hyperechoic are used to describe areas that produce low and high levels of echoes, respectively.

The amount of sound, or amplitude, of any echo is dependent on the size of the difference in acoustic impedance of the two adjacent media through which the sound is travelling (Fig. 1.13). The acoustic impedance of a medium is proportional to its density and, therefore, if two structures with large differences in density are adjacent, a large amplitude echo will be produced at their interface. This situation occurs at various sites in the body, for example, at the interface between soft tissues and bone. At such sites, so much of the sound is reflected backwards towards the transducer that a very bright area is displayed. In addition, very little sound energy is left to travel deeper into the body and, therefore, these interfaces represent a block to further penetration and an acoustic shadow is produced (Fig. 1.13). At the interface between the air in the lungs and the soft tissues of the intercostal muscles and the pleura the difference in the speed of sound travelling through the tissues (1540 $msec^{-1}$) and air (331 $msec^{-1}$) also contributes to these large

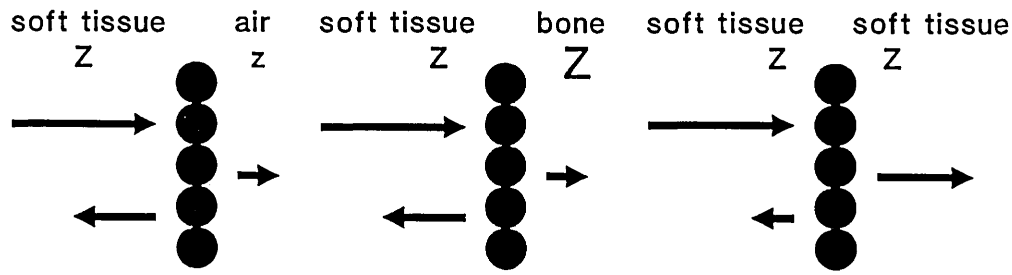


FIG. 1.13. THE INTERACTION OF ULTRASOUND AT VARIOUS INTERFACES WITHIN TISSUES: THE AMPLITUDE OF AN ECHO IS DEPENDENT ON THE MAGNITUDE OF THE DIFFERENCE IN ACOUSTIC IMPEDANCES (Z) OF THE TWO TISSUES PRODUCING THE INTERFACE. LARGE DIFFERENCES REDUCE THE SOUND ENERGY OF THE SOUND WAVE AND RESULT IN AN ACOUSTIC SHADOW BECAUSE THE SOUND WAVE LOOSES MUCH OF ITS ENERGY I.E. AT BONE:SOFT TISSUE AND SOFT TISSUE:AIR INTERFACES.

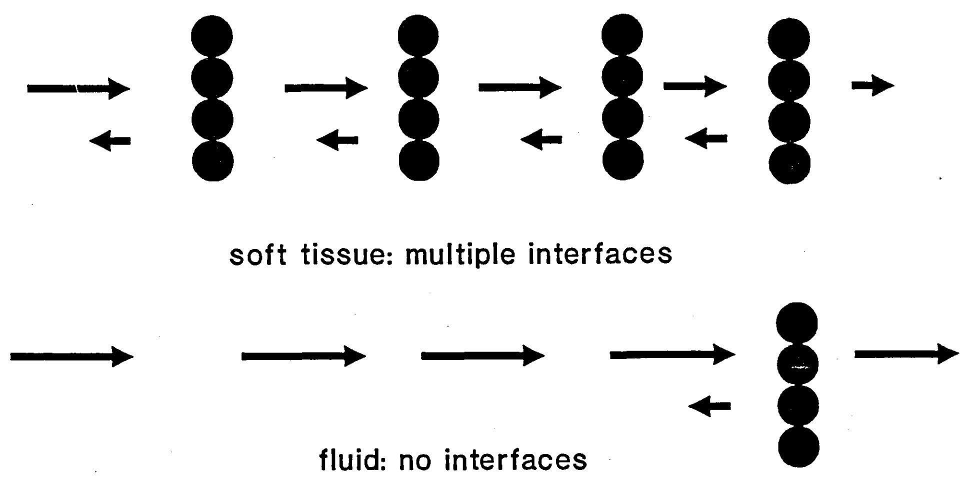


FIG. 1.14. ACOUSTIC ENHANCEMENT: THERE ARE NO ECHOES PRODUCED WITHIN A FLUID AREA THUS THERE IS NO ATTENUATION. THE SOUND EMERGING FROM A FLUID AREA HAS RELATIVELY MORE ENERGY THAN IF IT HAD TRAVELLED THROUGH THE EQUIVALENT DISTANCE OF SOFT TISSUE.

differences in acoustic impedance (Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984).

The differences in acoustic impedance within soft tissue structures or organs are small and, therefore, the amplitude of echoes at interfaces within soft tissue structures or organs are also small. Consequently, sound can travel through a soft tissue structure, producing numerous echoes, without reducing the energy of the sound beam so much that acoustic shadows are produced (Fig. 1.13). Soft tissue structures and organs are imaged by ultrasonography as areas composed of numerous dots with varying shades of grey. Each organ or structure tends to have a characteristic pattern by which these structures can be identified. The boundaries of organs produce specular reflections with large amplitudes and these are only displayed when the sound hits these interfaces at right angles (Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984).

There are no interfaces within a fluid-filled area and thus, echoes are not produced by cystic structures. In addition, because there has been no reflection of the beam as it passes through a fluid-filled area, at the far border, the sound beam has relatively more sound energy than if it had passed through an equivalent distance of soft tissue (Fig. 1.14). Consequently, the echoes that are produced by soft tissues deep to a fluid-filled area also have relatively more energy and, therefore, larger amplitudes. This gives rise to a phenomenon known as acoustic enhancement or through transmission. It is a useful means by which the presence of fluid can be confirmed as the areas deep to it will be brighter than similar tissues at a similar depth which do not have an overlying fluid-filled area (Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984).

There are a number of other types of artifacts which the ultrasonologist must be aware of in order to interpret ultrasonograms correctly. The commonest of these are described as refraction, reverberation, off normal incidence and noise effects.

Refraction of the sound beam can occur when it traverses a round or curved interface. This produces curving of the beam and leaves a shadow deep to that interface. This occurs most commonly at the side wall of a fluid-filled structure or vessel.

Reverberation occurs at interfaces where there is a large difference in acoustic impedance and may also occur between the transducer and the skin surface. Echoes returning to the transducer are reflected at its surface back into the body where they continue until they reach an interface and are reflected back towards the transducer. By the time the sound reaches the transducer for a second time, the sound has travelled exactly twice the true distance between the interface and the transducer. Of course, the transducer is unable to appreciate this and displays this echo as if it had arisen from a site twice its true distance from the transducer. Reverberation produces series of parallel echoes. A similar process can also occur within the body so that sound may bounce backwards and forwards between two large interfaces in the body, thereby producing mirror images. The process is observed with specular reflectors because these produce echoes that have sufficient energy to travel longer distances without losing so much energy that they can no longer be detected by the unit.

Specular echoes are produced by large surfaces and the sound beam must meet the interface at right angles for the echo to be reflected towards the transducer because the angle of reflection is dependent on the angle of incidence (Fig. 1.4). If the sound beam is not directed towards a specular reflector at right angles, then the resultant echo will be directed such that the transducer cannot detect it and an anechoic area will be displayed in that location. This phenomenon is described as off-normal incidence.

The final common form of artifact observed in ultrasonograms is due to random electron movements within the ultrasonographic unit and any surrounding electrical equipment which may produce electronic noise. This may be superimposed on the image as low level echoes (Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984).

Some artifacts have been observed more commonly than others while imaging of the soft tissue structures of the limb. Reverberation artifacts have been reported to be associated with muscular aponeuroses and with the interface between the stand-off pads and the skin and off-normal incidence has resulted in hypoechoic areas within tendons (Colby, 1985; Fornage, 1987; Fornage, 1989a).

SECTION 1.3. ULTRASONOGRAPHY OF THE EQUINE LIMB.

In 1982, Rantanen first proposed the use of ultrasonographic imaging as a means to study the morphology of the soft tissues of the equine limb. He stated that the technique was a useful adjunct to conventional means of diagnosis in the investigation of villonodular synovitis, tendon injury, joint effusions, tenosynovitis and myositis and this preliminary report illustrated the clinical application of ultrasonographic imaging in the equine limb with a case with soft tissue swelling on the dorsal aspect of the radiocarpal joint in which ultrasonographic examination was able to provide the tentative diagnosis (Rantanen, 1982). Descriptions of the normal anatomy of the distal interphalangeal joint, the navicular bursa, the navicular bone, the superficial and deep digital flexor tendons, the inferior check ligament, the dorsal aspect of the metacarpophalangeal joint and the sesamoidean ligaments followed this publication (Hauser, Rantanen, Modransky, 1982; Hauser and Rantanen, 1983; Modransky, Rantanen, Hauser, Grant, 1983; Rantanen, Genovese and Gaines, 1983; Hauser, Rantanen and Genovese, 1984; Pharr and Nyland, 1984; Spaulding, 1984).

It was established that normal tendons had an even hypoechoic appearance with parallel, aligned linear echoes in longitudinal images while the suspensory ligament had a more mixed appearance which reflected its histological appearance, being a composition of collagenous connective tissue, areolar connective tissue, fat, muscle fibres, nerves and blood vessels (Hauser and Rantanen, 1983; Rantanen and others, 1983; Hauser and others, 1984; Pharr and Nyland, 1984; Spaulding, 1984; Genovese, Rantanen, Hauser and others, 1985; McClellan and Colby, 1986).

Spaulding, (1984), performed a qualitative anatomical, radiographic, positive and negative contrast radiographic and ultrasonographic study on the soft tissue structures associated with the palmar aspect of the metacarpophalangeal joint. Attempts to image the area distal to the metacarpophalangeal joint were not successful in that study because of the contour of the palmar surface of that region and the size of the transducer used (Spaulding, 1984). The ultrasonographic anatomy of the flexor tendons, the associated digital sheath and the palmar pouch of the metacarpophalangeal joint capsule was described in qualitative terms. The digital sheath and the palmar pouch were recognised as anechoic areas bounded by more echogenic structures. The proximal extremity of the palmar pouch had an irregular border while, more distally, a smooth contour was apparent which was demonstrated by positive and negative contrast radiography and ultrasonography. Positive contrast tendinography could delineate the digital sheath but was not effective in demonstrating the size and shape of the tendons, while negative contrast techniques outlined the digital sheath and the tendon but did not demonstrate its internal structure. Ultrasonography had the advantage that it was a non-invasive procedure (Spaulding, 1984).

Rantanen (1982) had documented that high frequency transducers were required to image the superficial structures of the limb successfully, and he advocated the use of sector scanners because they have better inherent lateral resolution. However, the first attempt to compare the various techniques and pieces of equipment appropriate for imaging the soft tissues of the limb was not undertaken until 1984 (Pharr and Nyland, 1984). Various techniques were investigated and the authors concluded that poor quality images were obtained if the hair coat was not removed but that shaving rather than clipping the hair did not justify the extra time required to prepare the limb (Pharr and Nyland, 1984). Subsequently, it has been stated that, in addition to clipping, shaving of the hair is recommended (Henry, Patton and Goble, 1986; Genovese, Rantanen and Simpson, 1987). Pharr and Nyland, (1984) utilised both sector and linear array transducers, with and without, an echolucent stand-off apparatus. However, both ultrasonographic units were equipped with 5 MHz transducers and, therefore, did not have good resolving powers. The direct contact sector technique was found to be the easiest to perform but this had poor near-field visibility and produced inferior images of the skin and abaxial portions of the superficial digital flexor tendon. The use of an echolucent stand-off with the sector scanner improved the near field imaging, but it was more difficult to manipulate and the stand-off device produced a strong linear artifact which interfered with the image of either the suspensory or inferior check ligament. The linear unit which was utilised in this study had the advantage that it was portable, but there was less inherent offset and, therefore, the direct contact images achieved with this unit were inferior to those obtained with direct contact sector scanning. In longitudinal images, equal lengths of all structures could be imaged, and when used with an offset, the linear array produced superior images of abaxial structures, and the clearly-visible skin served as a useful landmark. The stand-off device utilised with the linear array unit (a water-filled latex glove) did not produce artifacts but that unit had poorer image quality and multiple linear artifacts were a consistent finding due to the fixed nature of the piezoelectric crystals (Pharr and Nyland, 1984). All subsequent reports have advocated the use of 7.5 MHz, short focused transducers and the majority of workers have favored sector arrays (Genovese and others, 1985; Rantanen, Hauser and Genovese, 1985; Hauser, 1986; Henry and others, 1986; Genovese, Rantanen, Hauser and others, 1986; McClellan and Colby, 1986; Genovese and others, 1987).

Hauser (1986) was the first to propose a protocol to standardise the examination technique for the structures on the palmar aspect of the metacarpal region and the plantar aspect of the metatarsus. He divided the metacarpal region into three zones and the metatarsal region into four zones and further subdivided each zone into parts A and B and suggested that these zones should be adopted as standard imaging sites from which frozen images should be recorded during each examination, the allocation of a particular title to each zone would then serve as a quick and readily understood reference (Hauser, 1986). Some subsequent publications have adopted these titles but, although they are intended to simplify ultrasonographic terminology, they have the disadvantage that they are readily understood only by those who are familiar with the technique and their significance is not apparent to the uninitiated, whereas direct reference to the various anatomical landmarks is universal (Genovese and others, 1986; Genovese and others, 1987).

Some quantitative information has been published on the normal dimensions of the various structures which can be investigated ultrasonographically (Genovese and others, 1986). Unfortunately, the authors do not state the number of individuals on which these values have been determined, nor do they specify the age, sex or breed of the individuals to which these values refer.

A grading system was devised to describe the various ultrasonographic lesions which can be identified. This system was based on the echogenicity of the lesion relative to the surrounding tissues and four types of lesion were identified, with the brightest or most echogenic being type one and the darkest or least echogenic being type four (Genovese and others, 1985).

All reports published to date have been enthusiastic about the potential clinical applications of the technique in investigation of a variety of soft tissue injuries. However, many reports have stressed that it should be used in conjunction with traditional means of evaluation of lameness (Hauser and Rantanen, 1983; Pharr and Nyland, 1984; Spaulding, 1984; Genovese and others, 1985; Rantanen and others, 1985; Genovese and others, 1986; Genovese and others, 1987). Ultrasonography has also been proposed as an additional diagnostic aid in joint disease and the identification of foreign bodies, and a postmortem model of foreign body, and reports of the identification of a soft tissue mass, in association with villonodular synovitis and soft tissue proliferation within the palmar pouch of the metacarpophalangeal joint have illustrated these applications (Modransky and others, 1983; Cartee and Rumph, 1974; Spaulding, 1984). The ultrasonographic features of wooden and metallic objects within muscle in this model and in clinical cases of intramuscular foreign bodies have been identified, but in one case a false positive diagnosis was made because of an artifact caused by connective tissue (Cartee and Rumph, 1974).

Some authors have stated that ultrasonographic lesions could be identified in the superficial digital flexor tendon in the absence of palpable, clinical abnormalities (Rantanen and others, 1985; Genovese and others, 1987). The technique has been advocated as an aid to diagnosis and prognosis of injuries to the superficial and deep digital flexor tendons, inferior check ligament and suspensory ligament, with acute lesions in these structures resulting in anechoic areas which gradually became more echogenic as healing progressed (Rantanen and others, 1983; Hauser and others, 1984; Spaulding, 1984; Genovese and others, 1985; Rantanen and others, 1985; Genovese and others, 1986; Genovese and others, 1987). In particular, the advantages of repeated ultrasonographic examinations to monitor healing, to produce a more accurate prognosis, and to determine if return to athletic activity is contraindicated, in horses with chronic lesions of the superficial digital flexor tendon or suspensory ligament, have been stressed (Rantanen and others, 1983; Pharr and Nyland, 1984; Genovese and others, 1985; Rantanen and others, 1985; Genovese and others, 1986; Hauser, 1986; Genovese and others, 1987).

The ability of ultrasonography to distinguish between acute and chronic lesions has been based on changes in echogenicity and various authors have attributed these changes to specific histological processes occurring within the tendons (Hauser and others, 1984;

Genovese and others, 1986; Hauser, 1986; Genovese and others, 1987). However, correlative studies between ultrasonographic and histological findings are few: comparisons of the features of the normal suspensory ligament and normal flexor tendon have been described (Hauser and others, 1984; Rantanen and others, 1985; Hauser, 1986) but, only one such report exists on injured tendons and ligaments in which the ultrasonographic and histological features of surgically-induced lesions are compared (Henry and others, 1986). In that study, the lesions were created within the superficial digital flexor tendon and the inferior check ligament, and the animals were examined ultrasonographically prior to euthanasia at various stages of healing (Henry and others, 1986). These authors concluded that the decreased echogenicity observed in acute lesions was due to haemorrhage, oedema and early granulation tissue within the lesion, and that echogenicity increased as the lesion progressed (Henry and others, 1986). The increase in echo intensity was proportional to the amount of collagen within the defect rather than the number of cells (Henry and others, 1986). However, the authors do not indicate how they were able to quantify the amount of collagen present within the lesion (Henry and others, 1986). Nevertheless, this report indicated that there was a relationship between the ultrasonographic and histological features of tendon and ligament injuries (Henry and others, 1986).

SECTION 1.4. ULTRASONOGRAPHY OF THE EXTREMITIES IN HUMAN SUBJECTS.

Interest in ultrasonographic imaging of soft tissue structures of the extremities in human subjects has paralleled that in veterinary medicine, although the reported applications of the technique have been wider, reflecting the different spectrum of diseases which affect the soft tissues of the human limb. The uses of ultrasonographic diagnosis in the human limb can be divided into five broad groups which are: the diagnosis of vascular lesions, notably venous thrombosis and arterial aneurysms (Lawson and Mittler, 1978; Bluth, Merritt and Sullivan, 1982; Slasky, Lenky, Skolnick and others, 1982); the characterisation of space-occupying lesions in the extremities; arthrosonography, imaging of the soft tissue structures associated with joints; the investigation of localised muscular injuries and the identification of tendinous or ligamentous damage.

Cystic lesions which have been identified by ultrasonographic means include popliteal cysts (Lawson and Mittler, 1978; Lukes, Herberts and Zachrisson, 1980; Lenkey, Skolnick, Slasky and others, 1981; Braunstein, Silver, Martel and others, 1981; Bluth, Merritt and Sullivan, 1982; Slasky and others, 1982; Yeh and Rabinowitz, 1982), wrist ganglia (De Flaviis, Nessi, Del Bo and others, 1987), and lymphoceles (Braunstein and others, 1981) and such lesions have an anechoic appearance with associated acoustic enhancement. Both abscesses and haematomata have been described (Lawson and Mittler, 1978; Lenkey and others, 1981; Braunstein and others, 1981; Bluth and others, 1982; Slasky and others, 1982; Yeh and Rabinowitz, 1982) and ultrasonography has proved useful in the diagnosis and management of a variety of soft tissue and bony neoplasms (Levine, Lee, Neff and others, 1979; Bernardino, Jing, Thomas and others, 1981; Vukanovic, Sidani, Ducommun and others, 1981; Bluth and others, 1982; Slasky and others, 1982; Yeh and Rabinowitz, 1982; Gooding, Hardiman, Sumers and others, 1987; Fornage, 1988; Fornage and Rifkin, 1988a).

In studies which compared the results of ultrasonographic and computed tomographic examinations of soft tissue tumours in 50 patients with suspected musculo-skeletal tumours (Levine and others, 1979), and 25 patients with a variety of neoplastic and non-neoplastic soft tissue lesions (Bernardino and others, 1981), the conclusions were similar: computed tomography was a more sensitive means for the identification of soft tissue lesions, but ultrasonography allowed the evaluation of space-occupying lesions in three dimensions and, therefore, the measurement of the lesion and it was a cost-effective and useful method by which therapy could be monitored in individual cases (Levine and others, 1979; Bernardino, Jing, Thomas and others, 1981). In these and other studies, ultrasonography had the advantage over computed tomography that the internal architecture of a mass could be evaluated (Levine and others, 1979; Bernardino, and others, 1981; Slasky and others, 1982), and the same attribute was documented when the results of ultrasonography was compared with xeroradiography in the investigation of soft tissue masses (Vukanovic and others, 1981).

Reports of patients with suspected foreign bodies localised in the hand, and of an **in vitro** model of muscular foreign body, demonstrated that different materials produced different ultrasonographic appearances (Fornage and Schernberg, 1986; Gooding, Hardiman, Sumers and others, 1987). The contours of steel and glass structures were extremely echogenic and these materials produced acoustic shadowing, while plexiglass and wood were less echogenic, but also produced acoustic shadows. The power of ultrasonography to localise masses in three dimensions proved useful in the pre-operative evaluation of foreign bodies (Fornage and Schernberg, 1986; Fornage and Schernberg, 1987). When compared to radiography, ultrasonography was more sensitive but the small number of subjects and case selection precluded any conclusions on the specificity of the technique (Fornage and Schernberg, 1986).

Conventional clinical and radiographic examinations have missed significant intra-articular or para-articular fluid accumulations, and the desire to develop non-invasive methods of detecting joint effusions stimulated interest in the potential of arthrosonography, ultrasonographic examination of the joints (Seltzer, Finberg and Weissman, 1980). The earliest reports of this application described the appearance of joint effusions and synovial thickening associated with the knee joint (Ambanelli, Manganelli, Nervetti and others, 1976; Cooperberg, Tsang, Truelove and others, 1978), and details of the normal ultrasonographic findings and those associated with effusion in other joints followed (Seltzer and others, 1980).

The ultrasonographic features of a variety of pathological entities in the joint have been described, including lesions associated with the collateral ligaments, the cartilage and the ultrasonographic appearance of patellar plica, a rare condition which results from the presence of an embryonic synovial remnant in the knee has been documented (Aisen, McCune, MacGuire and others, 1984; Derks, de Hooge and van Linge, 1986; De Flaviis, Nessi, Leonardi and others, 1988). The main focus of interest in ultrasonographic imaging of joints has remained the infant hip, in which ultrasonographic examination has proved to be a non--invasive and economical method by which acetabular development could be assessed, providing an early diagnostic tool for hip dysplasia in infants (Morin, Harcke and MacEwen, 1985; Zieger and Shulz, 1986; Graf, 1987).

An experimental study on healing muscular injuries in the rat, has demonstrated a close relationship between the ultrasonographic and histological findings (Lehto and Alanen, 1987), and traumatic lesions in athletes have produced five distinct ultrasonographic patterns: fluid-filled collections; small irregularly-shaped lesions with scattered low-level echoes; ill-defined echogenic areas; highly reflective zones with acoustic shadowing and mixed lesions with anechoic and echogenic areas (Fornage, Touche, Segal and others, 1983). Comparison with the findings on surgical exploration, in a proportion of these patients, has demonstrated that the anechoic lesions were predominantly fluid-filled while echogenic lesions represented areas of fibrosis. In addition, ultrasonographic examination has been used to identify and characterise localised muscular lesions of non--traumatic origin such as compressional rhabdomyolysis and posterior compartmental syndrome (Kaplan, 1980; Auerbach and Bowen, 1981; Slasky, Lenky, Skolnick and others, 1982).

There have been relatively few detailed investigations of the use of ultrasonography in characterization of human tendon lesions and, with the exception of the rotator cuff, there are no studies in which the specificity, sensitivity and accuracy of ultrasonographic examination in the diagnosis of tendon injuries have been determined (Crass, Craig, Bretzke and others, 1985; Mack, Matsen, Kilcoyne and others, 1985).

Alternative diagnostic methods for tendon injuries have not been widely utilized in the past and the evaluation of these injuries has been based on clinical findings (Fornage and Rifkin, 1988). But, for this reason, it is surprising that relatively few studies reporting the use of ultrasonography in other tendons exist. However, collaboration between ultrasonologists and sports physicians has resulted in a recent increase in interest in this area (Fornage and Rifkin, 1988).

The concept of utilizing ultrasonographic examination for the diagnosis of tendon injuries associated with the rotator cuff was first presented by Meyer in 1977. However, at that time, ultrasonographic technology was not sufficiently sophisticated to provide diagnostic information (Dillehay, Deschler, Rogers and others, 1984). In 1984, Dillehay and collegues again proposed ultrasonographic characterization of tendons, noting that the superficial locations of tendons and ligaments lent themselves to this procedure. These authors described the ultrasonographic appearance of the Achilles tendon in rabbits before and after the creation of intratendinous haematomata and tears and, in addition, they reported the ultrasonographic findings in normal and injured Achilles tendons in human subjects, using a high-resolution, short-focus, 7.5 or 8 MHz transducer (Dillehay and others, 1984). At the same time, other groups reported techniques for ultrasonographic examination and the normal and abnormal ultrasonographic anatomy of the patellar tendon (Fornage, Rifkin, Touche and others, 1984), and of the tendons of the rotator cuff: the supraspinatus, infraspinatus, subscapularis and teres major tendons, (Crass, Craig, Thompson and others, 1984).

Focal lesions of the Achilles and patellar tendons produced disruption of and reduction of the echogenicity of the tendon (Dillehay and others, 1984; Fornage and others, 1984), similar to that which had already been described in association with acute superficial digital flexor tendon injury in horses (Rantanen and others, 1983; Hauser and others, 1984; Spaulding, 1984). In contrast, the lesions associated with rotator cuff tears were most frequently represented on ultrasonographic examination by focal echogenic lesions although focal hypoechoic lesions were recorded occasionally (Crass and others, 1984; Bretzke, Crass, Craig and others, 1985; Crass and others 1985; Mack and others, 1985; Middleton, Edelstien, Reinus and others, 1985; Crass, Craig and Feinberg, 1988a). Comparison with findings on surgical intervention demonstrated that these hyperechoic lesions corresponded to areas which were composed of proliferation of bursal and granulation tissue (Crass and others, 1984). The authors of the reports on rotator cuff ultrasonography did not discuss this apparent dissimilarity of the ultrasonographic appearance of lesions of these tendons compared to those reported in other human tendons and those of other species and no further studies have been undertaken to compare the ultrasonographic and histopathologic appearances of tendon lesions in man (Bretzke and others, 1985; Crass and others, 1984; Crass and others, 1985; Mack and others, 1985; Middleton and others, 1985; Crass and others, 1988a). Equally, the effect of duration of the rotator cuff lesion was not considered in these reports (Bretzke and others, 1984; Crass and others, 1984; Crass and others, 1985; Mack and others, 1985; Middleton and others, 1985; Crass and others, 1988a). However, a spectrum of ultrasonographic abnormalities has been observed in association with chronic inflammatory and degenerative lesions in intact rotator cuff tendons, including alterations of the echogenicity and the thickness of the cuff in the absence of focal lesions (Crass, Craig and Feinberg, 1988b).

The value of ultrasonography as a diagnostic aid in rotator cuff injury was assessed by comparison of the technique with the results of arthoscopy, which had previously been widely used (Crass and others, 1985; Mack and others, 1985). The results of both techniques were similar, with ultrasonography being slightly more sensitive and accurate in one study (Crass and others, 1985), and slightly less sensitive, but more specific in the other (Mack and others, 1985). Inaccurate information was obtained when extremely obese subjects were examined, and ultrasonography could not distinguish between small complete tears or small incomplete tears, but neither could be diagnosed with arthroscopy (Crass and others, 1988a). Nevertheless, ultrasonography was proposed as the primary imaging modality to examine the rotator cuff for tears while arthroscopy, due to its invasive nature, discomfort and high cost, was reserved for those cases in which the ultrasonographic findings were non-diagnostic or were incompatible with the clinical presentation (Crass and others, 1988a).

In the initial report of the ultrasonographic appearance of human digital flexor tendons, these were described as being hypoechoic when compared to the surrounding tissues (Fornage, Schernberg and Rifkin, 1985). But, these authors subsequently concluded that the flexor tendons were hyperechoic, and that their earlier report was misleading because 3.5 and 5 MHz transducers were utilized, which produced artifacts related to their inferior lateral resolution, and they noted that the obliquity of the tendons in relation to the sound beam was also a potential cause of false hypoechogenicity (Fornage and Rifkin, 1986). Thus, in subsequent reports of the digital flexor tendons in humans (Fornage and Rifkin, 1988a; Fornage and Rifkin, 1988b; Fornage, 1989b), the ultrasonographic appearance was similar to that which had previously been described in the digital flexor tendons of horses, namely an echogenic, fibrillar pattern (Hauser and others, 1982; Hauser and Rantanen, 1983; Modransky and others, 1983; Rantanen and others, 1983; Hauser and others, 1984; Pharr and Nyland, 1984;

Spaulding, 1984).

Equally, sports-related, traumatic and acute and chronic inflammatory lesions in various tendons produced similar ultrasonographic abnormalities in man (Fornage and Rifkin, 1988b), as those reported in the superficial digital flexor tendon of the horse (Rantanen and others, 1983; Hauser and others, 1984; Spaulding, 1984; Genovese and others, 1985; Rantanen and others, 1985; Genovese and others, 1986; Genovese and others, 1987), and in human medicine, as in equine medicine, the technique has been advocated due to its ability to identify, localise and characterize tendon lesions and to determine the nature of lesion while documenting the changes which occur with time (Fornage and Rifkin, 1988).

SECTION 1.5. HEAT DETECTION AS A DIAGNOSTIC TOOL.

Celsus (30 B.C. - 38 A.D.) described heat, redness, pain and swelling as the cardinal signs of inflammation, and indeed, Hypocrites regarded heat as the chief diagnostic sign of disease (Gershon-Cohen, 1964; Jones and Hunt, 1983). The first recorded actual measurement of body temperature was made by a physician, Sanctorius Justipolitanus, in 1611 (Seguin, 1876). Sanctorius, who was a colleague of Galileo, used a simple air-expansion thermometer and he reported that "At last we have among us an instrument by which with a bulk we measure the withdrawal of heat from all the external parts of the body and of air; by which we discover, very surely, how much more or how much less, daily, we differ from the normal". However, in 1987, Land observed that this medical practice has changed only in incidental detail over the intervening 375 years (Land, 1987a). In fact, it was not until 250 years after Sanctorius's time that thermometry became established as a part of the routine examination of a patient. This final acceptance of thermometry by the medical establishment followed the work of Traube in the latter half of the nineteenth century who studied some 25,000 cases in his clinic and persuaded his colleagues to do likewise (Gershon-Cohen, 1964). The slow development of thermometry between that time and its first conception is all the more surprising considering that its use was fostered by some of the most eminent and learned men in science and medicine in the seventeenth, eighteenth and nineteenth centuries. Fahrenheit, Celsius and James Curie were amongst those who made observations on thermometry (McGuignan, 1937; Gershon-Cohen, 1964). De Haen recognised the advantages of an objective means of temperature recording over the subjective means of feeling for warmth or cold and he used the technique to study the progress of diseases and the effectiveness of therapies. In 1835, Becquerel and Breschet tested variations of temperature in different parts of the bodies of men and animals. They documented that the temperature of inflamed parts was higher than healthy ones and established that the mean temperature of man was 37^{o}C (Gershon-Cohen, 1964).

The accurate measurement of temperature for medical purposes began in the Eighteenth century when Fahrenheit produced the first accurately calibrated thermometers with reproducible scales. The early thermometers employed thermal expansion techniques, similar to those still most widely used today in the mercury in glass thermometer (Land, 1987a). Such an instrument is only capable of measuring its own temperature and, therefore, it has to be allowed to equilibrate with the body temperature before this can be achieved (Land, 1987a).

The measurement of body temperature by the detection of thermal radiation and graphic display of this information is the basis of all forms of thermography. Currently, the conventional, and most widely used, thermographic technology is based on the detection of infrared emissions from the skin surface, and the first medical thermograph of this type was made in 1956 (Baeu, 1964). This system used thermistors to determine the skin temperature and demonstrated that the skin temperature was increased over a breast tumour (Baeu, 1964).

The earliest veterinary applications of infrared thermography were reported in 1964 (Smith, 1964). However, the equipment used by this group, and that used concurrently by Delahanty and Georgi, had the disadvantage that it required the subject to stand completely motionless for a period of six minutes (Smith, 1964; Delahanty and Georgi, 1965). The second problem that Delahanty and Georgi encountered was that in areas with thick hair coats repeatable thermographs could not be obtained and subsequent reports have recorded similar difficulties (Delahanty and Georgi, 1965; Clark and Cena, 1977).

The first description of the successful clinical application of thermography in equine medicine was published by Stromberg (1971). He documented that increased thermal emissions occurred in association with lesions of the superficial digital flexor tendon in horses and related the thermographic findings to the degree of tendon injury (Stromberg, 1971). Subsequently, the applications of both infrared thermography and infrared thermometry in the investigation of various inflammatory lesions, osteoarthritis, Horner's Syndrome, navicular disease and the illegal practices of "soring" in Tennessee Walking horses and "gingering" in Arabian and Saddlebred horses, have been reported (Stromberg 1974; Purohit, Bergfeld, McCoy and others, 1977; Webbon, 1978a; Palmer, 1981, Purohit and McCoy, 1980, Purohit, McCoy and Bergfeld, 1980; Vaden, Purohit, McCoy and others, 1980, Turner, 1981; Turner, Fessler, Lamp and others, 1983; Bowman, Purohit, Ganjam and others, 1983).

Thermography has been utilised in studies of the geometric design of race tracks which demonstrated that there was an increased thermal emission from the fetlock of the forelimb nearest to the inside of the track and it was hypothesised that this was due to excessive strain on that limb due to poor curve design (Fredricson, Galin, Drevemo and others, 1976). Perhaps the most exciting application of thermography, to date, remains the study reported by Stromberg in 1971 and in 1973 in which he documented that alterations in thermal patterns could be detected in the skin overlying the flexor tendons up to two weeks prior to the onset of clinical signs of tendon injury in Standardbred racehorses. Webbon (1978a) performed a similar study with a portable infrared thermometer on a group of flat racehorses but he was unable to confirm Stromberg's results because of the small numbers of horses in the survey and the lack of tendon injuries in this group.

SECTION 1.6. THE PRINCIPLES OF MICROWAVE THERMOGRAPHY.

The temperature of an object is a measure of its thermal energy content. At the atomic level, thermal energy produces vibrational motion which leads to the emission of thermal radiation in the form of electromagnetic radiation. An increase in thermal energy produces an increase in vibrational motion and an increase in electromagnetic radiation. Consequently, the intensity of thermal radiation and its distribution in the electromagnetic spectrum is dependent on the thermal energy and, hence, the temperature of the material emitting that radiation (Land, 1987a).

At body temperature, the majority of thermal radiation is in the form of infrared waves which have wavelengths of the order of 0.1 to 0.01 mm. However, radiation with a spectrum of wavelengths is emitted and a small proportion of the total intensity of radiation has much longer wavelengths. Fig 1.15 illustrates this distribution of variation in radiation intensity with radiation wavelength for a source of thermal radiation at about the human body temperature of $37^{o}C$. The total emission is equal to the total area under the curve, but the emission at any given wavelength is proportional to the total emission. This is the basic principle which underlies microwave thermography. The measurement of the intensity of thermal emission at a given wavelength allows the thermal radiation to be determined and, therefore, the temperature of the source material to be quantified (Barrett and Myers, 1975a; Barrett and Myers, 1975b; Land, 1987a; Land, 1987b).

The distance that electromagnetic radiation can travel through body tissues is proportional to its wavelength and inversely proportional to the frequency. At frequencies of less than 6 GHz, electromagnetic radiation can penetrate distances of the order of several centimetres (England and Sharples, 1949; Cook, 1951; Schwan, 1971; Land; 1987b). The fundamental difference between microwave thermometery or thermography and infrared thermometery or thermography is that the microwave emission produced by deep body structures can be recorded whereas infrared techniques can only determine the infrared emission from the skin surface and skin surface temperature (Barrett and Myers, 1975a; Barrett and Myers, 1975b; Land, 1987a).

Thermal modelling of the infrared emission from the body surface of man and animals has been extensively studied. The total infrared emission has been shown to depend on a number of interacting factors including: the thermal conduction of heat from deep body tissues to the skin surface; the perfusion of cutaneous tissues; and the thermal balance at the skin which is influenced by radiation, convection and evaporative heat loss (Pennes, 1948; Lipkin and Hardy, 1954; Draper and Boag, 1971; Adams, Heisey, Smith and others, 1980; Love, 1980).

Thermal modelling of biological tissues has

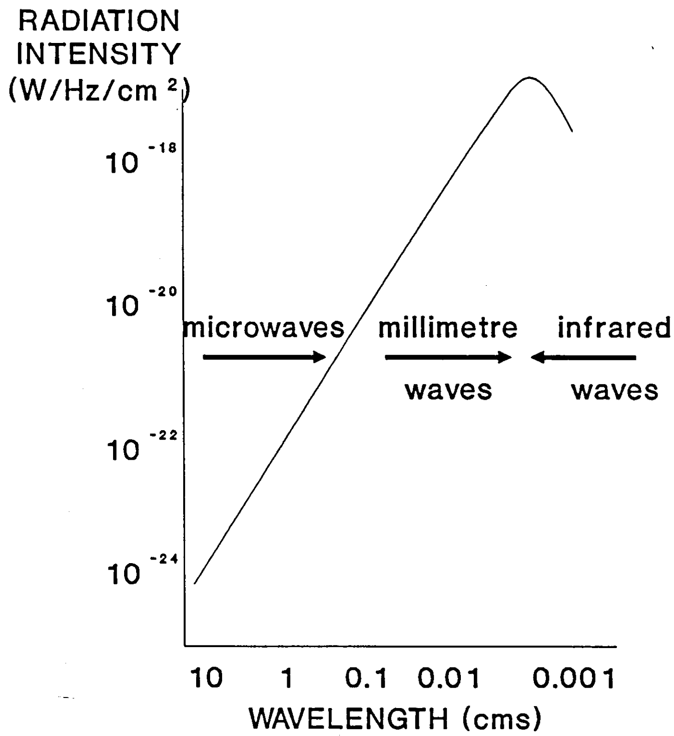


FIG. 1.15. THE VARIATION OF THERMAL RADIATION INTENSITY WITH RADIATION FROM THE MICROWAVE TO THE INFRARED REGIONS OF THE SPECTRUM FOR A SOURCE OF THERMAL RADIATION AT ABOUT THE HUMAN BODY TEMPERATURE OF 37°C (LAND, 1987a).

determined that the depth of penetration of microwave radiation depends not only on the wavelength, but also on the dielectric properties and on the water content of the tissue (Barrett, Myers and Sadowsky, 1980). These studies have also demonstrated that the measurement of microwave emission has allowed estimates of tissue perfusion in a number of regions of the human body including the breast and limbs (Land and Brown, 1987).

The microwave emission is not dependent on the thermal balance at the skin surface and, therefore, the influence of the surrounding environment is not critical, thus providing a major advantage of this system over infrared thermographic systems (Land, 1987a). But, like infrared thermography, the system shares the benefit of being a passive and non-invasive technique (Barrett and others, 1980; Land, 1987b). Unfortunately, microwave emission gives a coarser spatial resolution than that which can be achieved with infrared thermography (Barrett and others, 1980). A major limitation of infrared thermographic technology is that the skin surface temperature can be markedly influenced by the environmental temperature and, therefore, a controlled environment is required to perform the examinations (Chen and Pantazantos, 1980; Turner, Purohit and Fessler, 1986). The factors that must be controlled have been defined as motion, extraneous radiant energy, room temperature and airflow (Turner, Purohit and Fessler, 1986). Such conditions may be difficult to achieve in field conditions, particularly when dealing with equine subjects. Microwave thermography does not require similar controls in environment (Fraser, Land and Sturrock, 1987; Land, 1987a; Land, 1987b; Stallard, Land and George, 1987).

SECTION 1.7. CLINICAL APPLICATIONS OF MICROWAVE THERMOGRAPHY.

Reports of the clinical applications of microwave thermography in human medicine have emphasised its potential in the detection of subclinical breast cancer (Barrett and others, 1980; Myers, Barrett and Sadowsky, 1980). In part, this focus was the result of the desire to develop a cheap, non-invasive and versatile method which could be used to screen large groups of women from the at-risk population (McKirdy, Personal Communication). The technique has also been used to document temperature elevation in association with inflammatory joint disease (Fraser and others, 1987) and in acute appendicitis (Stallard and others, 1987).

SECTION 1.8. THE GLASGOW MICROWAVE THERMOGRAPHY UNIT.

The microwave thermography system which was used in this study was designed and built in the Department of Physics, University of Glasgow by a team of workers led by Dr. David Land. In addition to this study on its application in equine superficial digital flexor tendon injury, the system is currently under evaluation in two of the Glasgow teaching hospitals, where its use in the diagnosis of breast cancer, appendicitis and joint disease is being investigated.

The Glasgow microwave thermographic instrument has been described in detail by Land (1987a; 1987b). It consists of a radio aerial and a very sensitive microwave receiver. The aerial collects the microwaves emitted by the body and passes these as a microwave signal to the receiver which amplifies and measures the intensity of the signal. The information is then translated into a digital read-out of the temperature in degrees Celsius.

The microwave emission at normal body temperature ranges is very small and is similar in intensity to that generated by the electrical circuits of the equipment itself. Consequently, small changes in microwave emission could be masked by a constant emission caused by heat generated within the equipment. A comparison measurement technique is used to overcome this problem and the emission from the body is related to a standard reference source emitting microwaves. The input to the receiver is switched continuously and rapidly between the aerial and the reference source. The difference between these two input signals can then be determined and, because it is common to both the input from the aerial and the reference source, the effect of thermal noise generated by the equipment is cancelled out. The temperature of the source under interrogation can then be determined as the temperature of the reference source is known. The system has a temperature resolution of $0.1^{\circ}C$ in a response time of 2 seconds.

The design of the aerial is also critical: the impedance of the tissue to electromagnetic radiation is different to that of air and this difference in impedance results in a large fraction of the radiation being reflected back into the body (Ludeke, Koehler and

Kanzenbach, 1979; Land, 1987b). The microwave aerial is designed to prevent this by presenting an impedance near to the mean body tissue impedance, thereby reducing this reflection to a level which will permit accurate measurement of the radiation signal.

The unit is portable and is housed in a case which is a little larger than a briefcase. A paper printer is attached which provides a hard copy of each thermograph and a simultaneous digital read-out of the temperature of the tissues under investigation is provided.

SECTION 1.9. THE EQUINE SUPERFICIAL DIGITAL FLEXOR TENDON: MACROSCOPIC AND MICROSCOPIC ANATOMY.

The superficial digital flexor tendon is a continuation of the superficial digital flexor muscle from which it originates proximal to the carpal canal in the fore limb. Within the carpal canal, the tendon lies palmomedial to the deep digital flexor tendon but, as it courses distally throughout the metacarpal region, it adopts a palmar location lying immediately deep to the skin. At the level of the metacarpophalangeal joint, the superficial digital flexor tendon forms a ring through which the deep digital flexor tendon passes and distal to that the superficial digital flexor tendon, now lying lateral and medial to the deep digital flexor tendon, divides into two branches which insert on the palmar aspects of the first and second phalanges (Grossman, 1953). It has an accessory ligament which joins the superficial digital flexor tendon proximal to the carpus.

There are wide variations in the cross-sectional shape and area of the superficial digital flexor tendon: in the proximal regions, the tendon has a rounded shape on transverse section, and it becomes flattened in a dorsal to palmar direction while increasing in width from its lateral to medial borders in its distal regions, while the cross-sectional area is greatest at the musculo-tendinous junction and smallest in the mid metacarpal region (Webbon, 1973; Riemersma and De Bruyn, 1986).

There are two synovial sheaths associated with the superficial digital flexor tendon, described as the carpal and digital sheaths. At the carpus, a sheath encloses both the superficial and deep digital flexors with a mesotenon lying between the two tendons. This sheath extends through the carpal canal and terminates in the proximal metacarpal region. The digital synovial sheath is incomplete on the palmar aspect where the ring formed by the superficial digital flexor tendon is attached to the proximal digital annular ligament. The majority of the proximal pouch of the digital sheath lies between the deep digital flexor tendon and the branches of the suspensory ligament, while the distal pouch is located on the palmar aspect of the limb distal to the digital annular ligaments. The area of the superficial digital flexor tendon which is not enclosed within a synovial sheath, in the mid metacarpal region, is covered by a loose paratenon (Ottaway and Worden, 1940; Webbon, 1973).

The vasculature of the digital flexor tendons in horses has been demonstrated by microangiography in a variety of studies which have indicated that the intratendinous blood vessels of the superficial digital flexor tendon are less in the middle and distal segments (Norberg, Raker and Dodd, 1967; Stromberg and Tufvesson, 1969; Stromberg, 1971). Dissection of equine forelegs, following the intra-arterial insertion of latex, demonstrated that in their proximal and distal regions, the superficial and deep digital flexor tendons receive vessels from their muscles and periosteal insertions (Webbon, 1973). In the carpal sheath, branches of the median artery supply the surface of the tendon via the mesotenon and, between the carpal and digital sheaths, the blood supply entered the tendon from the paratenon. In the digital sheath, vessels arise from the palmar annular ligament in the palmar aspect and from branches of the digital arteries entering the sheath on the surface of the tendons (Webbon, 1973). Similar vessels supply the superficial digital flexor tendon distal to the metacarpophalangeal joint but no anastomosis between the two groups were found (Webbon, 1973).

Tendon is composed of a complex organisation of fibrils of protein, type I collagen, which is arranged in a triple helix, embedded in extracellular matrix and bound together in bundles or fascicles surrounded by connective tissue called endotenon (Williams, Heaton and McCullagh, 1980; Silver, Brown, Goodship and others, 1983). The distribution of sizes of collagen fibrils in normal superficial digital flexor tendons at maturity is bimodal with peaks at 50 nm and 150 - 200 nm (Parry, Craig and Barnes, 1978; Silver and others, 1983). The larger fibrils have increased intrafibrillar covalent crosslinks, and consequently more strength (Parry and others, 1978).

The normal equine superficial digital flexor tendon is characterised, on light microscopy, by eosinophilic collagen arranged longitudinally in bundles with an undulating waveform or crimp (Webbon, 1978; Williams and others, 1980; Silver and others, 1983). There is a minimal amount of endotenon tissue which on transverse section forms triangular areas containing blood vessels between the tendon bundles (Stromberg and Tufvesson, 1969; Stromberg, 1971).

The nuclei of normal tenocytes are well-stained and regularly arranged (Stromberg and Tufvesson, 1969; Stromberg, 1971; Webbon, 1978; Williams and others, 1980). At the musculo-tendinous junction and in the tendon within the carpal canal, the cells are numerous and the nuclei are plump and slightly elongated while in the metacarpal region the cells are less numerous and elongated (Webbon, 1978b). In some horses, a less regular arrangement of the cells in the metacarpal region has been described in which the tenocytes were sparse and columns of cells with plump nuclei were associated with these areas (Webbon, 1978b).

The endotenon is composed of collagen of types III, IV and V, which are scant in normal tendons (Williams and others, 1980; Silver and others, 1983). The endotenon is continuous with the epitenon, a connective tissue layer covering the tendon and areolar connective tissue and fat can be present between the tendon and this fibrous covering: these tissues collectively being the paratenon (Genovese and Simpson, 1989).

SECTION 1.10. THE EQUINE SUPERFICIAL DIGITAL FLEXOR TENDON: PHYSIOLOGICAL AND BIOMECHANICAL ATTRIBUTES.

The tendons serve principally as force transmitters and act as intermediaries in the attachment of muscle to bone. In addition to this passive role, the tendon acts as a dynamic amplifier during rapid muscle contraction, an elastic energy store and as a force attenuator (Evans and Barbenel, 1975). Regional variations in the histological and biochemical constitution of tendons are adaptations for taking up both compressive and tensile loads (Riemersma and De Bruyn, 1986; Okuda, Gorski, An and others, 1987).

In response to a tensile force, tissue deforms or stretches and, for a given load, the amount of extension which is induced is dependent on the cross-sectional area and the length of the specimen (Evans and Barbenel, 1975; Stephens, Nunamaker and Butterweck, 1989). The resistance to extension of a tissue can be determined from a load-extension curve while stress is defined as the internal effect generated within an object by an externally applied force and has the dimensions of force divided by area while strain refers to the geometric changes that occur in an object when a load is applied.

Stress-strain curves have been established for tendon tissue from which the slope of the curve defines a material property termed the modulus of elasticity. **In vitro** tensile testing has defined tendon as a non-linear elastic tissue: the stress-strain curve of tendon has an initial toe region where the slope of the stress-strain curves increases with increasing stress, and this is followed by a linearly elastic phase, during which stress and strain increase proportionately, therefore the modulus of elasticity is constant (Evans and Barbenel, 1975). Subsequently, a yield point is reached where further load application induces plastic deformation and the tissue does not return to its original length when unloaded (Evans and Barbenel, 1975). The name tendon is derived from Latin, tendo: to stretch thus, given the biomechanical limitations of the tissue it seems this is particularly inappropriate.

A number of studies on the mechanical behaviour of equine tendon **in vitro** have been reported (Abrahams, 1967; Evans and Barbenel, 1975; Lochner, Milne, Mills and others, 1980) but the application of **in vitro** observations to the clinical situation has been questioned, particularly with regard to strain, because **in vitro** experimental conditions are not physiological (Stephens and others, 1989). In particular, the slow rates of loading have not approximated the normal rates at which tendons are loaded in the moving animal (Stephens and others, 1989).

Studies utilizing a variety of investigative techniques have provided evidence that the load distribution and function within tendons is not uniform throughout their length: in other species, the proteoglycan content and the collagen orientation and type varies with location and areas of tendon which sustain compressive loads while passing over sesamoid bones have been shown to contain substantial amounts of fibrocartilage, suggesting that there are regional differences in mechanical attributes (Gillard, Merrilees, Bell-Booth and others, 1977; Koob and Vogel, 1987; Okuda and others, 1987). However, in an **in vitro** study of strain characteristics in the flexor tendon of the hind limbs, the slope of the load-strain curve of the superficial digital flexor tendon at the fetlock was found to be similar to that at the mid metatarsal site (Riemersma and Schamhardt, 1985).

Investigations of the biomechanical behaviour of the flexor muscle-tendon unit in live horses have been hampered by the difficulties associated with **in vivo** measurements (Stephens and others, 1989). Nevertheless, strain in the equine superficial digital flexor tendon has been recorded at a variety of gaits (Lochner and others, 1980; Stephens and others, 1989). The strain in the superficial digital flexor tendon increases with the speed of the gait (Lochner and others, 1980; Stephens and others, 1989) and the magnitude of the strains recorded in the mid metacarpal region of the superficial digital flexor tendon in horses exercising at the gallop has led the authors to postulate that the strain within the superficial digital flexor tendon varies and is greatest in that region (Stephens and others, 1989). However, in that study, the strains in other sites were not recorded and compared to that in the mid metacarpal site, and **in vitro** studies have not supported this theory (Riemersma and Schamhardt, 1985; Riemersma and De Bruyn, 1986).

SECTION 1.11. THE INCIDENCE OF SUPERFICIAL DIGITAL FLEXOR TENDON INJURY IN THE HORSE.

Injury to the superficial digital flexor tendon is an extremely common event in performance animals: it represents the commonest reason for days lost to racing amongst National Hunt racehorses and may also occur in Flat racehorses and, in fact, in any animal which is required to work at speed (Rooney and Genovese, 1981; Jeffcott, Rossdale, Freestone and others, 1982; Rossdale, Hopes, Wingfield Digby and others, 1985; Evans, 1988).

The frequency of superficial digital flexor tendon injury appears to vary with the population studied: in a survey of the frequency of superficial digital flexor tendon injury amongst a group of Thoroughbred racehorses in the U.S.A., 65 to 70% of 105 stables experienced at least one case during an eight month season. Initial injuries were reported in 7% of the 1087 horses while recurrence of a previous injury occurred in 6% of these horses, representing a reinjury rate of 48% in those horses which had previously sustained an injury (Rooney and Genovese, 1982).

Lameness was by far the most important cause of wastage in a survey of two, three and four year-old Thoroughbred racehorses in Britain and occurred in 53% of 246 horses studied, with the incident of lameness being sufficient to prevent them from racing subsequently in 33 cases (Jeffcott and others, 1982). However, in these animals, lamenesses associated with the foot, the fetlock and the carpus, rhadbomyolysis, splints and sore shins occurred more frequently than tendon injury. Superficial digital flexor tendon injury occurred in 5.7% of lame animals, and in 3 of the 33 horses which could no longer race (Jeffcott and others, 1982). In a subsequent study of horses of a similar age, conducted in Britain, tendon injuries occurred in 10% of 198 cases of diagnosed lameness (Rossdale and others, 1985).

It is generally accepted the horses which race over fences have a high incidence of superficial digital flexor tendon injury. A specific study of National Hunt racehorses in Britain has not been performed but one National Hunt yard was included in a survey of the incidence and causes of days lost to racing in six yards reported by Evans (1988) and the incidence of tendon injuries was highest in that yard.

SECTION 1.12. THE PATHOGENESIS OF EQUINE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY.

"This serious injury is of frequent occurrence, owing to the violent exertions to which the horse is too often urged," (Miles, 1875).

The precise pathogenesis of superficial digital flexor tendon injury has remained elusive despite centuries of veterinary interest in this condition. Most authors concur that the precipitating event of clinical injury is ultimately due to trauma produced by excessive force applied to the tendon. Tendon fibres exhibit an increase in their tensile strength and their modulus of elasticity with loading velocity, but increased tension within a tendon induces interfibrillar sliding of the collagen triple helices relative to each other. At physiological levels, this change is reversible but continued strain produces irreversible loss of the crimp of the collagen fibrils (Diamant, Keller, Baer and others, 1972; Mosler, Folkhard and Knorzer, 1985). X ray diffraction studies have demonstrated that intrafibrillar sliding processes precedes macroscopic slippage by seconds, and that not only very fast elongation but also very fast unloading of stretched fibres, reduce the stability of the fibre (Knorzer, Folkhard, Geercken and others, 1986).

A post mortem survey of equine digital flexor tendon injury has demonstrated that the superficial digital flexor tendon is the commonest site of flexor tendon injury and that the majority of these lesions occur in the metacarpal region (Webbon, 1977). This is the region with the smallest cross-sectional area and it has been suggested that this is an area of anatomical weakness and that tendon injuries occur there due to excessive overload because stress is highest at the sites where the cross-sectional area is least (Fackelman, 1973; Webbon, 1977). This conclusion would be valid in mechanical terms only if tendons had homogenous mechanical attributes and were isotropic, but mechanical and biochemical studies have shown that this is not the case (Riemersma and Schamhardt, 1985; Riemersma and De Bruyn, 1986). The cross-sectional area of a tendon does not reflect its strength and sites with the smallest cross-sectional area have the highest content of collagen, tendon fibres and dry substances (Riemersma and De Bruyn, 1986). Other sites may have an increase in cross-sectional area due to non-loadbearing collagen and other compounds which are required for other functions, such as the assimilation of transverse compressive forces and the attachment of retinacula (Riemersma and De Bruyn, 1986). In addition to variations in the overall cross-sectional area, the cross-sectional area of the tendon fibres is not constant along the length of a tendon but it has not been possible to demonstrate that this is representative of the strength of the tendon (Riemersma and De Bruyn, 1986).

The commonest site for tendon injury in the mid metacarpal region also corresponds with the area which is the least vascular (Stromberg, 1971, Stromberg, 1973). It has been suggested that degenerative lesions produced by tissue anoxia as a consequence of the sparse vascularity precede traumatic tendon injuries (Stromberg and Tufvesson, 1969; Stromberg, 1971, Stromberg, 1973). This suggestion has been supported by the observation of large acellular areas in macroscopically normal tendons which were found only in the metacarpal region of the superficial digital flexor tendon at the site corresponding to the commonest area of injury (Webbon, 1978b). There was no evidence of concurrent fibre damage associated with these areas but the author suggested that the techniques used in that study need not necessarily have demonstrated this (Webbon, 1978b). The shortfall of the theory that inefficient blood supply results in tendon necrosis, is that the vascularity rather than the perfusion of the tendon has been studied and, therefore, a functional deficit has not been demonstrated. Similar areas have been demonstrated in normal ponies which infrequently sustain flexor tendon injury, (Webbon, 1978b) and it has been pointed out that it seems unlikely that the tendons would have evolved in a manner which did not meet their physiological needs (McCullagh, Goodship and Silver, 1979).

The question of whether an existing degenerative lesion which produces a localised area of mechanical weakness remains unresolved and, if indeed these areas are a precursor to tendon injury, the precise mechanism by which they are induced remains unclear. However, it has been proposed that in both human and equine athletes multiple, microtraumatic events ultimately lead to clinically apparent tendon injury (Fackelman, 1973; Knorzer and others, 1986).

SECTION 1.13. HEALING OF SUPERFICIAL DIGITAL FLEXOR TENDON INJURY IN THE HORSE.

Tendon healing can be divided into four stages: insult, induction, fibroblastic repair and remodelling (Genovese and Simpson, 1989). Initial damage to the tendon involves random stretching, slipping and tearing of tendon fibres and there is substantial dissolution of the tendon matrix and fibre lysis due to the release of collagenases and proteases from damaged cells and from inflammatory cells attracted to the site of injury (Silver and others, 1983). Fragmented connective tissue fibres are surrounded by strands of fibrin and oedematous spaces and polymorphonuclear cells and macrophages migrate to the site (Silver and others, 1983).

Induction is characterised by the increase in fibroblasts within, and around, the tendon while small blood vessels colonise the area of haemorrhage (Genovese and Simpson, 1989). In a histological study of enzymatically-induced tendon injury, the areas of necrosis and tendon lysis had been completely replaced by new connective tissue one month after the injury (Silver and others, 1983). This tissue lacked the regular arrangement of normal tendon and the cells had large pale, basophilic nuclei (Silver and others, 1983).

The fibroblastic stage of healing is characterised by the presence of large numbers of fibroblasts with proliferation of the endotenon and paratenon (Stromberg and Tufvesson, 1969; Stromberg, 1971; Silver and others, 1983). Previously it was believed that tendon had little power to heal or regenerate on its own, relying on extrinsic healing with migration of fibroblasts from the paratenon. However, it has become clear that tendon has considerable intrinsic capabilities for phagocytosis of old collagen and synthesis of new collagen fibrils (Lundborg, 1976; Manske, Gelberman, Vande Berg and others, 1984; Lundborg, Rank, and Heinau, 1985). A histological study has demonstrated that the connective tissue cells present in healing equine tendon had an appearance which was similar to that of myofibroblasts but it was not possible to determine if these cells originated from the existing tenocyte population based on morphology alone (Williams and others, 1980). However, the characterisation of the collagen type within lesions, by immunofluoresence methods, indicated that the healing tendon contained large quantities of type III collagen which is normally present in muscle and not in tendon (Williams and others, 1980). These authors concluded that these findings supported the theory that the cells producing collagen in equine tendon injury were derived principally from smooth muscle of the blood vessels or from primitive mesenchymal cells. The frequency of peritendinous adhesions associated with tendon injury may provide further evidence that extrinsic healing predominates in equine superficial digital flexor tendon (Silver and others, 1983).

Type III collagen formed in tendon scar has a lower tensile strength than type I and it tends to form smaller fibrils than type I. Electron microscopic studies have confirmed that in healing and scarred equine tendon a population of small fibrils exists (Silver and others, 1983).

Remodelling of the lesions within tendons occurs over a period of months: six months after the injury in Silver's study the scar tissue was becoming more similar to normal tendon although the scar was still hypercellular with little subdivision into bundles apparent, and abnormalities in both histological and biochemical characteristics were detected fourteen months after injury (Silver and others, 1983). The combination of lack of organisation, inappropriate collagen type and fibril bundle size, and the tendency for extrinsic healing to produce adhesions, result in healing of tendon which is inefficient and incomplete and, thus the function of the tendon is unlikely to be restored to an adequate level.

SECTION 1.14. TREATMENT OF SUPERFICIAL DIGITAL FLEXOR TENDON INJURY IN THE HORSE.

"Of old, the farrier was ready with his firing-iron even in cases of sprain: the veterinary surgeon has in the interest in humanity driven him out" (Miles, 1875).

"The continued use of "firing" as a treatment for chronic injuries to the equine limb is a clear cut case of tradition holding more sway than science" (McCullagh and Silver, 1981).

The treatment of tendon injury in the horse is an extremely controversial topic and veterinary surgeons and horsemen have passionately held, often conflicting, views on the subject. Indeed, it seems that there are as many treatments for tendon injury as there are veterinary surgeons.

Treatments can be broadly divided into three main categories: those aimed at reducing the heat and swelling associated with the initial inflammation and which are essentially first-aid; those providing a means of increasing the rate of the repair process and improving the quality of repair; and those which aim to minimise the risk of recurrence.

The value of the application of various cooling liniments or cold water in the early stages to reduce swelling, the administration of anti-inflammatory drugs and provision of support with bandages or casting has not been investigated. However, these practices cannot be criticised as they adhere to the general principles of first-aid treatment. The application of shoes with raised heels is popular with some veterinarians and horsemen, in the belief that the raising of the heel will reduce the loading on the tendon. However, this practice has no rational basis because, in the vast majority of cases, it is the superficial digital flexor tendon that is involved and raising of the heel affects only the deep digital flexor tendon (Lochner and others, 1980).

The intratendinous administration of corticosteroids in normal ponies has resulted in focal necrosis of tenocyte nuclei adjacent to the injection site, and post-mortem examination of injured tendons treated with long-acting corticosteroids has demonstrated that this produced dystrophic calcification and retarded the rate of production of fibrous connective tissue (Pool, Wheat and Ferraro, 1980).

The traditional method of treatment of equine tendon injury is firing which remains popular in Britain today. There are various techniques of firing utilizing the application of hot irons, either in parallel lines onto the skin or using pins into the skin, subcutaneous tissue or, sometimes the tendon itself. The process of thermocautery has been practised since ancient times and it was first documented in the literature by the Roman, Vegetus who lived in 450 AD. He accounted for its efficacy by explaining that it released noxious humors. He expressed reservation about this mechanism of action and cautioned that it should not be used for traumatic injuries, being more appropriate for the treatment of abscesses (Vegetus Renatus, 1748) and in the first veterinary text which was published in English, Blundeville also warned "touche not the sinewes, chordes or lygaments, lest the member be weakened", (1565).

The first advocate of the use of firing for treatment of traumatic tendon injuries was Hunter, (1796), two hundred years later. He justified its use with the following explanation: "The part is grown hard and callous about the joints. The sinews and nervous parts which lie in contiguous thereto, being composed of almost an infinite number of fibres and nervous threads, which lie so close, and are so interwoven together, that nothing but what is of the most powerful nature, is able to give them relief, when they are by any means injured or impaired in their functions. And there is nothing more effectual for this purpose, than burning the outside". Therefore, his opinion can be paraphrased as "when the going gets tough, the tough get going" (Ocean, 1985).

Various other theories have been put forward to explain firing's effects: at one time it was believed that only one site of inflammation could exist at any one time and, therefore, by creating a second site of inflammation in the skin, this would in some way remove inflammation from the tendon and, alternatively, some proponents believed that the scarred skin acted as a natural bandage (Youatt, 1831; Walsh, 1875b). But even at that time, this theory was controversial and was dismissed by contemporaries (Ferguson, 1862; Walsh, 1875b). Another proposed mechanism was that the inflammatory process induced in the skin would increase the local blood supply and, thus, enhance repair which was based on the theory that the tendon had a very poor blood supply and consequently poor repair potential.

Currently, advocates of the technique frequently justify its use by stating that in the act of firing a horse one is able to convince the owner that positive steps have been taken and to persuade him to rest the horse for a suitably long period of time. Rest is an adjunct to most treatments and, in the absence of additional therapy, it may be as efficacious as any other treatment (Silver and others, 1983).

No clinical trial of the efficacy of the technique has been performed to date. However, an extensive study has been performed, using an experimental model of tendon injury in ponies created by injection of bacterial collagenase, trypsin, clostripain and kallikrein into the superficial digital flexor tendon. That study utilised both **in vivo** force plate gait analysis and, ultimately, pathological and histopathological methods to compare the effects of line and pin firing on tendon injury with untreated controls. The conclusions were that pin firing was detrimental and that line or bar firing had absolutely no effect, either beneficial or detrimental, on the tendon repair process (Silver and others, 1983).

Nevertheless, firing is still popular and currently there are two situations in which the act of thermocautery is still practised: in the Sahara Desert, Tibu and Bedouin tribesmen treat respiratory disease by the application of hot stones to their chests (McCullagh and Silver, 1981); equine veterinarians apply hot irons to the skin of horses legs to treat traumatic injuries of the underlying tendons or ligaments. The Tibu tribesmen are able to account for the efficacy of this practice to the satisfaction of their medical practitioners: they believe it is magic (McCullagh and Silver, 1981). Equine veterinarians can offer no such satisfactory justification.

The most widely documented method of treatment of tendon injury to date has been tendon splitting. This technique was first described in the early 1960's and since that time several retrospective analyses of clinical data have appeared which report successful results (Asheim, 1964; Asheim and Knudsen, 1967; Nilsson and Bjorck, 1969; Nilsson, 1970; Knudsen, 1976; Webbon, 1979; Cannon, 1981). However, histopathological investigations on the effects of the procedure on normal ponies and on experimentally-induced lesions have indicated that the technique was detrimental (Stromberg, Tufvesson and Nilsson, 1974; Silver and others, 1983). Nevertheless, the procedure is currently regaining popularity in the U.S.A.

A multitude of alternative treatments have been proposed which are believed to increase the rate of healing of tendon injuries including ionising radiation, ultrasonic therapy, laser therapy, blistering, electro-magnetic therapy and Carbon fibre implants (Morcos and Aswad, 1978; Franks, 1979; Littlewood, 1979; Goodship, Brown, Yeats and others, 1980; Lang, 1980; McKibbin and Paraschak, 1983; Vaughan, Edwards, Gerring, 1985; Watkins, Auer, Morgan and others, 1985; Antikatizides, 1986; Genovese and Simpson, 1989).

Carbon fibre implants are believed to promote the regular arrangement of fibroblasts in a longitudinal manner and thereby, improve the quality of healing (Goodship and others, 1980), while the other techniques are believed to improve the rate of fibroblastic proliferation. However, the use of these methods is largely empirical as there is no experimental evidence which proves that they have beneficial effects. Prospective clinical trials on the efficacy of carbon fibre implants have not been performed, and in some cases the reports on their use are anecdotal (Lang, 1980).

The aim of tendon repair is to restore the tendon to a functional unit which has tensile strength, a smooth gliding action over adjacent structures and a degree of elasticity. The smooth gliding action is inhibited by adhesion formation between the overlying subcutaneous structures and underlying deep digital flexor tendon (Selway, 1975). Those treatments that are designed to prevent recurrence are based on either the prevention of adhesion formation or the lengthening of the tendon to reduce the need for elasticity (Selway, 1975; Bramlage, 1986).

Prosthetic sheaths, similar to those used in hand surgery in humans have been employed in the surgical repair of flexor tendon in the horse but reports of their application in the horse are anecdotal (Selway, 1975). Peritendinous injection of sodium hyaluronate to enhance the mobility of the tendon (Whatmore, Rose and Wainscott, 1984; Churchill, 1985) has also been proposed but this effect is likely to be transitory at best.

Bramlage (1986) described a surgical technique of superior check ligament desmotomy which lengthens the superficial digital flexor tendon unit, and it is believed to reduce the need for elasticity of the tendon. This study of thirty-six cases reported that 79% returned to work and raced twice without recurrence of the injury while the remainder recurred prior to starting in two races.

The main shortcoming of the retrospective studies on the efficacy of methods of treatment of tendon injury which have been investigated, is that there has not been a standard means of defining a successful end point or a control population of untreated animals with which to compare the treated group, and in the majority of reports, no effort was made to define the severity of the initial injury. Vaughan, Edwards, and Gerring, (1985), did divide their study group of thirty-four horse into mild, moderate and severe based on subjective, clinical examination. However, they do not relate these categories to the final outcome.

Criteria that have been used to assess the success of a particular treatment are the ability to return to previous work; the ability to return to previous work within a set number of days; the number of races which an individual performs without recurrence; the rate of recurrence of injury for the group and the mean number of races of the study group following treatment. In a study on the efficacy of tendon splitting, Webbon (1979) used the latter method and compared his study group to data collected from the Raceform National Hunt Form Book on the horses listed on either side of the individuals under consideration. This report represents the only attempt made to date to compare the results of a particular mode of therapy with a control population although the clinical history of the control group was unknown (Webbon, 1979).

SECTION 1.15. THE CLINICAL PRESENTATION OF SUPERFICIAL DIGITAL FLEXOR TENDON INJURY IN THE HORSE.

The clinical presentation of superficial digital flexor tendon injury was described in the earliest veterinary and farriery texts. In the past, the condition was known as "clap or strain of the back sinews" and it was recognised as a common occurrence (Bracken, 1737). Flexor tendon injury was associated with swelling or roundness in the palmar metacarpal region and signs of inflammation and heat in that site (Bracken, 1737). Miles (1875) cautioned that there were degrees of this injury and when it was mild, lameness was generally not a feature and careful palpation was necessary to detect slight swelling and tenderness on pressure while Bracken (1755), stated that a good hand and eye were required to appreciate mild injuries. It was recognised that these signs should not be disregarded as continued work would result in further injury (Miles, 1875). In severe cases the metacarpophalangeal joint may be dorsiflexed and lameness may be marked (Walsh, 1875a).

SECTION 1.16. DIAGNOSTIC METHODS FOR THE INVESTIGATION OF EQUINE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY.

Additional ancillary aids for the diagnosis and evaluation of tendon injury were not available until a technique for negative contrast radiographic studies of the flexor tendons and associated structures was first described in 1961 by Williams and Campbell. In the normal, standing horse the superficial and deep digital flexor tendons, the inferior check, suspensory and straight sesamoidean ligaments could be demonstrated using soft tissue radiographic exposures following the introduction of air both subcutaneously and into the common digital sheath.

Verschooten and De Moor (1978) reported a series of 33 cases clinically affected with swelling of the palmar metacarpal or metatarsal regions in which air tendonography was used to diagnose superficial and deep digital flexor injury, palmar annular desmitis with and without associated superficial digital flexor tendinitis and to differentiate soft tissues swelling from tendinitis. They also concluded that peritendinous inflammation, oedema or adhesion formation could be identified by the blurring of the edges of the tendons. The size and location of superficial digital flexor tendon injuries could be identified. However, the radiographs could not be used to distinguish acute from chronic injury. In this report, details of the normal dimensions of the soft tissue structures of the metacarpal region obtained from ten normal horses and a protocol for obtaining and evaluating air tendinograms was described (Verschooten and De Moor, 1978).

The other techniques which have been utilised in the clinical investigation of tendon injury are ultrasonography and infrared thermography or thermometery, and the existing literature on the use of both of these techniques in the evaluation of tendon injuries has been discussed above.

Ultrasonography is a non-invasive means by which the internal structure of soft tissues may be demonstrated. The ability of ultrasonography to distinguish between acute and chronic lesions has been based on changes in echogenicity, while peritendinous disease has resulted in indistinctness of the edges of the superficial digital flexor tendon (Hauser and others, 1984; Genovese and others, 1986; Hauser, 1986; Genovese and others, 1987). Thermography is also non-invasive but its findings are generally nonspecific, and the infrared thermographic abnormalities associated with superficial digital flexor tendon injury have been reported in detail (Stromberg, 1971; Stromberg, 1973).

SECTION 1.17. GENERAL AIMS OF THE STUDY.

Genovese and co-authors, (1986), have pointed out that research efforts in the field of equine orthopaedics since the 1950's have concentrated on joint and bone diseases. They suggested that, in part, this could be attributed to the fact that diagnostic techniques, such as radiography and arthroscopy, have greatly facilitated the investigation of these diseases, and observed that research into the soft tissue components of the locomotor system has been neglected, due to the difficulty associated with making an objective morphological study of these structures. Further, they envisaged that ultrasonographic imaging would provide the required objective means of evaluation of soft tissues and thus, research into the diseases of these soft tissues could be expected to follow (Genovese and others, 1986).

In the case of superficial digital flexor tendon, it is clear from the literature that investigations on the efficacy of modes of therapy have suffered from the lack of standardisation of the lesions which were treated and the absence of either a meaningful control population or even any data on the expected outcome of a lesion of particular severity in the absence of treatment. The varying incidence of this injury in different equine populations, depending on their breed and occupation means that comparison of the results of one mode of therapy in a given population with previously reported data from a different population of horses must be performed with reservation (Rooney and Genovese, 1981; Jeffcott and others, 1982; Rossdale and others, 1985; Evans, 1988).

The spectrum of severity which occurs in association with equine superficial digital flexor tendon injury has long been recognised (Miles, 1875), but the variable efficiency of the various diagnostic methods has not been compared critically and data on the most accurate means of determination of severity is lacking.

The progression of ultrasonographic changes associated with superficial digital flexor injury has been reported (Hauser and others, 1984; Genovese and others, 1986; Hauser, 1986; Genovese and others, 1987). However, currently there is no published study which describes these changes within groups of animals which were monitored over a period of time and the expected rate of change of these parameters has not been determined.

Microwave thermography is a new non-invasive diagnostic technique which offers technical advantages over infrared thermography and is ideally suited to a field situation (Land, 1987a; Land, 1987b). It has not been used previously in the horse but it has potential application in the same areas as infrared thermography most notably in the early diagnosis of tendon injury.

The overall aim of this study was to investigate the application of microwave thermography and ultrasonography as non-invasive diagnostic techniques for the evaluation of soft tissue injury in the equine limb. Superficial digital flexor tendon lesions appeared to represent the most common soft tissue injury occurring in the performance horses in the South of Scotland and North-Eastern England, the regions from where Glasgow University Veterinary School derives its referral population and, thus, the investigation of this injury has been the focus of this work.

The study was designed to attempt to answer the questions which were defined above: to evaluate the relationship between ultrasonographic and pathological features of superficial digital flexor tendon injury; to describe the ultrasonographic features associated with acute tendon injury in a group of horses which could be re-examined throughout the course of healing of these lesions, thus relating the eventual outcome of these cases with the ultrasonographic appearance and documenting the ultrasonographic changes associated with healing and determining the expected time course of these changes; to compare the effacacy if ultrasonography with another diagnostic technique, air tendinography; to define the normal microwave thermographic appearance of the palmar metacarpal region and to determine the value of microwave thermography in the investigation of flexor tendon injury.

CHAPTER 2.

ULTRASONOGRAPHIC AND MACROSCOPIC STUDIES OF THE FLEXOR TENDONS OF THE FORE LIMBS IN NORMAL HORSES

SECTION 2.1.: INTRODUCTION AND AIMS OF THE STUDY.

The ultrasonographic findings in normal digital flexor tendons have been described previously in qualitative terms (Hauser and others, 1982; Hauser and Rantanen, 1983; Modransky and others, 1983; Rantanen and others, 1983; Hauser and others, 1984; Spaulding, 1984; Genovese and others, 1986). Some data are available on the normal dimensions of the soft tissue structures of the palmar aspect of the equine limb but, unfortunately, these quantitative parameters were not related to the height, age or weight of the animal nor was the breed or the occupation of the animals from which this information were derived, stated (Genovese and others, 1986). Details of the ultrasonographic anatomy and the examination technique of the palmar soft tissue structures distal to the metacarpophalangeal joint are limited to one report (McClellan and Colby, 1986).

The majority of the existing literature on normal ultrasonographic anatomy of the equine distal limb reports the findings with sector transducers (Hauser and others, 1982; Hauser and Rantanen, 1983; Modransky and others, 1983; Rantanen and others, 1983; Hauser and others, 1984; McClellan and Colby, 1986; Genovese and others, 1986). However, linear array transducers have been utilised to image these structures previously and the majority of studies on ultrasonographic examination of the flexor tendons in humans have employed these transducers (Spaulding, 1984; Henry and others, 1986;

Fornage and Rifkin, 1988a; Fornage and Rifkin, 1988b; Fornage, 1989b), and one study comparing sector and linear array transducers in the equine digital flexor tendons has been described (Pharr and Nyland, 1984).

The purposes of this study were to become proficient in the identification of the flexor tendons and associated structures on ultrasonograms; to establish the optimum technique for examination of the soft tissue structures of the palmar aspect of the distal limb using a 7.5 MHz linear array transducer; to obtain qualitative and quantitative data on the ultrasonographic findings in a group of horses which were representative of the referral population in the University of Glasgow Veterinary School; to correlate these data with the age, weight and height of the horses and to determine if there was a consistent relationship between the sizes of the flexor tendons and an adjacent landmark, the metacarpal bone diameter, and the circumference of the limb in normal horses in the hope that such a relationship could be used to predict the expected normal size in individual horses.

PART 2.1. A PRELIMINARY CADAVER STUDY OF THE ULTRASONOGRAPHIC FINDINGS IN THE PALMAR METACARPAL REGION.

SECTION 2.1.1: MATERIALS AND METHODS.

Animals.

The distal parts of the fore limbs were removed from six normal equine cadavers by section proximal to the carpus. These animals were all riding-type, they represented a variety of ages, and had clinically normal flexor tendons.

Ultrasonographic Examinations.

The limbs were prepared for examination by clipping and shaving the palmar aspect of the limb between the carpal and metacarpophalangeal joints and by application of echolucent gel. The limbs were fixed in an extended position in a clamp and transverse and longitudinal images of the palmar aspect of the limb were obtained at 20 mm intervals from 60 to 300 mm distal to the accessory carpal bone using an ultrasonographic unit equipped with a 7.5 MHz linear array transducer both with and without an echolucent stand-off pad. Frozen images of these sites were recorded using a video recorder. In addition, the entire area was imaged in real-time and recorded for review.

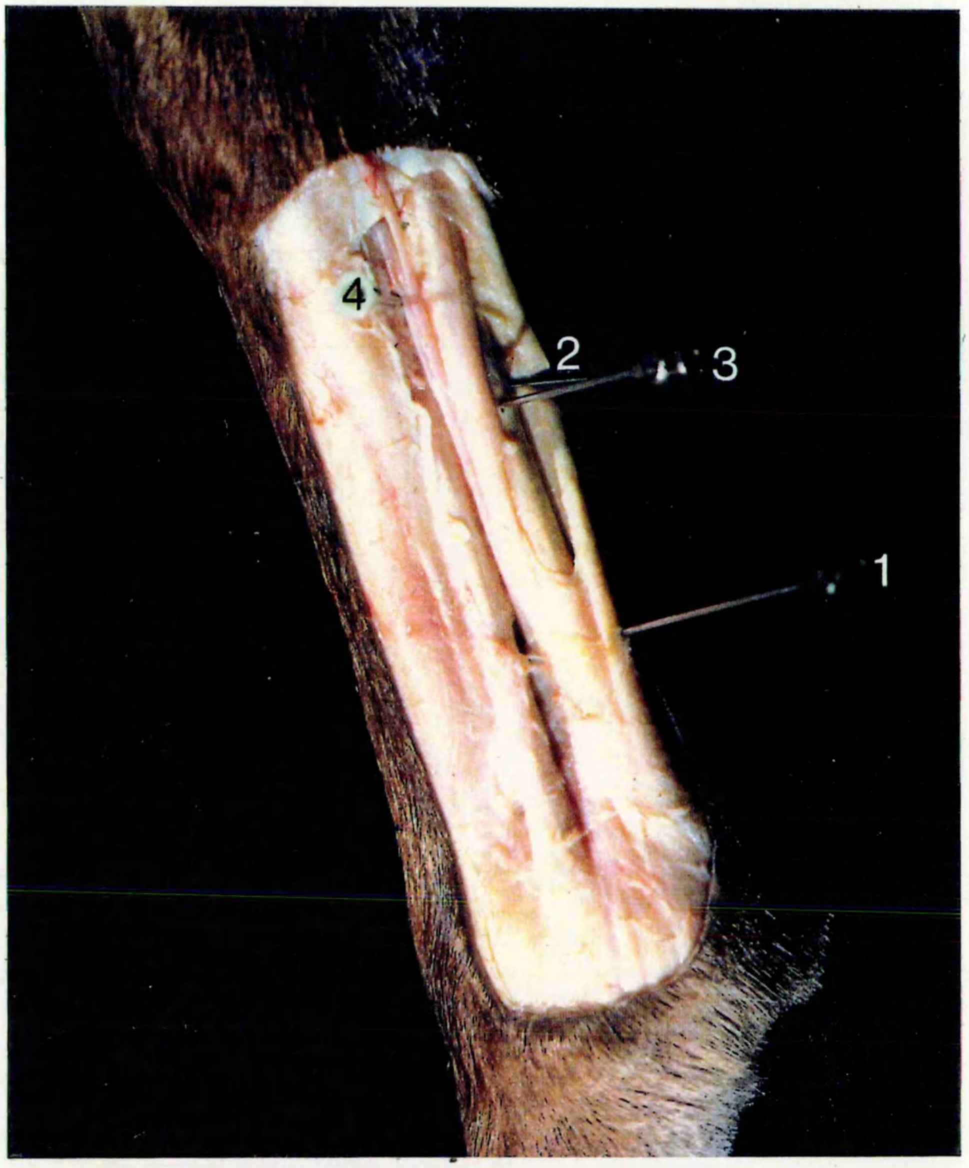
Identification Of The Soft Tissue Structures Of The Palmar Metacarpal Region.

Attempts were made to identify the following structures: the superficial and deep digital flexor tendons, the accessory ligament of the deep digital flexor tendon and the suspensory ligament. A variety of paravertebral and hypodermic needles were inserted into these structures under ultrasonographic guidance. The limbs were then dissected to confirm that the needles had been placed correctly.

SECTION 2.1.2: RESULTS.

The ultrasonographic images obtained from the cadavers were of poor quality. On transverse images, the superficial digital flexor tendon was represented by a hypoechoic structure immediately beneath the skin and the image quality could be improved by exerting tension on the tendon. When this was done the longitudinal images demonstrated that it was composed of numerous linear echoes. In this study, the superficial digital flexor tendon generally had a lower echogenicity than the deep digital flexor tendon which lay immediately dorsal to it. The deep digital flexor tendon was also imaged more satisfactorily when it was placed under tension. When this was done it also had a multi-linear appearance in longitudinal images. In the transverse images, it was represented by an oval echogenicity as were the accessory ligament of the deep digital flexor tenon and the suspensory ligament.

FIG. 2.1. A CADAVER SPECIMEN AND A CORRESPONDING LONGITUDINAL ULTRASONOGRAM IN WHICH NEEDLES HAVE BEEN INSERTED INTO THE SUPERFICIAL DIGITAL FLEXOR TENDON (1), BETWEEN THE FLEXOR TENDONS (2), INTO THE DEEP DIGITAL FLEXOR TENDON (3), AND INTO THE ACCESSORY LIGAMENT OF THE DEEP DIGITAL FLEXOR TENDON (4). IN THE ULTRASONOGRAM THE NEEDLE IN THE SUPERFICIAL DIGITAL FLEXOR TENDON IS REPRESENTED BY AN ECHOGENIC AREA (1).



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2
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1

1
SUPERFICAL FLEXOR TENDON
DIS=009MM

The placement of the needles was difficult because of the resistance of the tendon to their insertion. However, subsequent dissection in the limbs in which they were inserted satisfactorily demonstrated that the individual structures were identified correctly (Fig. 2.1). The needles produced a hyperechoic area with a distal acoustic shadow when the ultrasound beam was orientated in the same plane. However, this was difficult to achieve in most cases.

Insertion of needles subcutaneously, between the suspensory ligaments and the deep digital flexor tendons, was useful as they could be manipulated and thereby identified.

The echolucent stand-off pad was found to be essential to provide images of the palmar aspect of the superficial digital flexor tendon.

PART 2.2. A QUALITATIVE AND QUANTITATIVE STUDY ON THE NORMAL ULTRASONOGRAPHIC ANATOMY OF THE EQUINE DIGITAL FLEXOR TENDONS.

SECTION 2.2.1: MATERIALS AND METHODS.

Anatomical specimens.

Two fore limbs were obtained from a normal horse after being removed proximal to the carpus. They were frozen and one was subsequently sectioned in transverse planes at approximately 40 mm intervals. The other was sectioned in a longitudinal plane to provide specimens for comparison with the ultrasonographic images.

Animals.

Twenty five horses were selected on the basis that they were Thoroughbreds and had clinically normal flexor tendons and no known history of tendon injury. Their heights were recorded using a standard measuring stick and their weights were estimated using a calibrated girth and length tape and their ages were estimated from their dentition.

Measurement Of The Metacarpal Bone Diameter And Circumference Of The Limbs.

Adhesive tape marked at 20 mms intervals was attached to lateral aspect of the limb to indicate position at 20 mm intervals from 60 to 300 mms distal to the accessory carpal bone. The circumference of the limb at each point was recorded using a tape accurate to 1 mm and the width of the metacarpal bone at equivalent points was obtained with callipers accurate to 0.1 mms.

Ultrasonographic Examination.

The limbs were prepared for examination by clipping and shaving the palmar aspect of the limb from the carpal joint distally and by application of echolucent gel. Transverse and longitudinal images of the palmar aspect of the limb were obtained using an ultrasonographic unit equipped with a 7.5 MHz linear array transducer using an echolucent stand-off pad. Frozen images were obtained at 20 mm intervals from 60 to 300 mm distal to the accessory carpal bone and these were recorded using a video recorder. In addition, the entire area was imaged in real-time and recorded for review.

Qualitative Assessment Of The Ultrasonograms.

The ultrasonograms were subsequently reviewed and the following features were noted: the shape and relative location of the tendons, the accessory ligament of the deep digital flexor tendon and the suspensory ligament; the existence, incidence, location and type of ultrasonographic artifacts.

Quantitative Assessment Of The Ultrasonograms.

The lateral to medial diameter and the dorsal to palmar dimensions of the superficial and deep digital flexor tendons were obtained at each recording site using a video callipers system.

Mathematical Analysis.

The mean and range of the ages, height and weight of the animals were established. The means, standard deviations and ranges of the circumference of the limb, the metacarpal bone diameter, the lateral to medial diameters and dorsal to palmar diameters of the superficial digital flexor tendons were calculated at each recording site.

Correlation coefficients were calculated for the following pairs of data: the lateral to medial diameter of the superficial and deep digital flexor tendons correlated to the age, height, weight, metacarpal bone diameter and circumference of the limb at each recording site; the dorsal to palmar diameter of the superficial and deep digital flexor tendons correlated to the age, weight, height, metacarpal bone diameter and circumference of the limb at each recording site; the dorsal to palmar diameter of the superficial digital flexor tendon correlated to the lateral to medial diameter of the superficial and of the deep digital flexor tendon and the dorsal to palmar diameter of the deep digital flexor tendon at each recording site; the lateral to medial diameter of the superficial digital flexor tendon correlated to the lateral to medial diameter and the dorsal to palmar diameter of the deep digital flexor tendon at each recording site, the dorsal to palmar diameter of the deep digital flexor tendon correlated to the lateral to medial diameter of the deep digital flexor tendon at each recording site. Groups of data with R value of less than 0.4 were discarded.

Linear regression analysis was performed in the groups of data which demonstrated a correlation co-efficient of greater than 0.4 in an attempt to establish a relationship between the variables.

SECTION 2.2.2: RESULTS.

The mean age of the horses included in this study was 11.4 years with a range from 5 to 20 years. The mean height was 16 h.h. with a range 15.1 to 16.3 and the mean estimated weight was 510 kgs with a range of 410 to 580 kgs.

Qualitative Assessment Of The Ultrasonograms.

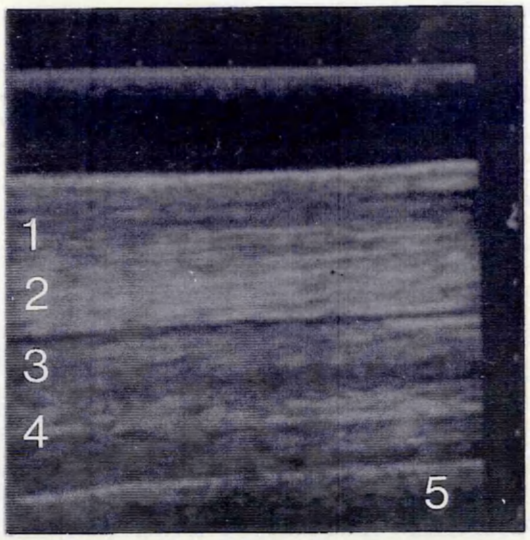
The normal ultrasonographic appearance of the soft tissue structures of the palmar metacarpal region is illustrated in Figs. 2.2, 2.4, 2.5, 2.6, 2.7, 2.8 and 2.9. In longitudinal images of the proximal and mid metacarpal region the superficial and deep digital flexor tendons, the accessory ligament of the deep digital flexor tendon and suspensory ligament were identified (Fig. 2.2). In longitudinal images of the distal metacarpal regions only the flexor tendons were identified. Distal to the metacarpophalangeal joint it was not possible to obtain longitudinal images of the palmar aspect of the limb in normal horses due to the bulk of the transducer and curvature of the distal limb. Optimum images of each structure were not obtained simultaneously in any region. As is to be expected, the ultrasonographic anatomy in longitudinal images corresponded to that observed in the gross anatomical specimen (Figs. 2.2 and 2.3).

FIG. 2.2. THE NORMAL ULTRASONOGRAPHIC APPEARANCE OF THE SOFT TISSUE STRUCTURES OF THE PALMAR METACARPAL REGION.

IN THE PROXIMAL METACARPAL REGION (UPPER) THE SUPERFICIAL DIGITAL FLEXOR TENDON IS COMPOSED OF MULTIPLE LINEAR ECHOES AND LIES IMMEDIATELY BENEATH THE SKIN. THE BOUNDARY BETWEEN IT AND THE DEEP DIGITAL FLEXOR TENDON (2) IS NOT DISTINCT AND THE DEEP DIGITAL FLEXOR TENDON IS ALSO COMPOSED OF LINEAR ECHOES. THE ACCESSORY LIGAMENT OF THE DEEP DIGITAL FLEXOR TENDON (3) IS SEPARATED FROM THE DEEP DIGITAL FLEXOR TENDON BY AN ANECHOIC SPACE. THE ACCESSORY LIGAMENT OF THE DEEP DIGITAL FLEXOR TENDON IS COMPOSED OF LINEAR ECHOES. THE SUSPENSORY LIGAMENT (4) LIES DORSAL TO THE METACARPAL BONE (5) AND IT HAS A LESS REGULAR APPEARANCE. IN THIS IMAGE ITS DORSAL ASPECT IS NOT IMAGED OPTIMALLY.

THE SAME STRUCTURES CAN BE SEEN IN THE MID METACARPAL REGION (MIDDLE) BUT THE ACCESSORY LIGAMENT OF THE DEEP DIGITAL FLEXOR TENDON (3) TAPERS DISTALLY AS DOES THE SUSPENSORY LIGAMENT (4) AS IT APPROACHES ITS BIFURCATION.

IN THE DISTAL METACARPAL REGION (LOWER) THE FLEXOR TENDONS (1 AND 2) CAN BE SEEN PASSING DORSAL TO THE PROXIMAL SESAMOIDS (6) WHICH ARE REPRESENTED BY CURVED ECHOGENICITIES. [NOTE THE PALMAR ASPECT OF THE LIMB IS DISPLAYED TO THE TOP AND THE DORSAL ASPECT IS DISPLAYED TO THE LEFT OF THESE IMAGES. THE REMAINDER OF THE ILLUSTRATIONS OF LONGITUDINAL ULTRASONOGRAMS ARE DISPLAYED IN THE SAME WAY UNLESS OTHERWISE INDICATED].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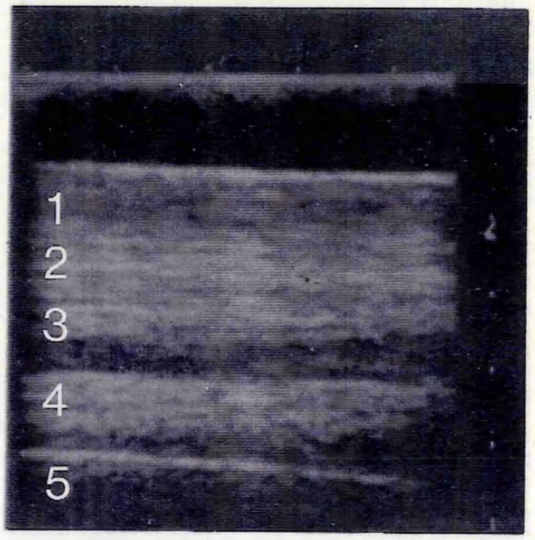
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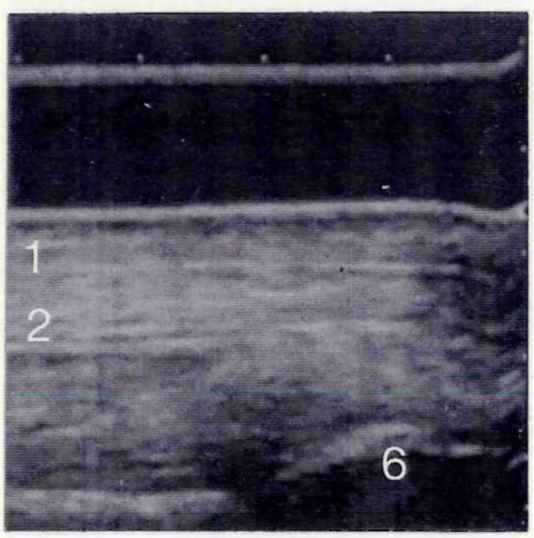
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FIG. 2.3. A LONGITUDINAL SECTION OF THE ANATOMY OF THE METACARPAL REGION. THE SUPERFICIAL DIGITAL FLEXOR TENDON (1), THE DEEP DIGITAL FLEXOR TENDON (2), THE ACCESSORY LIGAMENT OF THE DEEP DIGITAL FLEXOR TENDON (3), THE SUSPENSORY LIGAMENT (4), ARE LOCATED ON THE PALMAR ASPECT OF THE METACARPAL BONE (5) AND THE FLEXOR TENDONS COURSE DISTALLY OVER THE PROXIMAL SESAMOIDS (6) TO THEIR INSERTIONS ON THE PHALANGES.

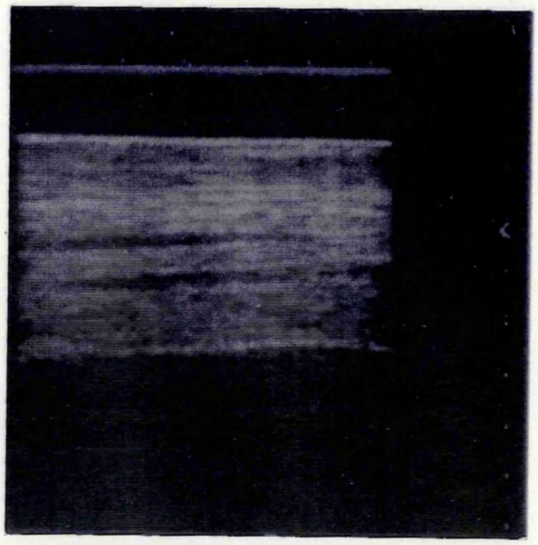

1
2
3
4
5
6

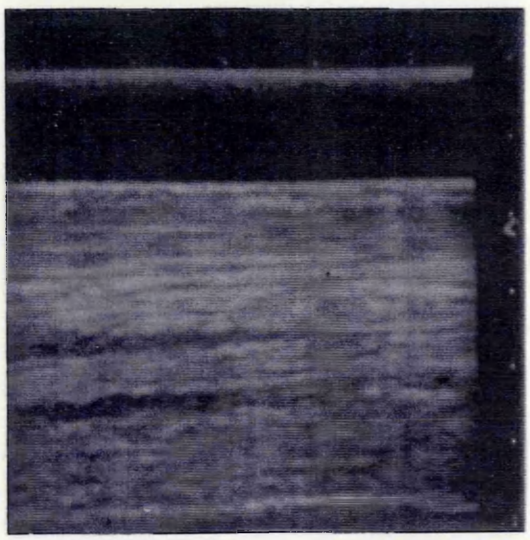
The superficial and deep digital flexor tendons had a moderate echogenicity and the overall echogenicity of the superficial digital flexor tendon and deep digital flexor tendon was either similar or the superficial digital flexor tendon was slightly less echogenic than the deep digital flexor tendon (Figs. 2.2 and 2.4). The superficial digital flexor tendon was never more echogenic than the deep digital flexor tendon. However, the echogenicity of the tendon was dependent on the gain settings which were utilised.

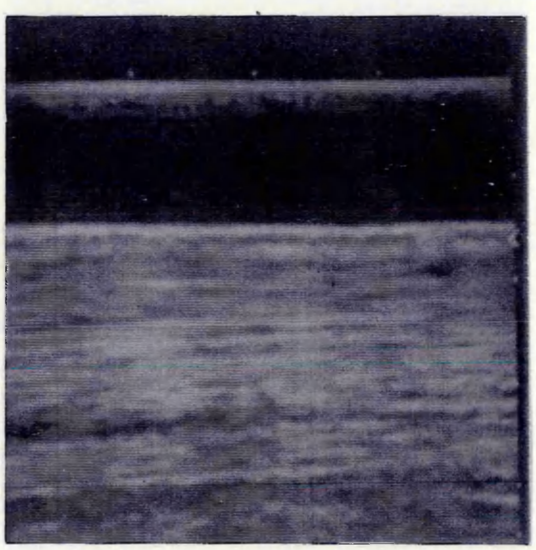
The flexor tendons were composed of multiple linear echoes (Figs. 2.2 and 2.4). These linear echoes were generally extremely echogenic and appeared to run for distances of several centimetres although it was not possible to identify and trace any particular one. Magnification of the images generally made the linear arrangement of these echoes easier to appreciate (Fig. 2.4).

The overlying skin and subcutaneous tissue lacked such a multi-linear appearance and were represented by a uniform area with a similar overall echogenicity (Figs. 2.2 and 2.4). This similarity in echogenicity meant that in many individuals the precise boundary between the superficial digital flexor tendon and the subcutaneous tissue could not be imaged with confidence. Similarly, the precise boundary between the superficial digital flexor tendon and deep digital flexor tendon was indistinct in many horses.

FIG. 2.4. NORMAL LONGITUDINAL ULTRASONOGRAMS OF THE PALMAR METACARPAL REGION: THE LINEAR ECHOES WHICH REPRESENT THE SUPERFICIAL AND DEEP FLEXOR TENDON CAN BE APPRECIATED MORE READILY IN MAGNIFIED IMAGES (MIDDLE AND LOWER).







The accessory ligament of the deep digital flexor tendon was also composed of regularly arranged linear echoes and had a similar or greater overall echogenicity when compared to the flexor tendons. Its shape, in longitudinal images was a tapering triangle (Fig. 2.2). In the proximal regions it was clearly delineated from the overlying deep digital flexor tendon by an anechoic area representing fluid within the carpal sheath. Distally, it became more closely opposed to the deep digital flexor tendon and it was indistinguishable in most horses at approximately 200 mms distal to the accessory carpal bone (Fig. 2.2).

The origin of the suspensory ligament at the distal carpal proximal metacarpal bones could be identified and in images made from the palmar aspect this structure was apparent dorsal to the check ligament in the proximal and mid metacarpal regions. In the distal metacarpal region it could not be appreciated from the palmar aspect of the limb. The overall echogenicity of the suspensory ligament was generally similar to the other palmar metacarpal soft tissue structures although the arrangement of the linear echoes was not as regular. However, in this study the main aim was to image the flexor tendons and, therefore, a short focus transducer with an echolucent stand-off pad was utilised which did not provide optimum images of the suspensory ligament.

The palmar contour of the metacarpal bone was represented by an echogenic structure with acoustic shadows dorsal to it (Figs. 2.2 and 2.4). The proximal sesamoids were represented by similar echogenic areas with acoustic shadows and their curved palmar surface was reflected in the shape of these echogenicities (Fig. 2.2).

In transverse images the superficial digital flexor tendon had a variable shape. In proximal images, the tendon was a roughly oval shape in which it was most rounded in its medial region (Fig. 2.5). It became progressively flattened in a dorsal to palmar direction and enlarged laterally to medially in distal images (Figs. 2.6, 2.7, 2.8).

Its echogenicity was fairly uniform but occasionally more hyperechoic and hypoechoic areas were observed. These had irregular shapes and no distinct outlines and did not persist as the transducer was moved proximally or distally. The overall echogenicity of the superficial digital flexor tendon was similar to or less than that of the deep digital flexor tendon.

The border between the superficial and deep digital flexor tendon was quite distinct in most images. Occasionally, particularly if the echogenicity of the two tendons was identical, the border was not clear.

The deep digital flexor tendon also had a fairly uniform echogenicity with irregular variations. The border between it and the dorsally-placed accessory ligament was distinct in the proximal metacarpal region where an anechoic area was frequently observed which

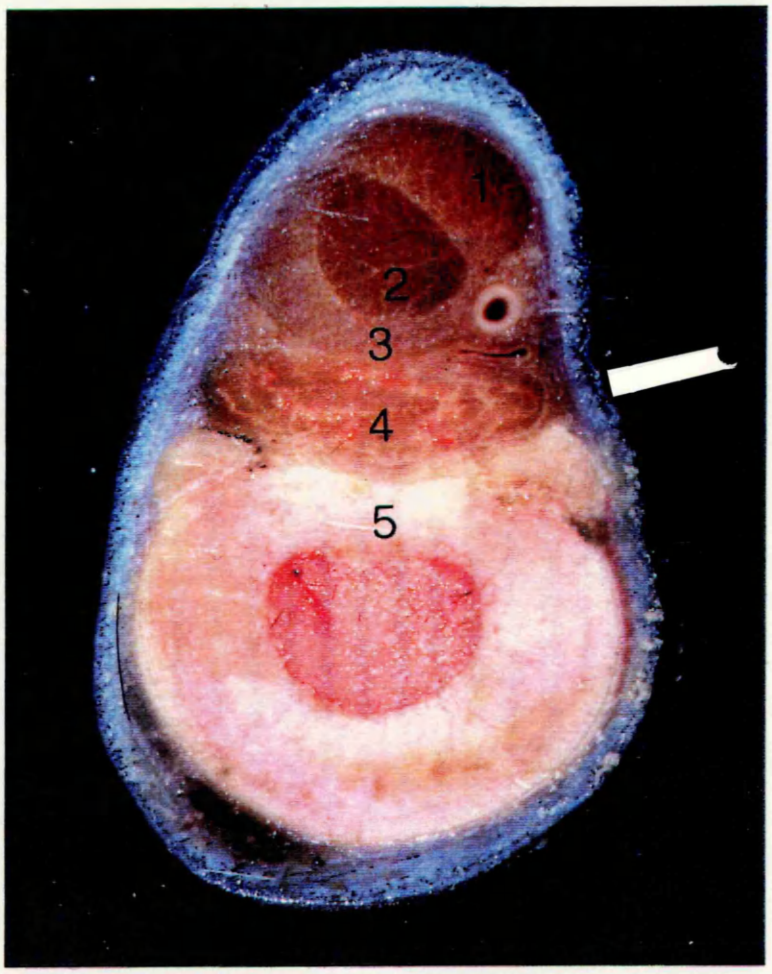
FIG. 2.5. THE TRANSVERSE GROSS AND ULTRASONOGRAPHIC ANATOMY OF THE PROXIMAL METACARPAL REGION, 60 MMS DISTAL TO THE ACCESSORY CARPAL BONE.

FROM THE PALMAR ASPECT THE SUPERFICIAL DIGITAL FLEXOR TENDON (1), THE DEEP DIGITAL FLEXOR TENDON (3), THE ACCESSORY LIGAMENT OF THE DEEP DIGITAL FLEXOR TENDON (3), AND THE SUSPENSORY LIGAMENT (4) CAN BE VISUALISED LYING PALMAR TO THE METACARPAL BONE (5).

THE SUPERFICIAL DIGITAL FLEXOR TENDON IS ROUNDED ON ITS MEDIAL ASPECT AND THE TENDONS AND THE ACCESSORY LIGAMENT OF THE DEEP DIGITAL FLEXOR TENDON HAVE AN EVEN ECHOGENICITY. THE DORSAL ASPECT OF THE SUSPENSORY LIGAMENT HAS AN ARTIFACT PRODUCED BY OFF-NORMAL INCIDENCE.

THE CARPAL SHEATH (6) IS REPRESENTED BY AN ANECHOIC AREA BETWEEN THE DEEP DIGITAL FLEXOR TENDON AND ITS ACCESSORY LIGAMENT.

[NOTE: THE PALMAR ASPECT IS DISPLAYED TO THE TOP OF THESE ILLUSTRATIONS AND THE MEDIAL ASPECT IS DISPLAYED TO THE RIGHT, THE REMAINDER OF THE ILLUSTRATIONS OF TRANSVERSE ULTRASONOGRAMS IN THIS DISSERTATION ARE DISPLAYED WITH THE SAME ORIENTATION UNLESS INDICATED]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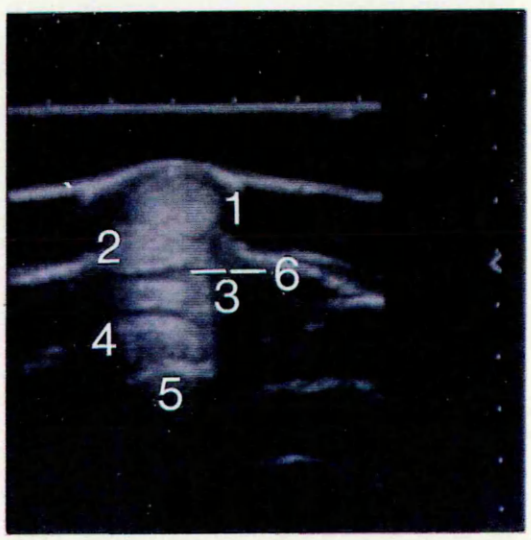
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FIG. 2.6. A SERIES OF TRANSVERSE ULTRASONOGRAMS MADE AT 20 MM INTERVALS FROM 80 (UPPER LEFT) TO 180 (LOWER RIGHT) MMS DISTAL TO THE ACCESSORY CARPAL BONE.

THE SUPERFICIAL DIGITAL FLEXOR TENDON BECOMES PROGRESSIVELY ENLARGED IN A LATERAL TO MEDIAL PLANE AND PROGRESSIVELY DECREASED IN A DORSAL TO PALMAR PLANE IN THE DISTAL IMAGES. THE ECHOGENICITY OF THE SUPERFICIAL DIGITAL FLEXOR TENDON IS FAIRLY UNIFORM ALTHOUGH THERE ARE SLIGHT IRREGULAR VARIATIONS THROUGHOUT ITS CROSS-SECTION.

IN THE IMAGES 140 (MIDDLE LEFT), 160 (MIDDLE RIGHT) AND 180 (LOWER LEFT) MMS DISTAL TO THE ACCESSORY CARPAL BONE THE MEDIAL DIGITAL VESSELS ARE REPRESENTED BY ANECHOIC CIRCULAR STRUCTURES (>>).

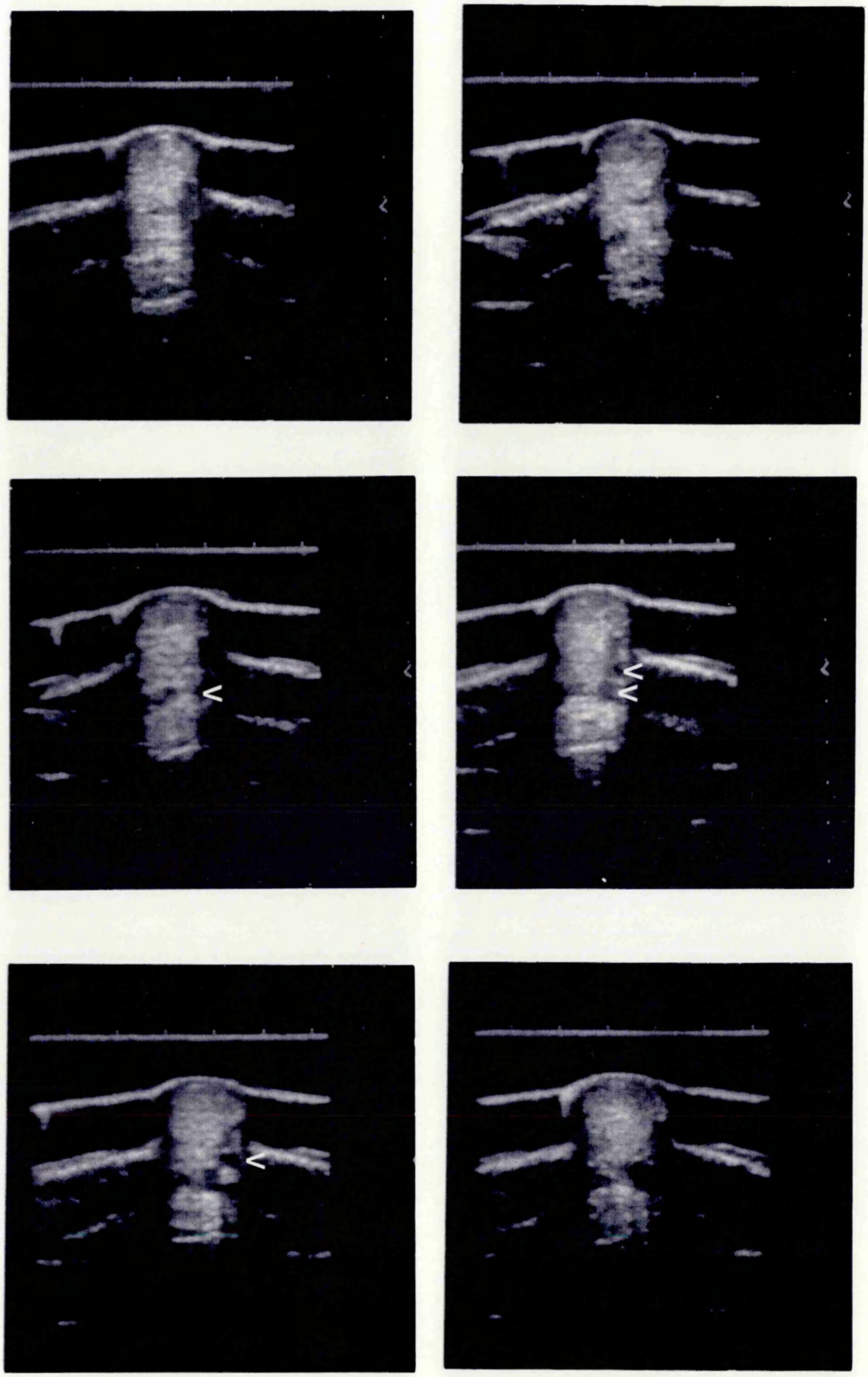


FIG. 2.7. A SERIES OF TRANSVERSE ULTRASONOGRAMS MADE AT 20 MMS INTERVALS FROM 200 (UPPER LEFT) TO 260 (LOWER RIGHT) MMS DISTAL TO THE ACCESSORY CARPAL BONE. THE SUPERFICIAL DIGITAL FLEXOR TENDON BECOMES PROGRESSIVELY ENLARGED IN A LATERAL TO MEDIAL PLANE AND PROGRESSIVELY DECREASED IN A DORSAL TO PALMAR PLANE IN THE DISTAL IMAGES.

IN THE IMAGE MADE 260 MMS DISTAL TO THE ACCESSORY CARPAL BONE (LOWER RIGHT) THE RING FORMED BY THE SUPERFICIAL DIGITAL FLEXOR TENDON IS REPRESENTED BY AN ECHOGENIC LINEAR STRUCTURE (>>)

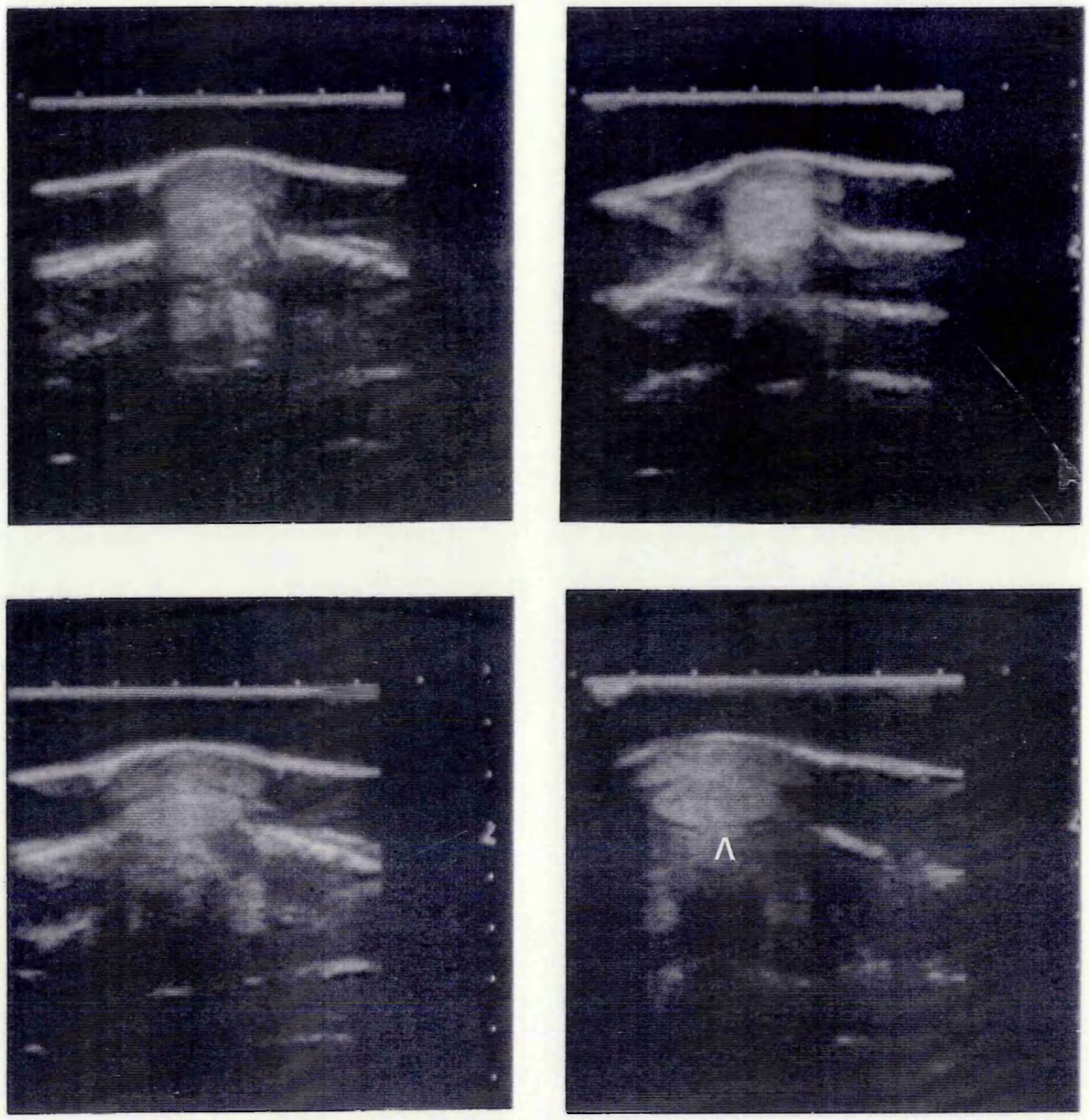
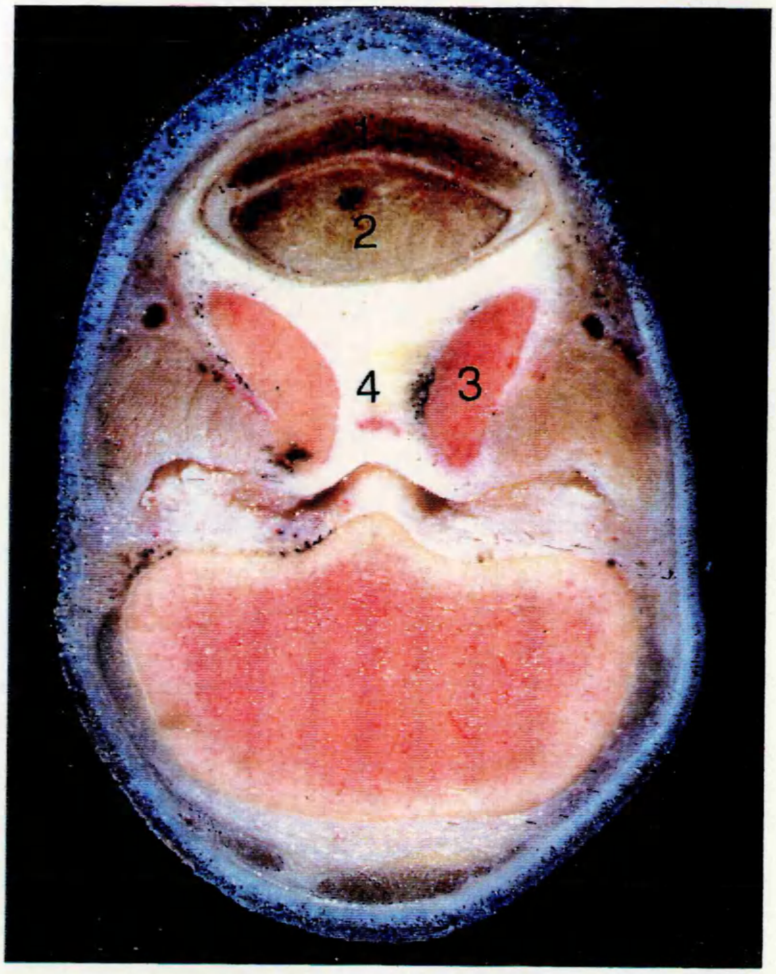


FIG. 2.8. A TRANSVERSE ANATOMICAL SPECIMEN AT THE LEVEL OF THE METACARPOPHALANGEAL JOINT AND TRANSVERSE ULTRASONOGRAMS RECORDED 280 MMS (LOWER LEFT) AND 300 MMS (LOWER RIGHT) DISTAL TO THE ACCESSORY CARPAL BONE.

THE SUPERFICIAL (1) AND DEEP (2) DIGITAL FLEXOR TENDONS LIE PALMAR TO THE PROXIMAL SESAMOIDS (3) WHICH ARE CONNECTED BY THE INTERSESAMOIDEAN LIGAMENT (4).

THE DIGITAL SHEATH IS REPRESENTED BY AN ECHOGENIC LINEAR STRUCTURE BETWEEN THE PALMAR ASPECT OF THE SUPERFICIAL DIGITAL FLEXOR TENDON AND THE SKIN/ECHOLUCENT STAND-OFF BLOCK INTERFACE (LOWER LEFT, >>). IN THE PALMAR REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON A SMALL HYPOECHOIC AREA IS FREQUENTLY OBSERVED AT THE SAME LEVEL.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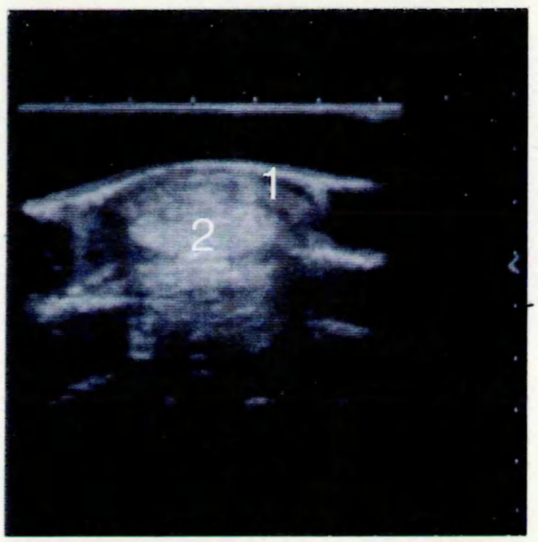
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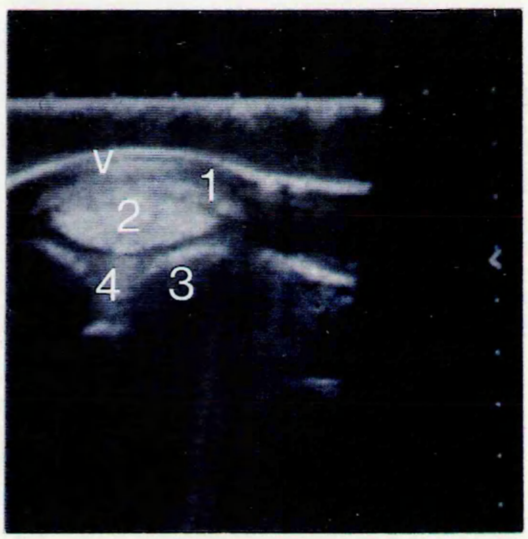
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represented fluid within the carpal sheath. More distally, the accessory ligament became confluent with the deep digital flexor tendon and this was usually complete at approximately the same level as the bifurcation of the suspensory ligament, 200 to 220 mms distal to the accessory carpal bone.

The common digital vessels produced anechoic circular areas medial to the accessory ligament of the deep digital flexor tendon and in real-time the pulsations of the artery could sometimes be appreciated.

In the most distal images, 260 to 280 mms distal to the accessory carpal bone, the ring formed by the superficial digital flexor tendon around the deep digital flexor tendon could be discerned (Fig. 2.7). In this area a hypoechoic region was present dorsal to the tendons produced by the fibrocartilage of the metacarpophalangeal joint (Fig. 2.8) The contour of the proximal sesamoids could be imaged in the most distal images and they were represented by two bird wing-shaped structures (Fig. 2.8). The intersesamoidean ligament produced a hypoechoic area between the sesamoids (Fig. 2.8). At this location, the digital sheath could occasionally be observed arising from the palmar mid-line of the superficial digital flexor tendon (Fig. 2.8). This was represented by a hypoechoic area dorsal to the skin/echolucent stand-off interface. At this point, there was frequently a slightly hypoechoic area on the dorsal aspect of the superficial digital flexor tendon (Fig. 2.8).

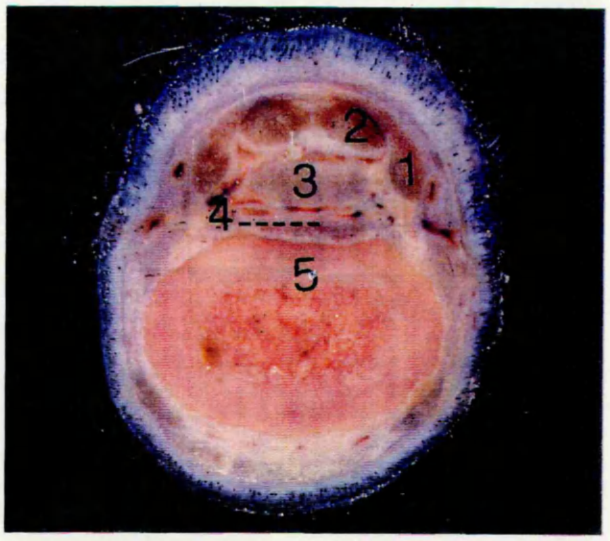
Distal to the metacarpophalangeal joint transverse images of the palmar soft tissue structures could be obtained readily in normal horses. The following structures could be identified: the superficial and deep digital flexor tendons and the straight and oblique sesamoidean ligaments. Each individual structure had to be imaged separately to avoid off-normal incidence artifacts. From the palmar aspect of the limb a thin slip of the superficial digital flexor could be appreciated proximal to its bifurcation (Fig. 2.9) but in this region the majority of the tendon lay lateral and medial as it coursed to its insertions on the distal aspect of the first phalanx and proximal aspect of the second phalanx. Consequently, in this region the superficial digital flexor tendon was best imaged from the lateral and medial aspects of the palmar phalangeal region where it was represented by oval structures with even echogenicity. The deep digital flexor tendon had either an oval shape or more distally a dumbbell shape. Swinging the transducer in an arc from a distal and dorsal to a proximal and dorsal orientation resulted in the deep digital flexor becoming more echogenic as the optimum imaging plane was obtained. This was usually with the sound beam directed at an angle approximately 10 - 15^{o} dorsal to the transverse plane (Fig. 2.9). This procedure also influenced which components of the sesamoidean ligaments could be identified. The straight

FIG. 2.9. A TRANSVERSE ANATOMICAL SPECIMEN AND FOUR ULTRASONOGRAMS MADE IN THE MID FIRST PHALANGEAL REGION. THE MAJORITY OF THE SUPERFICIAL DIGITAL FLEXOR TENDON (1) LIES LATERAL AND MEDIAL TO THE DEEP DIGITAL FLEXOR TENDON (2) WHICH HAS A DUMBBELL SHAPE IN TRANSVERSE SECTION. THE STRAIGHT (3) AND OBLIQUE (4) SESAMOIDEAN LIGAMENTS ARE LOCATED DORSAL TO THE FLEXOR TENDONS AND PALMAR TO THE FIRST PHALANX (5).

IT IS NOT POSSIBLE TO IMAGE ALL THE SOFT TISSUE STRUCTURES IN THIS AREA SIMULTANEOUSLY AND OBLIQUE IMAGES ARE USEFUL. THE UPPER LEFT IMAGE IS A MID LINE TRANSVERSE ULTRASONOGRAM AND THE CENTRAL PORTIONS OF THE SUPERFICIAL (1) AND DEEP (2) FLEXOR TENDONS AND THE STRAIGHT AND OBLIQUE SESAMOIDEAN LIGAMENTS ARE APPARENT.

FROM THE SAME LOCATION AND BY DIRECTING THE ULTRASONOGRAPHIC BEAM CRANIO-DORSALLY AS DEMONSTRATED IN THE UPPER RIGHT IMAGE, THE DEEP DIGITAL FLEXOR TENDON (2) AND STRAIGHT SESAMOIDEAN LIGAMENT CAN BE IMAGED MORE CLEARLY.

LATERAL (LOWER LEFT) AND MEDIAL (LOWER RIGHT) OBLIQUE IMAGES ALLOW THE INSERTIONS OF THE SUPERFICIAL DIGITAL FLEXOR TENDON (1) AND THE OBLIQUE SESAMOIDEAN LIGAMENT (4) TO BE IMAGED MORE CLEARLY.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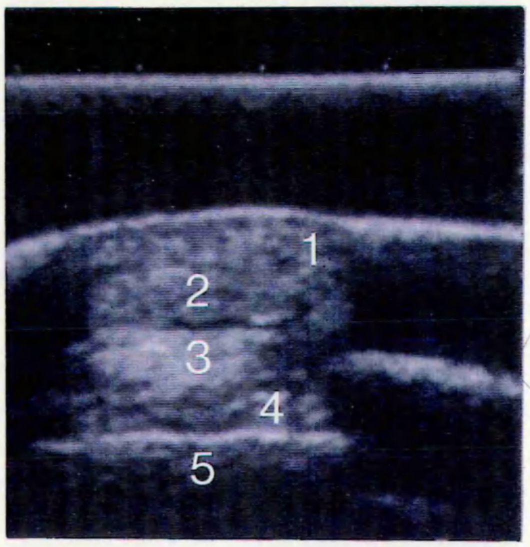
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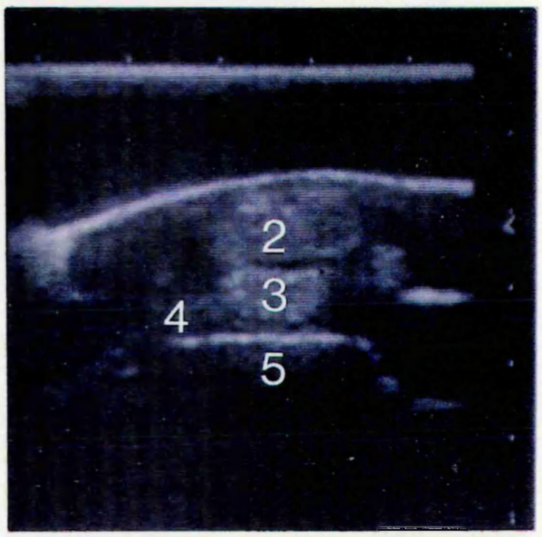
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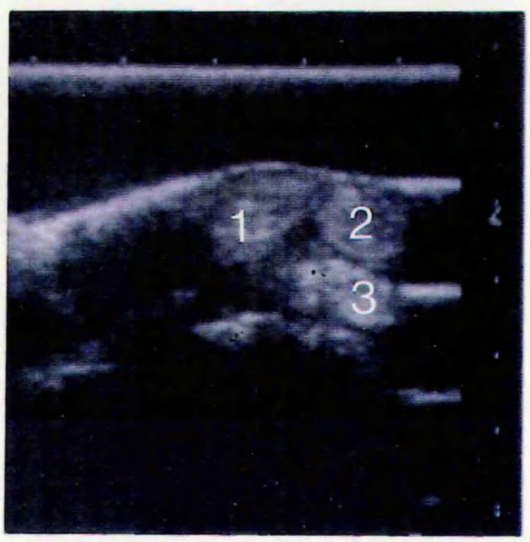
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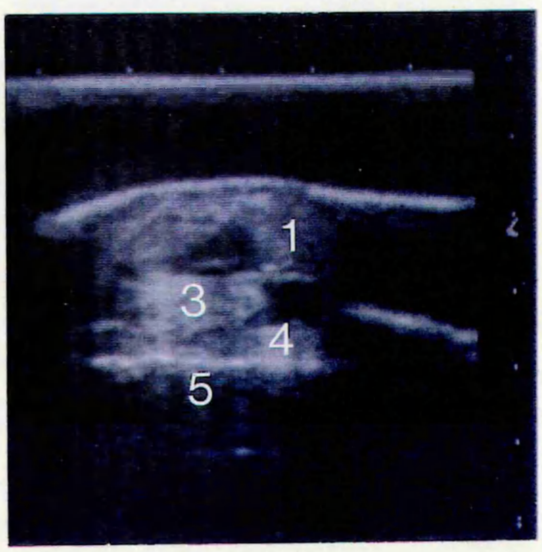
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sesamoidean ligament was imaged most clearly in a slightly more caudal plane than the deep digital flexor tendon when the sound beam was slightly dorsally orientated. The oblique sesamoidean ligaments were triangular structures which similarly could only be imaged in certain planes and were often best seen in oblique images. In the planes in which these structures were not clearly defined they were represented by hypoechoic areas.

Artifact Production.

A number of ultrasonographic artifacts were recognised frequently. Careful preparation of the limb and removal of the hair was critical to the production of adequate images. Reverberation artifacts were often produced at the interface between the skin and echolucent stand-off block and these produced a series of parallel, equidistant echogenic lines (Fig. 2.10). This could be avoided by careful removal of the hair, the application of copious echolucent gel and water, and exertion of reasonable pressure on the transducer to eliminate air between the limb and the stand-off block. Hypoechoic areas could be produced within the tendons and ligaments if the sound beam was not orientated correctly (Fig. 2.10). These off-normal incidence artifacts could be eliminated by rocking the transducer in an arc proximally and dorsally in transverse images or in an arc from medial to lateral in longitudinal images until the optimum image was obtained. The ideal imaging plane was not identical for each structure and for this reason each structure had to

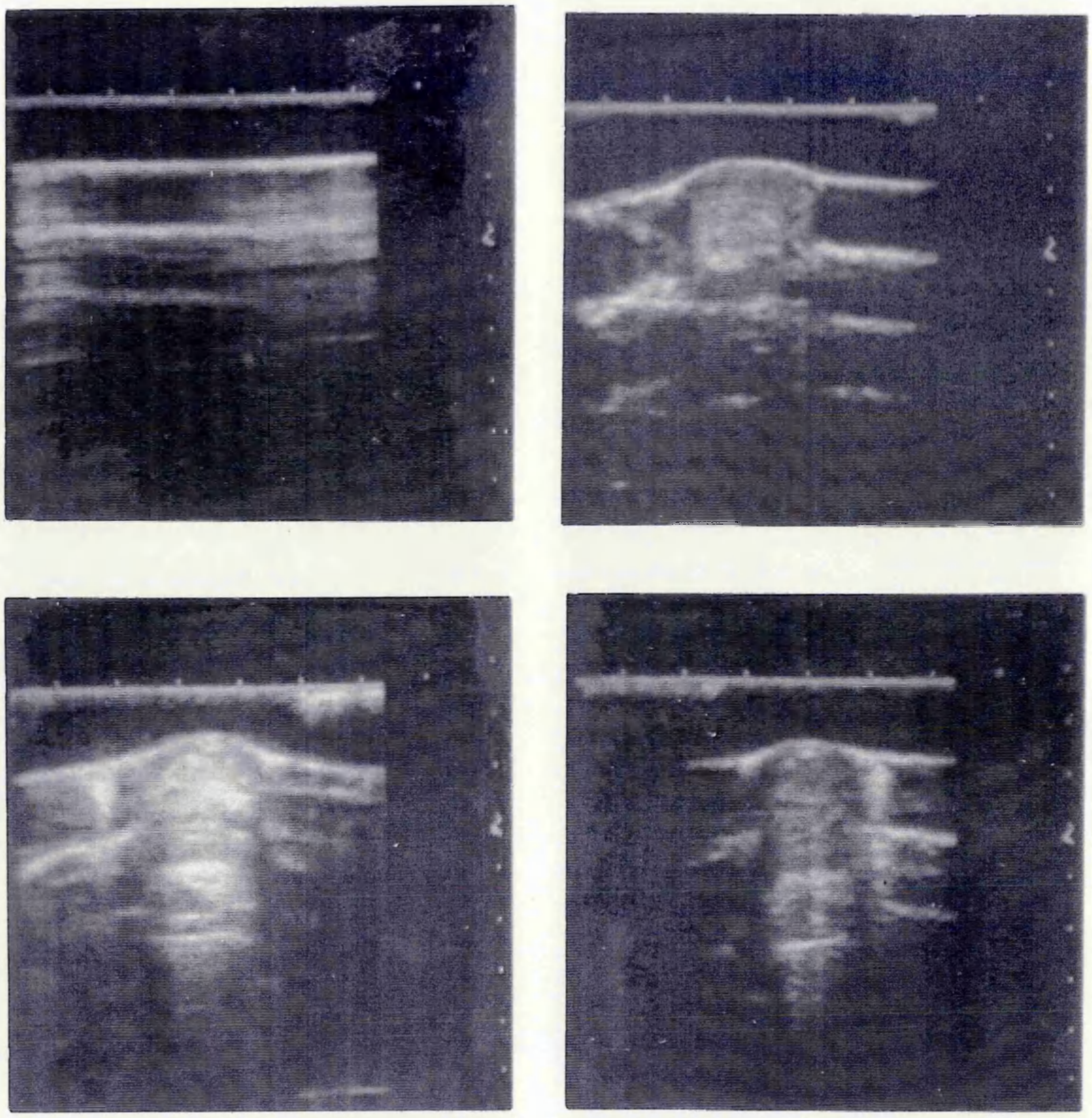
FIG. 2.10. ULTRASONOGRAPHIC ARTIFACTS WHICH ARE FREQUENTLY ENCOUNTERED WHEN IMAGING THE FLEXOR TENDONS AND ASSOCIATED STRUCTURES.

THE UPPER LEFT IMAGE DEMONSTRATES A REVERBERATION ARTIFACT PRODUCED BY THE INTERFACE BETWEEN THE STAND-OFF BLOCK AND THE SKIN SURFACE.

THE UPPER RIGHT IMAGE DEMONSTRATES OFF-NORMAL INCIDENCE ARTIFACTS IN THE SUPERFICIAL AND DEEP DIGITAL FLEXOR TENDONS WHICH HAVE RESULTED IN HYPOECHOIC CENTRAL REGIONS WITH MORE ECHOGENIC PERIPHERIES.

IN THE LOWER LEFT IMAGE THE OVERALL GAIN SETTING IS TOO HIGH SO THAT THE DETAIL OF THE TENDONS IS OBSCURED BY EXTRANEOUS ECHOES.

IN THE LOWER RIGHT IMAGE THE NEAR FIELD TIME GAIN COMPENSATION IS SET TOO LOW SO THAT THE FLEXOR TENDONS ARE HYPOECHOIC WHEN COMPARED TO THE PALMAR ASPECT OF THE SUSPENSORY AND THERE IS AN OFF-NORMAL INCIDENCE ARTIFACT WHICH HAS PRODUCED AN HYPOECHOIC REGION IN THE DORSAL ASPECT OF THE SUSPENSORY LIGAMENT. IN THIS IMAGE THERE IS INSUFFICIENT CONTACT BETWEEN THE TRANSDUCER AND THE MEDIAL AND LATERAL ASPECTS OF THE LIMB SO THAT THE MEDIAL AND LATERAL PORTIONS OF THE TENDONS AND LIGAMENTS ARE NOT IMAGED.



be imaged separately. This problem occurred most frequently in transverse images in the proximal metacarpal region, where the superficial digital flexor tendon and suspensory ligament, and in the distal metacarpal region, where the superficial and deep digital flexor tendons could rarely be imaged well simultaneously and in the phalangeal region where each structures had to be imaged in isolation. In the longitudinal images artifacts occurred most frequently in the proximal metacarpal region where the plane which produced the best images of the superficial digital flexor tendon rarely produced good images of the accessory ligament of the deep digital flexor tendon or the suspensory ligament.

An appropriate power output had to be selected to produce images in which the detail was not obscured by extraneous sound or in which the echoes were of insufficient amplitude to be displayed clearly (Fig. 2.10). Similarly, the time gain compensation had to be set carefully to avoid either increased or decreased brightness of the near field relative to the remainder of the image (Fig. 2.10).

Quantitative Assessment Of The Ultrasonographic Appearance Of the Flexor Tendons.

The dorsal to palmar and lateral to medial dimensions of the superficial and deep digital flexor tendons at each location in each individual are listed in Appendix 2.1 with the ages, sexes, weights and heights of these animals and the mean and standard deviations of each recorded parameter. The means and ranges of the dorsal to palmar and lateral to medial dimensions of the superficial and deep digital flexor tendons of the fore limbs at the 12 recorded locations in this group of 25 normal horses are presented in Table 2.1. The superficial digital flexor tendon was widest from dorsal to palmar in the proximal metacarpal region and from lateral to medial in the distal metacarpal region as was appreciated in the qualitative analysis. The deep digital flexor tendon was narrowest from dorsal to palmar in the mid metacarpal region were it was also narrowest from lateral to medial. It was largest both from its lateral to medial borders and from its dorsal to palmar borders in images obtained in the distal metacarpal region.

Few of the correlation coefficients which were obtained when pairs of the variables were related were greater than 0.4. Those groups that did have correlation coefficients greater than 0.4 are listed with their correlation coefficients in Table 2.2. Further, there ere no pairs of variables which were related consistently throughout the limb and, therefore, it was not possible to obtain linear relationships between the dimensions of the superficial digital flexor tendon and the age, height or weight of the horse which were closely correlated in several locations. Surprisingly, the correlation between the dorsal to palmar dimension

	DDFT		SDFT	
	[mean DP (mms) x mean LM (mms)]	range	[mean DP (mms) x mean LM (mms)]	range
60mmDAC	8.66 x 13.06	7.00 - 11.50, 9.00 - 16.00	6.14 x 15.30	5.00 - 8.00, 10.50 - 18.00
80mmDAC	8.40 x 12.80	6.50 - 11.50, 10.50 - 18.00	6.16 x 15.48	4.00 - 9.00, 12.00 - 21.00
100mmDAC	8.76 x 12.80	6.50 - 11.50, 10.50 - 18.00	5.90 x 15.50	5.00 - 9.00, 12.00 - 20.00
120mmDAC	8.40 x 12.60	6.50 - 11.50, 9.00 - 18.00	5.75 x 16.30	5.00 - 8.00, 13.50 - 21.00
140mmDAC	7.98 x 11.90	6.00 - 10.00, 9.00 - 18.00	5.69 x 16.30	4.00 - 7.50, 13.50 - 21.00
160mmDAC	8.56 x 12.61	6.50 - 11.50, 9.00 - 15.00	5.34 x 16.96	3.00 - 8.00, 12.00 - 21.00
180mmDAC	8.92 x 12.14	7.00 - 11.50, 10.00 - 15.00	5.01 x 17.85	3.50 - 7.00, 13.50 - 22.5
200mmDAC	9.53 x 13.70	6.50 - 11.50, 12.00 - 16.50	5.02 x 18.75	3.00 - 7.50, 13.50 - 22.50
220mmDAC	10.60 x 15.0	6.00 - 14.00, 11.00 - 21.00	4.38 x 21.33	3.00 - 6.00, 18.00 - 27.00
240mmDAC	10.69 x 16.8	8.50 - 12.00, 14.00 - 23.00	4.05 x 23.32	3.00 - 6.00, 16.50 - 31.50
260mmDAC	10.75 x 19.6	8.50 - 12.00, 15.00 - 26.00	3.90 x 26.80	3.00 - 7.00, 21.00 - 32.00
280mmDAC	10.58 x 22.5	8.50 - 13.00, 18.00 - 28.50	3.41 x 29.10	2.50 - 5.00, 25.50 - 30.00

DDFT = deep digital flexor tendon
SDFT = superficial digital flexor tendon
DP = dorsal to palmar dimension
LM = lateral to medial dimension
mmDAC = millimeters distal to the accessory carpal bone

TABLE 2.1. THE MEANS AND RANGES OF THE DORSAL TO PALMAR AND LATERAL TO MEDIAL DIMENSIONS OF THE DIGITAL FLEXOR TENDONS OF THE FORE LIMBS IN A GROUP OF TWENTY-FIVE NORMAL HORSES WITH A MEAN AGE OF 11.44, A MEAN HEIGHT OF 16 h.h. AND A MEAN WEIGHT OF 510 kgs.

LOCATION (mms dacb)	PAIRS OF VARIABLES	CORRELATION COEFFICIENTS
60	AGE, SDP	0.547*
60	AGE, SLM	-0.774*
60	AGE, DLM	-0.603*
60	DDP, DLM	-0.472#
100	MCW, DDP	-0.453*
140	MCW, SLM	0.440*
140	MCW, DLM	0.414*
140	SLM, DLM	-0.621*
160	DDP, DLM	0.683*
180	CIRC, DLM	0.406*
180	MCW, DLM	0.408*
200	HEIGHT, DLM	0.413*
200	WEIGHT, DLM	0.550*
200	DDP, DLM	0.728*
220	SDP, DLM	-0.431*
240	MCW, SDP	0.448*
240	DDP, DLM	0.691*
260	WEIGHT, SDP	-0.437*
260	WEIGHT, DDP	0.404*
260	WEIGHT, DLM	0.583*
260	SLM, DLM	0.810*
280	WEIGHT, SDP	-0.437*
280	WEIGHT, SLM	0.404*
280	WEIGHT, DLM	0.583*
280	SLM, DLM	0.810*
300	HEIGHT, SLM	0.447*
300	WEIGHT, SLM	0.453*
300	WEIGHT, DLM	0.493*
300	CIRC, DLM	0.432*
300	SDP, SLM	-0.422*
300	SLM, DLM	-0.492*

dacb = distal to the accessory carpal bone
S/DDP = dorsal to lateral dimension of the superficial/deep digital flexor.
S/DLM = lateral to medial dimension of the superficial/deep digital flexor tendon.
CIRC = circumference of limb
MCW = lateral to medial dimension of the metacarpal bone and overlying soft tissue.
* = significant at $p < 0.01$
# = significant at $p < 0.05$

TABLE 2.2. THE LOCATION AND CORRELATION COEFFICIENTS OF PAIRED VARIABLES IN TWENTY FIVE NORMAL HORSES.

and the lateral to medial dimension of the superficial digital flexor tendon was not close at many locations with the exception being at the point 300 mms distal to the accessory carpal bone where the correlation co-efficient between these variables was 0.422. Equally, there was no close correlation between the dorsal to palmar dimension and lateral to medial dimensions of the deep digital flexor tendons at any location with the exceptions of the points 60 mms 160 mms, 200 mms, and 240 distal to the accessory carpal bone. The lateral to medial dimensions of the superficial and deep digital flexor tendons had correlation coefficients greater than 0.4 at the points 140 mms, 260 mms, 280 mms and 300 mms distal to the accessory carpal bone.

SECTION 2.3: DISCUSSION.

The aim of the preliminary study (Part 2.1) was merely to become familiar with the normal ultrasonographic appearance of the palmar metacarpal area and, in this respect, it was successful. The poor quality of the ultrasonograms obtained suggested that further study of cadavers was unlikely to prove fruitful.

The ultrasonographic appearance of the soft tissue structures of the palmar aspect of the metacarpal region in these horses was similar to that which has been described previously (Hauser and Rantanen, 1983; Spaulding, 1984; Pharr and Nyland, 1984; Hauser, 1986). Quantitative data on the dimensions of the flexor tendons were obtained and the dimensions recorded in the ultrasonograms obtained from this group were similar to, but not identical to, those reported previously (Genovese and others, 1986). It was not possible to consistently relate pairs of variables throughout the limb, although significant relationships were established in a variety of the pairs of parameters which were investigated. Neither the height nor the weight of the horse influenced the dimensions of the flexor tendons and, similarly, the dimensions of the limb and the metacarpal bone and, as was anticipated in a group of adults, the age of the animal had no influence on the size of the flexor tendons.

The size and shape of the digital flexor tendons varied as they coursed distally, with the superficial digital flexor tendons becoming progressively narrower in their dorsal to palmar dimension and wider in their lateral to medial dimension, and the deep digital flexor tendon being narrowest in both planes in the mid metacarpal region (Figs. 2.5 to 2.8). These variations appeared to be consistent between individuals. These ultrasonographic shapes corresponded with those that have been recognised in anatomical studies of the flexor tendons (Webbon, 1973; Riemersma and Schamhardt, 1985; Riemersma and De Bruyn, 1986). In view of this finding, it was surprising that significant correlations could not be identified between the lateral to medial dimensions and the dorsal to palmar dimensions consistently.

The ultrasonographic appearance of the soft tissue structures of the palmar aspect of the equine digit have been described in brief (McClellan and Colby, 1986). These authors indicated that the straight, oblique and inter-seamoidean ligaments, the superficial and deep digital flexor tendons, the distal digital sheath, the palmar digital vessels, the proximal interphalangeal joint, the navicular bursa, the proximal surface of the navicular bone and the navicular ligament could be identified with an ultrasonographic unit equipped with a sector transducer. These structures could not all be located in this study in which a linear array transducer was employed. Only transverse images were satisfactory distal to the metacarpophalangeal joint in these normal horses and the bulk of the transducer limited the accessibility between the bulbs of the heels, such that the navicular area was not identified. Equally, the proximal interphalangeal joint could not be assessed readily on transverse images. However, excellent images of the flexor tendons, the sesamoidean ligaments and the digital sheath and palmar digital vessels could be obtained, providing each structure was imaged separately so that the optimum imaging plane, at ninety degrees to the long axis of the structure, was identified.

The reverberation and off-normal incidence artifacts which were observed frequently were those that have been reported previously in both equine and human tendons (Colby, 1985; Fornage, 1987; Fornage, 1989a). Reverberation artifacts could be avoided by careful preparation of the limb and application of copious echolucent gel. Shaving of the limb was preferred in this study although opinion as to whether this is necessary is divided: Pharr and Nyland (1984) concluded that poor quality images were obtained if the hair coat was not removed but that shaving rather than clipping the hair did not justify the extra time required to prepare the limb. Subsequently, shaving of the hair has been recommended (Henry and others, 1986; Genovese and others, 1987).

Off-normal incidence artifacts resulting in false hypoechoic or anechoic areas occur commonly in situations where large, specular echoes are produced as non-specular echoes are multi-directional and a proportion of these should reach the transducer regardless of its orientation (Shirley and others, 1978; Bartrum and Crow, 1983; Powis and Powis, 1984; see also Fig. 1.4). In the longitudinal planes, specular echoes can be anticipated where the long collagen bundles are likely to produce specular echoes but in transverse planes, the tissue interfaces within tendon are small and, therefore, only non-specular echoes are expected. Nevertheless, off-normal incidence artifacts were observed frequently in transverse images if the sound beam was not perpendicular to the axis of the structure under investigation. Each soft tissue structure in the palmar aspect of the limb had a slightly different orientation of the long axis, particularly in a dorsal to palmar plane, in the proximal and distal thirds of the metacarpal region and distal to the metacarpophalangeal joint. For this reason, optimum imaging planes were obtained by visualising each structure separately.

The aim of this study was to develop a suitable technique for ultrasonographic examination of the soft tissue structures of the palmar aspect of the equine limb using an ultrasonographic unit equipped with a 7.5 MHz linear array transducer and a separate echolucent, stand-off pad. A suitable method was developed and adequate images could be obtained providing care was taken to find the most effective imaging plane. The normal ultrasonographic appearance of these structures had been described previously but qualitative information was obtained which had not been reported in detail in the past.

CHAPTER 3.

CLINICAL, ULTRASONOGRAPHIC, MACROSCOPIC AND HISTOPATHOLOGICAL STUDIES ON SUPERFICIAL DIGITAL FLEXOR INJURY IN THE HORSE.

SECTION 3.1. INTRODUCTION AND AIMS OF THE STUDY.

Ultrasonography is an extremely useful aid in the diagnosis of soft tissue injury, and has been adopted by equine veterinarians for the assessment and monitoring of tendon injury (Rantanen and others, 1983; Hauser and others, 1984; Spaulding, 1984; Genovese and others, 1985; Rantanen and others, 1985; Genovese and others, 1986; Genovese and others, 1987; Reef, Martin and Elser, 1988). While it has frequently been stated that ultrasonographic findings reflect the age and stage of healing of lesions, few studies have been undertaken with the aim of correlating histological and ultrasonographic findings and establishing to what extent the ultrasonographic changes were representative of the exact nature of the lesions (Henry and others, 1986; Reef and others, 1988).

The purpose of this study was to document the clinical, ultrasonographic, macroscopic and microscopic features in horses with naturally-occurring superficial digital flexor tendons with a range of durations and severity, and to compare these findings to establish if the ultrasonographic pattern was consistently representative of the underlying pathology in these injuries.

SECTION 3.2. MATERIALS AND METHODS.

Animals.

Twenty-eight injured superficial digital flexor tendons from fourteen horses with superficial digital flexor tendon injuries in which euthanasia was unavoidable due to the severity of the tendon injury or for other humane reasons were included in the study. The duration of the injuries ranged from two days to approximately 14 months. All the horses were Thoroughbred, National Hunt Racehorses and ranged in age from four to eight years-old.

Ten superficial digital flexor tendons which had normal ultrasonographic appearances were obtained from horses of Thoroughbred or Thoroughbred type breeds and aged between five and twenty years old and these tendons were used as controls to which the pathological and histological findings in the affected limbs were compared.

Clinical and Ultrasonographic Examinations.

The clinical and ultrasonographic examinations were performed prior to euthanasia and the maximum available history was obtained from the owners, in particular, details of the current and any previous tendon injuries were noted. The limbs were prepared for examination by clipping and shaving the palmar aspect of the limb between the carpal and metacarpophalangeal joints and by application of echolucent gel. An ultrasonographic unit with a 7.5 MHz linear array transducer and a echolucent stand-off block were used in this study. Transverse and longitudinal images of the limb were obtained at 20 mm intervals from 60 to 300 mm distal to the accessory carpal bone and frozen images of these sites were recorded using a video recorder. In addition, the entire area was imaged in real-time and recorded for review.

Ultrasonographic Interpretation.

The length of the lesion was estimated and expressed in multiples of 20 mms. The percentage of the cross-sectional area of the tendon affected was estimated at its widest point and the location, echogenicity, distinctness of the lesion from the surrounding tendon and the distinctness of the superficial digital flexor tendon from the adjacent skin and deep digital flexor tendon, the presence and appearance of linear echoes on longitudinal images and the presence of peritendinous lesions were noted. The echogenicity of lesions was described as 1 = anechoic; 2 = hypoechoic; 3 = anechoic and hypoechoic; 4 = mixed hypoechoic areas; 5 = hyperechoic foci while the distinctness of the lesion was described as 1 = difficult to discern with the whole tendon being heterogeneous; 2 = moderately difficult to discern with a slightly hypoechoic area present; 3 = obvious delineation with a well-defined hypoechoic area present; 4 = marked delineation with a large difference in echogenicity between lesion and rest of tendon. The linear echo arrangement was also allocated a number: 0 = absent; 1 = minimal, short echoes; 2 = few, irregularly arranged linear echoes; 3 = numerous but irregular, shortened linear echoes; 4 = numerous linear echoes, some of which were shortened and irregular; 5 = normal.

Macroscopic Examination.

The flexor tendons were examined **in situ** following removal of the skin and a pin was inserted to mark the position 60 mms distal to the accessory carpal bone. The carpal sheath was dissected from the tendons and the superficial and deep digital flexor tendons were sectioned proximal to this level. The accessory ligament of the deep digital flexor tendon was sectioned at its origin. The proximal palmar annular ligament was sectioned medial to the lateral sesamoid and the superficial digital flexor tendon was sectioned at its insertions. The deep digital flexor tendon was sectioned at the distal end of the second phalanx and the superficial and deep digital flexor tendons were removed together with the accessory ligament of the deep digital flexor tendon. The superficial digital flexor tendon was separated from the other structures by section of the ring at the level of the metacarpophalangeal joint. The dorsal aspect of the digital sheath was incised and the synovial surface inspected. A series of transverse and longitudinal incisions were made in the superficial and deep digital flexor tendons at 80, 160 and 240 mms distal to the accessory carpal bone so that the internal structure of the tendon could be examined. Sections were made at similar sites in the deep digital flexor tendon and in the mid portion of the accessory ligament of the deep digital flexor tendon so that their internal structures could be inspected.

Histological Technique.

Transverse tissue samples were taken at four sites: 60, 140, 220 and 300 mms distal to the accessory carpal bone and longitudinal sections were taken at 20 mm intervals from 60 to 300 mms distal to the accessory carpal bone and fixed in 10% formaldehyde with disodium hydrogen orthophosphate/sodium dihydrogen orthophosphate (buffered neutral formaldehyde) for several days.

Following fixation and trimming, the tissue blocks were placed in 3% mercuric chloride in 10% formaldehyde solution (formol-sublimate) followed by 70% alcohol; each for at least 24 hours. Following processing from alcohol, through xylene to wax, the blocks were vacuum impregnated and embedded in paraffin wax. Sections were cut 5-6 um in thickness with a rotary microtome (Leitz 1512) and stained with haematoxylin and eosin.

Selected sections were also stained with Martius Scarlet Blue (MSB; Lendrum, Fraser, Slidders and Henderson, 1962), Masson's trichrome (Masson, 1929), Perls' Prussian Blue technique for haemosiderin (Perls, 1867) and Methyl Blue Van Gieson (MBVG). The MBVG method was modified from the technique described by Herovici (1963) by using 0.5% aqueous methyl blue and 1% acid fuschin in aqueous picric acid and increasing the immersion time to 40 minutes. Where formalin pigment (acid formaldehyde haematein) was present it was removed with saturated alcoholic picric acid.

In addition, a selected transverse tissue samples were cut from fresh tissue on a cryostat microtome and stained as above.

SECTION 3.3. RESULTS.

Clinical Cases.

CASE 3.1: ACUTE, SUBCLINICAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A four year-old Thoroughbred gelding was presented for reasons unrelated to tendon injury. It had been in full work and the trainer was not aware of a tendon problem.

Careful palpation demonstrated that there was localised heat associated with the mid metacarpal portions of both flexor tendons but there was no apparent palmar swelling on visual inspection or palpation of the tendons in an extended or flexed position. Pain was noted on compression of the lateral and medial borders of the superficial digital flexor tendon.

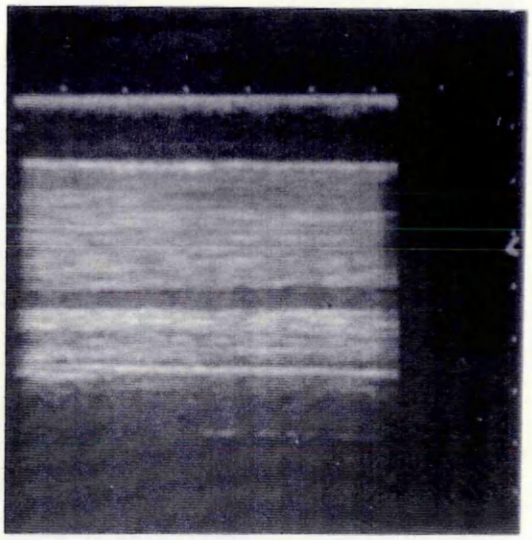
Ultrasonographic Findings.

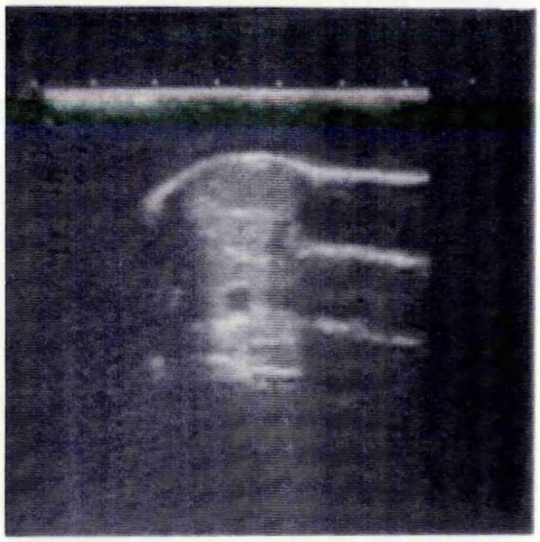
The ultrasonographic findings were similar in both superficial digital flexor tendons: the proximal regions had a normal even echogenicity on transverse images and longitudinal images demonstrated that they were composed of regularly arranged, linear echoes. In the mid metacarpal region in both superficial digital flexor tendons the echogenicity was altered: on transverse images there was a well-defined, central hypoechoic area which extended from approximately 120 to 200 mms distal to the accessory carpal bone (Fig. 3.1) but the overall shape of the tendon was not altered and its dimensions

FIG. 3.1. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH SUBCLINICAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.1).

A HYPOECHOIC LINEAR LESION IS APPARENT IN THE LONGITUDINAL IMAGE IF THE MID METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON (UPPER).

IN THE TRANSVERSE IMAGES OF THE MID METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON THE CENTRAL ZONE HAS REDUCED ECHOGENICITY (MIDDLE AND LOWER).





fell within the normal ranges described in Chapter 2. On longitudinal images, these areas were difficult to identify and could only be visualised when the sound beam was orientated in axial planes where the lesion was a linear area in which the linear echoes had been replaced by a uniform hypoechoic band (Fig. 3.1).

Macroscopic Findings.

The superficial and deep digital flexor tendons of both fore limbs were examined after they had been removed from the limbs by section at the levels of the accessory carpal bone and the proximal sesamoids and they were placed in buffered formaldehyde.

Neither of the superficial digital flexor tendons were noticeably enlarged in this case and the external surface of the tendons were normal. Transverse and longitudinal sections demonstrated that there were small brownish red areas associated with a pale cream region in the central part of the tendon. These areas were most noticeable between 140 and 160 mms distal to the accessory carpal bone. At the point 140 mms distal to the accessory carpal bone, the right superficial digital flexor tendon measured 7 by 17 mms and the left superficial digital flexor tendon measured 5 by 16 mms, while at the point 20 mms distal to that the right superficial digital flexor tendon measured 6 by 17 mms and the left superficial digital flexor tendon measured 5 by 17 mms.

Histopathological Findings.

The histological findings were similar in both superficial digital flexor tendons. The peripheral zone of the tendon was normal with regularly arranged collagen fibres and tenocytes with elongated darkly-stained nuclei. In the central zone there was a paucity of tenocytes and the cells in the endotenon had large rounded nuclei. There was some evidence of an inflammatory reaction with increased numbers of neutrophils. There was no evidence of haemorrhage but sections stained for haemosiderin indicated that small deposits were present in association with the acellular areas in both tendons.

In the left superficial digital flexor tendon there were some areas in which there were longitudinal bands with increased numbers of fibroblasts (Fig. 3.2). Sections stained with MSB, Masson's trichrome and the modified methyl blue van Gieson demonstrated that in the central acellular area the stain penetrated the tissue well suggesting that it was an area of fibrous tissue with a surrounding, peripheral area of normal tendon (Fig. 3.3).

CASE 3.2: ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A seven year-old Thoroughbred gelding was examined two days after it sustained a reinjury to an existing chronic superficial digital flexor tendon lesion.

FIG. 3.2. THE HISTOLOGICAL FINDINGS IN A HORSE WITH SUBCLINICAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURY: A LONGITUDINAL SECTION DEMONSTRATING AN ACELLULAR AREA ASSOCIATED WITH BANDS OF INCREASED CELLULARITY WITHIN THE CENTRAL ZONE OF THE MID METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON IN CASE 3.1 [L.S., H. & E., X 63].

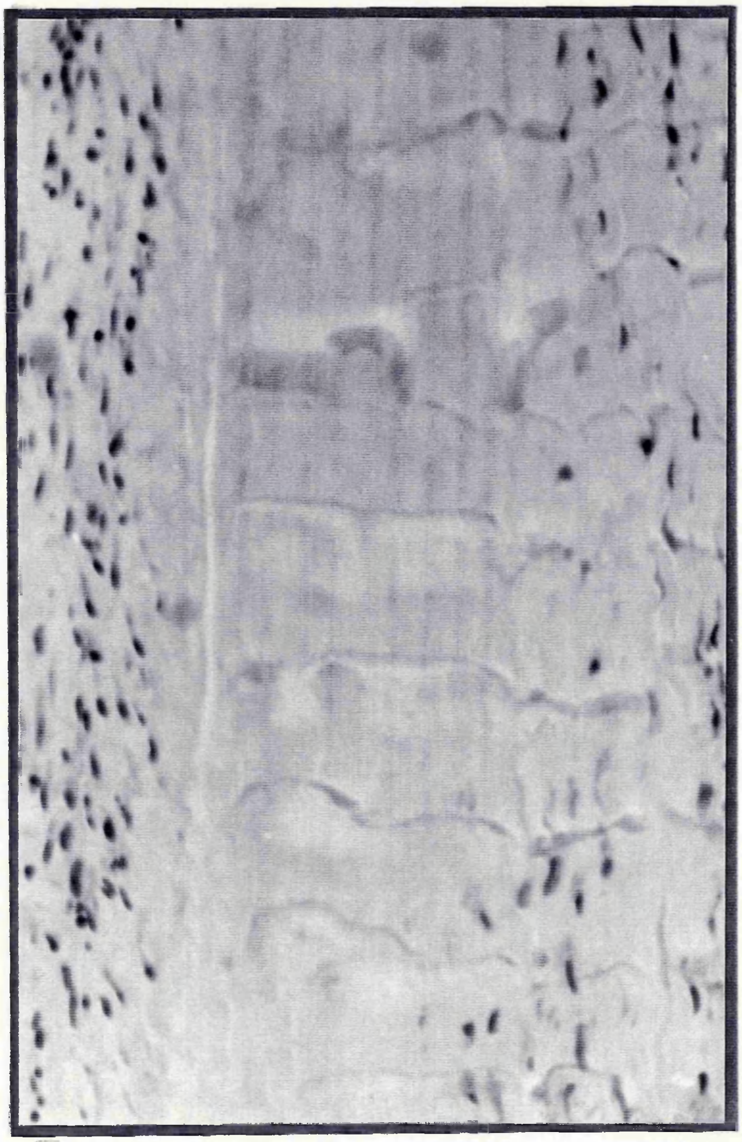
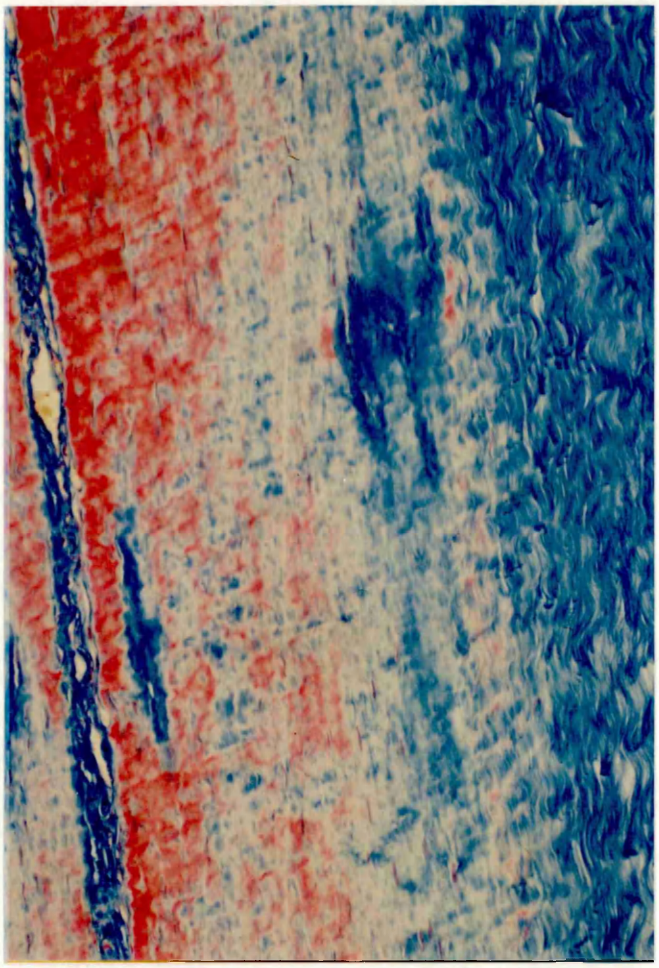


FIG. 3.3. THE HISTOLOGICAL FINDINGS IN A HORSE WITH SUBCLINICAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.1) THE ACELLULAR AREA (BLUE) WHICH WAS COMPOSED OF COLLAGEN WHICH WAS NOT ARRANGED IN REGULARLY ARRANGED BUNDLES [L.S., MSB X 100].



The right fore superficial digital flexor tendon was markedly enlarged in a palmar and medial direction and it was hot, soft and painful with considerable subcutaneous oedema. There was hyperextension of the metacarpophalangeal joint and the horse was moderately lame at the walk. The left fore superficial digital flexor tendon was slightly enlarged on the palmar aspect and it was warm and soft on palpation.

Ultrasonographic Findings.

The entire right superficial digital flexor tendon was affected from 60 to 300 mms distal to the accessory carpal bone. Transverse images of the proximal metacarpal region demonstrated that the tendon was composed of large hypoechoic areas with a thin echogenic rim surrounding them. In the mid metacarpal region this echogenic rim was absent and the tendon was enlarged in a medial as well as palmar direction. The hypoechoic areas were irregular and contained numerous ill-defined anechoic areas. The tendon was separated from the overlying skin by a hypoechoic region. The proportion of anechoic to hypoechoic regions increased in the distal transverse images (Fig. 3.4). The longitudinal images had a similar diffuse hypoechoic appearance and the linear echoes were completely absent (Fig. 3.4).

The left fore superficial digital flexor tendon contained a hypoechoic area which was central in location in transverse images and was surrounded by an area with normal, even echogenicity (Fig. 3.5). On

FIG. 3.4. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH AN ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.2, RIGHT FORE).

THE LINEAR ECHOES ARE ABSENT IN THE LONGITUDINAL IMAGES (UPPER LEFT AND RIGHT) AND THE SUPERFICIAL DIGITAL FLEXOR TENDON IS COMPOSED OF NUMEROUS LOW LEVEL ECHOES.

THE PROXIMAL TRANSVERSE IMAGES DEMONSTRATE A ECHOGENIC RIM AROUND THE CENTRAL HYPOECHOIC REGION (MIDDLE LEFT) BUT IN THE MID METACARPAL REGION THIS RIM IS ABSENT AND THE ENTIRE CROSS SECTIONAL AREA OF THE TENDON IS DISRUPTED (MIDDLE RIGHT).

THERE IS A HYPOECHOIC REGION BETWEEN THE SUPERFICIAL DIGITAL FLEXOR TENDON AND THE OVERLYING SUBCUTANEOUS TISSUES (>>, MIDDLE RIGHT AND LOWER RIGHT) AND THE LESION IS LEAST ECHOGENIC IN THE DISTAL IMAGES (UPPER RIGHT AND LOWER RIGHT).

[NOTE THERE IS A REVERBERATION ARTIFACT IN THE UPPER LEFT IMAGE].

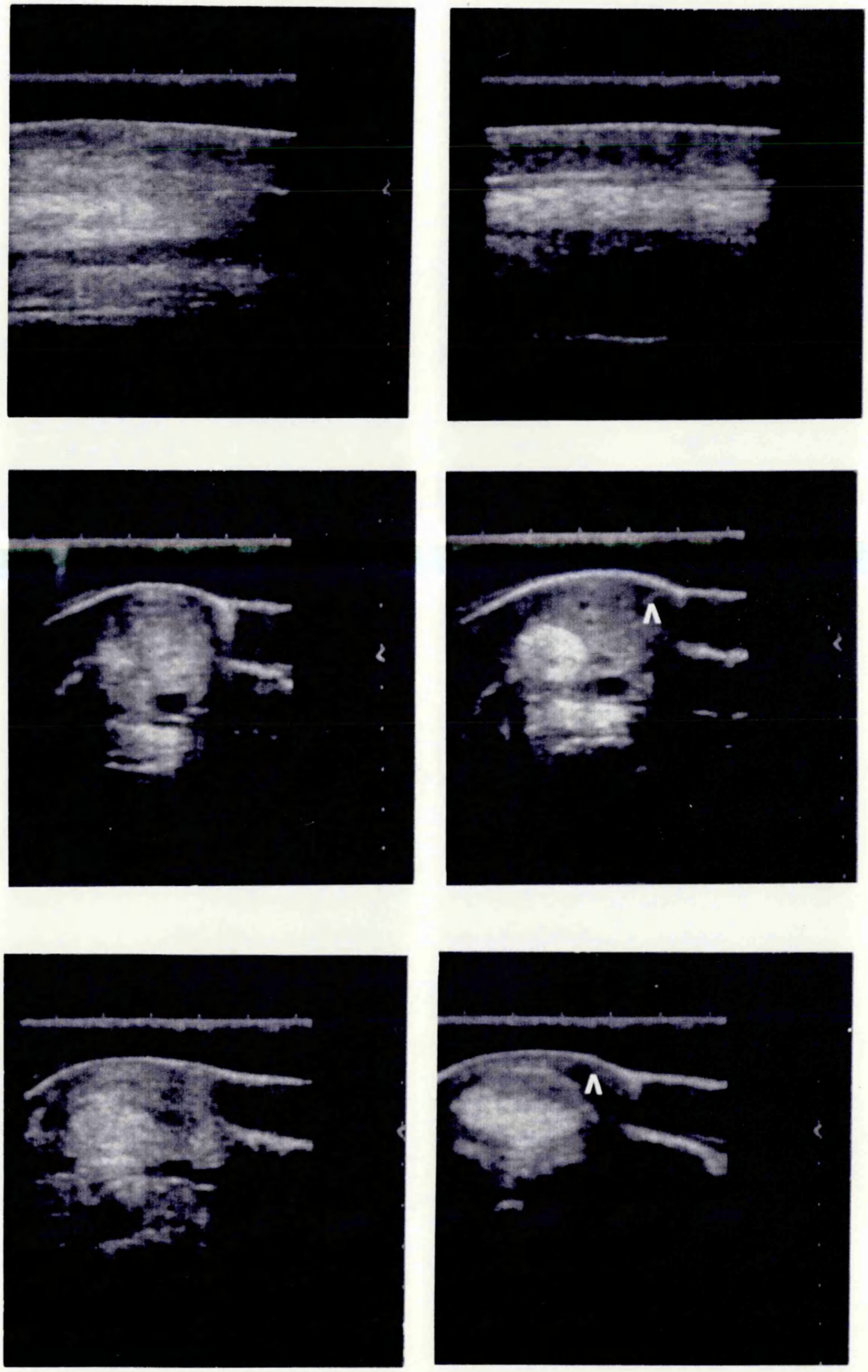
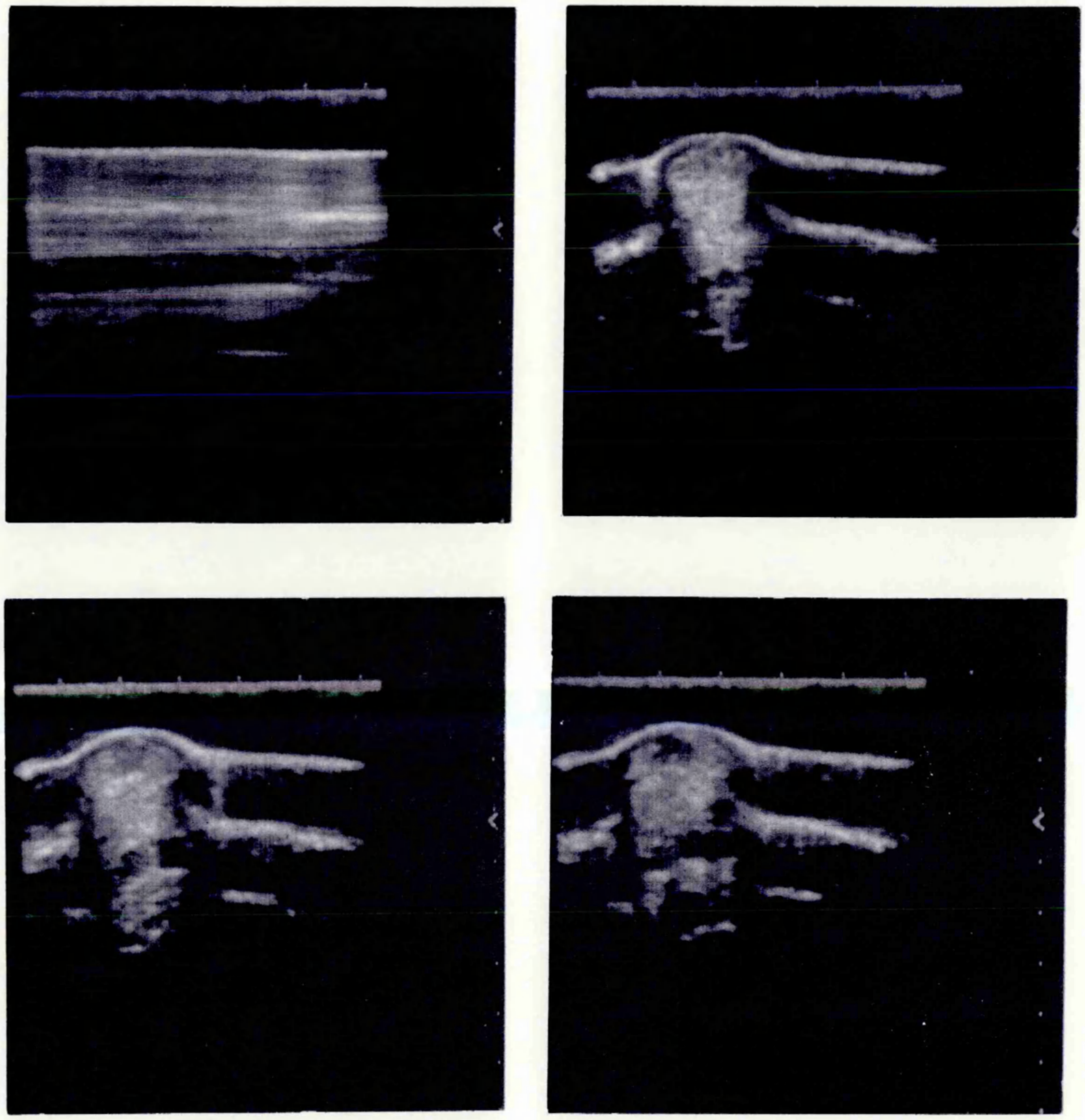


FIG. 3.5. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH AN ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.2, LEFT FORE).

A LINEAR HYPOECHOIC AREA IS APPARENT IN THE LONGITUDINAL IMAGE OF THE MID METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON (UPPER LEFT).

IN THE PROXIMAL METACARPAL REGION THE ECHOGENICITY OF THE SUPERFICIAL DIGITAL FLEXOR TENDON IS EVEN (UPPER RIGHT) BUT IN THE MID METACARPAL REGION THERE IS A WELL-DEFINED HYPOECHOIC LESION (LOWER LEFT AND RIGHT).

[NOTE THE THERE IS A REVERBERATION ARTIFACT IN THE UPPER LEFT IMAGE AND INCOMPLETE CONTACT ON THE LATERAL ASPECT OF IMAGE LOWER RIGHT]



longitudinal images the palmar and dorsal regions of the superficial digital flexor tendon were normal but the central area was composed of a linear hypoechoic area (Fig. 3.5).

Macroscopic Findings.

There was extensive subcutaneous haemorrhage on the medial aspect of the carpus, around the medial and lateral aspects of the metacarpophalangeal and proximal interphalangeal joints of the right fore limb. The superficial digital flexor tendon was enlarged from the level of the carpus to the metacarpophalangeal joint, but distal to this it was of normal dimensions: the maximum dorsal-palmar diameter was at the point 140 mms distal to the accessory carpal bone where the tendon measured 20 mms while the maximum lateral to medial diameter was at the level of the proximal sesamoids where the tendon measured 40 mms. The tendon had a soft consistency and its external surface was pink. Following section of the tendon, a large haemorrhagic area was identified in the central core in which there were numerous shreds of fibres.

In the left fore limb, there was no evidence of subcutaneous haemorrhage. The mid section of the superficial digital flexor tendon was enlarged on the palmar aspect from 100 mms to 240 mms distal to the accessory carpal bone. The surface of the tendon had a normal colour but, following section, a red area was apparent in the mid section of the tendon in the area which was enlarged. The most proximal part of the lesion was centrally placed within the tendon and it was surrounded by a rim of macroscopically normal tendon tissue while the distal part of the lesion was confirmed to be located on the lateral aspect of the transverse sections of the tendon.

Histopathological Findings.

Throughout the length of right superficial digital flexor tendons from 60 to 260 mms distal to the accessory carpal bone, within the central portion of the tendon there was collagenolysis, haemorrhage, both old and new fibrin deposition and oedema with numerous neutrophils (Fig. 3.6). The fibroblasts in the endotenon were arranged in bands and appeared to be streaming into the lesion along the fibrin strands. They had large, pale, oval granular nuclei and the cytoplasm was prominent and basophilic.

The histological findings in the left superficial digital flexor tendon were similar but were confined to the area from 80 to 240 mms distal to the accessory carpal bone.

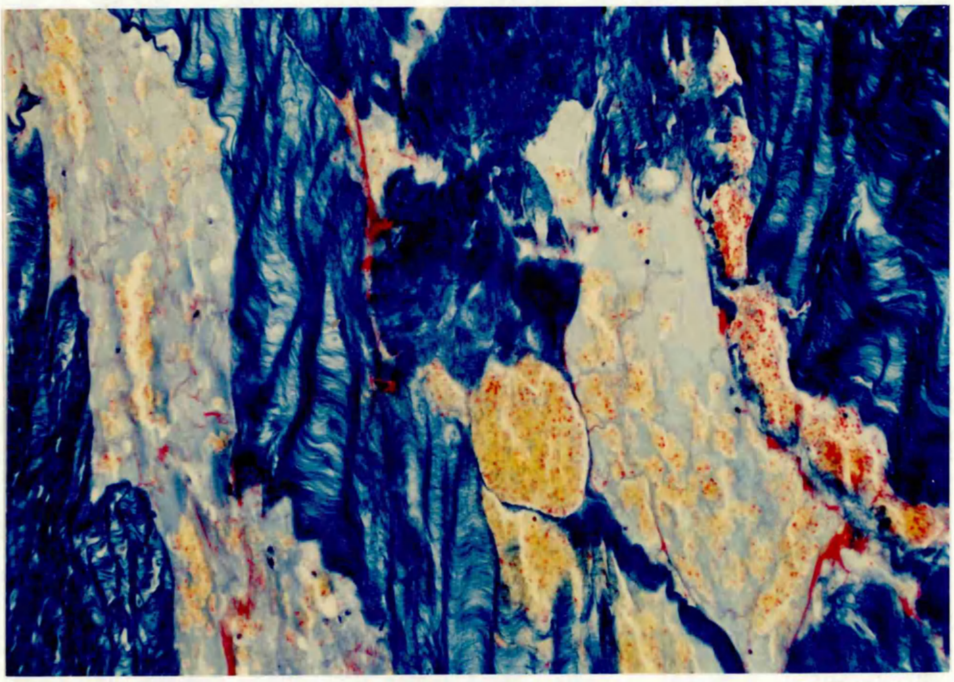
CASE 3.3: ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A six year-old Thoroughbred gelding was examined four days after it sustained bilateral superficial digital flexor tendon injuries.

The left fore superficial digital flexor tendon was

FIG. 3.6. A TRANSVERSE SECTION OF TENDON FROM A HORSE WITH ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.2). THE COLLAGEN FIBRES (BLUE) ARE SHREDDED AND THERE ARE OLD (GREY) AND NEW (RED) FIBRIN CLOTS WITH NUMEROUS RED BLOOD CELLS (YELLOW). WITHIN THE FIBRIN CLOTS THE DARKLY STAINED NUCLEI OF FIBROBLASTS CAN BE SEEN [MSB x 100].



markedly enlarged in a palmar and medial direction and it was hot, soft and painful with considerable subcutaneous oedema. There was slight hyperextension of the metacarpophalangeal joint and the horse was moderately lame at the walk. The right fore superficial digital flexor tendon was moderately enlarged on the palmar aspect and it was warm, soft and painful on palpation.

Ultrasonographic Findings.

The left fore superficial digital flexor tendon was abnormal throughout its length from 60 to 300 mms distal to the accessory carpal bone. There was a diffuse reduction in echogenicity in both the transverse and longitudinal images but no distinct anechoic areas were identified in either plane (Fig. 3.7). In the transverse images the echogenicity was mainly even and hypoechoic but numerous small irregular anechoic areas were present (Fig. 3.7). Similarly, in longitudinal images, the echogenicity was even and there was no evidence of linear echo arrangement. The shape of the superficial digital flexor tendon in transverse images was striking: the tendon was enlarged in a palmar medial direction such that it splayed around the deep digital flexor tendon on the medial aspect of the limb.

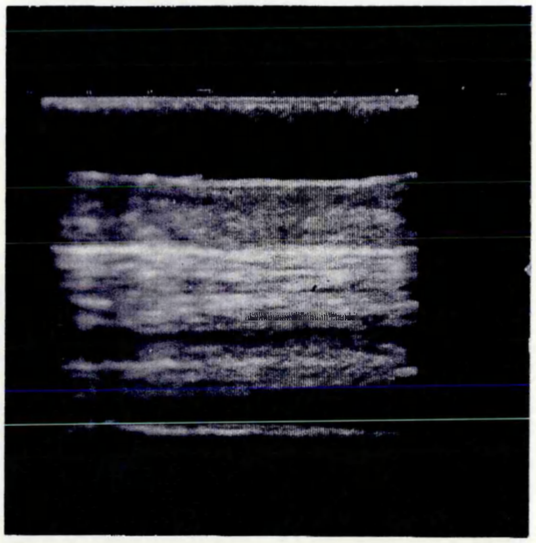
The right superficial digital flexor tendon contained an hypoechoic central area which extended from 80 to 280 mms distal to the accessory carpal bone (Fig. 3.8). This was located in the central portion of the

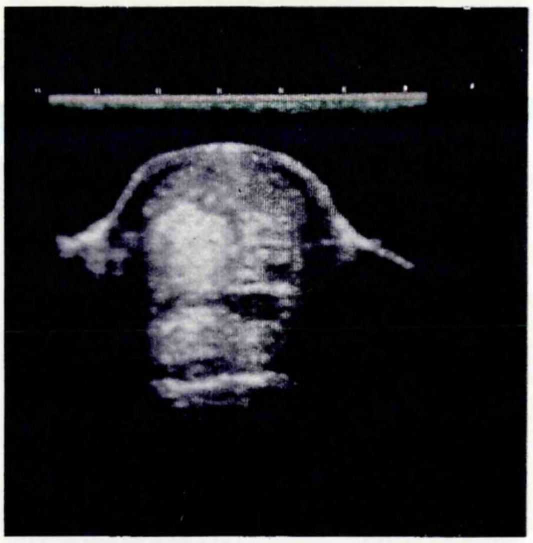
FIG 3.7. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH AN ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.3, LEFT FORE).

THE LONGITUDINAL IMAGES OF THE SUPERFICIAL DIGITAL FLEXOR TENDON THROUGHOUT THE ENTIRE METACARPAL REGION ARE COMPOSED OF NUMEROUS HYPOECHOIC DOTS (UPPER).

THE TRANSVERSE IMAGES DEMONSTRATE A DIFFUSE REDUCTION IN ECHOGENICITY OF THE SUPERFICIAL DIGITAL FLEXOR TENDON WITH NUMEROUS ILL-DEFINED ANECHOIC AREAS. THE TENDON IS MARKEDLY ENLARGED AND IS SPLAYED AROUND THE MEDIAL ASPECT OF THE DEEP DIGITAL FLEXOR TENON (MIDDLE AND LOWER).

[NOTE THERE IS A REVERBERATION ARTIFACT AND A MISSING CRYSTAL ARTIFACT IN IMAGE A AND INCOMPLETE CONTACT ON THE LATERAL ASPECT OF THE LOWER IMAGE].





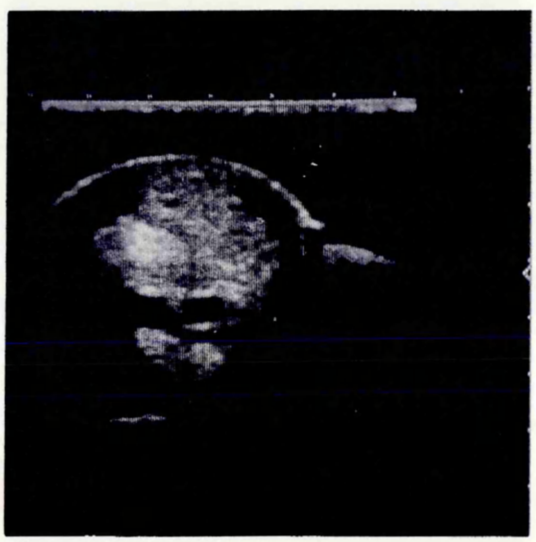
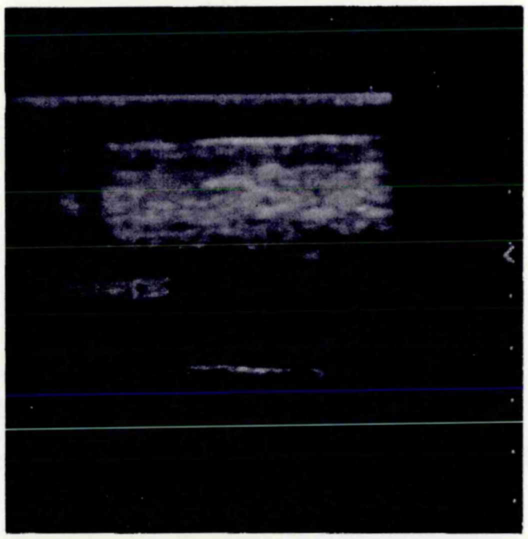


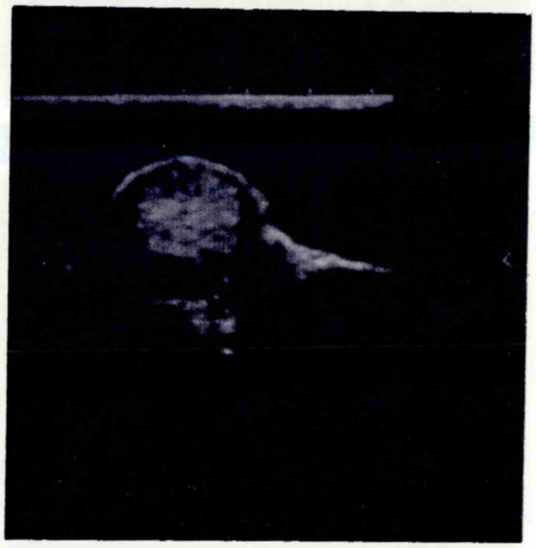
FIG. 3.8. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH AN ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.3, RIGHT FORE).

THERE IS A LINEAR HYPOECHOIC AREA IN THE CENTRAL ZONE OF THE MID METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON IN THE LONGITUDINAL IMAGE (UPPER).

THE TRANSVERSE IMAGES DEMONSTRATED THAT THE LESION IS A WELL-DEFINED HYPOECHOIC AREA (LOWER).

[NOTE THERE IS A MISSING CRYSTAL ARTIFACT IN THE UPPER IMAGE].





tendon on both transverse and longitudinal images.

Macroscopic Findings.

The superficial and deep digital flexor tendons of both fore limbs were examined after they had been removed from the limbs by section at the levels of the accessory carpal bone and the proximal sesamoids and placed in buffered formaldehyde.

The left superficial digital flexor tendon was enlarged throughout its length and the surface was brown. Shredding of the fibres could be seen beneath the paratenon and was present throughout the entire tendon being most marked in the distal portion.

The right superficial digital flexor tendon had a normal surface but the mid section was enlarged in a palmar direction. The transverse sections at this level demonstrated a haemorrhagic core containing debris and shreds of fibres which extended from approximately 120 mms to 200 mms distal to the accessory carpal bone.

Histopathological Findings.

Throughout the length of the superficial digital flexor tendons there was congestion, haemorrhage and oedema with an active fibroblast response typified by large numbers of large oval fibroblasts with prominent basophilic cytoplasm arranged in streams between the collagen fibres where there were also numerous neutrophils (Fig. 3.9). There was necrosis of the collagen fibres with karyolysis and ghost nuclei (Fig. 3.10). The right superficial digital flexor tendon

FIG. 3.9. HISTOLOGICAL FINDINGS IN A HORSE WITH ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY: THERE IS SEVERE CONGESTION, OEDEMA AND HAEMORRHAGE WITH AN ACTIVE FIBROBLASTIC RESPONSE IN AN ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.3, LEFT FORE) [L.S., H. & E. , X 100].

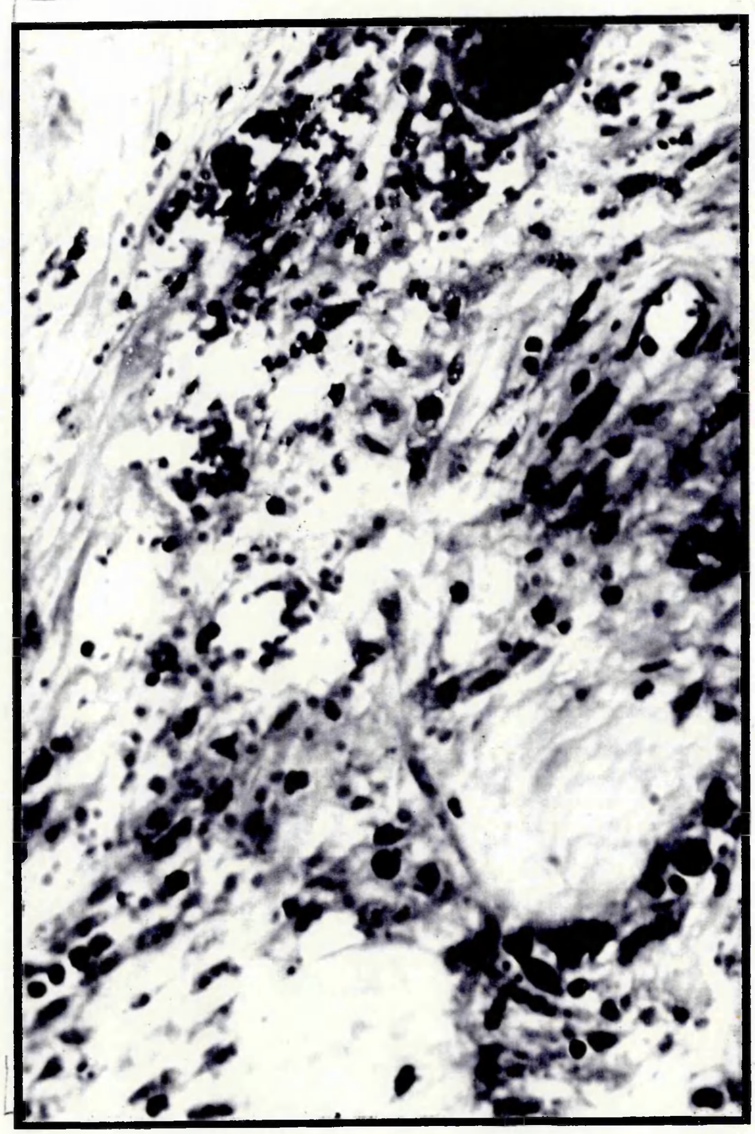
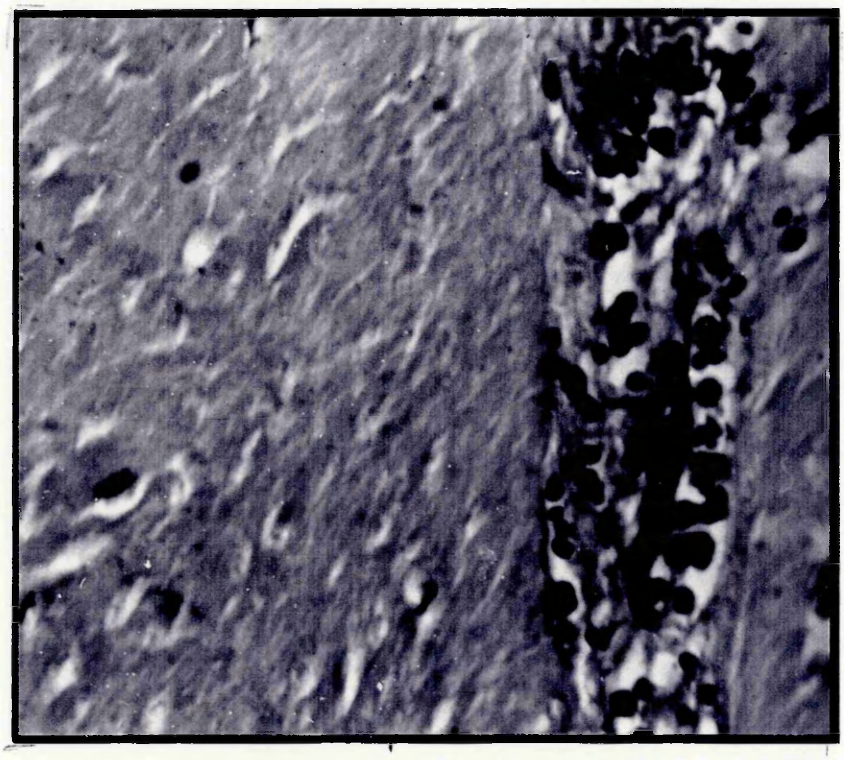


FIG. 3.10. HISTOLOGICAL FINDINGS IN A HORSE WITH ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY: THERE IS WIDE-SPREAD NECROSIS OF THE COLLAGEN AND GHOST NUCLEI IN AN ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3, LEFT FORE) [L.S., H. & E., X 250].



contained some normal fibres at the periphery but the endotenon in these areas contained numerous large fibroblasts and neutrophils with small haemorrhages.

CASE 3.4: ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A seven year-old Thoroughbred gelding was examined six days after it sustained a reinjury to an existing chronic superficial digital flexor tendon lesion.

The left fore superficial digital flexor tendon was markedly enlarged in a palmar and medial direction and it was hot, soft and painful with considerable subcutaneous oedema. There was hyperextension of the metacarpophalangeal joint and the horse was moderately lame at the walk (Fig. 3.11).

The clinical findings in the right fore superficial digital flexor tendon were equivocal, in that it was not enlarged on the palmar aspect but it was warm and soft on palpation and compression of the lateral and medial borders elicited pain (Fig. 3.11).

Ultrasonographic Findings.

The left superficial digital flexor tendon was markedly enlarged in both longitudinal and transverse images (Fig. 3.12). The images obtained from 60 to 220 mms had a similar appearance: there was an alteration in echogenicity within the entire cross-section of the tendon being composed of a mixture of anechoic and hypoechoic areas with no distinct borders between

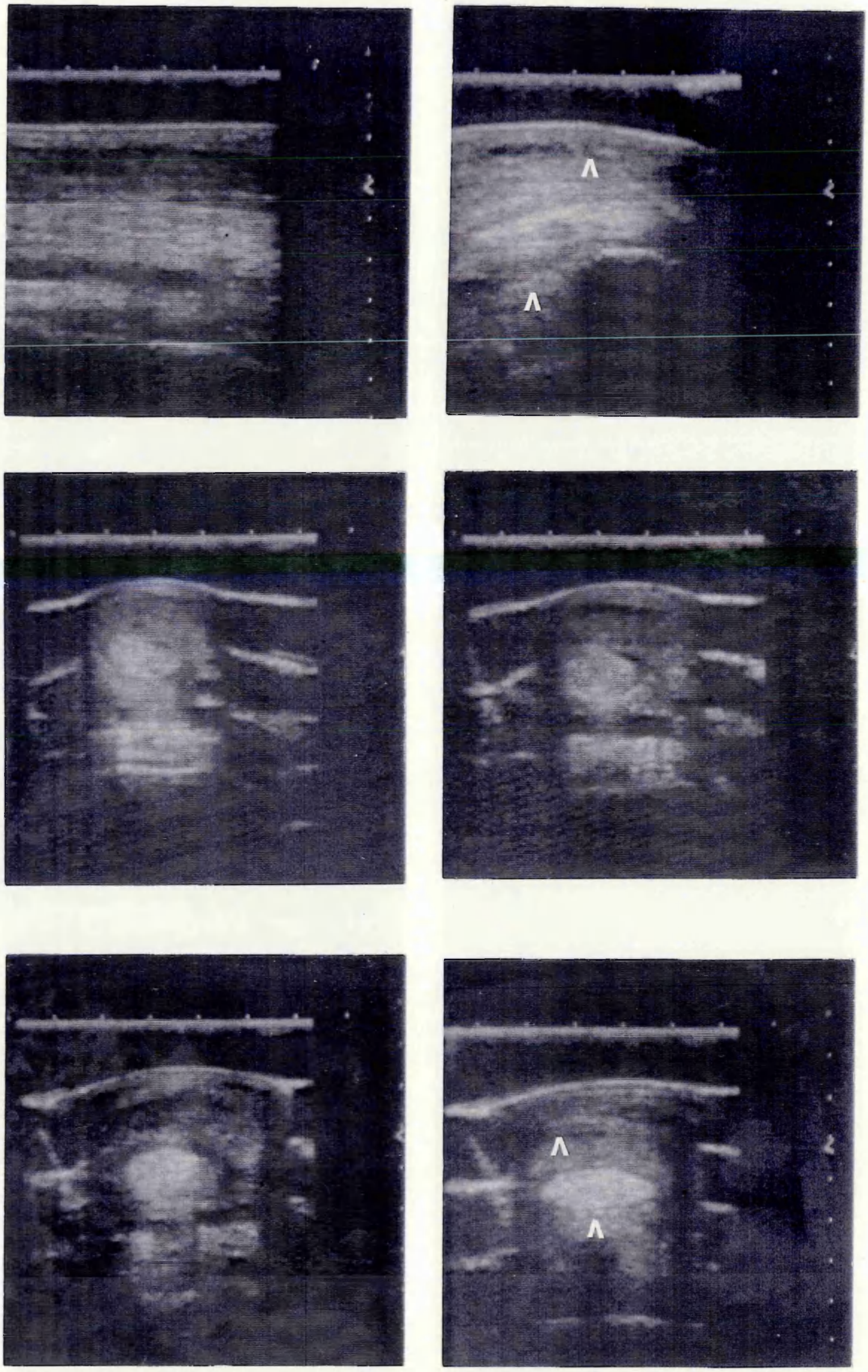
FIG. 3.11. CLINICAL FINDINGS IN A HORSE WITH ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY: THERE IS MARKED PALMAR ENLARGEMENT OF THE LEFT FORE SUPERFICIAL DIGITAL FLEXOR TENDON AND THE LEFT METACARPOPHALANGEAL JOINT IS HYPEREXTENDED BUT THERE IS NO PALMAR ENLARGEMENT IN THE RIGHT FORE IN THIS HORSE WITH ACUTE BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES (CASE 3.4).

FIG. 3.12. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH AN ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.4, LEFT FORE).

THE SUPERFICIAL DIGITAL FLEXOR TENDON IS MARKEDLY ENLARGED THROUGHOUT THE METACARPAL REGION AND ITS ECHOGENICITY IS REDUCED. IN THE DISTAL METACARPAL REGION, 240 MMS DISTAL TO THE ACCESSORY CARPAL BONE, THE TENDON IS ALMOST ENTIRELY ANECHOIC (LOWER LEFT).

THE TENDON IS SEPARATED FROM THE OVERLYING SKIN BY A HYPOECHOIC AREA (UPPER LEFT AND RIGHT, MIDDLE LEFT AND RIGHT AND LOWER LEFT). THE DIGITAL SHEATH IS THICKENED (>>, UPPER AND LOWER RIGHT).

[NOTE THERE IS INCOMPLETE CONTACT ON THE LATERAL ASPECTS OF THE MIDDLE LEFT AND LOWER LEFT AND RIGHT IMAGES, ON THE MEDIAL ASPECTS OF THE IMAGES MIDDLE LEFT AND RIGHT AND LOWER RIGHT, AND ON THE DISTAL ASPECT OF THE UPPER RIGHT IMAGE].



these areas. In the transverse images obtained from the distal regions (240 - 280 mms distal to the accessory carpal bone), the tendon was entirely anechoic with a thin echogenic rim.

The skin was separated from the tendon throughout the entire metacarpal region by a hypoechoic area and the digital sheath was thickened.

The ultrasonographic findings in the right superficial digital flexor tendon were much less obvious and the majority of the tendon had a normal size, shape and echogenicity. However, in the transverse images a small well-defined, circular, hypoechoic area was identified which extended from approximately 140 to 220 mms distal to the accessory carpal bone (Fig. 3.13). On longitudinal images, this area was almost anechoic and had an elliptical shape. The areas dorsal to and palmar to this lesion were composed of linear echoes (Fig. 3.13).

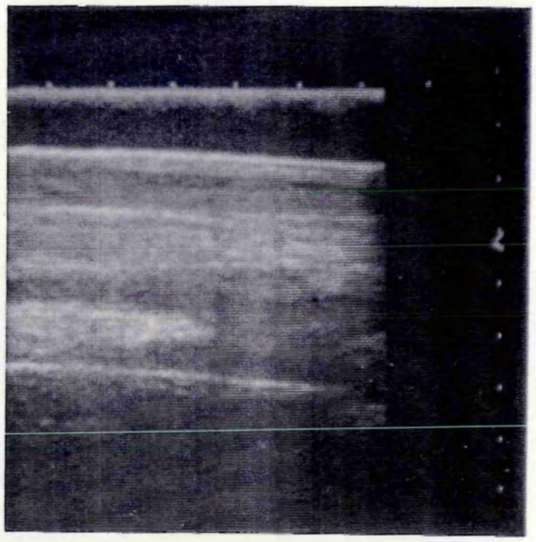
Macroscopic Findings.

There was extensive subcutaneous haemorrhage around the palmar aspect of the left metacarpophalangeal joint. The digital sheath was thickened and on its inner aspect a circular area of soft, creamy pink tissue was adherent between the superficial digital flexor tendon and the sheath (Fig. 3.14). The left superficial digital flexor tendon was enlarged from the carpus to its insertions onto the first and second phalanges. The mid section of the tendon had a maximum dorsal to palmar diameter of 19 mms and the tendon was widest at the proximal sesamoids

FIG. 3.13. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH AN ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.4, RIGHT FORE).

THERE IS AN ELLIPTICAL, HYPOECHOIC LESION WITHIN THE MID METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON WHICH IS DEMONSTRATED IN THE LONGITUDINAL IMAGES (UPPER AND MIDDLE).

THIS LESION IS A WELL-DEFINED CIRCULAR AREA WITHIN THE CENTRAL ZONE OF THE MID METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON IN THE TRANSVERSE IMAGES (LOWER).



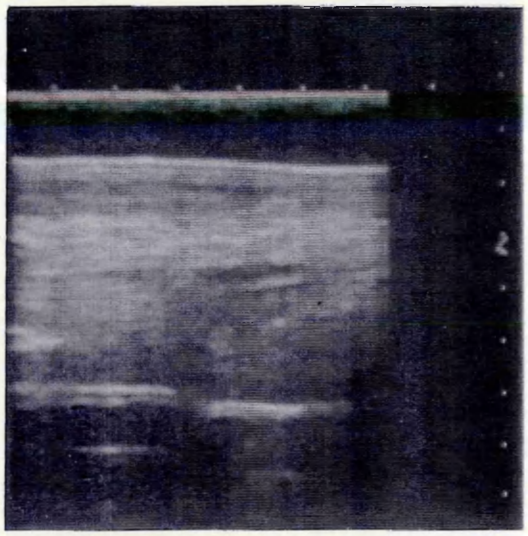
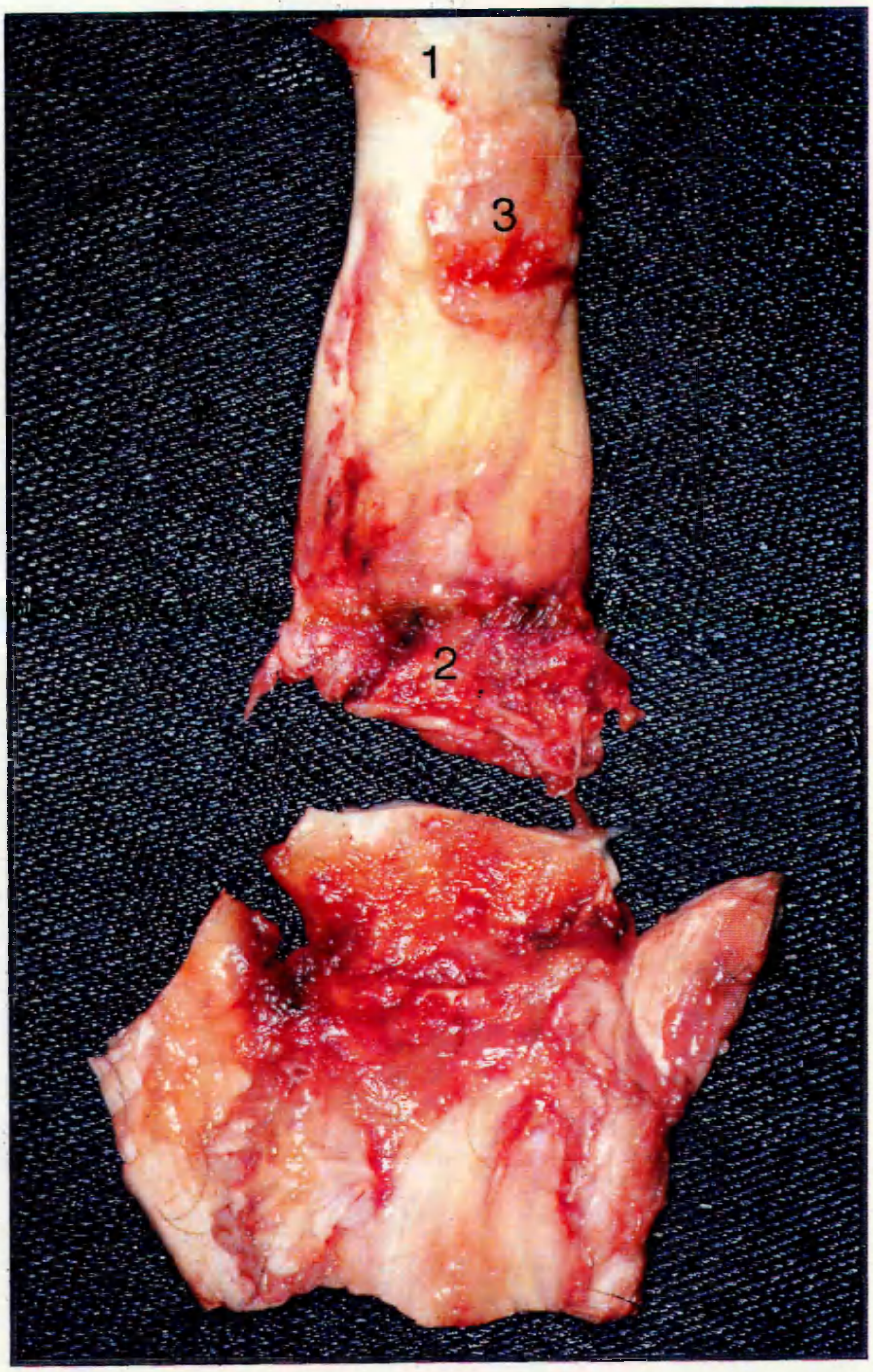


FIG. 3.14. THE GROSS PATHOLOGICAL FINDINGS IN THE LEFT FORE LIMB IN CASE 3.4 WHICH HAD AN ACUTE, SEVERE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY. THE TENDON HAS DISINTEGRATED INTO TWO PIECES AND THE PROXIMAL PART HAS A WHITE SURFACE (1) WHILE AT THE POINT OF SEPARATION THERE IS HAEMORRHAGE AND SHREDS OF FIBRES (2). A SOFT TISSUE MASS WAS ADHERENT BETWEEN THE TENDON AND THE OVERLYING SHEATH (3).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where it measured 40 mms. Proximal to the level of the proximal sesamoids, the tendon was firm and had a white surface (Fig. 3.14). Within the digital sheath, at 260 to 300 mms distal to the accessory carpal bone, the tendon had completely disintegrated. There were shreds of fibres and haemorrhage (Fig. 3.14). The process of lifting the tendon from the limb resulted in the tendon separating into two sections (Fig. 3.14). Transverse sections of the proximal part of the tendon had a creamy appearance and there were numerous red specks scattered throughout the tendon which tended to coalesce but there was no single large lesion. In transverse sections proximal to the point of disintegration, the entire cross section was haemorrhagic leaving a very thin rim of solid tissue around the periphery. Distal to the point of separation, the appearance and consistency were similar to the more proximal parts.

In the right fore limb, there was no evidence of subcutaneous haemorrhage. The superficial digital flexor tendon was not obviously enlarged overall but in the mid portion from 140 to 200 mms distal to the accessory carpal bone, the palmar aspect was swollen. Transverse sections at that level demonstrated that there was a pale central area which appeared to be slightly softer than the remainder of the tendon.

Histopathological findings.

The sections of the left fore superficial digital flexor tendon taken 60 and 80 mms distal to the accessory carpal bone had a regular arrangement of fibres and the tenocytes were dark and elongated. Very small areas in which there was a relative reduction in the number of cells were identified. The endotenon was several cells thick in the central zone and this was consistent with the presence of a previous injury.

In the sections taken from levels 100 mms to 280 mms distal to the accessory carpal bone there was widespread haemorrhage. This was scattered throughout the tendon, being located both in the endotenon and between the necrotic fibres (Fig. 3.15).

The sections taken at 220 and 240 contained large aggregations of coagulated protein with fragmented collagen fibres and areas of necrosis, collagenolysis and fibrin deposition. The fibroblasts throughout the mid and distal part of the tendon were increased in number with pale, granular oval nuclei. The paratenon contained numerous haemorrhages and was composed of a layer several cells thick (Fig. 3.16).

The right fore superficial digital flexor tendon was much less affected. Very small areas of haemorrhage, collagenolysis and oedema with an active fibroblastic response were identified in the endotenon of the central and palmar aspects of the sections taken from 120 to 160 mms distal the accessory carpal bone. There was an acellular band running throughout the central zone in which no haemosiderin deposition was identified. The peripheral zone of the tendon was normal throughout its

FIG. 3.15. A LONGITUDINAL SECTION FROM THE MID METACARPAL REGION OF THE LEFT SUPERFICIAL DIGITAL FLEXOR TENDON IN A HORSE WITH ACUTE TENDON INJURY (CASE 3.4). THERE IS WIDESPREAD HAEMORRHAGE (YELLOW) AND FIBRIN DEPOSITION (GREY) BETWEEN THE COLLAGEN FIBRES (BLUE) AND FIBROBLASTS ARE ALIGNED ALONG THE FIBRIN STRANDS [MSB X 250].

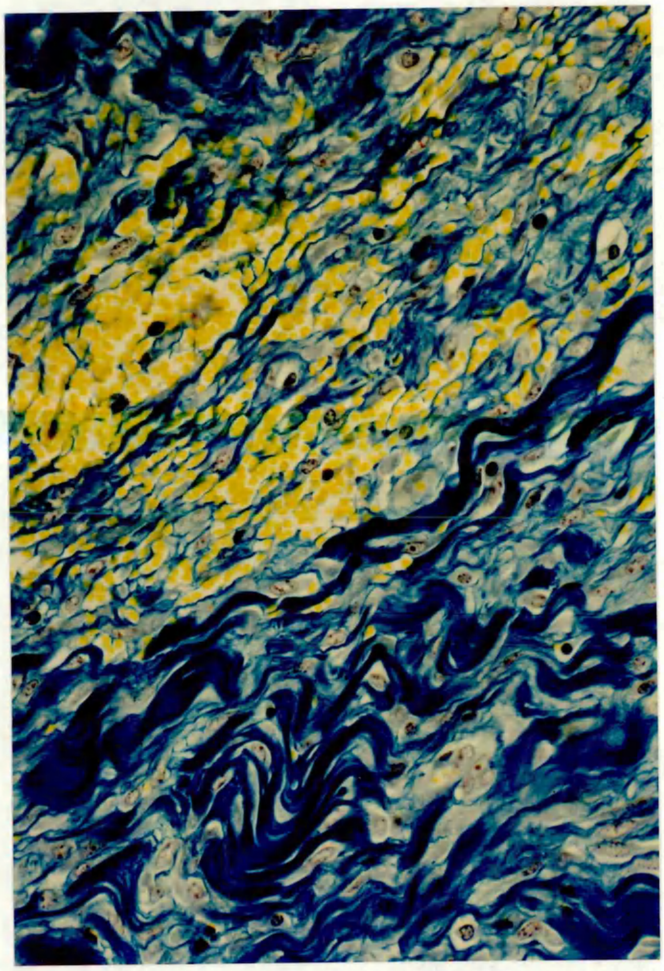

FIG. 3.16. A LONGITUDINAL SECTION FROM THE MID METACARPAL REGION OF THE PARATENON OF THE LEFT SUPERFICIAL DIGITAL FLEXOR TENDON IN A HORSE WITH ACUTE TENDON INJURY (CASE 3.4). THERE IS WIDESPREAD HAEMORRHAGE (1) AND IT IS HYPERCELLULAR [H. & E., X 250].

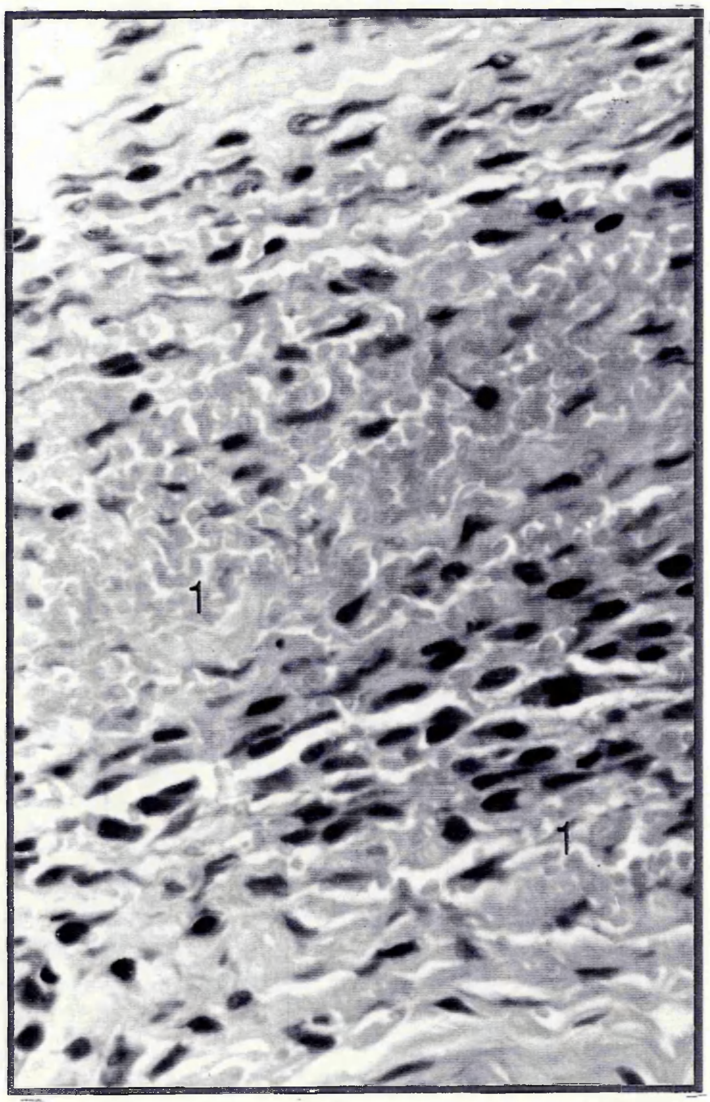
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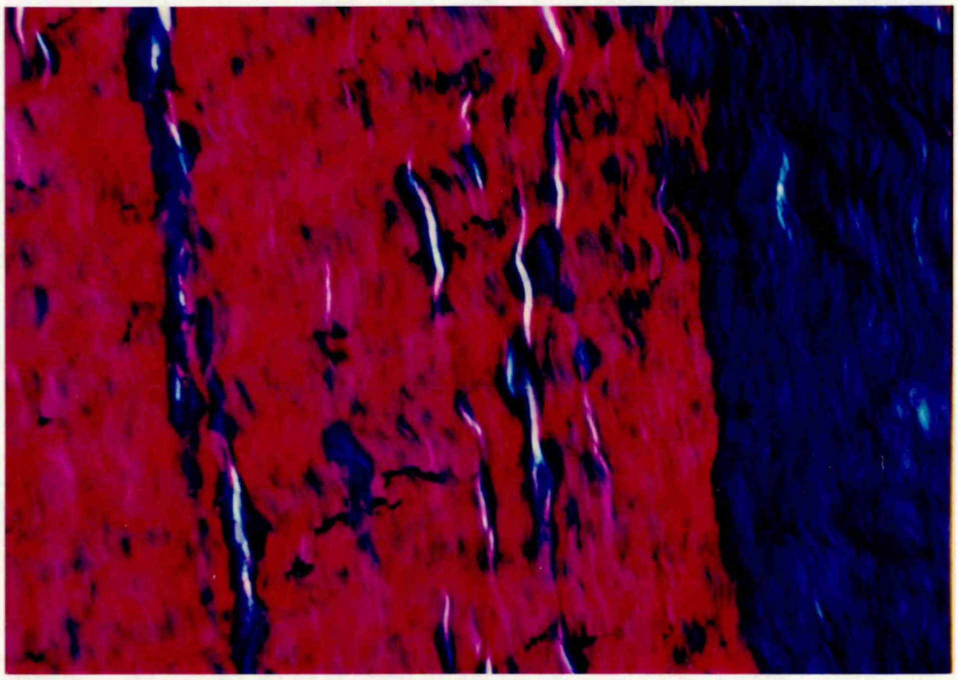
FIG. 3.17 HISTOLOGICAL FINDINGS IN AN HORSE WITH ACUTE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.4): A CENTRAL ACELLULAR AREA (BLUE) IS SURROUNDED BY NORMAL TENDON (PINK) [L.S., MBVG X 250]



length. Sections stained with Martius scarlet blue and the modified methyl blue van Gieson demonstrated that the central acellular area was composed of collagen and there was recent fibrosis (Fig. 3.17).

CASE 3.5: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A five year-old Thoroughbred gelding was presented approximately eight weeks after it sustained a bilateral tendon injury. Details of its previous history were not available.

The horse was sound at the walk, but the right superficial digital flexor tendon was moderately enlarged in a palmar direction in the mid metacarpal region (Fig. 3.18). The left superficial digital flexor tendon was not enlarged but there was pain elicited on compression of the lateral and medial borders of both superficial digital flexor tendons and there was heat detected on palpation of the palmar metacarpal regions.

Ultrasonographic Findings.

There was a well-defined, anechoic area in the central area in the mid and distal metacarpal regions of the right superficial digital flexor tendon (Fig. 3.19). In the transverse images obtained from 80 to 120 mms distal to the accessory carpal bone, this lesion had an irregular shape but in images obtained from 140 to 220 mms distal to the accessory carpal bone, this area was elliptical. It was largest in the mid metacarpal region

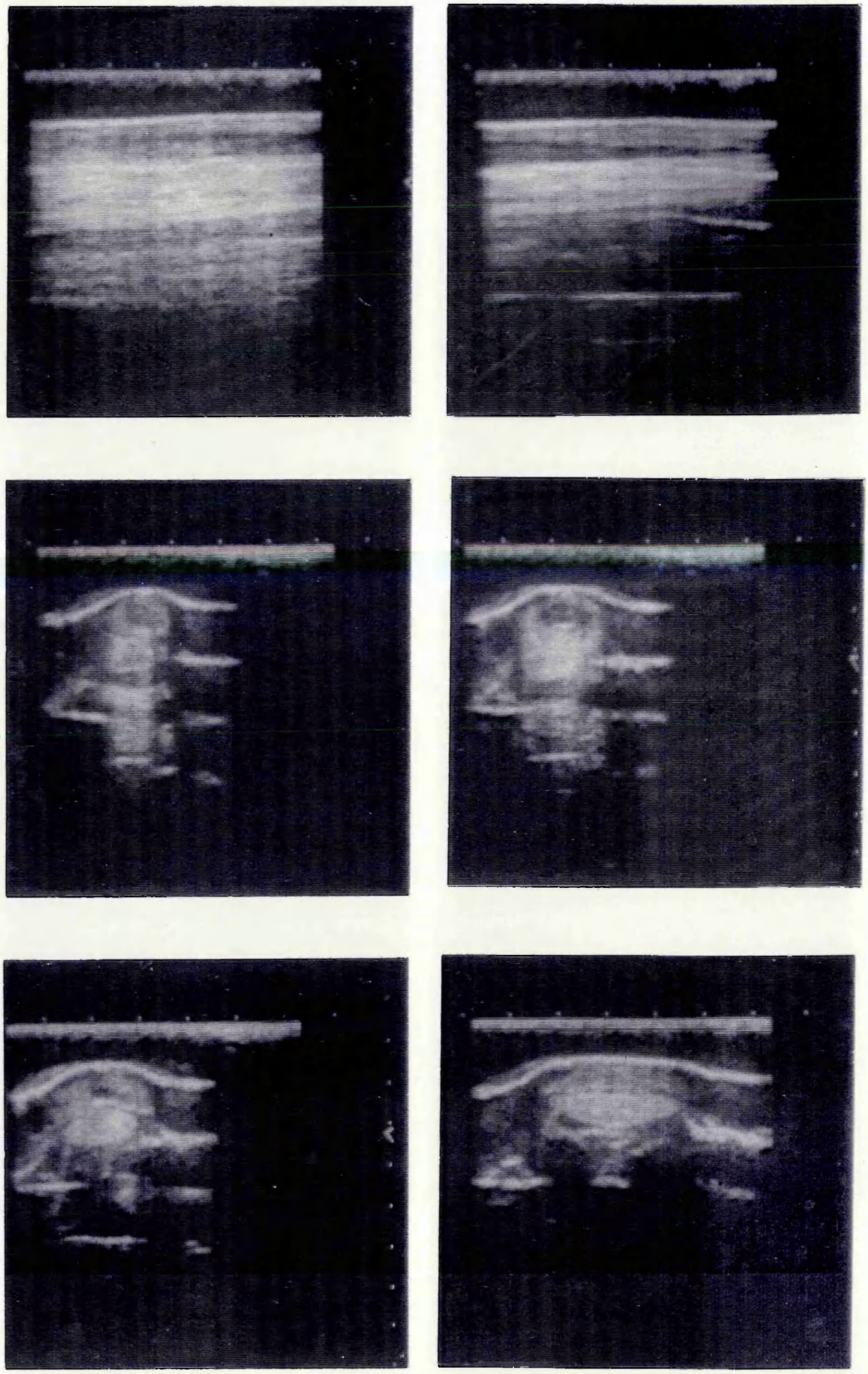
FIG. 3.18. THE CLINICAL FINDINGS ASSOCIATED WITH SUPERFICIAL DIGITAL FLEXOR TENDON INJURY IN CASE 3.5: RIGHT SUPERFICIAL DIGITAL FLEXOR TENDON IS ENLARGED ON THE PALMAR ASPECT OF THE METACARPAL REGION IN THIS HORSE WITH A TENDON INJURY OF EIGHT WEEKS' DURATION (CASE 3.5).

FIG. 3.19. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF EIGHT WEEKS' DURATION (CASE 3.5, RIGHT FORE).

THERE IS AN ELLIPTICAL ANECHOIC AREA WITHIN THE MID METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON WHICH IS COMPOSED OF IRREGULAR LOW-LEVEL ECHOES IN THE LONGITUDINAL IMAGES (UPPER, LEFT AND RIGHT).

IN THE PROXIMAL AND DISTAL TRANSVERSE IMAGES IT HAS AN IRREGULAR SHAPE (MIDDLE LEFT, 80 MMS DISTAL TO THE ACCESSORY CARPAL BONE; LOWER LEFT, 240 MMS DISTAL TO THE ACCESSORY CARPAL BONE) BUT IN THE MID METACARPAL REGION IT HAS AN OVAL SHAPE AND IS LOCATED CENTRALLY (MIDDLE RIGHT). AT THE LEVEL OF THE PROXIMAL SESAMOIDS THE TENDONS ARE NORMAL (LOWER RIGHT).

[NOTE THERE ARE A REVERBERATION ARTIFACTS IN THE MIDDLE RIGHT, LOWER LEFT AND RIGHT IMAGES].



and became progressively smaller in the distal images.

The right superficial digital flexor tendon was enlarged in dorsal to palmar direction but not in a lateral to medial direction. However,the medial and lateral edges of the tendon were rounded.

The ultrasonographic changes in the left fore were subtle. The longitudinal images were normal. However, in the transverse images of the mid metacarpal region from 100 to 180 mms distal to the accessory carpal bone, there was a very small circular hypoechoic area which was not clearly defined (Fig. 3.20). A hypoechoic area was also identified with in the distal region but this was considered to be normal (Fig. 3.20).

Macroscopic Findings.

There was no subcutaneous haemorrhage or swelling in the right fore limb. The superficial digital flexor tendon was moderately enlarged on its palmar aspect but the surface of the tendon was a normal cream colour. The palmar surface of the tendon was smooth but fibrous adhesions were located between the superficial and deep digital flexor tendons in the mid and distal regions (Fig. 3.21). The largest dorsal to palmar diameter was at the point 140 mms distal to the accessory carpal bone at which the diameter was 10 mms. Transverse sections demonstrated that there was a central lesion running from 80 to 220 mms distal to the accessory carpal bone. The most proximal part of this lesion was white with small red specks but the majority of the lesion was one

FIG. 3.20. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH A SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF EIGHT WEEKS' DURATION (CASE 3.5, LEFT FORE).

THE ULTRASONOGRAPHIC CHANGES ARE SUBTLE: THE LONGITUDINAL IMAGES WERE NORMAL (UPPER LEFT AND RIGHT) BUT ON TRANSVERSE IMAGES OF THE PROXIMAL AND MID METACARPAL REGION A HYPOECHOIC AREA WAS IDENTIFIED WITHIN THE CENTRAL ZONE OF THE SUPERFICIAL DIGITAL FLEXOR TENDON. IT IS MOST OBVIOUS IN THE IMAGE MADE 100 MMS DISTAL TO THE ACCESSORY CARPAL BONE (MIDDLE LEFT) AND IS LESS WELL-DEFINED IN ITS MORE DISTAL REGIONS (MIDDLE RIGHT AND LOWER LEFT).

A SEPARATE HYPOECHOIC AREA IS PRESENT IN THE DISTAL METACARPAL REGION BUT THIS IS CONSIDERED TO BE A NORMAL FINDING (LOWER RIGHT).

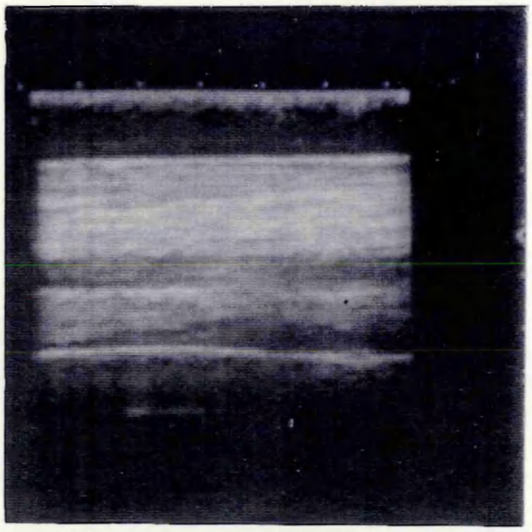
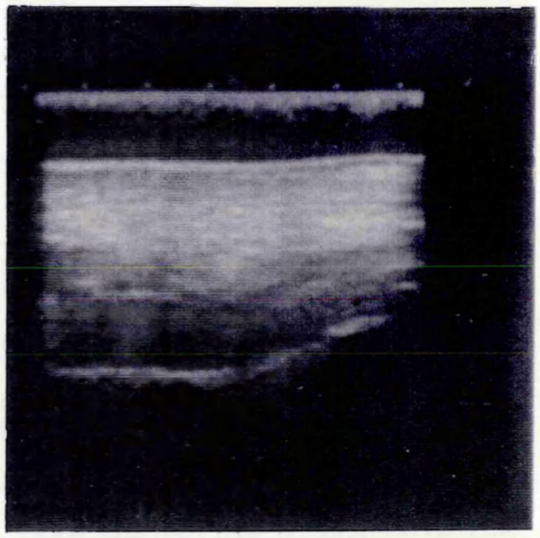
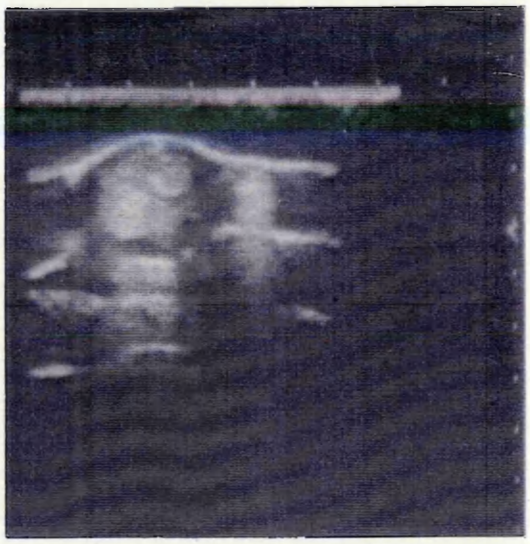
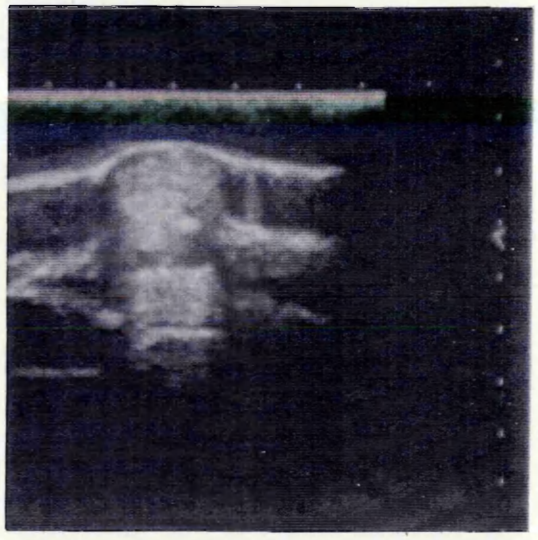
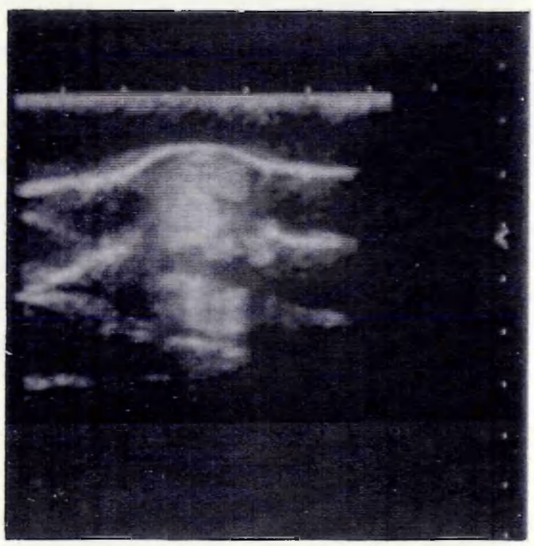
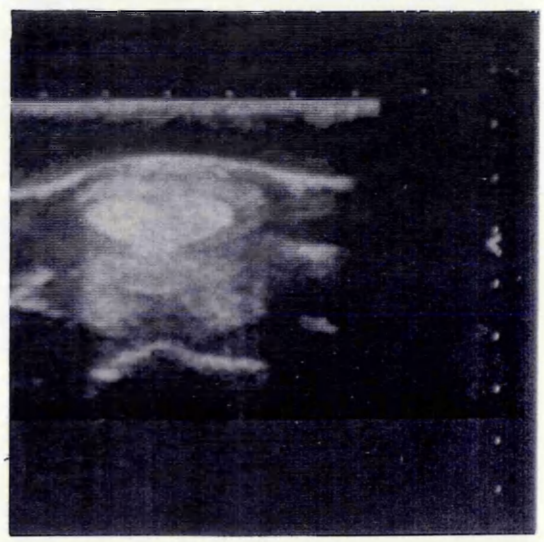
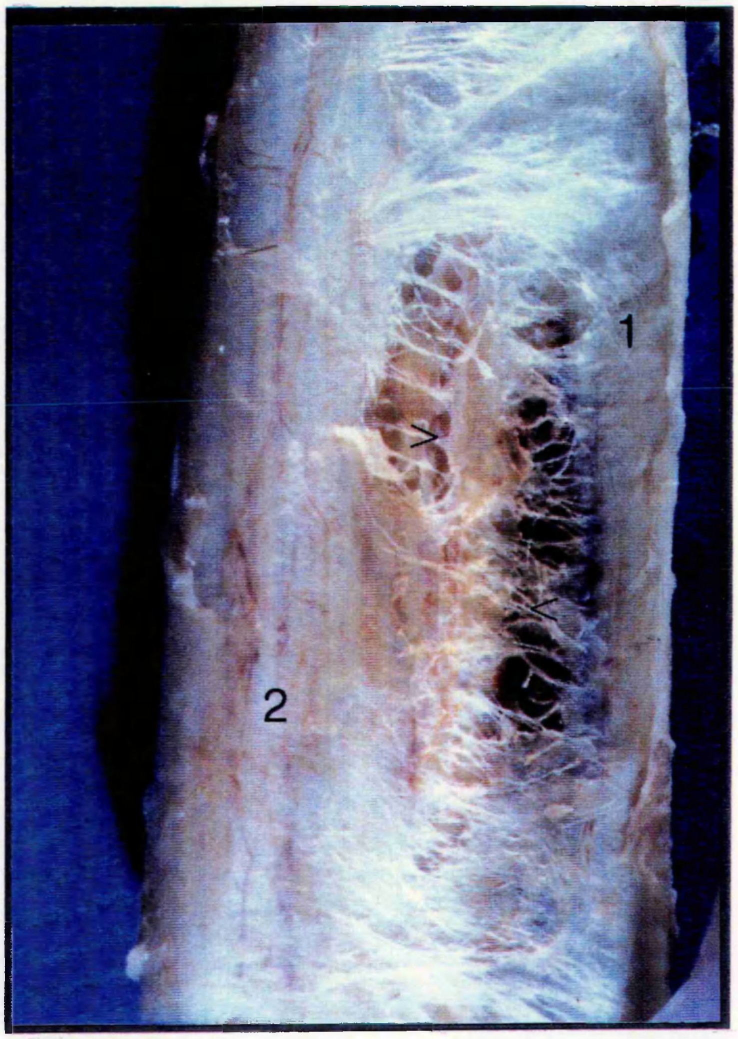







FIG. 3.21. THE RIGHT FLEXOR TENDONS OF CASE 3.5 WHICH A MODERATELY SEVERE SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF EIGHT WEEKS' DURATION. THERE ARE FIBROUS ADHESIONS BETWEEN THE SUPERFICIAL (1) AND DEEP (2) FLEXOR TENDONS.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confluent red area with slightly irregular edges. The surrounding tendon was a normal colour.

The findings in the left fore limb were similar except that the lesion which was identified in the mid region of the tendon was much less extensive. It ran from 100 to 200 mms distal to the accessory carpal bone and occupied a smaller proportion of the cross-sectional area. The tendon was slightly enlarged in a palmar direction in this area.

Histopathological findings.

The endotenon in the proximal sections of the right fore superficial digital flexor tendon contained an increased number of cells with enlarged granular nuclei. At, and distal to, 140 mms distal to the accessory carpal bone extending to the level of 220 mms distal to accessory carpal bone, areas of haemorrhage with fibrin deposits, collagen fibre necrosis, oedema and granulation tissue were found in the central zone of the superficial digital flexor tendon. Immature tendon typified by an area with numerous enlarged fibroblasts arranged in parallel with granular oval nuclei was also present (Fig. 3.22). Collagen was present in these areas but it did not have a normal arrangement (Fig. 3.23). There was widespread deposition of haemosiderin in the paratenon and endotenon but very little within the collagen bundles themselves. A rim of normal tendon fibres surrounded this area but in that zone the endotenon contained numerous cells.

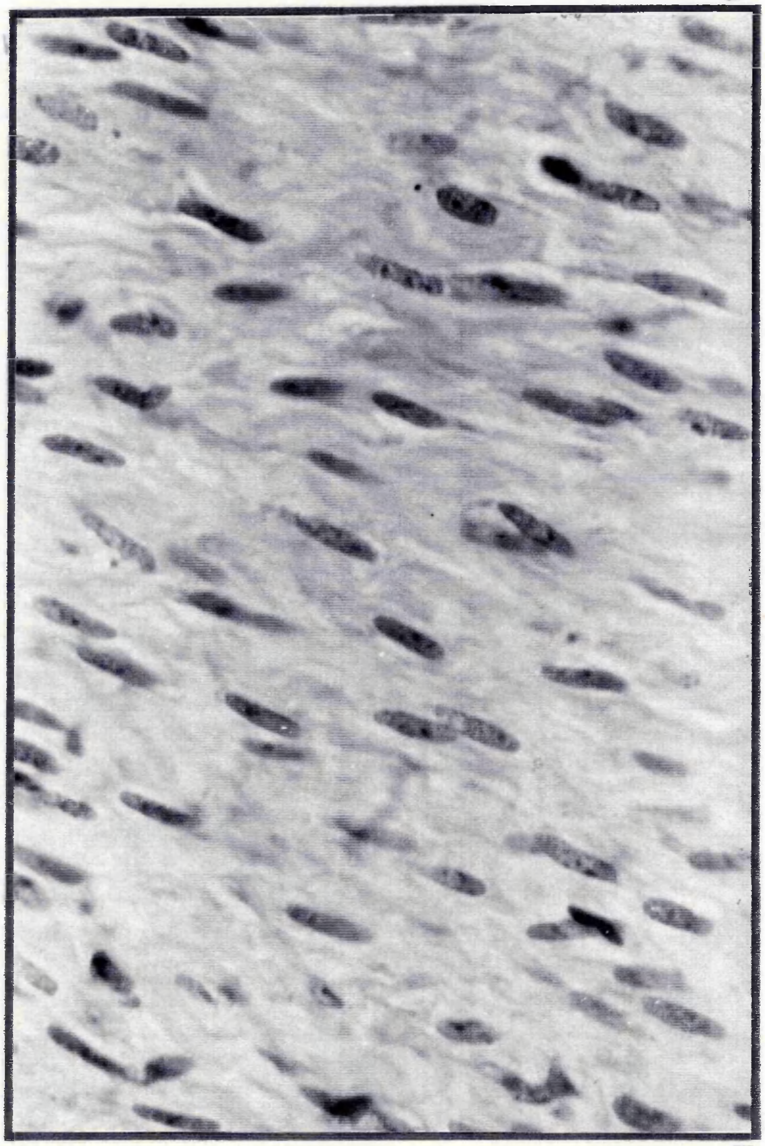
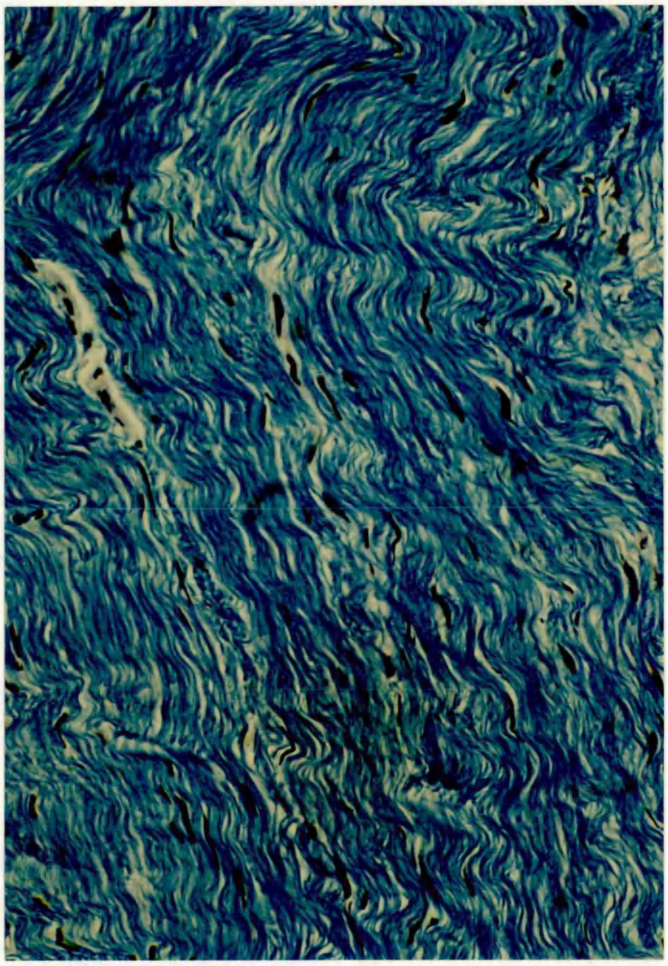


FIG. 3.23. THE HISTOLOGICAL FINDINGS IN A HORSE WITH SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF EIGHT WEEKS DURATION (CASE 3.5): COLLAGEN FIBRES HAVE AN IRREGULAR ARRANGEMENT WHICH TYPIFIES AN AREA OF IMMATURE TENDON TISSUE [L.S., MSB X 100]



The findings in the right superficial digital flexor tendon were similar and located in the same position except that the lesions occupied less of the cross-sectional area and length of the tendon.

CASE 3.6: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A seven year-old Thoroughbred gelding was presented approximately three months after it sustained bilateral tendon injuries.

The horse was slightly lame at the walk and there was slight hyperextension of the metacarpophalangeal joints. Both superficial digital flexor tendons were markedly enlarged in palmar and medial directions in the mid metacarpal region. There was pain elicited on compression of the lateral and medial borders of both superficial digital flexor tendons while heat was detected on palpation of the palmar metacarpal regions. The tendons felt firm in the proximal metacarpal region but localised, softer areas were palpable approximately 80 mms proximal to the level of the proximal sesamoids.

Ultrasonographic Findings.

The ultrasonographic findings were similar in both superficial digital flexor tendons. They were enlarged in palmar and medial directions (Fig. 3.24). The echogenicity of the tendons was heterogeneous and it was composed of irregular anechoic and hypoechoic regions. In addition, there were numerous hyperechoic areas which

FIG. 3.24. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF THREE MONTHS' DURATION (CASE 3.6, LEFT FORE).

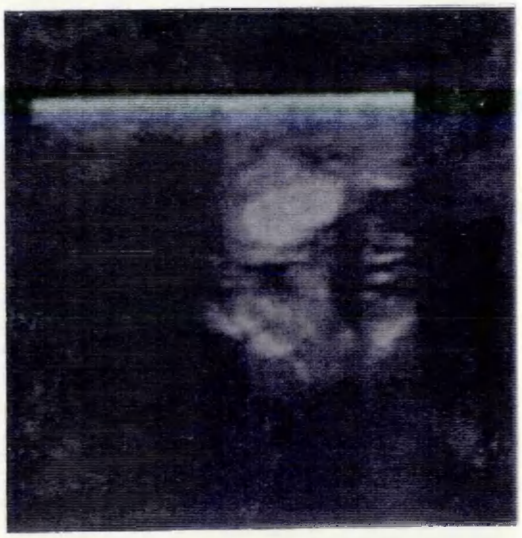
THE TRANSVERSE IMAGES DEMONSTRATE THAT THE ECHOGENICITY OF THE SUPERFICIAL DIGITAL FLEXOR TENDON IS HETEROGENEOUS AND IT IS COMPOSED OF MIXTURE OF ANECHOIC AND HYPOECHOIC REGIONS (UPPER LEFT AND RIGHT AND LOWER LEFT AND RIGHT).

HYPERECHOIC AREAS ARE PRESENT WHICH RANGE IN SIZE FROM SPECKS (MIDDLE RIGHT: [1]) TO 5 MMS (MIDDLE RIGHT: [2]).

A MEDIAL OBLIQUE IMAGE ILLUSTRATES THAT THE SUPERFICIAL DIGITAL FLEXOR TENDON IS SPLAYED AROUND THE DEEP DIGITAL FLEXOR TENDON (MIDDLE LEFT).

[NOTE THERE IS INCOMPLETE CONTACT ON THE LATERAL ASPECTS OF THE UPPER LEFT, MIDDLE RIGHT AND LOWER LEFT IMAGES].






ranged in size from being specks to approximately 5 mms in diameter. These were scattered throughout the length of both tendons. In longitudinal images there were no linear echoes apparent.

Macroscopic Findings.

The superficial digital flexor tendons of both fore limbs were surrounded by excess soft tissue associated with the paratenon. There were white fibrous adhesions between the tendons and the overlying subcutaneous tissues were also adhesed to the tendons in localised areas throughout the palmar region.

The tendons were enlarged in a medial and palmar direction from 80 mms to 260 mms distal to the accessory carpal bone and they were firm with a white surface. The largest dorsal to palmar diameter was at the point 200 mms distal to the accessory carpal bone in the right fore limb where it was 20 mms and at the point 180 mms distal to the accessory carpal bone in the left fore limb where it was 18 mms. The cut surface of transverse sections had numerous randomly distributed irregular areas of firm white, softer red and cream tissues.

Histopathological Findings.

In both superficial digital flexor tendons the histological findings were similar and there appeared to be both active haemorrhagic and repair processes occurring simultaneously with haemorrhage, fibrin, oedema, granulation tissue, immature tendon and scar formation (Fig. 3.25). The areas of immature fibre

FIG. 3.25. THE HISTOLOGIC FINDINGS IN A HORSE WITH BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF THREE MONTHS' DURATION (CASE 3.6, LEFT FORE): THERE IS AN AREA OF GRANULATION TISSUE WITH A MARKED FIBROBLASTIC REACTION ARISING IN THE ENDOTENON BETWEEN TWO FASCICLES (1) AND THE FIBROBLASTS WITHIN THE FASCICLES HAVE PALE NUCLEI [L.S., H. & E. , X 100].

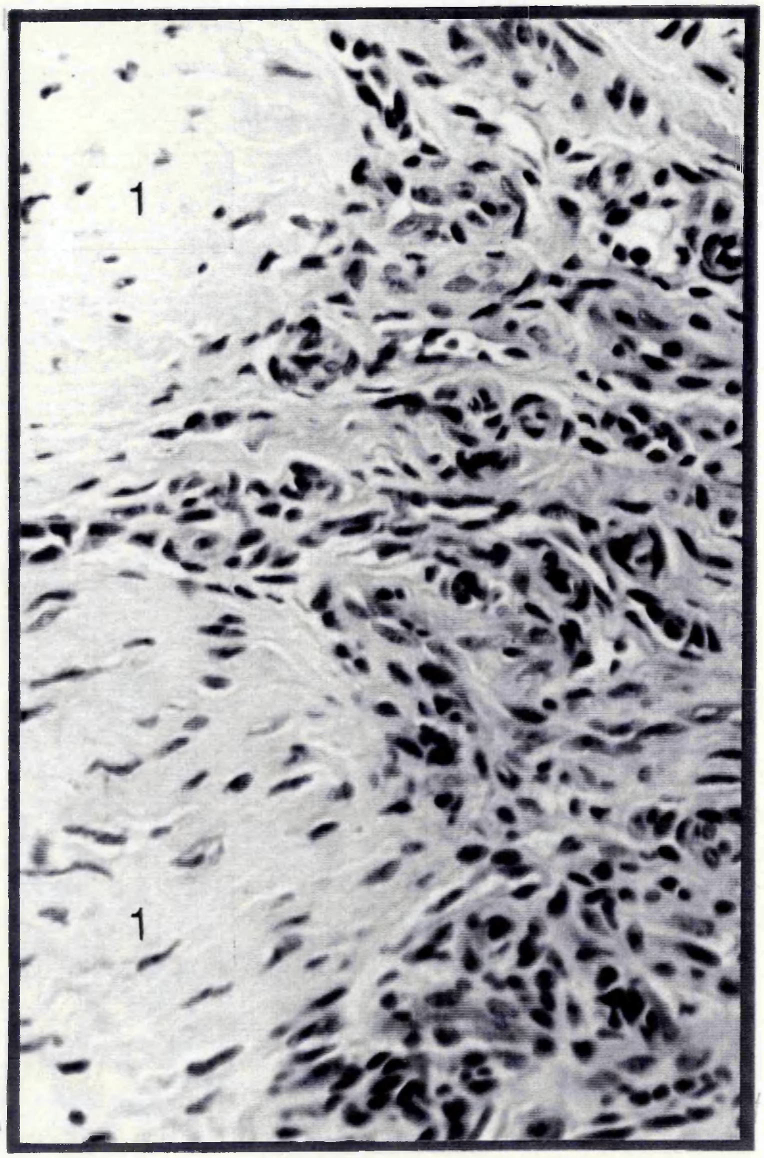

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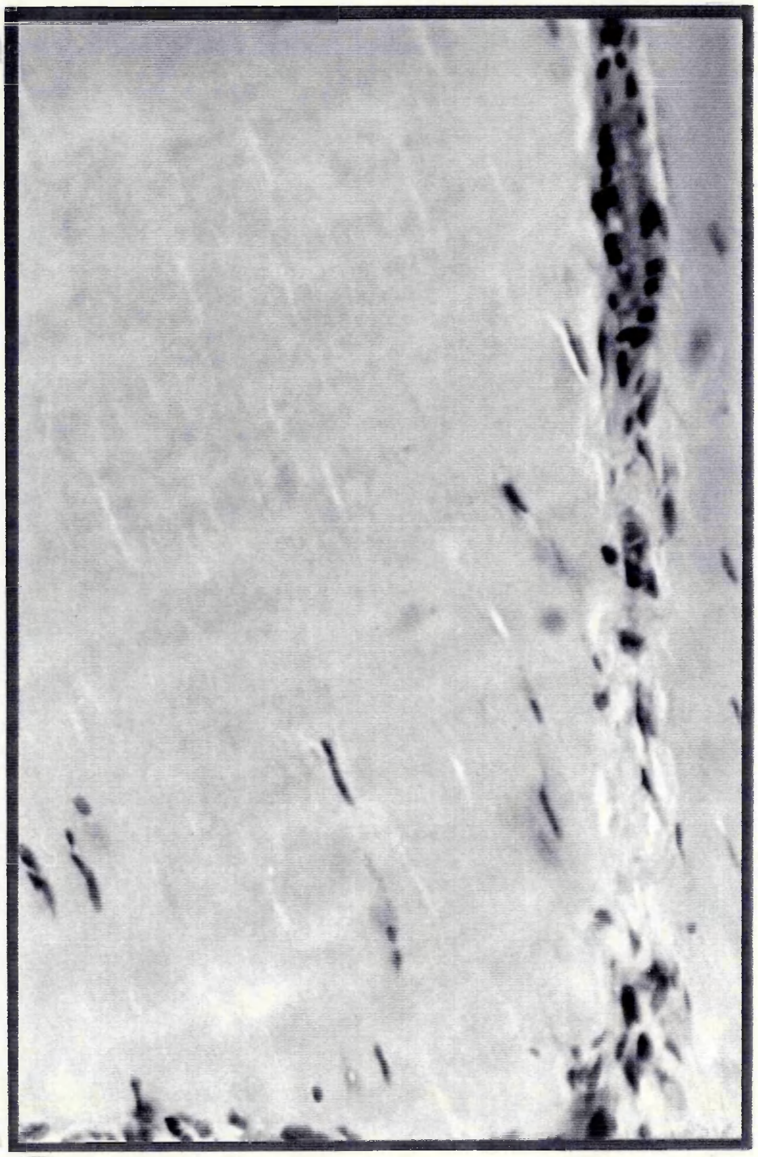
FIG. 3.26. THE HISTOLOGIC FINDINGS IN A HORSE WITH BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF THREE MONTHS' DURATION (CASE 3.6, LEFT FORE): THERE IS AN ACELLULAR AREA COMPOSED OF DENSE COLLAGENOUS TISSUE REPRESENTING SCAR FORMATION [L.S., H. & E., X 100].



formation were primarily identified at the periphery of the lesion. Large acellular areas occupied the central areas of the tendon (Fig. 3.26) and these were interspersed with areas of haemorrhage and granulation tissue. There was widespread haemosiderin deposition associated with the haemorrhagic areas within the collagen fibres and in the endotenon.

CASE 3.7: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

An eight year-old Thoroughbred mare was presented but details of its previous history were not available.

The horse was sound at the walk, both superficial digital flexor tendons were firm and cool and markedly enlarged in a palmar direction throughout the mid metacarpal region. There were firm swellings in the distal metacarpal region and the borders of the tendons could not be clearly distinguished.

Ultrasonographic Findings.

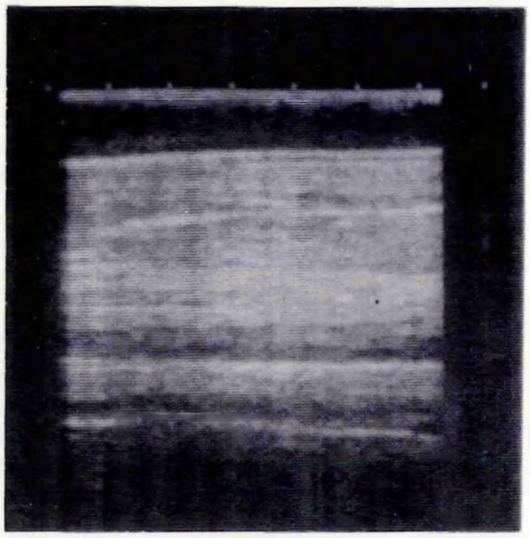
The ultrasonographic findings were similar in both superficial digital flexor tendons. The tendons were enlarged in palmar-medial direction throughout the metacarpal region. On longitudinal images the echogenicity was heterogeneous with numerous elliptical hypoechoic areas scattered throughout the tendons (Fig. 3.27). There were some linear echoes present in the palmar and dorsal zones but these were shorter than normal (Fig. 3.27). In the central zone, linear echoes

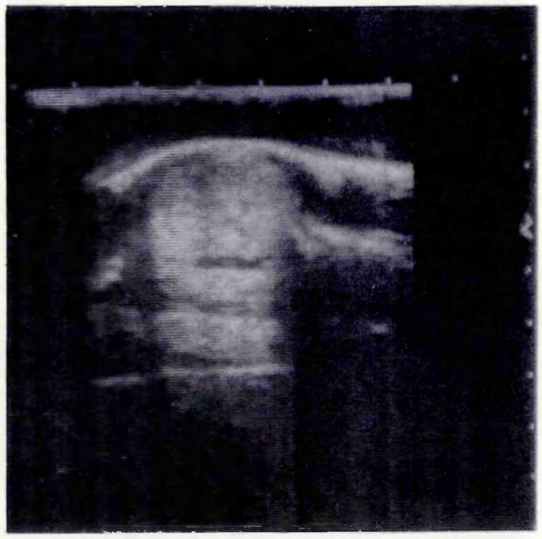
FIG. 3.27. THE ULTRASONOGRAPHIC FINDINGS FROM A HORSE WITH CHRONIC BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES (CASE 3.7, RIGHT FORE).

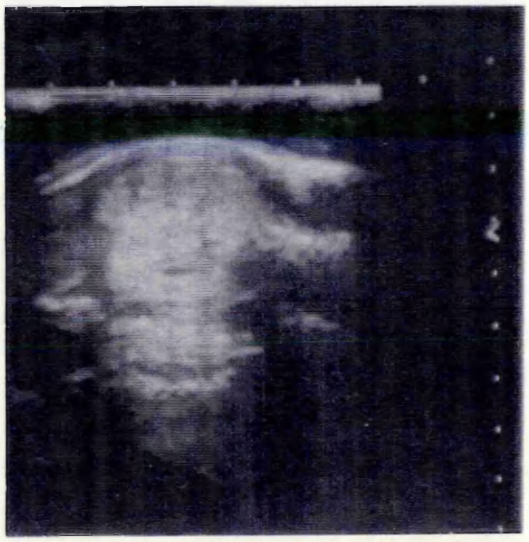
IN THE LONGITUDINAL IMAGE LINEAR ECHOES ARE PRESENT IN THE DORSAL AND PALMAR ZONES OF THE SUPERFICIAL DIGITAL FLEXOR TENDON BUT THESE ARE NOT PRESENT IN THE CENTRAL ZONE WHICH CONTAINS ELLIPTICAL HYPOECHOIC REGIONS (UPPER LEFT).

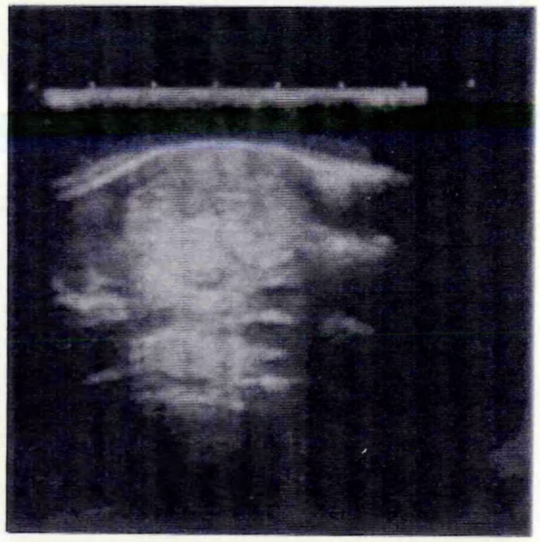
THE TRANSVERSE IMAGES THE BOUNDARY OF THE LESION IS DISTINCT BUT WITHIN THE LESION THE ECHOGENICITY IS HETEROGENEOUS. IN THIS TENDON (RIGHT) IT WAS COMPOSED OF VARIOUS HYPOECHOIC AREAS WITH NUMEROUS PINPOINT HYPERECHOIC FOCI (UPPER RIGHT, MIDDLE LEFT AND RIGHT AND LOWER LEFT AND RIGHT).

[NOTE THERE IS A REVERBERATION ARTIFACT IN THE LOWER RIGHT IMAGE AND INCOMPLETE CONTACT ON THE MEDIAL AND LATERAL ASPECTS OF THIS IMAGE].









were not detected. On transverse images the outer boundary of the lesion was quite distinct but its echogenicity was mixed. In the left superficial digital flexor tendon it was principally hypoechoic with some anechoic areas while in the right superficial digital flexor tendon it was hypoechoic but it contained areas with varying levels of echogenicity (Fig. 3.27). Hyperechoic foci were identified in both tendons (Fig. 3.27). Subcutaneous hypoechoic regions were present on the palmar aspect of the superficial digital flexor tendons and the digital sheaths appeared to be thickened. These ultrasonographic findings were considered to represent lesions of approximately four to five months duration.

Macroscopic Findings.

The superficial and deep digital flexor tendons of both fore limbs were examined after they had been removed from the limbs by section at the levels of the accessory carpal bone and the proximal sesamoids and placed in buffered formaldehyde.

The left superficial digital flexor tendon was enlarged in a palmar and medial direction from 60 to 300 mms distal to the accessory carpal bone. The maximum dorsal to palmar diameter was at the point 200 mms distal to the accessory carpal bone where it was 20 mms. This was also the widest part in a lateral to medial plane and the tendon measured 32 mms at this location. The tendon was firm and white and the paratenon and palmar aspect of the digital sheath were thickened although the synovial surface was smooth and appeared macroscopically normal. The lesion was central in location and extended from 60 to 300 mms distal to the accessory carpal bone. In its most proximal part, it was represented by a pale central area. In the mid and distal metacarpal regions the lesion was soft and greenish with numerous haemorrhagic areas.

The right superficial digital flexor tendon was also enlarged in a similar location. Transverse sections demonstrated that in this limb the lesion was also central in location but it was composed of pale cream tissue with haemorrhagic areas which were most apparent around the periphery of the lesion. Surrounding the lesions in both superficial digital flexor tendons there were rims of macroscopically normal tendon.

Histopathological Findings.

In the left superficial digital flexor tendon there appeared to be both active haemorrhagic and repair processes occurring simultaneously with haemorrhage, granulation tissue, and the presence of immature tendon. The haemorrhage and granulation tissue were located in the central zone of the mid portion superficial digital flexor tendon and the endotenon was particularly prominent with large oval fibroblasts and numerous neutrophils (Fig. 3.28). The modified Methyl Blue Van Gieson and Martius Scarlet Blue stains demonstrated that these areas contained

FIG. 3.28. HISTOLOGICAL FINDINGS IN A HORSE WITH CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.7): FIBROBLASTS (1) AND NEUTROPHILS (2) IN THE ENDOTENON OF THE LEFT SUPERFICIAL DIGITAL FLEXOR TENDON WITH A CHRONIC INJURY [H. & E., X 250].

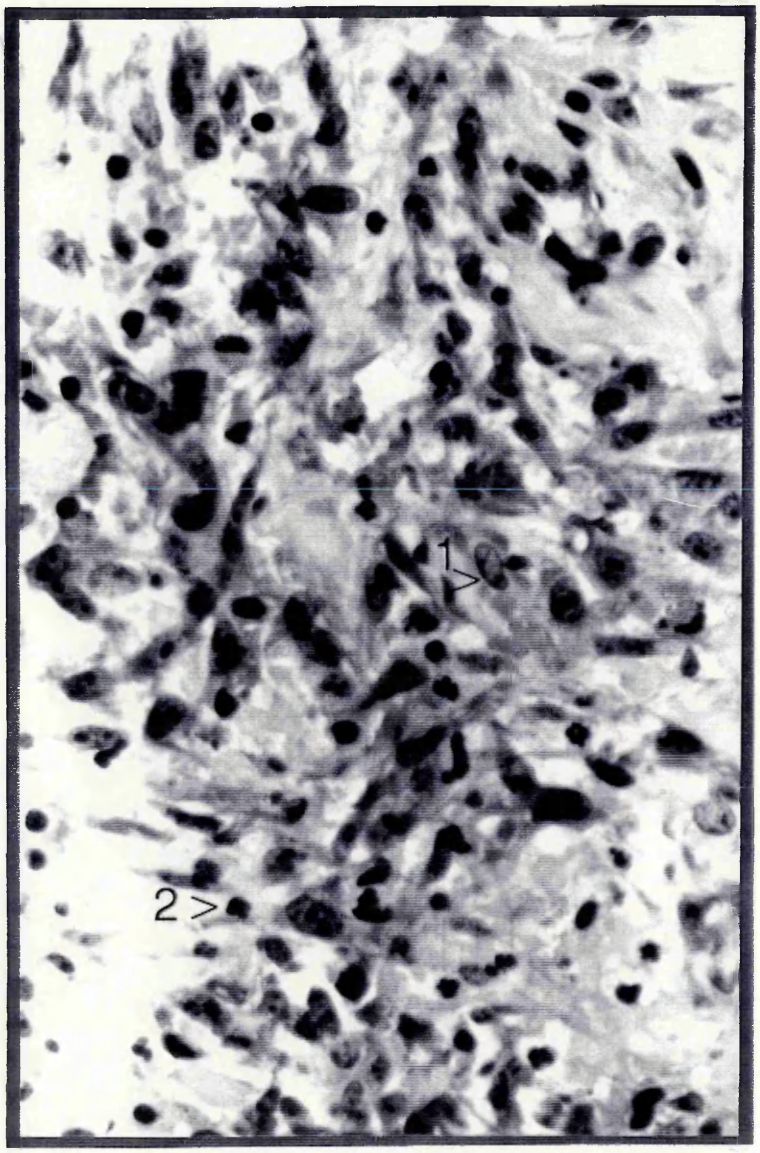

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FIG. 3.29. A LONGITUDINAL SECTION FROM THE CENTRAL ZONE OF THE RIGHT SUPERFICIAL DIGITAL FLEXOR TENDON IN A HORSE WITH CHRONIC TENDON INJURY (CASE 3.7): THERE ARE HAEMORRHAGIC AREAS AND IMMATURE TENDON WITH NUMEROUS FIBROBLASTS AND IRREGULARLY ARRANGED COLLAGEN [MASSON X 100].

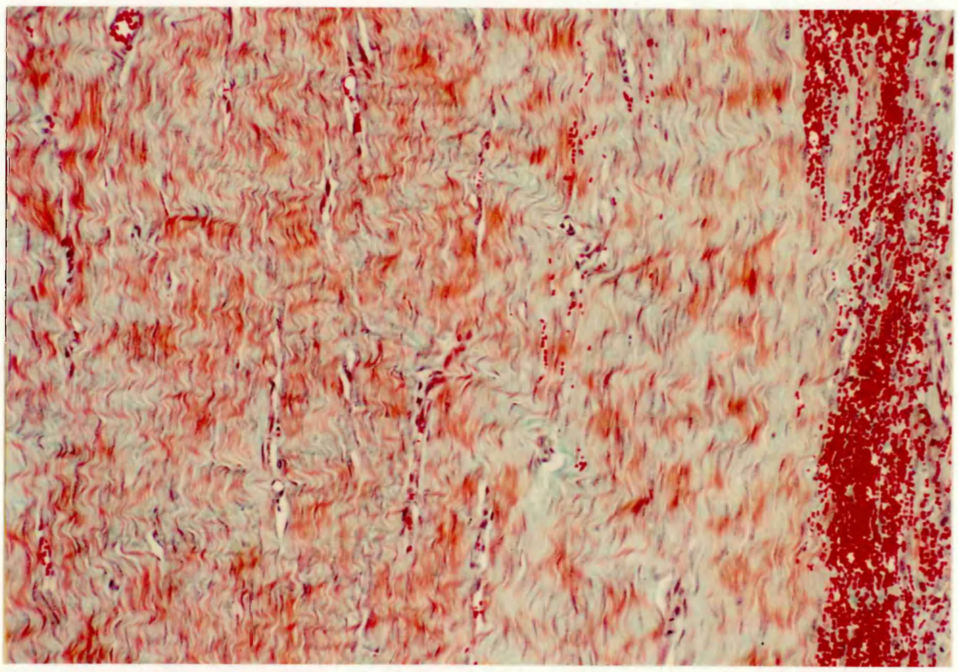
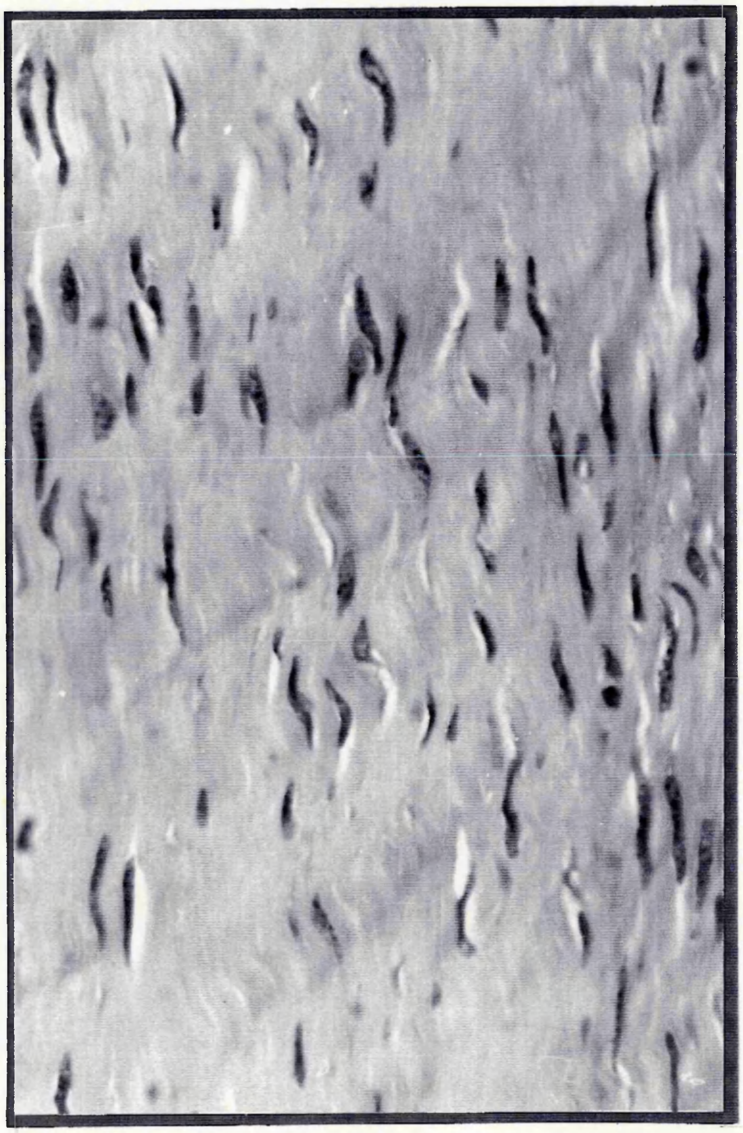


FIG. 3.30. HISTOLOGICAL FINDINGS IN A HORSE WITH CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.7): THE FIBROBLASTS ARE EXTREMELY NUMEROUS AND THE COLLAGEN BUNDLES ARE NOT REGULARLY ARRANGED [H. & E., X 250].



irregularly-arranged collagen (Fig. 3.29).

The lesion in the right superficial digital flexor tendon was principally composed of immature tendon tissue: the fibroblasts were extremely numerous and their arrangement was not regular (Fig. 3.30). However, there was scar formation but less haemorrhage. Haemosiderin was identified in the paratenon and the endotenon but not within the collagen fibres. The lesion was located within the central part of the tendon and extended from 120 to 240 mms distal to the accessory carpal bone.

CASE 3.8: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A seven year-old Thoroughbred gelding was presented five months after it sustained bilateral superficial digital flexor tendon injuries.

The horse was sound at the walk, both superficial digital flexor tendons were firm and cool and the left was markedly enlarged in a palmar direction throughout the mid metacarpal region while the right was slightly enlarged in the same region. The borders of the tendons could not be clearly distinguished and the lateral edges were rounded.

Ultrasonographic Findings.

The left superficial digital flexor tendon was enlarged throughout the metacarpal region. In longitudinal images, a central lesion was identified which was hypoechoic and contained some linear echoes although these were not arranged in parallel and they were short. In addition, there were hypoechoic areas with no linear echoes (Fig. 3.31). These areas were larger and more numerous in the distal metacarpal region. The transverse images demonstrated that the lesion was central in location and that it extended throughout the metacarpal region. The boundary of its proximal part was ill-defined being more evident in the mid and distal metacarpal regions. It was hypoechoic and did not contain anechoic areas although various levels of echogenicity were present (Fig. 3.31). A subcutaneous hypoechoic region was identified palmar to the superficial digital flexor tendon.

The right superficial digital flexor tendon was enlarged in the mid metacarpal region and it contained a central hypoechoic area in this region. On longitudinal images this area was a hypoechoic with numerous, short linear echoes (Fig. 3.32). In the transverse images this area was a fairly uniform oval hypoechoic region which had a distinct border (Fig. 3.32).

Macroscopic Findings.

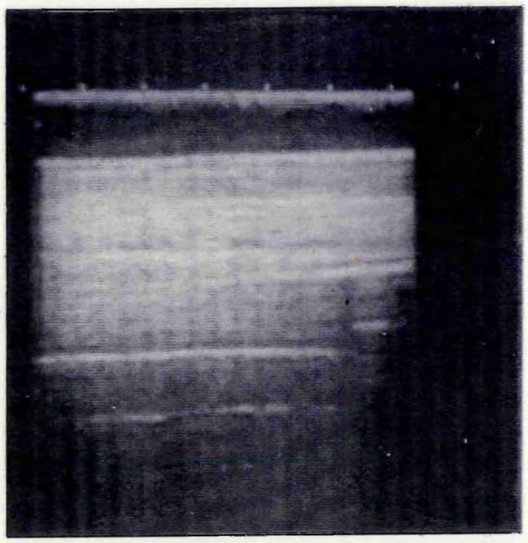
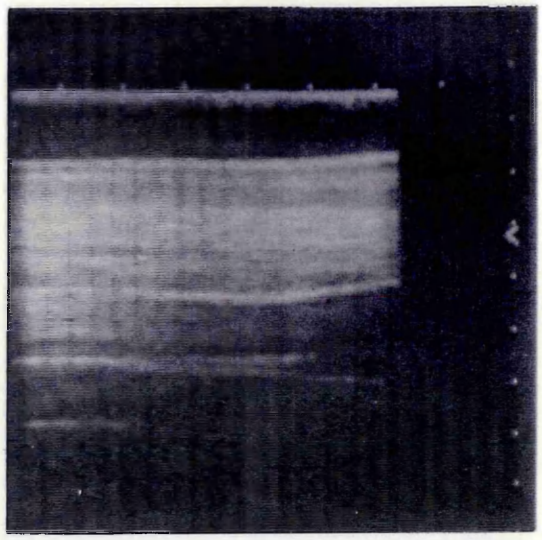
The paratenons of both fore superficial digital flexor tendons were slightly thickened and there were fibrous adhesions between the dorsal aspect of the superficial digital flexor tendons and the palmar aspect of the deep digital flexor tendons in both limbs.

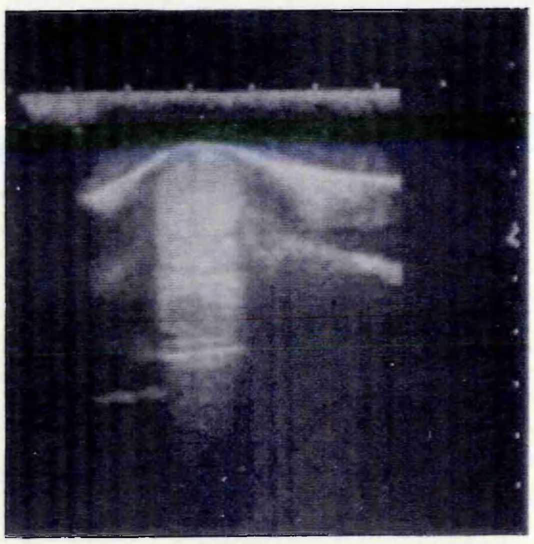
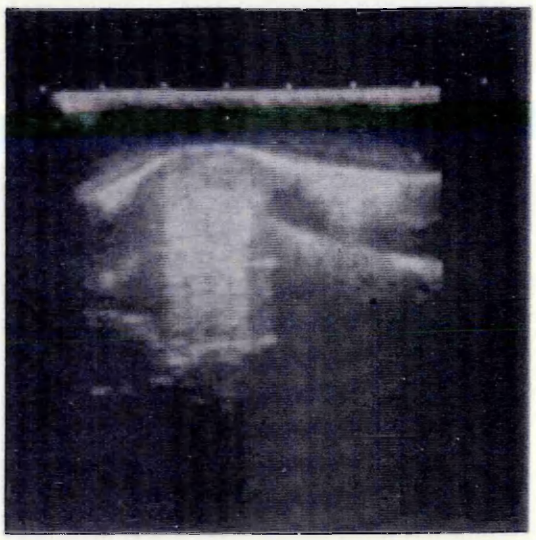
FIG. 3.31. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH A SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF FIVE MONTHS' DURATION (CASE 3.8, RIGHT).

THE LONGITUDINAL IMAGES DEMONSTRATE A CENTRAL HYPOECHOIC AREA IN THE MID METACARPAL REGION WHICH CONTAINS SOME LINEAR ECHOES (UPPER LEFT AND RIGHT). THIS AREA WAS ABSENT IN THE PROXIMAL METACARPAL REGION (UPPER LEFT).

THE TRANSVERSE IMAGES DEMONSTRATE THAT IN THE PROXIMAL METACARPAL REGION THE LESION IS ILL-DEFINED (MIDDLE LEFT) AND IN THE MID AND DISTAL METACARPAL REGIONS IT IS A UNIFORM CIRCULAR HYPOECHOIC AREA WITH A DISTINCT BORDER (MIDDLE RIGHT AND LOWER LEFT AND RIGHT).

[NOTE THERE ARE REVERBERATION ARTIFACTS IN IMAGES A AND B].

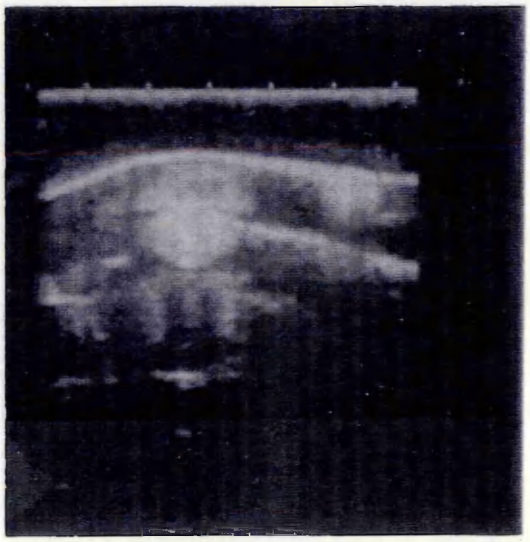
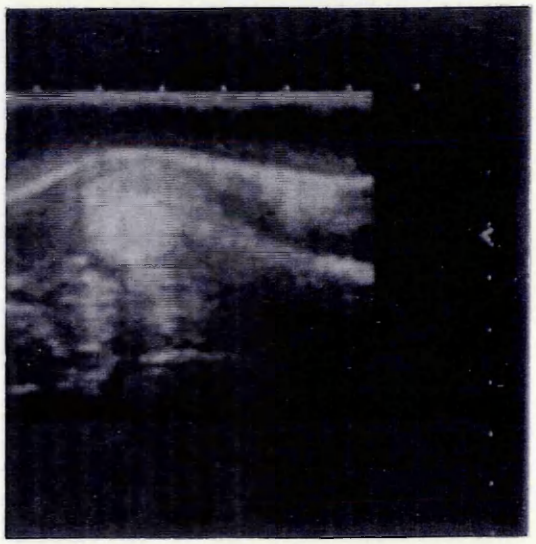
 

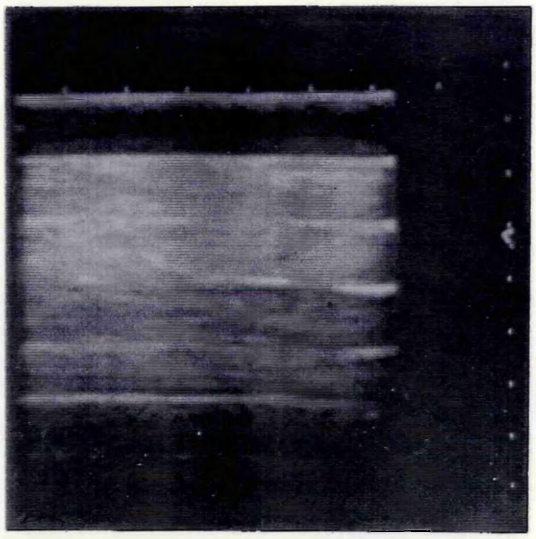
FIG. 3.32. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH A SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF FIVE MONTHS' DURATION (CASE 3.8, LEFT).

IN THE LONGITUDINAL IMAGE (UPPER), THE LESION OCCUPIES MOST OF THE TENDON. IT IS HYPOECHOIC AND CONTAINS A FEW SHORT LINEAR ECHOES AND NUMEROUS HYPOECHOIC REGIONS.

IN THE TRANSVERSE IMAGES FROM THE PROXIMAL METACARPAL REGION (MIDDLE, 120 MMS DISTAL TO THE ACCESSORY CARPAL BONE) IT IS CENTRAL IN LOCATION AND ITS BORDERS ARE ILL-DEFINED.

IN THE TRANSVERSE IMAGES FORM THE MID AND DISTAL METACARPAL REGIONS (LOWER, 200 MMS DISTAL TO THE ACCESSORY CARPAL BONE), ITS BORDER IS MORE DISTINCT AND IT CONTAINS A VARIETY OF HYPOECHOIC REGIONS WITH HYPERECHOIC FOCI.

[NOTE THERE IS INCOMPLETE CONTACT IN THE MID SECTION OF THE UPPER IMAGE WHICH HAS REVERBERATION ARTIFACTS AND THERE IS INCOMPLETE CONTACT ON THE MEDIAL ASPECTS OF THE MIDDLE AND LOWER IMAGES].



The left superficial digital flexor tendon was enlarged in a palmar direction in the entire metacarpal region. Its maximum dorsal to palmar diameter was at the level 200 mms distal to the accessory carpal bone where it measured 18 mms. A central lesion was identified with irregular borders being composed of brown tissue with numerous pinpoint white scars.

The right superficial digital flexor tendon was not as large but palmar swelling was apparent in the mid metacarpal region. A central lesion was identified which extended from 140 to 240 mms distal to the accessory carpal bone. It was composed of a mixture of brown and white tissues. On longitudinal sections, this area was less well-defined but the central portion had lost its normal banded appearance and the tissue was more amorphous.

Histopathological Findings.

The central zone of the left superficial digital flexor tendon contained numerous acellular areas interspersed with bands of extremely cellular areas with collagen fibres. Methyl blue van Gieson stain demonstrated that the collagen bundles associated with the cellular areas were not arranged in parallel although they were orientated along the long axis of the tendon. These fibres did not have the normal undulating waveform and were very straight. There were haemosiderin deposits apparent in the endotenon. In sections taken at and distal to 180 mms distal to the accessory carpal bone, the paratenon was extremely thick and contained fibroblasts with oval, granular nuclei and numerous haemosiderin deposits. There were no localised areas of granulation tissue or haemorrhage.

The right superficial digital flexor tendon was less extensively affected. A lesion was apparent in the central zone which extended from 80 mms to 240 mms distal to the accessory carpal bone. In the more proximal sections, this manifested itself by demonstrating an increased number of cells in the endotenon but distally, there were also acellular scars and areas in which the fibroblasts were extremely numerous.

CASE 3.9: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A seven year-old Thoroughbred mare was presented approximately six months after sustaining bilateral tendon injury. Details of its history previous to this were not available.

The horse was sound at the walk, both superficial digital flexor tendons were firm and cool and the left was markedly and progressively enlarged in a palmar direction throughout the mid and distal metacarpal regions. The borders of the tendons could not be clearly distinguished in the left fore. The right fore was less enlarged but a distinct palmar swelling, which was also firm and had indistinct borders, was apparent in the mid metacarpal region.

Ultrasonographic Findings.

The left fore was enlarged from 80 to 280 mms distal to the accessory carpal bone. A lesion was identified on both longitudinal and transverse images in this region (Fig. 3.33). Proximally, it had indistinct borders and it was represented by a diffuse reduction in echogenicity (Fig. 3.33). In the mid and distal metacarpal regions, it was slightly less ill-defined and on transverse images it was composed of a mixture of hypoechoic regions with numerous hyperechoic areas and a small number of extremely anechoic areas. There were linear echoes present in the dorsal and palmar zone of the longitudinal images of the mid and distal metacarpal regions but these were short and irregular within the lesion (Fig. 3.33).

The ultrasonographic findings in the right superficial digital flexor tendon were less dramatic (Fig. 3.34). The longitudinal and transverse images of the proximal metacarpal region were normal. But in the mid metacarpal region an ill-defined central hypoechoic area was identified with some pinpoint hyperechoic foci within it which had some irregular linear echoes on longitudinal images (Fig. 3.34). These ultrasonographic findings were considered to be consistent with lesions of approximately seven to nine months' duration.

FIG. 3.33. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH CHRONIC BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES (CASE 3.9, LEFT).

THE PROXIMAL REGIONS HAVE A NORMAL APPEARANCE (UPPER LEFT) AND THE LESION IS ILL-DEFINED IN THE TRANSVERSE IMAGE AT 80 MMS DISTAL TO THE ACCESSORY CARPAL BONE (MIDDLE LEFT).

THE MID METACARPAL REGION CONTAINS A HYPOECHOIC LESION WITH FEW LINEAR ECHOES AND SOME EXTREMELY HYPOECHOIC AREAS (UPPER RIGHT).

TRANSVERSE IMAGES OF THE MID AND DISTAL METACARPAL REGIONS DEMONSTRATE THAT THE LESION IS SOMEWHAT MORE DISTINCT AND IS MODERATELY HYPOECHOIC WITH BOTH ANECHOIC AND HYPERECHOIC AREAS (MIDDLE RIGHT AND LOWER LEFT AND RIGHT). THERE IS A HYPOECHOIC REGION PALMAR TO THE SUPERFICIAL DIGITAL FLEXOR TENDON IN THE DISTAL METACARPAL REGION (LOWER RIGHT, 240 MMS DISTAL TO THE ACCESSORY CARPAL BONE).

[NOTE THERE IS INCOMPLETE CONTACT ON THE MEDIAL ASPECT OF THE LOWER RIGHT IMAGE].

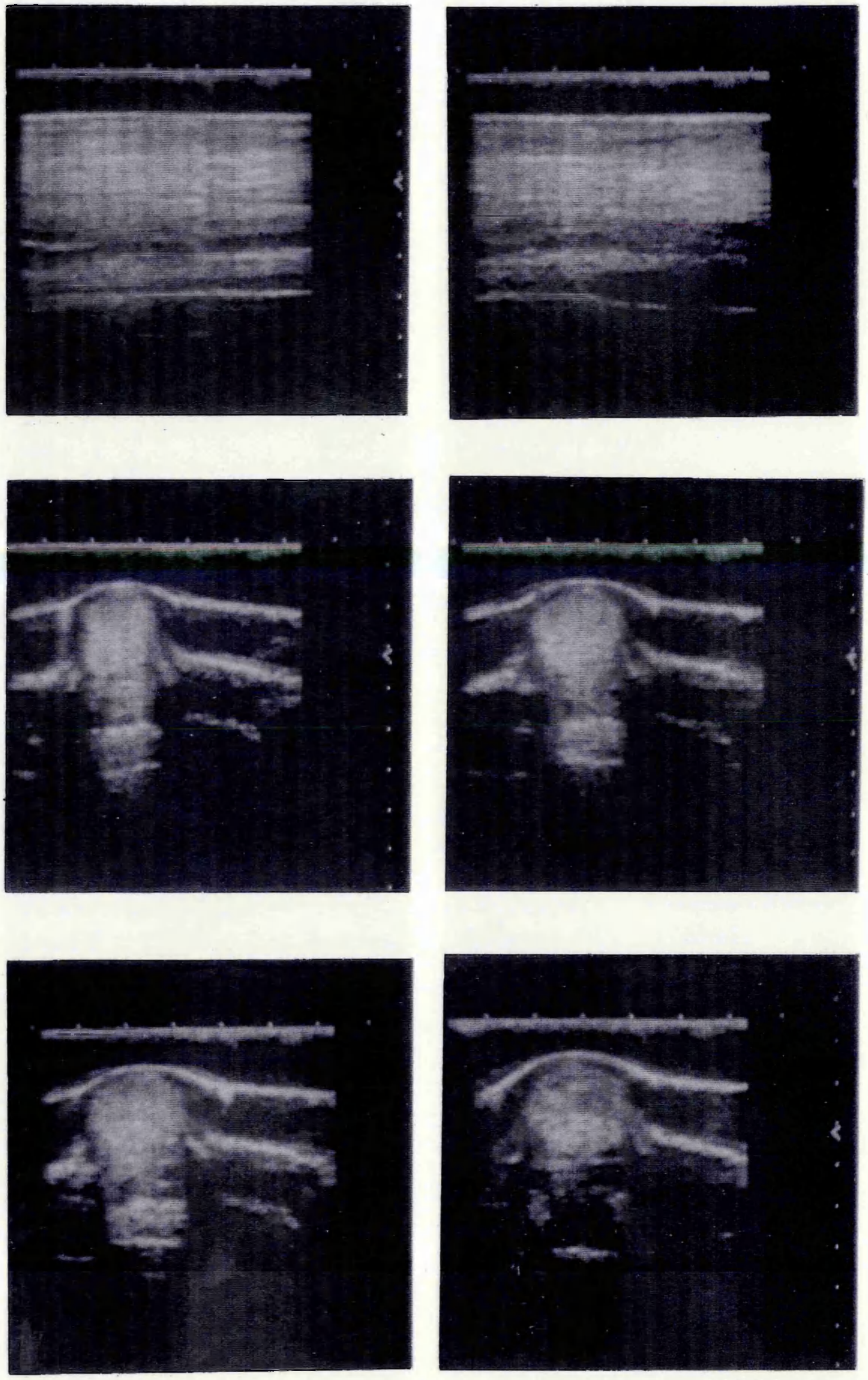
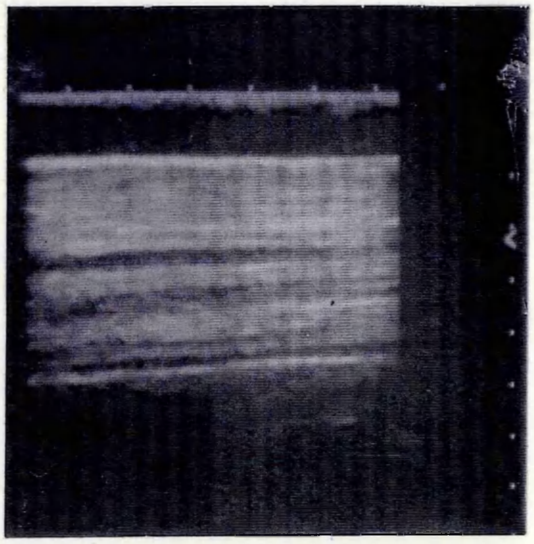
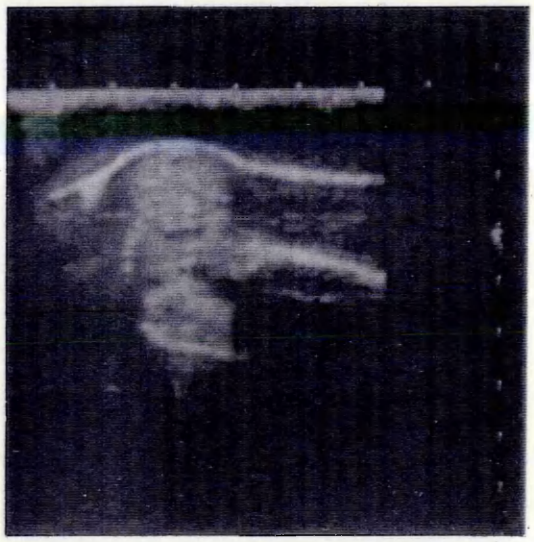
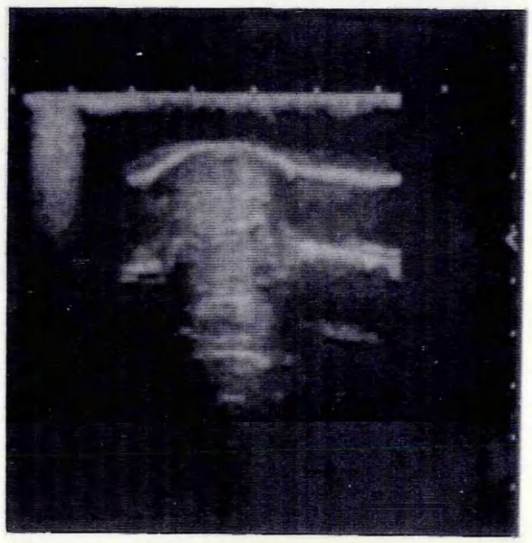


FIG. 3.34. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH CHRONIC BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES (CASE 3.9, RIGHT).

THE PROXIMAL LONGITUDINAL AND TRANSVERSE IMAGES ARE NORMAL (UPPER AND MIDDLE) BUT IN THE TRANSVERSE IMAGE OF THE MID METACARPAL REGION (LOWER, 180 MMS DISTAL TO THE ACCESSORY CARPAL BONE) THERE IS A ILL-DEFINED CENTRAL HYPOECHOIC AREA WITH A FEW HYPERECHOIC FOCI.







Macroscopic Findings.

There was a large amount of soft tissue surrounding the left superficial digital flexor tendon in the distal metacarpal region of the limb from 180 mms distal to the accessory carpal bone to the level of the proximal sesamoids. This could not be separated from the overlying subcutaneous tissues or from the superficial digital flexor tendon and it was adherent to the accessory ligament of the deep digital flexor tendon laterally and medially. It was firm and white and, on section, it was found to be composed of fibres running in a lateral to medial direction around the tendon. In addition, there were fibrous adhesions between the dorsal aspect of the superficial digital flexor tendon and palmar aspect of the deep digital flexor tendon. The palmar aspect of the digital sheath was also thickened but the synovial surface appeared to be normal.

The left superficial digital flexor tendon was enlarged from 80 to 280 mms distal to the accessory carpal bone with the largest dorsal to palmar diameter being 14 mms at the level 120 mms distal to the accessory carpal bone. In this region the tendon was firm and its surface was white. Transverse and longitudinal sections demonstrated that the internal structure of the central region of the tendon was disrupted. There were numerous firm white scars and reddish brown areas surrounded by a peripheral zone of macroscopically normal tendon in the more proximal regions. However, in the mid and distal parts of the tendon, there was no such rim of normal tendon. From 300 mms distally, the tendon was normal.

The right fore superficial digital flexor tendon was slightly enlarged in a palmar direction in the distal region from 160 to 260 mms distal to the accessory carpal bone. The surface of the tendon was smooth and there was no evidence of adhesion formation. In the centre of the tendon there was a pale area which was surrounded by macroscopically normal tendon. The junction between the normal and abnormal areas was ill-defined but this area was more distinct following fixation.

Histopathological Findings.

There were large areas of chronic fibrosis within the majority of the left superficial digital flexor tendon: the central zone contained numerous bands of extremely cellular areas and some acellular scars. There were numerous haemosiderin deposits in the endotenon which also had an increased number of cells. There were no localised areas of granulation tissue or haemorrhage within the tendon. There was no distinct layer of normal tendon around the periphery and there was fibrosis of the paratenon and epitenon.

The right superficial digital flexor tendon was less extensively affected: a lesion was apparent in the central zone which extended from 80 mms to 240 mms distal to the accessory carpal bone. In the more proximal sections, this manifested itself by demonstrating an increased number of cells in the endotenon but distally there were acellular scars and areas in which the fibroblasts were extremely numerous. Small amounts of haemosiderin were present in the endotenon and in the acellular scars.

CASE 3.10: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A five year-old Thoroughbred gelding was presented approximately six months after sustaining a severe right superficial digital flexor tendon injury and a mild left superficial digital flexor tendon injury.

The horse was sound at the walk, both superficial digital flexor tendons were firm and cool and the right was markedly and progressively enlarged in a palmar direction throughout the mid and distal metacarpal regions and the borders of the tendons could not be clearly distinguished.

The left fore superficial digital flexor tendon was very slightly enlarged in a palmar direction and the lateral borders of the tendon were rounded in the mid metacarpal region.

Ultrasonographic Findings.

The ultrasonographic findings in the right fore were dramatic: the superficial digital flexor tendon was markedly enlarged in a palmar direction and it extended laterally and medially around the deep digital flexor tendon. Its echogenicity was diffusely reduced and on longitudinal images there were numerous irregular linear echoes which were short and were not arranged in parallel (Fig. 3.35). On transverse images the lesion appeared to occupy the entire cross-sectional area of the tendon and no boundary could be identified (Fig. 3.35). Its echogenicity was heterogeneous on transverse images and it was moderately reduced with numerous hyperechoic foci. A very distinct hypoechoic structure was present palmar to the distal region of the superficial digital flexor tendon.

The ultrasonographic findings in the left superficial digital flexor tendon were subtle: the tendon was slightly enlarged in the mid metacarpal region. The echogenicity was fairly uniform and there were no distinct areas of alteration but on longitudinal images irregularity of the linear echoes was apparent. They were less numerous than normal and they were not closely aligned (Fig. 3.35).

Macroscopic Findings.

There was an increased amount of soft tissue surrounding the right superficial digital flexor tendon in the distal third of the metacarpal region and the location and appearance of this tissue was similar to the peritendinous tissue described in the left superficial digital flexor tendon in case 3.9 (Fig. 3.36). This could not be separated from the overlying

FIG. 3.35. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES OF SIX MONTHS' DURATION (CASE 3.10, RIGHT, UPPER LEFT AND RIGHT; LEFT, LOWER LEFT AND RIGHT).

THERE IS AN OVERALL REDUCTION IN THE ECHOGENICITY OF THE RIGHT SUPERFICIAL DIGITAL FLEXOR TENDON (UPPER LEFT AND RIGHT). IN THE LONGITUDINAL IMAGE THE IRREGULAR ARRANGEMENT OF THE LINEAR ECHOES IS APPARENT (UPPER LEFT).

IN THE TRANSVERSE IMAGE THE ENTIRE CROSS-SECTIONAL AREA OF THE SUPERFICIAL DIGITAL FLEXOR TENDON HAS AN ALTERED ECHOGENICITY AND HYPERECHOIC FOCI ARE PRESENT (UPPER RIGHT).

BOTH IMAGES OF THE RIGHT SUPERFICIAL DIGITAL FLEXOR TENDON DEMONSTRATE A HYPOECHOIC STRUCTURE LYING PALMAR TO THE FLEXOR TENDONS (>>, UPPER LEFT AND RIGHT).

THE LEFT SUPERFICIAL DIGITAL FLEXOR TENDON HAS IRREGULAR LINEAR ECHOES (LOWER LEFT) BUT THERE IS NO DISTINCT LESION IN THE TRANSVERSE IMAGE (LOWER RIGHT).

[NOTE, THESE ULTRASONOGRAMS ARE INVERTED SUCH THAT IN LONGITUDINAL IMAGES DISTAL IS DISPLAYED ON THE LEFT AND IN TRANSVERSE IMAGES MEDIAL IS DISPLAYED ON THE LEFT. THE UPPER AND LOWER LEFT IMAGES DEMONSTRATE AND ARTIFACT PRODUCED BY A DAMAGED CRYSTAL AND THERE IS INCOMPLETE CONTACT ON THE LATERAL ASPECT OF THE UPPER RIGHT IMAGE AND ON THE MEDIAL AND LATERAL ASPECTS OF THE LOWER RIGHT IMAGE].

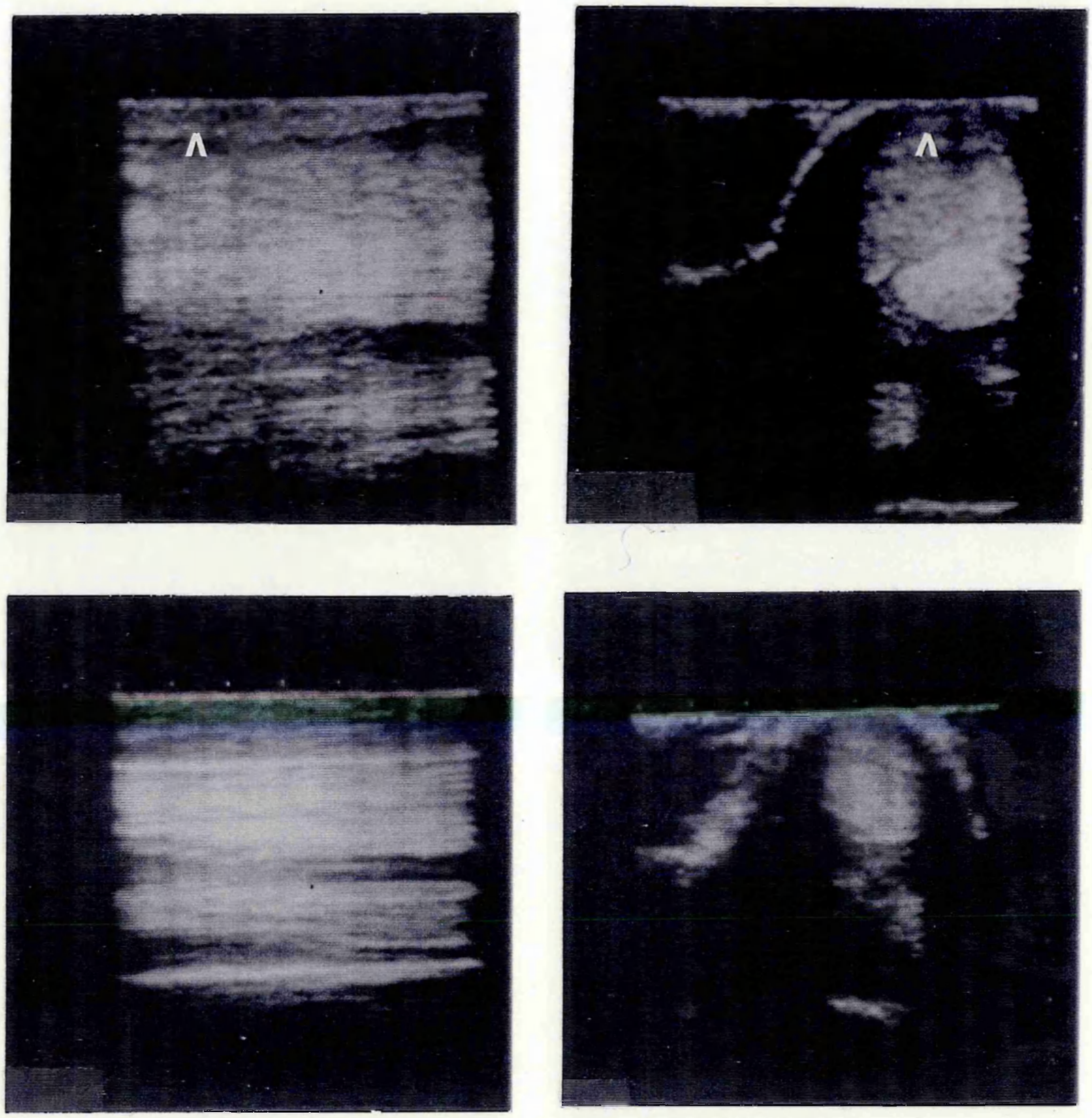
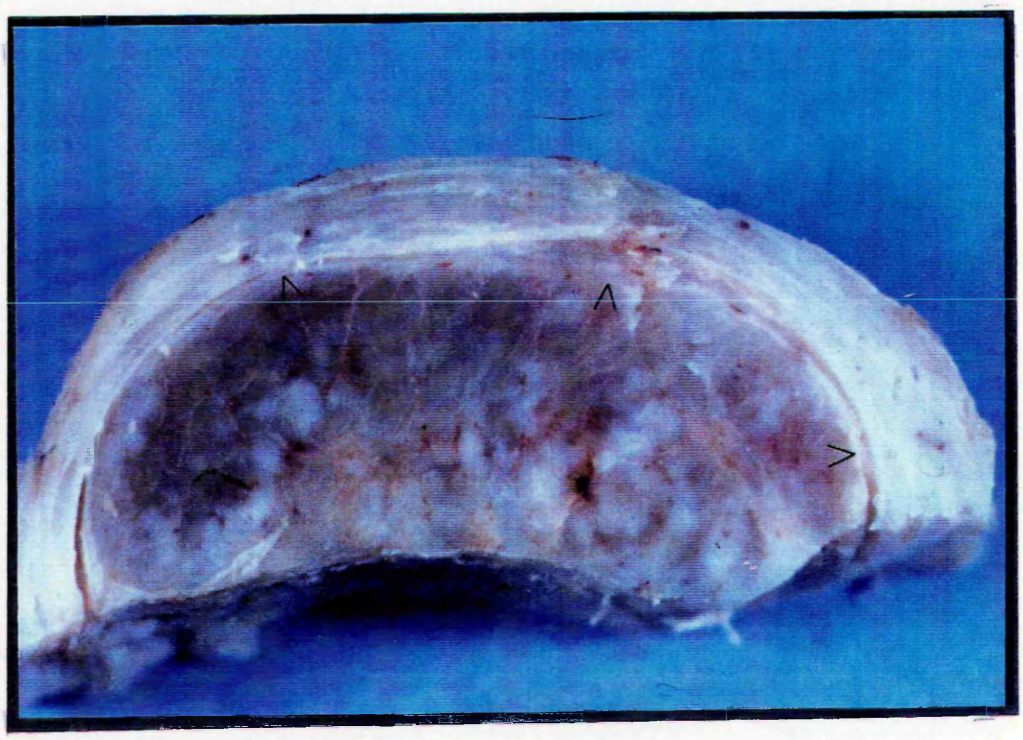


FIG 3.36. A FIXED TRANSVERSE SECTION OF THE RIGHT FORE SUPERFICIAL DIGITAL FLEXOR TENDON AT A LEVEL 220 MMS DISTAL TO THE ACCESSORY CARPAL BONE FROM A HORSE (CASE 3.10) WHICH HAD A SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF SIX MONTHS' DURATION. THE PARATENON IS MARKEDLY THICKENED (>>) AND THE CUT SURFACE OF THE TENDON IS IRREGULAR WITH NUMEROUS WHITE SCARS AND A BROWN CENTRAL ZONE WHICH OCCUPIES THE ENTIRE CROSS-SECTIONAL AREA OF THE TENDON.



subcutaneous tissues or from the superficial digital flexor tendon and it was adherent to the accessory ligament of the deep digital flexor tendon laterally and medially (Fig. 3.36). The tendon was markedly enlarged in the entire metacarpal region and was firm and cream in colour. Transverse and longitudinal sections demonstrated that the normal regular arrangement of fibres had been replaced with firm white tissue with localised red and pink areas scattered throughout the tendon from 60 to 28 mms distal to the accessory carpal bone (Fig. 3.36).

The left superficial digital flexor tendon had no surrounding excess soft tissue and it was much less swollen. The mid region contained a palmar swelling with its maximum dimension being 11 mms at the point 120 mms distal to the accessory carpal bone. The external surface of the tendon was unremarkable and the appearance of the transverse and longitudinal sections demonstrated very subtle changes: the central core of the tendon was pale.

Histopathological Findings.

There were large areas of chronic fibrosis within the majority of the tendon, the endotenon and the paratenon of the right superficial digital flexor tendon. The endotenon was particularly prominent in the mid and distal sections (Fig. 3.37). The collagen bundles were disorganised and lacked an undulating waveform. The paratenon was composed of chronic granulation tissue

FIG. 3.37. THE HISTOLOGICAL FINDINGS IN A HORSE WITH A SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF SIX MONTHS' DURATION (CASE 3.10, RIGHT FORE): THE ENDOTENDINOUS CONNECTIVE TISSUE (1), WHICH SEPARATED THE COLLAGEN BUNDLES (2) WAS THICKENED AND CELLULAR [L.S., H. & E., X 100]).

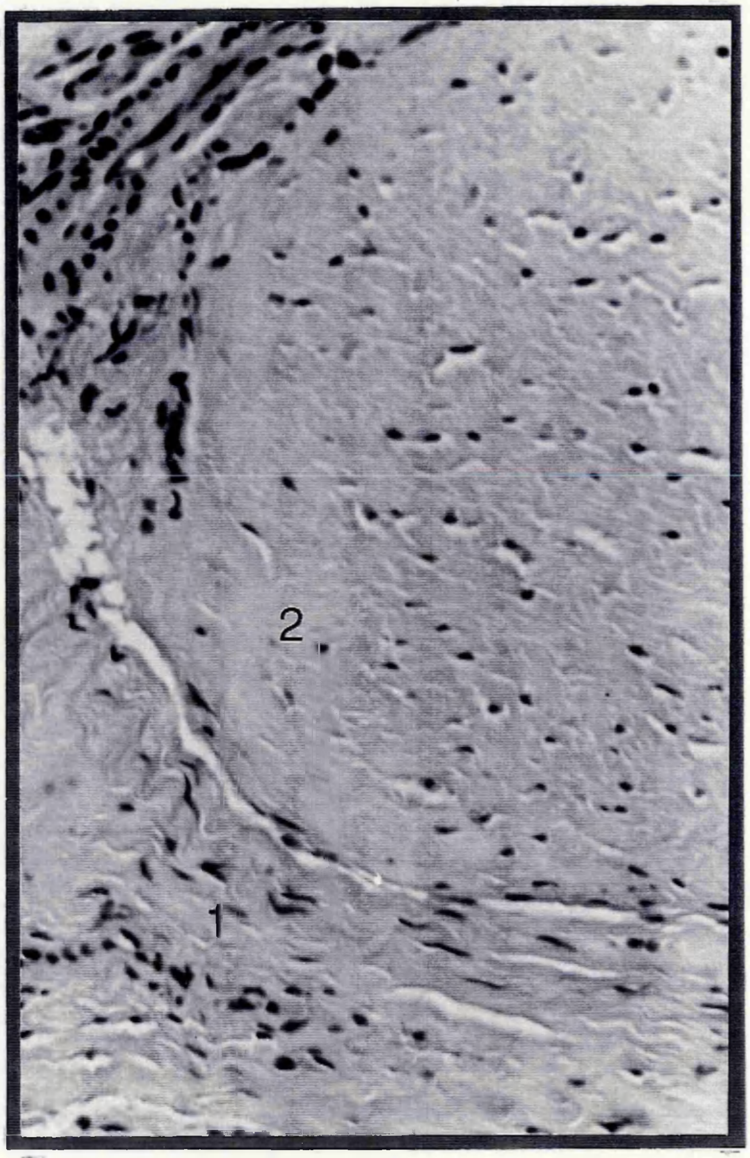

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FIG. 3.38. THE HISTOLOGICAL FINDINGS IN THE DISTAL PORTION OF THE METACARPAL REGION, IN A HORSE WITH A SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF SIX MONTHS' DURATION (CASE 3.10, RIGHT FORE): A LAYER OF FIRM WHITE TISSUE WAS FOUND ATTACHED TO THE SUPERFICIAL DIGITAL FLEXOR TENDON AND THE OVERLYING SUBCUTANEOUS TISSUE WHICH WAS AN AREA OF CHRONIC GRANULATION TISSUE WITH COLLAGEN FIBRES AND NUMEROUS FIBROBLASTS [H. & E., X 250].

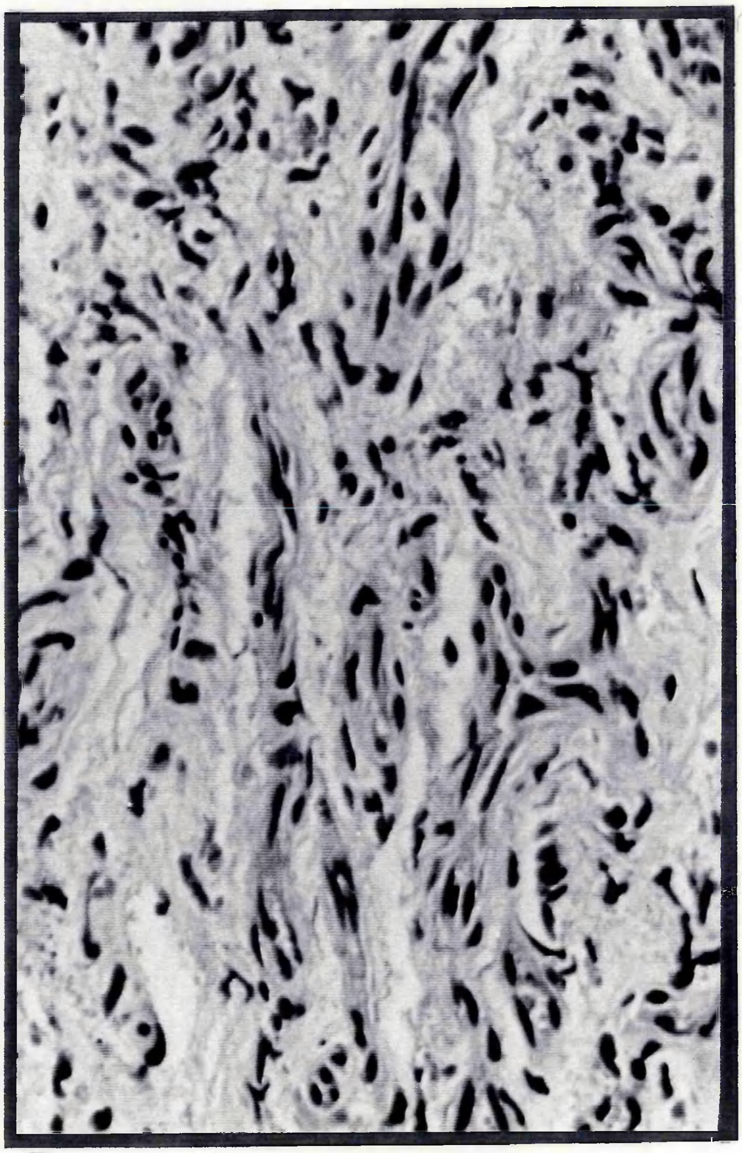
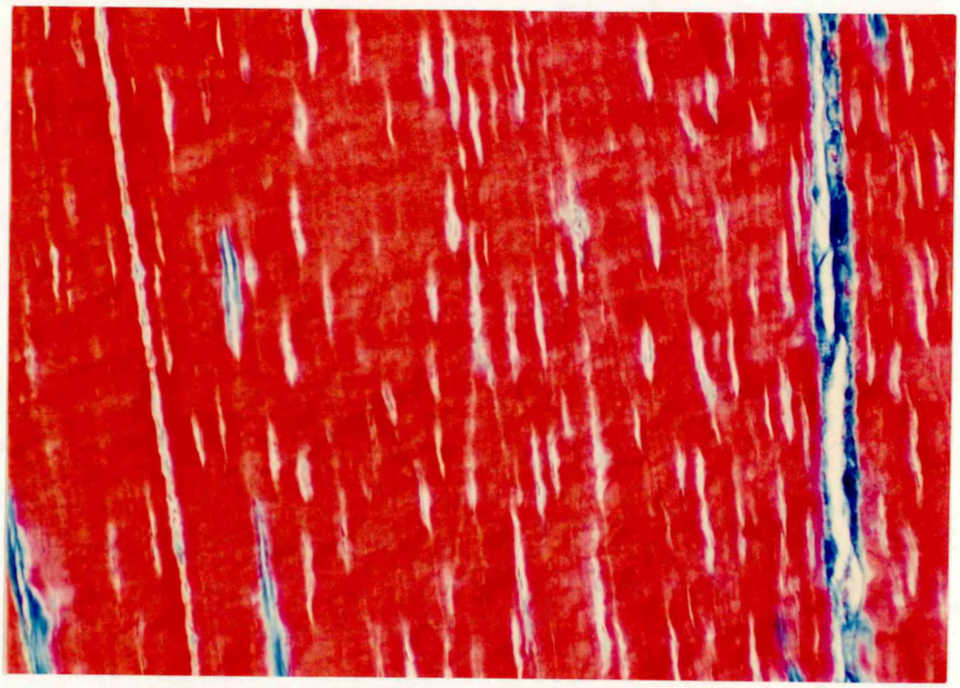


FIG. 3.39. THE HISTOLOGICAL FINDINGS IN A HORSE WITH SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF SIX MONTHS' DURATION (CASE 3.10, LEFT FORE). THE FIBROCYTES WERE NUMEROUS IN SOME AREAS AND ABSENT IN OTHER BUT THE COLLAGEN STAINED NORMALLY THROUGHOUT THE TENDON [L.S., MSB X 250].



with numerous cells arranged in columns between collagen fibres (Fig. 3.38).

In the left superficial digital flexor tendon, the histological findings indicated that much of the tendon was normal but that there were small acellular scars which were surrounded by areas of relatively increased cellularity. These were located in the central zone of the mid portion of the tendon and were associated with small haemosiderin deposits. In the central zone there were also areas in which, although the collagen fibres appeared to be arranged in parallel the tenocytes were larger and had more granular nuclei than normal. The modified Methyl Blue Van Gieson and Martius Scarlet Blue stained the collagen bundles in the same way in both the regions with increased and decreased cellularity (Fig. 3.39).

CASE 3.11: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A seven year-old Thoroughbred gelding was presented approximately seven months after sustaining bilateral superficial digital flexor tendon injuries.

The horse was sound at the walk and the superficial digital flexor tendons were firm and cool and the left contained a slight palmar swelling in the mid metacarpal region. The right was progressively enlarged in a palmar direction throughout the mid and distal metacarpal regions. The borders of the tendons could not be clearly distinguished in the right fore.

Ultrasonographic Findings.

The right fore superficial digital flexor tendon was moderately enlarged throughout its length. Its echogenicity was diffusely heterogeneous with numerous hyperechoic pinpoint specks and this appearance was uniform in the transverse images (Fig. 3.40). In the longitudinal images there were irregular linear echoes present in the majority of the metacarpal region of the superficial digital flexor tendon (Fig. 3.40) but a well-defined anechoic area was identified within the distal metacarpal region. A hypoechoic structure was apparent lying palmar to the superficial digital flexor tendon and the border between this and the superficial digital flexor tendon was extremely indistinct in some images (Fig. 3.40).

The left fore superficial digital flexor tendon was less enlarged but the changes in echogenicity and the linear echoes were similar except that no anechoic area was identified.

Macroscopic Findings.

The paratenons of both fore superficial digital flexor tendons were slightly thickened but there were no fibrous adhesions between the flexor tendons. The right superficial digital flexor tendon was enlarged from 60 to 260 mms distal to the accessory carpal bone. Its maximum dorsal to palmar diameter was located 200 mms distal to the accessory carpal bone where it measured 20

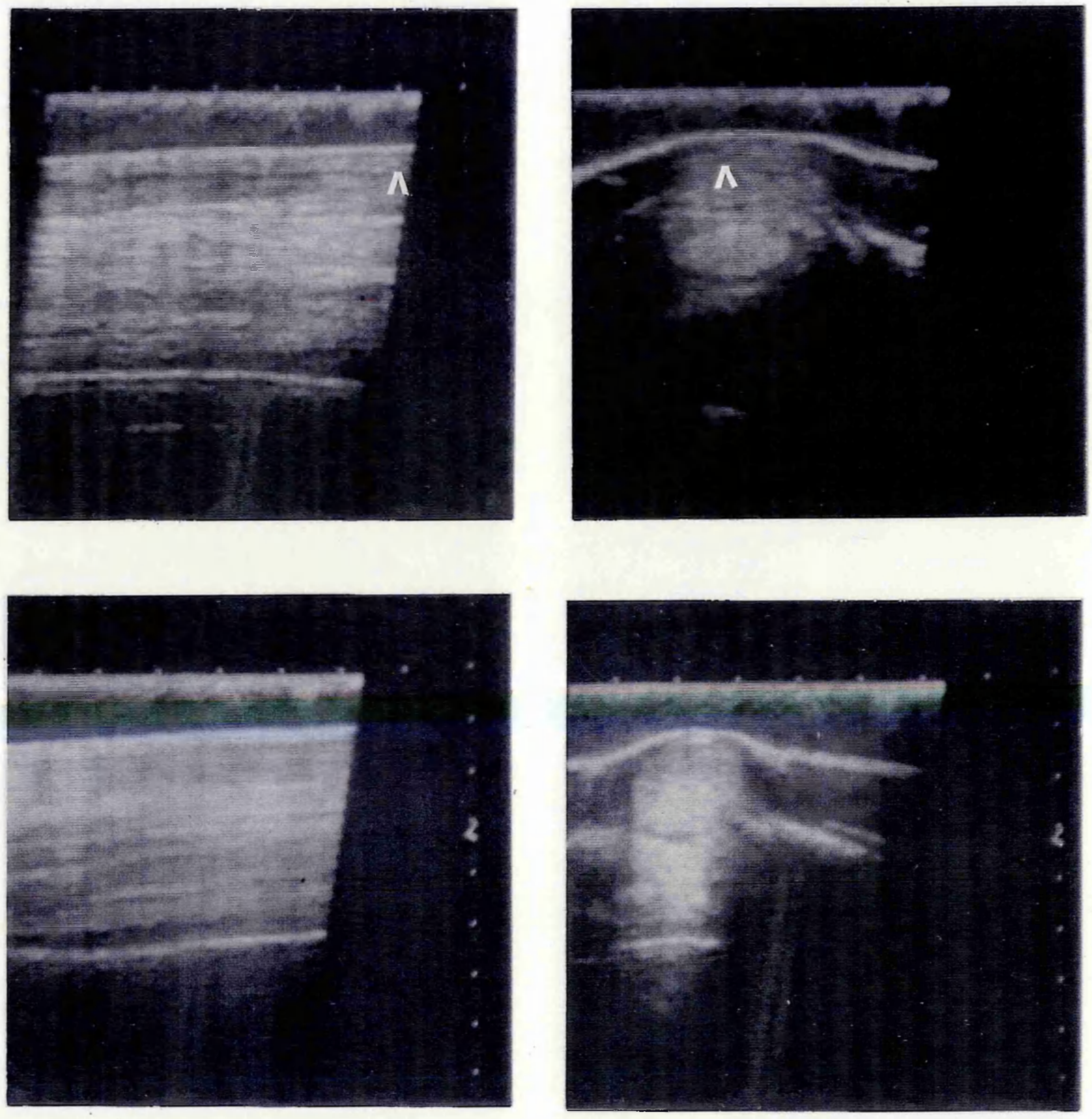
FIG. 3.40. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES OF SEVEN MONTHS' DURATION (CASE 3.11, RIGHT, UPPER LEFT AND RIGHT; LEFT, LOWER LEFT AND RIGHT).

THERE IS A LINEAR ANECHOIC AREA WITHIN THE DISTAL METACARPAL REGION OF THE RIGHT SUPERFICIAL DIGITAL FLEXOR TENDON (UPPER LEFT).

A ECHOGENICITY OF THE SUPERFICIAL DIGITAL FLEXOR TENDON IS DIFFUSELY HETEROGENEOUS WITH HYPERECHOIC FOCI IN THE TRANSVERSE IMAGE (UPPER RIGHT). A HYPOECHOIC STRUCTURE IS APPARENT PALMAR TO THE RIGHT SUPERFICIAL DIGITAL FLEXOR TENDON (>>, UPPER LEFT AND RIGHT) BUT ITS DORSAL BORDER IS EXTREMELY INDISTINCT IN THE TRANSVERSE IMAGE (UPPER RIGHT).

THE LEFT SUPERFICIAL DIGITAL FLEXOR TENDON HAS IRREGULAR LINEAR ECHOES (LOWER LEFT). THERE IS AN ILL-DEFINED, HYPOECHOIC AREA IN THE CENTRAL ZONE OF THE MID METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON (LOWER RIGHT, 140 MMS DISTAL TO THE ACCESSORY CARPAL BONE).

[NOTE THERE IS INCOMPLETE CONTACT THROUGHOUT THE LEFT UPPER AND LOWER IMAGES AND ON THE LATERAL AND MEDIAL ASPECTS OF THE UPPER RIGHT IMAGE].



mms. The external surface of the tendon was firm and white. A lesion was identified on section of the tendon which extended from 60 to 240 mms distal to the accessory carpal bone. It was composed of soft brown tissue and was surrounded by a rim of normal tendon. A second lesion was located in the lateral aspect of the tendon which was red and haemorrhagic. It extended from 220 to 260 mms distal to the accessory carpal bone.

The left superficial digital flexor tendon was less enlarged but a palmar swelling was present in the mid metacarpal region. The external surface of this tendon was normal but there was a centrally-located lesion within the mid metacarpal region which extended from 140 to 180 mms distal to the accessory carpal bone. This lesion was difficult to discern but became more apparent following fixation of the tissue when it appeared paler and denser than the surrounding tissue.

Histopathological Findings.

The central zone of the right superficial digital flexor tendon contained numerous fibroblasts but acellular areas were not apparent. A small haemorrhage was present in the section taken from 240 mms distal to the accessory carpal bone and it was associated with increased fibroblast activity.

A lesion was apparent in the central zone of the left superficial digital flexor tendon which extended from 80 mms to 240 mms distal to the accessory carpal bone. In the more proximal sections there were acellular areas but the endotenon did not contain increased numbers of cells while distally there were acellular scars, haemosiderin deposits and areas in which the fibroblasts were extremely numerous and had enlarged granular nuclei. As in the previous case (3.10), staining of the acellular areas with Methyl Blue Van Gieson did not demonstrate active fibrosis and the appearance of these areas was identical to the surrounding tissue.

CASE 3.12: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

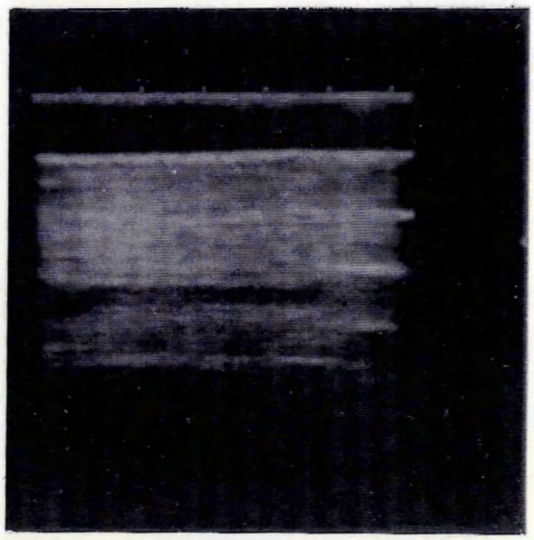
An eight year-old Thoroughbred mare was presented approximately twelve months after sustaining bilateral superficial digital flexor tendon injuries.

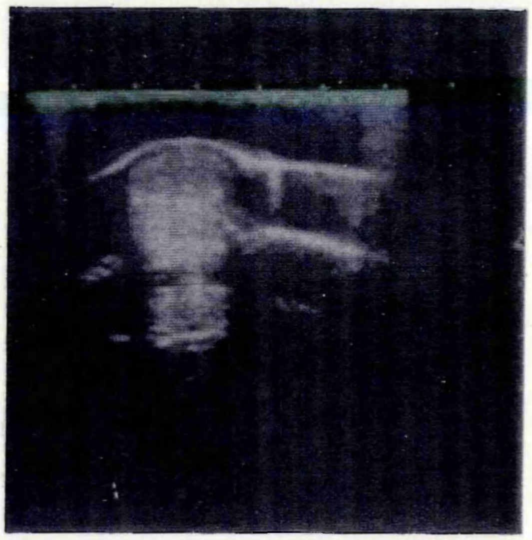
The horse was sound at the walk and there were firm palmar swellings in the mid metacarpal regions of both fore superficial digital flexor tendons. The borders of the tendons could not be clearly distinguished in the areas of the swellings and the lateral edges were rounded.

Ultrasonographic Findings.

The ultrasonographic findings were similar in both superficial digital flexor tendons. They were enlarged and rounded in the mid and distal metacarpal regions and on longitudinal images, the longitudinal images demonstrated that there were numerous linear echoes present but that these had an irregular orientation and were shorter than normal (Fig. 3.41). On transverse

FIG. 3.41. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES OF TWELVE MONTHS' DURATION (CASE 3.12, RIGHT, UPPER AND MIDDLE; LEFT, LOWER).
IN THE LONGITUDINAL IMAGE, THE LINEAR ECHOES ARE NUMEROUS BUT IRREGULAR (UPPER).
TRANSVERSE IMAGES OF THE MID METACARPAL REGIONS OF BOTH SUPERFICIAL DIGITAL FLEXOR TENDONS (MIDDLE, RIGHT; LOWER, LEFT) DEMONSTRATE THAT THERE ARE CENTRAL HYPOECHOIC LESIONS CONTAINING HYPERECHOIC FOCI WITH MODERATELY WELL-DEFINED BORDERS.
[NOTE THERE ARE REVERBERATION ARTIFACTS IN THE UPPER IMAGE].





images, ill-defined hypoechoic areas were apparent within the central zones of both flexor tendons. Their precise boundaries were difficult to discern in some areas and they contained occasional hyperechoic foci (Fig. 3.41).

Macroscopic Findings.

The paratenons of both fore superficial digital flexor tendons were thickened and there were fibrous adhesions between the flexor tendons.

The right superficial digital flexor tendon was enlarged from 100 to 260 mms distal to the accessory carpal bone. Its maximum dorsal to palmar diameter was 140 mms at the level distal to the accessory carpal bone where it measured 13 mms. The external surface of the tendon was firm and white. A lesion was identified on section of the tendon which extended from 80 to 200 mms distal to the accessory carpal bone. It was composed of soft brown tissue with numerous pinpoint white scars and it was surrounded by a rim of macroscopically normal tendon although the border of the lesion was not clearly defined.

The left superficial digital flexor tendon was also enlarged and a palmar swelling was present in the mid and distal metacarpal regions which extended from 120 to 220 mms distal to the accessory carpal bone. The external surface of this tendon was normal but there was a centrally located lesion within the mid metacarpal region which extended from 60 to 200 mms distal to the the accessory carpal bone. The proximal part of this lesion was pale while the majority was composed of a purplish brown material with pinpoint white scars. The surrounding tissue was normal but the border of the lesion was indistinct and, from 120 to 180 mms distal to the accessory carpal bone, it occupied the majority of the cross-sectional area of the tendon.

Histopathological Findings.

A lesion was apparent in the central zone of the right superficial digital flexor tendon. From 140 mms to 220 mms distal to the accessory carpal bone, there were acellular areas surrounded by columns of plump, darkly-stained cells. Occasional haemosiderin deposits were present in the endotenon and in some of the central areas there were increased numbers of fibroblasts with rather oval but darkly-stained nuclei (Fig. 4.42). However, in the peripheral zones, the majority of the fibroblasts had elongated darkly-stained cells.

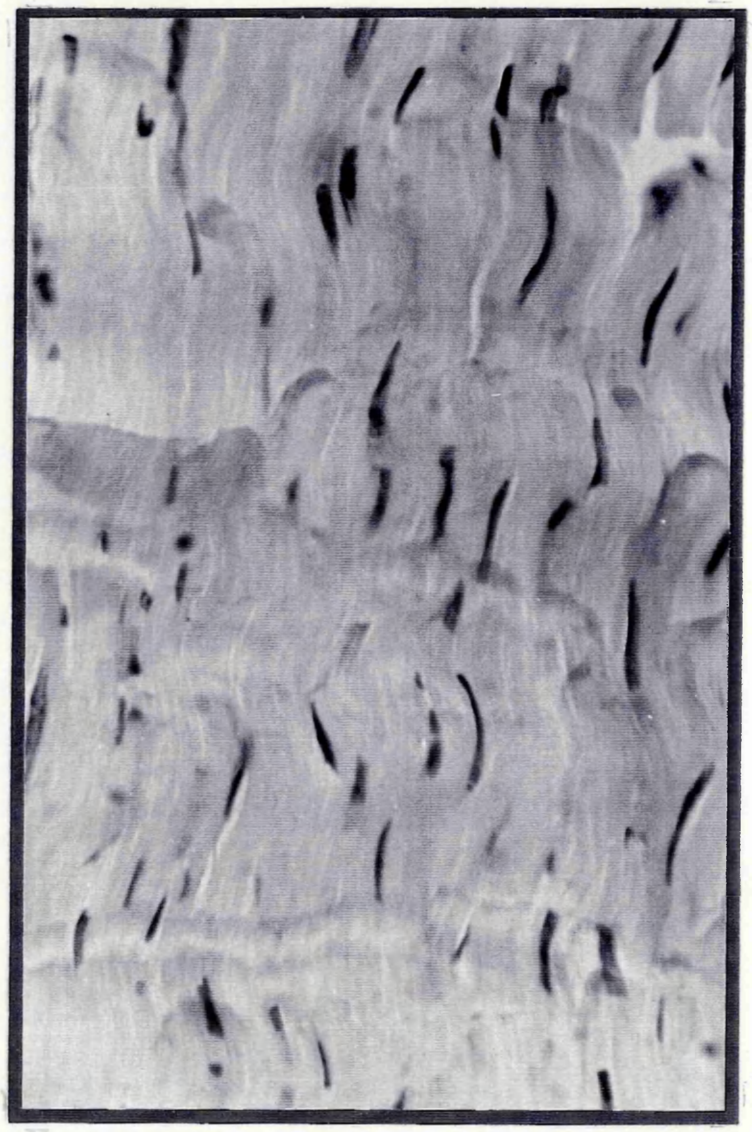
CASE 3.13: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A six year-old Thoroughbred gelding was presented approximately twelve months after it sustained a severe right superficial digital flexor tendon injury and a mild left superficial digital flexor tendon injury.

The horse was sound at the walk and both superficial digital flexor tendons were firm and cool. The right superficial digital flexor tendon was markedly,

FIG. 3.42. THE HISTOLOGICAL FINDINGS IN THE CENTRAL ZONES OF THE MID METACARPAL REGIONS OF THE SUPERFICIAL DIGITAL FLEXOR TENDONS OF A HORSE WITH BILATERAL TENDON INJURIES OF TWELVE MONTHS' DURATION (CASE 3.12, LEFT): THERE ARE CELLULAR AREAS IN WHICH THE FIBROBLASTS ARE ARRANGED IN PARALLEL BUT THEIR NUCLEI ARE RATHER OVAL ALTHOUGH THEY ARE DARKLY-STAINED [L.S., H. & E. X 250].



and progressively, enlarged in a palmar direction throughout the metacarpal region. The borders of the tendons could not be clearly distinguished and the lateral edges were rounded.

Ultrasonographic Findings.

The left superficial digital flexor tendon was enlarged throughout the metacarpal region and it had a diffusely heterogeneous hypoechoic central lesion containing hyperechoic foci in the transverse images (Fig. 3.43). This lesion occupied the majority of the cross-sectional area. An irregular and ill-defined border between the lesion and the remaining tendon was apparent near the periphery of the tendon (Fig. 3.43). Longitudinal images demonstrated that there were numerous irregular linear echoes throughout the entire metacarpal region of the superficial digital flexor tendon (Fig. 3.43). A hypoechoic structure lay palmar to the superficial digital flexor tendon in the transverse images from 240 to 300 mms distal to the accessory carpal bone.

The ultrasonographic findings in the right superficial digital flexor tendon were less dramatic. In longitudinal images in the mid metacarpal region, the linear echo-arrangement was slightly irregular (Fig. 3.43). In transverse images of the mid metacarpal region there was a central hypoechoic area but the border between this and the remainder of the tendon was indistinct (Fig. 3.43). The proximal and distal images were normal.

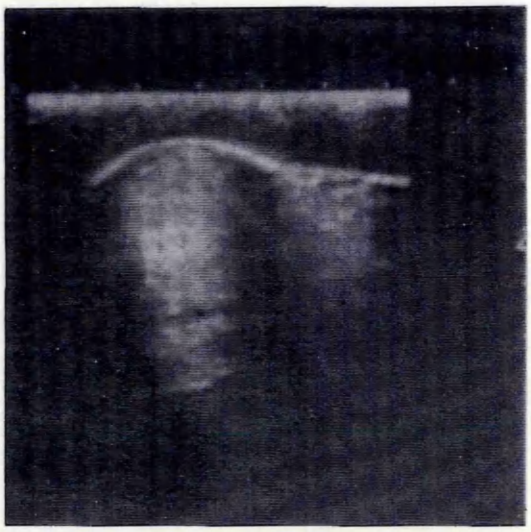
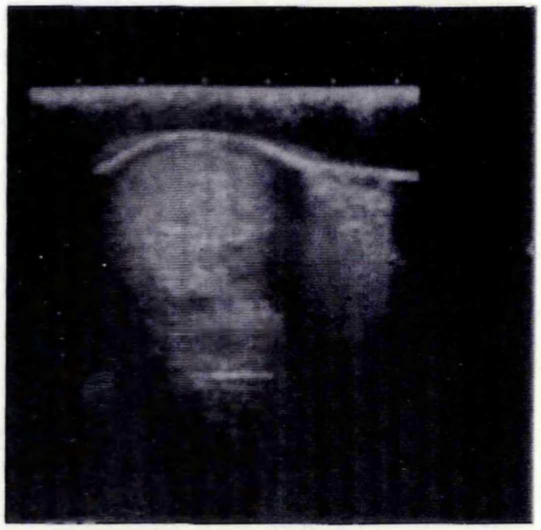
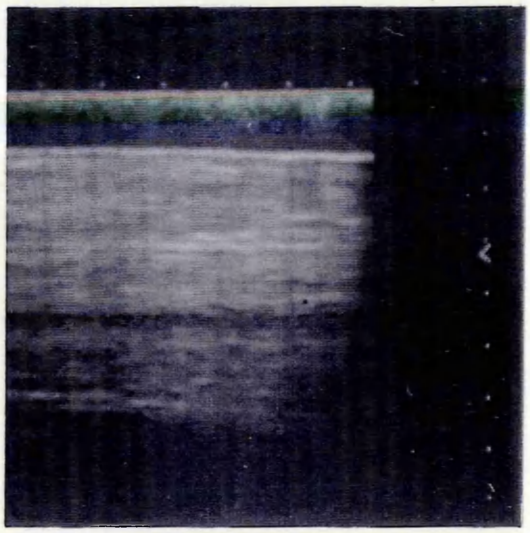
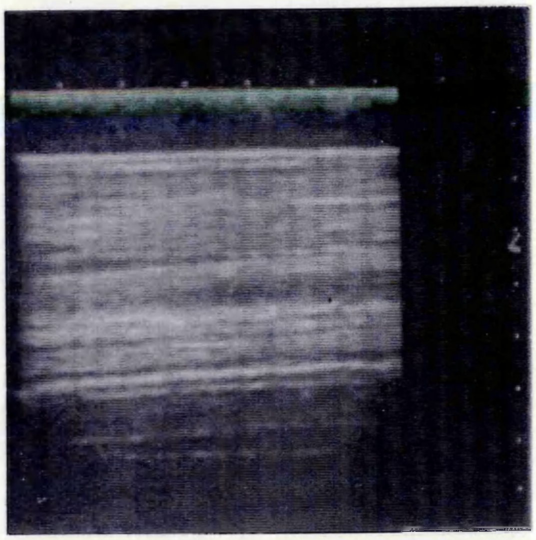
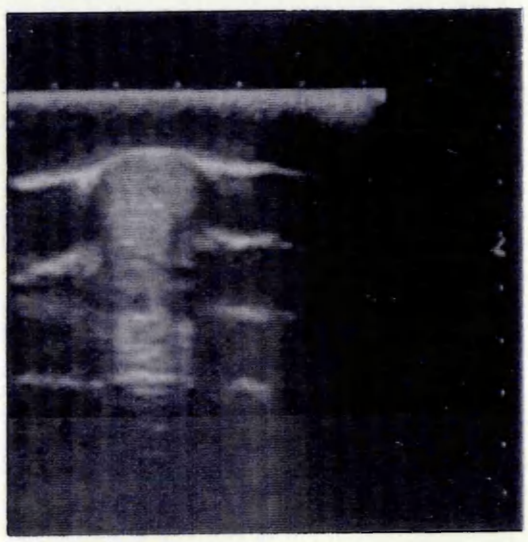
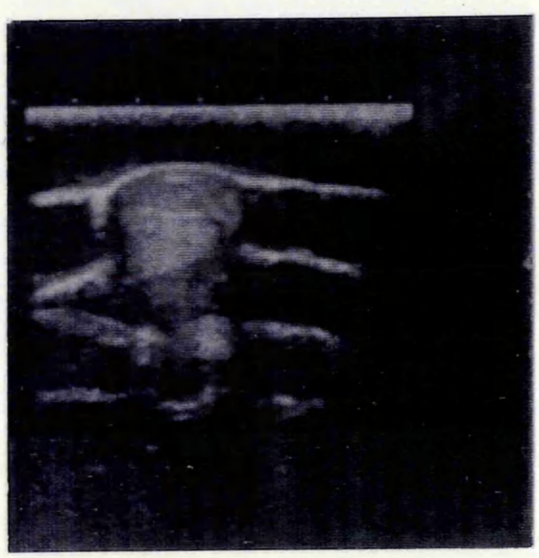
FIG. 3.43. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES OF TWELVE MONTHS' DURATION (CASE 3.13, LEFT, UPPER LEFT AND RIGHT AND MIDDLE LEFT; RIGHT, MIDDLE RIGHT AND LOWER LEFT AND RIGHT).

THE TRANSVERSE IMAGES OF THE LEFT SUPERFICIAL DIGITAL DEMONSTRATE A CENTRAL LESION WHICH IS HYPOECHOIC AND HAS AN ILL-DEFINED BORDER.

THIS LESION CONTAINS NUMEROUS IRREGULAR LINEAR ECHOES (MIDDLE LEFT) AND THIS CAN BE APPRECIATED WHEN IT IS COMPARED WITH THE IMAGE FROM THE CONTRALATERAL LIMB WHICH HAS A MILDER LESION TYPIFIED BY A SLIGHTLY IRREGULAR ARRANGEMENT OF LINEAR ECHOES (MIDDLE RIGHT).

THE TRANSVERSE IMAGES OF THE RIGHT SUPERFICIAL DIGITAL FLEXOR TENDON CONTAIN AN ILL-DEFINED CENTRAL HYPOECHOIC LESION (LOWER LEFT AND RIGHT).

[NOTE THERE IS INCOMPLETE CONTACT ON THE LATERAL ASPECT OF IMAGE A AND DISTAL ASPECT OF THE MIDDLE LEFT IMAGE WHICH ALSO HAS REVERBERATION ARTIFACTS].

Macroscopic Findings.

There was an increased amount of soft tissue surrounding the right superficial digital flexor tendon in the distal third of the metacarpal region and its location and appearance was similar to the peritendinous tissue described in the left superficial digital flexor tendon in cases 3.10 and 3.11. There were fibrous adhesions between the dorsal aspect of the superficial digital flexor tendon and the palmar aspect of the deep flexor tendon.

The right superficial digital flexor tendon was enlarged from 60 to 300 mms distal to the accessory carpal bone. Its maximum dorsal to palmar diameter was 160 mms distal to the accessory carpal bone where it measured 20 mms. Proximal to the area with the markedly thickened paratenon, the external surface of the tendon was firm and white. A lesion was identified on section of the tendon which extended from 60 to 300 mms distal to the accessory carpal bone. It was composed of a mixture of brown and white tissues and there was no clear rim of macroscopically normal tendon.

The left superficial digital flexor tendon was not enlarged and the external and cut surfaces of this tendon were normal.

Histopathological Findings.

The right superficial digital flexor tendon had a uniform appearance throughout the entire cross-sectional area from 60 to 240 mms distal to the accessory carpal

FIG. 3.44. THE HISTOLOGICAL FINDINGS IN A HORSE WITH SUPERFICIAL DIGITAL FLEXOR TENDON INJURY OF 12 MONTHS' DURATION THERE ARE ACELLULAR AREAS WITH ADJACENT REGIONS IN WHICH THERE IS AN INCREASED NUMBER OF CELLS AND THE ENDOTENON IS PROMINENT [L.S., H. & E., X 40].

bone: there were bands of increased cellularity interspersed with normal areas and some patchy acellular areas. The fibroblasts had slightly rounded nuclei and the endotenon was prominent (Fig. 3.44) and contained haemosiderin deposits. Sections taken distal to this had a normal appearance.

Much of the left superficial digital flexor tendon had a normal appearance and the collagen bundles were arranged in parallel with elongated darkly-stained tenocytes. There were columns of plump dark cells in the proximal sections. In the sections taken from 120 to 160 mms distal to the accessory carpal bone, the central zone had an increased number of cells although these had a normal morphology. From 180 to 240 mms distal to the accessory carpal bone these central areas also contained small irregular acellular areas. At, and distal to, 260 mms distal to the accessory carpal bone, there were numerous cells with rounded nuclei which were darkly-stained.

CASE 3.14: CHRONIC SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES.

History and Clinical Findings.

A seven year-old Thoroughbred mare was presented with chronic bilateral superficial digital flexor tendon injuries of at least twelve months' duration.

The horse was sound at the walk, the right superficial digital flexor tendon was progressively enlarged in a palmar direction in the mid and distal metacarpal region with the enlargement of the left fore being confined to the mid metacarpal region. There was pain elicited on compression of the lateral and medial borders of both superficial digital flexor tendons and there was very slight heat detected on palpation of the palmar metacarpal regions.

Ultrasonographic Findings.

The right superficial digital flexor tenon was enlarged throughout the metacarpal region. Longitudinal images demonstrated that its echogenicity was normal overall but that the arrangement of the linear echoes was slightly irregular although they were very numerous and closely packed (Fig. 3.45). The transverse images, also had a normal echogenicity overall, but the central region was heterogeneous with some hyperechoic foci and some irregular hypoechoic areas (Fig. 3.45). There was a faint boundary between the central region and the periphery (Fig. 3.45). A hypoechoic structure lay palmar to the superficial digital flexor tendon in the distal metacarpal regions and the border between this and the underlying tendon was indistinct (Fig. 3.45).

The left superficial digital flexor tendon had an apparently normal region in its most proximal region. In the mid and distal metacarpal regions, there was an area in which, in longitudinal images, numerous linear echoes could be identified but these were rather irregular in their distribution (Fig. 3.46). The transverse images of the entire metacarpal region of the

FIG. 3.45. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH A CHRONIC RIGHT SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.14).

THE LONGITUDINAL IMAGE OF THE MID METACARPAL REGION ILLUSTRATES THAT THE TENDON HAS NUMEROUS CLOSELY PACKED LINEAR ECHOES THAT HAVE A SLIGHTLY IRREGULAR ARRANGEMENT (UPPER LEFT).

THE TRANSVERSE IMAGES DEMONSTRATE THAT THE CENTRAL ZONE OF THE SUPERFICIAL DIGITAL FLEXOR TENDON IS HETEROGENEOUS AND CONTAINS HYPERECHOIC FOCI AND THAT THERE IS A FAINT BORDER BETWEEN THE CENTRAL AREA AND THE PERIPHERY (UPPER RIGHT AND LOWER LEFT AND RIGHT).

IN THE DISTAL METACARPAL REGION THERE IS A HYPOECHOIC STRUCTURE PALMAR TO THE SUPERFICIAL DIGITAL FLEXOR TENDON (LOWER RIGHT, 240 MMS DISTAL TO THE ACCESSORY CARPAL BONE).

[NOTE THERE IS INCOMPLETE CONTACT AT THE LATERAL AND MEDIAL ASPECTS OF THE LOWER RIGHT IMAGE].

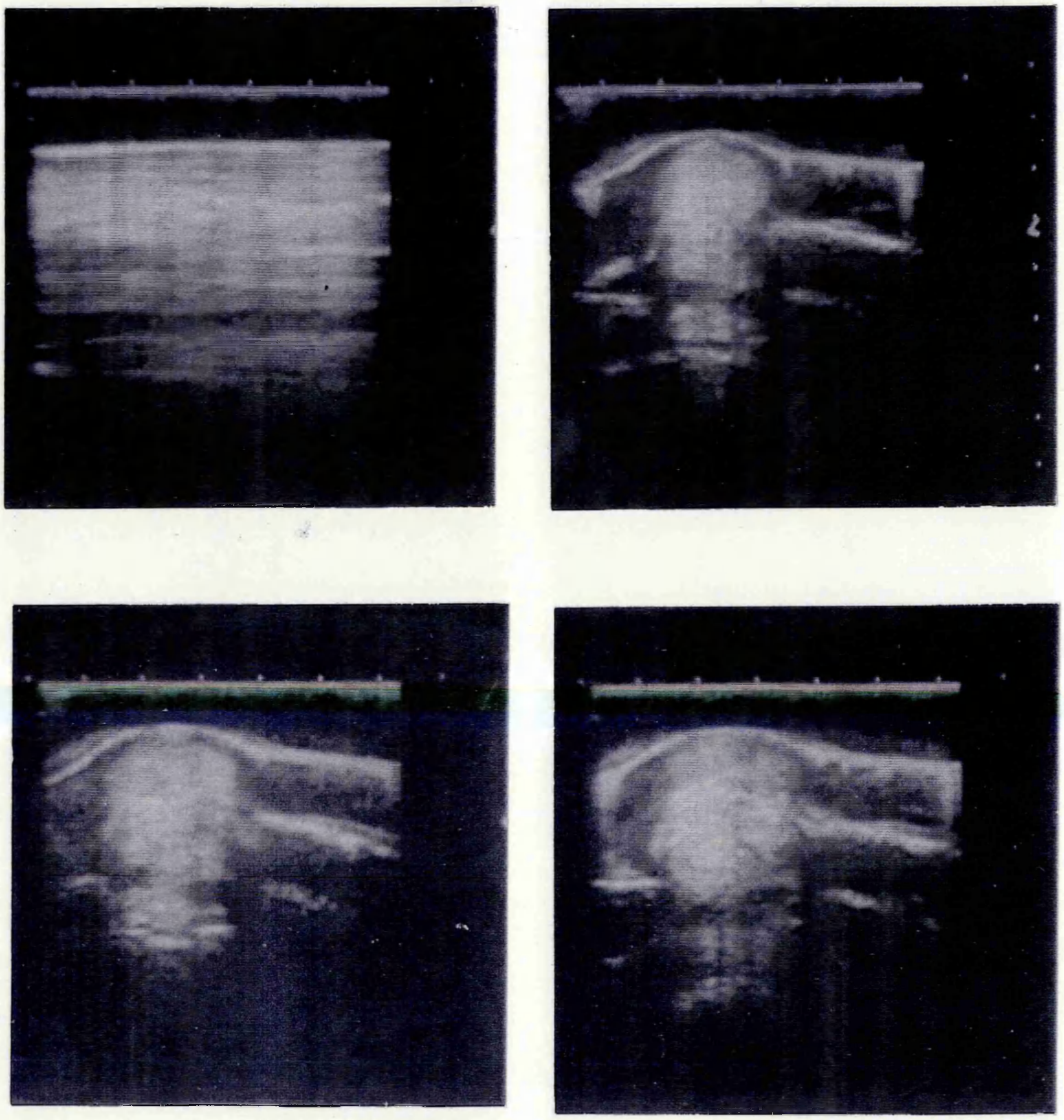
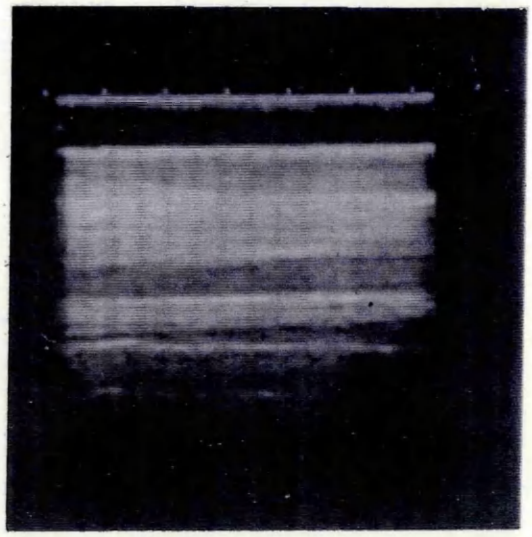
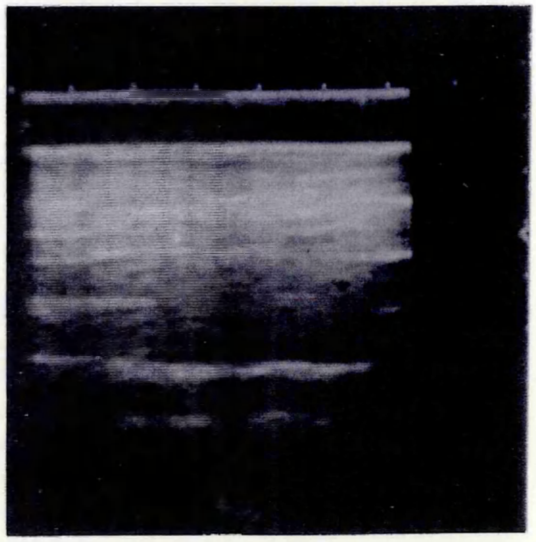
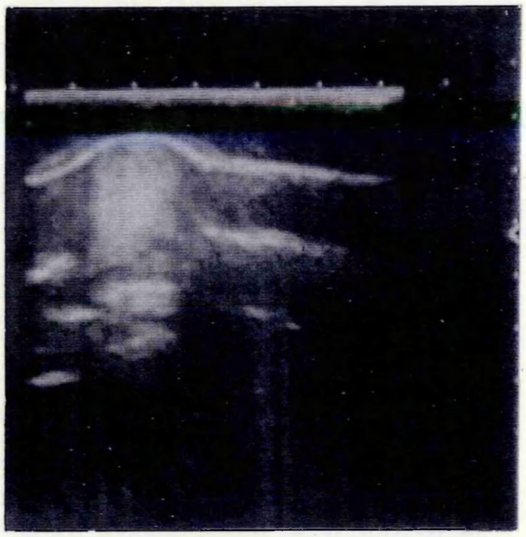
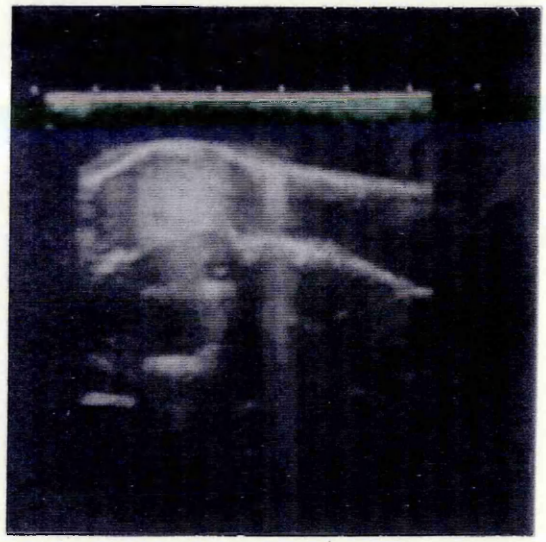


FIG. 3.46. THE ULTRASONOGRAPHIC FINDINGS IN A HORSE WITH A CHRONIC LEFT SUPERFICIAL DIGITAL FLEXOR TENDON INJURY (CASE 3.14).

THE LONGITUDINAL IMAGE OF THE PROXIMAL METACARPAL REGION OF THE SUPERFICIAL DIGITAL FLEXOR TENDON IS NORMAL (UPPER LEFT). IN THE MORE DISTAL AREA OF THAT IMAGE AND THE IMAGE OF THE MID METACARPAL REGION (UPPER RIGHT) THE LINEAR ECHOES HAVE A SLIGHTLY IRREGULAR ARRANGEMENT.

THE TRANSVERSE IMAGES ARE APPARENTLY NORMAL (LOWER LEFT AND RIGHT).

[NOTE THERE IS INCOMPLETE CONTACT THROUGHOUT THE UPPER IMAGES AND ON THE LATERAL ASPECT OF THE LOWER RIGHT IMAGE].

left superficial digital flexor tendon were apparently normal (Fig. 3.46).

Macroscopic Findings.

There was an increased amount of soft tissue around the right fore superficial digital flexor tendon and there were fibrous adhesions between the superficial and deep digital flexor tendons and the subcutaneous tissues and the superficial digital flexor tendon. The tendon was enlarged in a palmar direction throughout its length with the maximum dorsal to palmar diameter 160 mms distal to the accessory carpal bone where the tendon measured 19 mms. The cut surface of the tendon demonstrated that the majority of the cross-sectional area was abnormal with irregular areas of brown, white and red tissue. The white areas were firm scars which ranged in dimension up to about 1 mm in diameter.

The left fore superficial digital flexor tendon was less swollen but palmar enlargement was evident from 120 to 200 mms distal to the accessory carpal bone. In that region a central, well-defined area of abnormal tissue which contained a mixture of brownish and white regions was found. The peripheral tendon tissue appeared macroscopically normal.

Histopathological Findings.

The right proximal sections from 60, 80 and 100 mms distal to the accessory carpal bone contained numerous oval cells arranged in parallel while distal to this, large acellular areas were identified which were particularly frequent in the sections from the dorso-lateral quadrant of the tendon. Haemosiderin deposits were present in the endotenon surrounding these scars and the cells of the endotenon were increased in number and had round nuclei. The collagen bundles in these areas were not arranged in parallel and lacked an undulating waveform. Vascularised granulation tissue was present particularly in the sections taken from 240 and 260 mms distal to the accessory carpal bone. In these sections it was located in the central zone and at the periphery the collagen bundles were arranged in parallel although there was an increased number of fibroblasts. In the sections taken at, and distal to, 280 mms distal to the accessory carpal bone, there were no areas of scar formation or granulation tissue and the collagen bundles were arranged in parallel but there was an increased number of fibroblasts. Histological examination of the paratenon demonstrated that its was composed of chronic granulation tissue.

The histological findings in the left superficial digital flexor tendon were less dramatic: from 60 to 100 mms distal to the accessory carpal bone, the tendon appeared histologically normal. In the section taken from 120 mms distal to the accessory carpal bone a central acellular area was identified in which bands of collagen were surrounded by active fibroblasts. This area extended to 200 mms distal to the accessory carpal bone. Distal to that, the tendon appeared normal but the arrangement of the sparse tenocytes was irregular.

Ultrasonographic Findings In Normal Superficial Digital Flexor Tendons.

The animals which were used as controls had normal ultrasonographic findings consistent with those described in Chapter 2, that is even echogenicity in transverse images with the longitudinal images being composed of numerous regularly-arranged linear echoes.

Macroscopic And Histological Findings In Normal Superficial Digital Flexor Tendons.

The normal superficial digital flexor tendons were easily freed from the surrounding loose connective tissue and were covered with a smooth transparent paratenon in the mid metacarpal region and surrounded by but not adhered to the fibrous carpal sheath in the proximal metacarpal region. The digital sheath was adherent only to the palmar mid line aspect of the superficial digital flexor tendon and it contained clear yellowish synovial fluid. Longitudinal sections demonstrated the fibrous nature of tendons and transverse sections had a yellow colour interlaced with numerous white strands dividing the tendon into fascicles.

The histological findings were consistent within the group. The superficial digital flexor tendon was composed of bundles of collagen which were separated by strands of connective tissue, the endotenon, carrying blood vessels and the bundle formation was most apparent in transverse section (Fig. 3.47). The endotenon was

FIG. 3.47. A TRANSVERSE SECTION OF A NORMAL SUPERFICIAL DIGITAL FLEXOR TENDON (MID METACARPAL REGION): THE COLLAGEN IS ARRANGED IN BUNDLES WHICH ARE SEPARATED BY ENDOTENDINOUS CONNECTIVE TISSUE CARRYING BLOOD VESSELS [H & E, X 100].

continuous with the paratenon in the mid metacarpal region (Fig. 3.47) and in the areas in which the tendon was enclosed in a synovial sheath, flattened synovial cells lay along the outermost edge of the tendon.

The longitudinal sections demonstrated that the eosinophilic collagen bundles were arranged parallel to the long axis of the tendon with an undulating waveform (Fig. 3.48). Interspersed between the collage bundles were numerous tenocytes which stained darkly and had elongated nuclei (Fig. 3.48).

The methyl blue Van Gieson stain (Herovici, 1963), produced consistent results in the normal tendons when it was modified by increasing the concentrations of acid fuschin and aqueous methyl blue and increasing the immersion time. This stain is designed to differentiate old and new collagen and mature fibrous tissue should appear blue. When used in normal tendon, the collagen in the endotendinous connective tissue appeared blue but the collagen bundles were pink (Fig. 3.49). Similarly, Martius Scarlet Blue, (Lendrum and others, 1962), stained the collagen in the endotendinous connective tissue blue, the expected colour, but the tendon collagen bundles were red (Fig. 3.50). A similar effect was noted with Masson's stain in which the collagen in the endotenon was green while the remaining collagen was red (Masson, 1929).

FIG. 3.48. A LONGITUDINAL SECTION OF A NORMAL SUPERFICIAL DIGITAL FLEXOR TENDON (MID METACARPAL REGION): THE COLLAGEN IS ARRANGED IN BUNDLES PARALLEL TO THE LONG AXIS OF THE TENDON WITH ELONGATED, DARKLY STAINED FIBROCYTES [H & E, X 100].

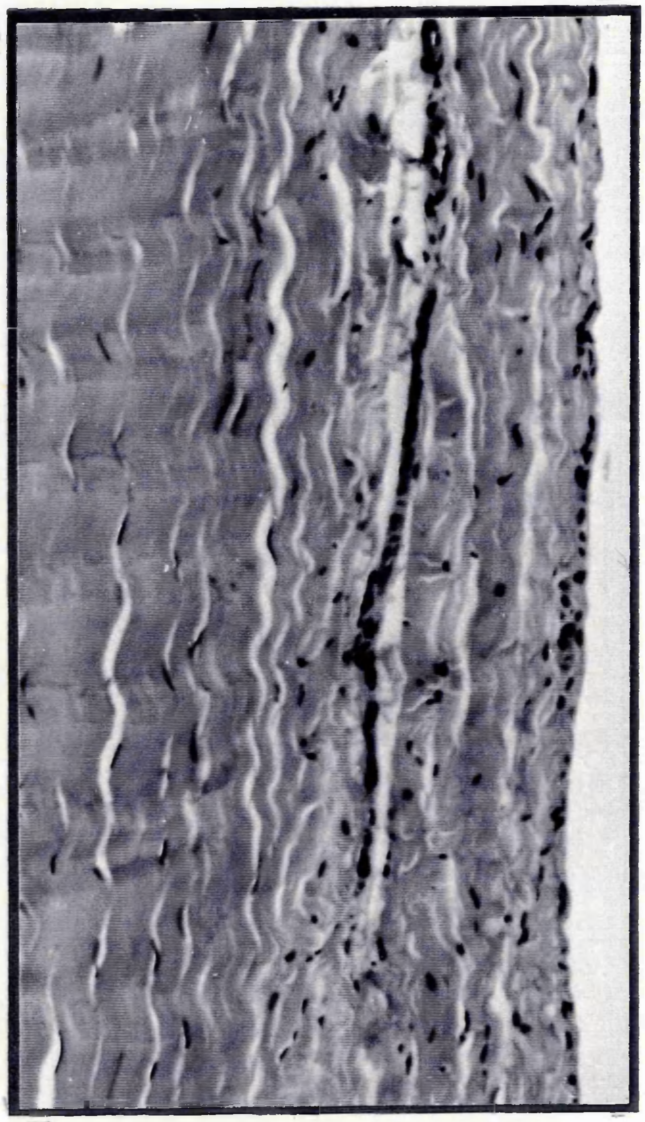


FIG. 3.49. A LONGITUDINAL SECTION OF A NORMAL SUPERFICIAL DIGITAL FLEXOR TENDON (MID METACARPAL REGION): WITH THE MODIFIED METHYL BLUE VAN GIESON THE COLLAGEN BUNDLES WERE STAINED PINK [MBVG, X 100].

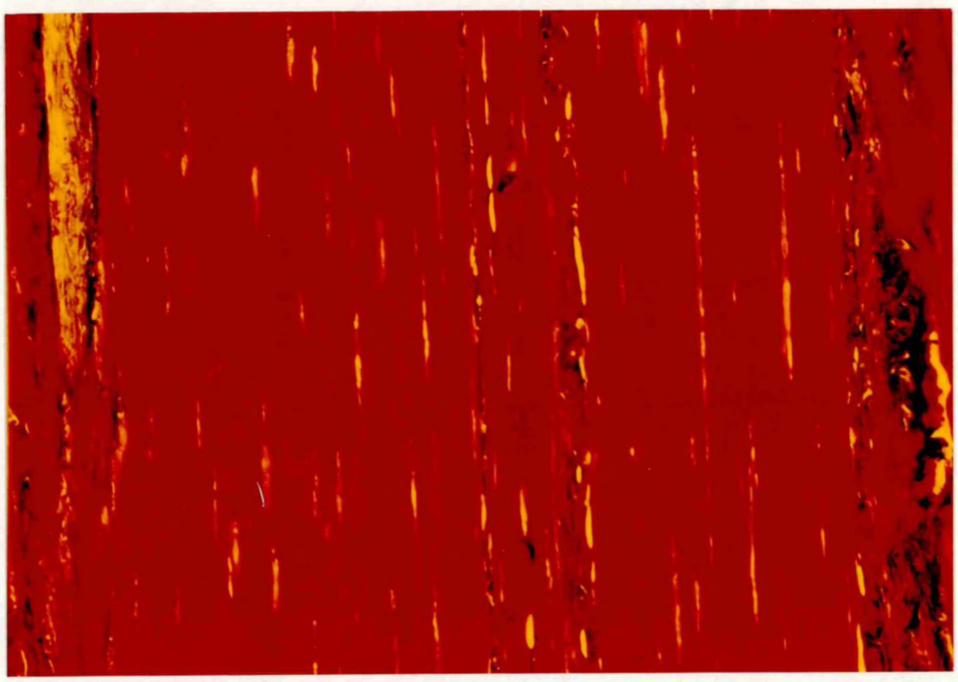
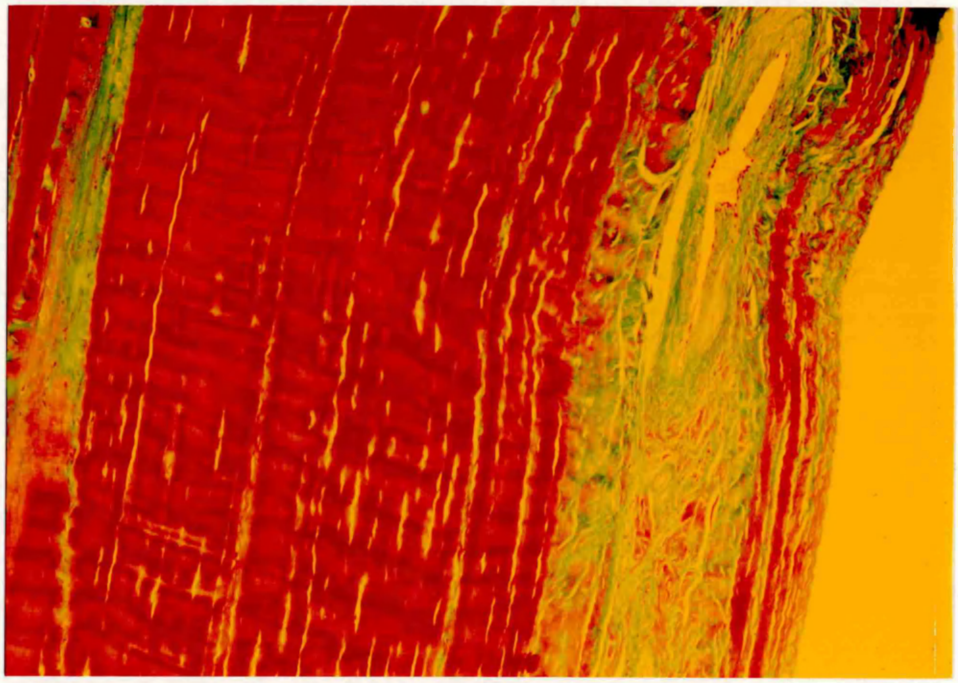


FIG. 3.50. A LONGITUDINAL SECTION OF A NORMAL SUPERFICIAL DIGITAL FLEXOR TENDON (MID METACARPAL REGION): MARTIUS SCARLET BLUE STAINED THE COLLAGEN BUNDLES BLUE WHILE THE COLLAGEN IN THE ENDOTENDINOUS CONNECTIVE TISSUE WAS RED [MSB, X 40].



Ultrasonographic Findings In Injured Superficial Digital Flexor Tendons.

The ultrasonographic findings are summarised in Table 3.1. Three separate ultrasonographic appearances were associated with acute superficial digital flexor tendon injury. The most severe injuries produced a complex appearance with a mixture of anechoic and hypoechoic areas which were irregularly-shaped and located and comprised almost the entire length and breadth of the tendon (Cases 3.2, right and 3.4, left; Figs. 3.4 and 3.12). In both of these cases, the skin was separated from the underlying tendon by a hypoechoic area (Figs. 3.4 and 3.12).

Less severe, acute injuries were associated with a simpler pattern in which an area within the tendon was replaced with either an anechoic or hypoechoic region which was oval or circular and varied in length (Cases 3.1, 3.2, left, 3.3, right, 3.4, right, 3.5 and the distal third in Case 3.11, right; Figs. 3.1, 3.5, 3.8, 3.13, 3.19, 3.20 and 3.40). Such areas could be easily defined from the surrounding tissue because their echogenicity was markedly less than that of the surrounding tendon (Figs. 3.1, 3.5, 3.8, 3.13, 3.19, 3.20 and 3.40).

The third ultrasonographic appearance associated with acute flexor tendon injury was observed in only one case, (3.3, left) in which there was no distinct lesion but the entire cross-sectional area had a reduced

TABLE 3.1. A SUMMARY OF THE ULTRASONOGRAPHIC FINDINGS IN 14 HORSES WITH BILATERAL SUPERFICIAL DIGITAL FLEXOR TENDON INJURIES OF VARIOUS DURATIONS.

L = left, R = right, P = proximal, M = middle, D = distal thirds,
CSA = cross sectional area of the tendon occupied by the lesion,
BORDER = distinctness of the lesion border graded 0 to 4,
ECHOGENICITY: 1 = anechoic, 2 = hypoechoic, 3 = anechoic and hypoechoic, 4 = mixed hypoechoic areas, 5 = hyperechoic foci.
LINEAR ECHOES = regularity of linear echo arrangement, graded 1 to 5,
P/T LES = anechoic or hypoechoic area between the skin and the superficial digital flexor tendon.
* = could not be determined.

CASE	LOCATION P	M	D	LENGTH (mms)	CSA (%)	TENDON ENLARGED	BORDER	ECHOGENICITY	LINEAR ECHOES	P/T LES
3.1L	-	+	-	60	30	-	4	2		
3.1R	-	+	-	60	30	-	4	2		
3.2L	-	+	+	80	30	+	4	2		
3.2R	+	+	+	240	100	+	*	3		+
3.3L	+	+	+	240	100	+	*	2		+
3.3R	-	+	+	200	50	+	4	2		
3.4L	+	+	+	220	100	+	*	3		+
3.4R	-	+	-	80	40	-	4	2		
3.5L	-	+	-	80	25	-	2	2		
3.5R	-	+	+	140	50	+	4	1		
3.6L	+	+	+	240	100	+	*	3 + 5		
3.6R	+	+	+	240	100	+	*	3 + 5		
3.7L	+	+	+	240	80	+	4	4 + 5	1	+
3.7R	+	+	+	240	80	+	4	4 + 5	1	+
3.8L	+	+	+	240	100	+	3	2	1	+
3.8R	-	+	-	100	50	+	3	4	2	
3.9L	+	+	+	200	100	+	2	4 + 5	2	+
3.9R	-	+	-	120	50	+	1	2 + 5	3	
3.10L	-	+	-	*	*	+	1	4	3	
3.10R	+	+	+	240	100	+	*	4 + 5	3	+
3.11L	+	+	+	240	*	+	0/4	1, 4 + 5	3	+
3.11R	+	+	+	240	*	+	0	4 + 5	3	+
3.12L	-	+	+	180	*	+	1	4 + 5	4	
3.12R	-	+	+	180	*	+	1	4 + 5	4	
3.13L	+	+	+	240	*	+	1	4	3	+
3.13R	-	+	-	100	*	+	1	4 + 5	4	
3.14L	-	+	+	*	*	+	0	4	4	
3.14R	+	+	+	*	*	+	1	4 + 5	4	+

echogenicity and the longitudinal linear echoes were replaced by short echogenic dots (Fig. 3.7).

There was a gradual increase in echogenicity as the age of the lesions increased. Initially, this was irregular and produced a heterogeneous echogenicity. In Cases 3.6 (left and right, twelve weeks' duration) and 3.7 (left, sixteen weeks' duration) the appearance was complex with anechoic, hypoechoic and hyperechoic areas (Figs. 3.24 and 3.27). Conversely, the distinctness of the boundary of the lesion gradually decreased with time so that in the chronic lesions this was increasingly difficult to discern (Cases 3.8, left, 3.9, right and 3.11, left and right; Figs. 3.31, 3.34, 3.40). In the most chronic lesions there was no distinct boundary and the appearance of the tendon was diffusely heterogeneous (Cases 3.12, left and right, 3.13, left and right and 3.14, left and right; Figs 3.41, 3.45 and 3.46).

Linear echoes were observed earliest in Case 3.8, (left and right, Figs. 3.31 and 3.32), at approximately five months' duration and reduced numbers of irregularly arranged linear echoes were noted in Case 3.9 (left, Fig. 3.33). These were present but short and reduced in number in Cases 3.9 (right), 3.10 (right), 3.12 (left and right), 3.13 (left and right) and 3.14 (left and right), [Figs. 3.34, 3.41, 3.43, 3.45 and 3.46].

Intratendinous hyperechoic foci were observed frequently in the older lesions (Cases 3.6 right and left, 3.7 left, 3.8, right, 3.9, left, 3.12, left and right, 3.13, left and right and 3.14, right; Figs. 3.27, 3.31, 3.34, 3.35 and 3.40).

The division between the superficial and deep digital flexor tendons was irregular in the majority of the chronic lesions and a hypoechoic structure lying between the superficial digital flexor tendon and the skin was observed in several horses (Cases 3.7, left and right, 3.8, right, 3.9, left and right, 3.10, left and right, 3.12, left and right, 3.13, left and right, and 3.14, left and right; Figs. 3.27, 3.35, 3.45 and 3.46). This feature was not present in the chronic mild injuries (3.8, left and 3.11, left and right).

Macroscopic and Histological Findings In Injured Superficial Digital Flexor Tendons.

The histological findings are summarised in Table 3.2. The acute lesions were located either centrally in the mid metacarpal region (Cases 3.2, left, 3.3, right and 3.4, right) or comprising the bulk of the length and cross sectional area (Cases 3.2 right, 3.3 left and 3.4, left). The lesion in cases 3.4 was so severe within the digital sheath that the entire cross-sectional area of the tendon was affected and removal of the tendon from the sheath caused it to disintegrate into two pieces (Fig. 3.14). In lesions of less than two weeks' duration, histological findings of haemorrhage, fibrin deposition, collagenolysis and necrosis predominated (Cases 3.2; 3.3; 3.4; Figs. 3.6; 3.9; 3.10; 3.15; 3.16) and this was accompanied by a fibroblastic response

TABLE 3.2. A SUMMARY OF THE HISTOPATHOLOGICAL FINDINGS IN 14 HORSES WITH BILATERAL TENDON INJURY OF VARIOUS DURATIONS.

L = LEFT
R = RIGHT
1 = SUBCUTANEOUS HAEMORRHAGE AND OEDEMA
2 = HAEMORRHAGE, COLLAGENOLYSIS, OEDEMA, CONGESTION
3 = INFLAMMATION
4 = GRANULATION TISSUE
5 = FIBROBLAST PROLIFERATION
6 = IMMATURE FIBROUS TISSUE
7 = RECENT FIBROSIS
8 = SCAR FORMATION
9 = HAEMOSIDERIN DEPOSITION
10 = ADHESION FORMATION AND/OR FIBROSIS OF THE PARATENON
11 = PERITENDINOUS HAEMORRHAGE AND OEDEMA
+ INDICATES A FEATURE WHICH WAS PRESENT.

CASE	HISTOPATHOLOGICAL FINDINGS 1	2	3	4	5	6	7	8	9	10	11
3.1L			+		+		+	+	+		
3.1R		+	+		+		+	+	+		
3.2L		+			+						
3.2R	+	+	+		+						+
3.3L	+	+	+		+						+
3.3R		+	+		+						
3.4L	+	+	+		+			+		+	
3.4R					+		+	+	+		+
3.5L			+	+	+	+			+	+	
3.5R		+	+	+	+	+			+		
3.6L		+	+	+	+	+	+	+	+	+	
3.6R		+	+	+	+	+	+	+	+	+	
3.7L		+	+	+	+	+	+	+	+	+	
3.7R				+	+	+	+	+	+	+	
3.8L					+	+	+	+	+	+	
3.8R					+	+	+	+		+	
3.9L					+	+	+	+	+	+	
3.9R					+	+	+	+			
3.10L					+	+		+	+		
3.10R					+	+	+	+	+	+	
3.11L		+			+	+		+	+	+	
3.11R					+	+		+	+	+	
3.12L					+	+		+			
3.12R					+	+		+			
3.13L					+	+		+	+	+	
3.13R					+	+		+			
3.14L					+	+		+	+		
3.14R					+	+		+	+	+	

with pale, enlarged cells with granular nuclei and the presence of neutrophils.

The duration of the lesions observed in Case 3.1 was unknown. The horse had raced the day previously and it is likely that they were incurred at that time. There were acellular areas in the central zones of the mid metacarpal regions of these tendons but there was little evidence of active haemorrhage although moderate amounts of haemosiderin were identified in association with the endotenon (Figs. 3.2 and 3.3).

In the chronic lesions there was frequently a variety of processes occurring at the same time and varying degrees of granulation tissue, haemorrhage, fibroplasia, collagen remodelling and scar formation were apparent. The intratendinous lesions were soft and brownish and granulation tissue and marked fibroplasia were the striking feature of the lesions examined from eight to sixteen weeks' duration (Cases 3.5, 3.6 and 3.7). In all of these cases collagen was present but it was irregularly-arranged and the lesions were extremely cellular. The endotendinous tissue was also extremely cellular and the intratendinous and endotendinous cells were large with oval, granular nuclei (Figs. 3.23, 3.25, 3.28, 3.29 and 3.30). In all of these cases there was evidence of active haemorrhage (Figs. 3.29) and also haemosiderin deposition indicative of previous haemorrhage

The gross appearance of older lesions was variable and ranged from brown to pale yellow or white areas within the tendon. Extremely firm white pinpoint scars were identified in Cases 3.6 right and left, 3.7 left, 3.8, right, 3.9, left, 3.12, left and right, 3.13, left and right and 3.14, right (Fig. 3.29). Histological examination in these areas demonstrated that there were numerous acellular areas composed of irregularly arranged, dense collagen (Fig. 3.26) and in the more chronic lesions (Cases 3.10, 3.11, 3.12, 3.13 and 3.14), the distribution of the cells was patchy and irregular with areas of both increased and decreased numbers of cells but a more regular arrangement of collagen (Figs. 3.39, 3.42 and 3.44). While in most of the chronic lesions greater than sixteen weeks' duration, the normal tendon had been replaced by chronic fibrosis, an area of granulation tissue was identified in the distal portion of the right superficial digital flexor tendon in a lesion which was greater than twelve months old (Case 3.14). Endotendinous proliferation was a also a feature of the more chronic lesions (Fig. 3.37 and 3.44).

The paratenon was thickened, white and fibrous in several of the most severely affected cases (Case 3.9, left, 3.10, right, 3.11, left and right, 3.13, left and 3.14, right) and microscopically it was composed of extremely organised granulation tissue with abundant collagen (Fig. 3.38).

Comparison of Macroscopic, Histological and Ultrasonographic Findings In Superficial Digital Flexor Tendon Injury.

Table 3.3 lists the histological findings, the associated ultrasonographic features and the cases in which these observations were made. The location and extent of the lesions detected on ultrasonographic examination and gross post-mortem examination corresponded well and the ultrasonographic features changed with time in the same way as the histological findings did. Both the ultrasonographic and histological findings tended to merge from one category to the next so that numerous parameters could be used to describe the ultrasonographic findings and there were overlaps between the ultrasonographic appearance and the tissue process that it represented.

TISSUE TYPE (CASES)	ULTRASONOGRAPHIC FINDINGS
FOCAL NECROSIS AND HAEMORRHAGE (3.1, L, R, 3.2, L, 3.3, R, 3.4, R)	WELL-DEFINED HYPOECHOIC AREAS
(3.5, R, 3.11, L)	WELL-DEFINED ANECHOIC AREA
WIDESPREAD NECROSIS AND HAEMORRHAGE (3.2, R, 3.4, L, 3.6, L, R)	MULTIPLE AN- AND HYPOECHOIC AREAS
(3.3, L)	DIFFUSELY HYPOECHOIC
PERITENDINOUS HAEMORRHAGE AND OEDEMA (3.2, R, 3.4, L)	SUBCUTANEOUS HYPOECHOGENICITY
FIBROPLASIA AND GRANULATION TISSUE (3.5, L, R)	WELL-DEFINED HYPOECHOGENICITY
(3.6, L, R, 3.7, R, 3.14, R)	MULTIPLE, COMPLEX HYPOECHOGENICITIES
IMMATURE, ORGANISING TENDON (3.6, L, R, 3.7, L, R, 3.8. L, R)	FEW LINEAR ECHOES DISTINCT LESION BOUNDARY
SCAR FORMATION (3.6, L, R, 3.7, L, R, 3.8, L, R, 3.9, L, 3.12, L, R, 3.13, L, R, 3.14, L, R)	FOCAL HYPER-ECHOGENICITIES
CHRONIC FIBROSIS (3.9, L, R, 3.10, L, R, 3.12, L, R, 3.13, L, R, 3.14, L, R)	IRREGULAR LINEAR ECHOES, INDISTINCT LESION BOUNDARY
PERITENDINOUS FIBROSIS (3.8, R, 3.10, R, 3.11, L, R, 3.13, L, 3.14, R	SUBCUTANEOUS ECHO-GENICITY WITH ILL-DEFINED TENDON EDGES

L = left fore superficial digital flexor tendon
R = right fore superficial digital flexor tendon

TABLE 3.3: A COMPARISON OF THE HISTOLOGICAL AND ULTRASONOGRAPHIC FINDINGS IN TWENTY EIGHT INJURED SUPERFICIAL DIGITAL FLEXOR TENDONS.

SECTION 3.4. DISCUSSION.

The normal histological appearances of equine superficial digital flexor tendon have been described previously (Stromberg and Tufvesson, 1969; Stromberg, 1971; Webbon, 1978b). Similarly, the gross pathological and histological features of equine superficial digital flexor tendon injury and repair have been well documented (Stromberg and Tufvesson, 1969; Stromberg, 1971; Webbon, 1977; Williams and others, 1980; Silver and others, 1983; Kaneps, Hultgren, Riebold and Shires, 1984; Watkins and others, 1985).

The histological findings in the control group were similar to those that have been established previously (Figs. 3.47 - 3.50; Stromberg and Tufvesson, 1969; Stromberg, 1971; Webbon, 1978b). Stromberg (1971), has shown that the vasculature is less extensive in the mid metacarpal region and suggested that this may lead to ischemic lesions. In addition, to the regular arrangement of collagen bundles and tenocytes which was observed in the control horses in that study, Webbon identified acellular areas within the mid metacarpal region of the superficial digital flexor tendon in grossly normal tendon and postulated that these areas might represent degenerative precursors of traumatic tendon injury (Webbon, 1978b). No such areas were identified in the control group in this study. However, the sample number was small which may explain this lack of variation.

Substantial dissolution of the tendon matrix and fibre lysis follows the initial injury, due to the release of collagenases and proteases from damaged cells and from inflammatory cells attracted to the site of injury (Silver and others, 1983). Fragmented connective tissue fibres are surrounded by strands of fibrin and oedematous spaces and polymorphonuclear cells and macrophages migrate to the site and these areas of necrosis and tendon lysis are replaced by new connective tissue by one month after the injury (Silver and others 1983). This tissue lacks the regular arrangement of normal tendon and the cells had large pale, basophilic nuclei (Silver and others, 1983). The findings in the acute and subacute cases (Case 3.2, 3.3, 3.4 and 3.5; Figs. 3.6, 3.9, 3.10 and 3.15) were consistent with these processes. The duration of the lesions in Case 3.1 was unknown as the clinical signs were mild and were detected as an incidental findings during an examination following another traumatic injury. The pertinent histological findings in this horse were acellularity of the central cores of the superficial digital flexor tendon with abnormal stain uptake. These lesions were similar to the findings in Case 3.4 (right) and were believed to represent early, necrotic lesions but haemosiderin deposition was also present suggesting more long-standing, and perhaps previous subclinical injury and haemorrhage. The appearance of these lesions (Cases 3.1, left and right, 3.4, right) was similar to lesions attributed to ischemia-induced degeneration (Stromberg, 1971). However, in this study, examination of the histological findings alone does not elucidate their aetiology and the history of recent, fast work supported a traumatic origin.

The fibroblastic stage of healing is characterised by the presence of large numbers of fibroblasts with proliferation of the endotenon and paratenon and fibroplasia was the predominant feature in the lesions of two to six months' duration in this study [Cases 3.5 - 3.8; Figs. 3.22, 3.23, 3.25, 3.29 and 3.30], (Stromberg and Tufvesson, 1969; Stromberg, 1971; Silver and others, 1983). Recent haemorrhage was also noted in lesions of eight weeks' (Case 3.5), three months' (Case 3.6), and seven months' (Case 3.11) durations, suggesting that a cycle of repair and further damage was occurring in these animals. None of these animals was in work at that time, but immature tendon has less tensile strength (Goldin, Block and Pearson, 1980; Steiner, 1982) which may account for lesions being created without large strains being applied to the tendons.

Previously, it was believed that tendon had little power to heal or regenerate on its own, relying on extrinsic healing with migration of fibroblasts from the paratenon. However, it has become clear that tendon has considerable intrinsic capabilities for phagocytosis of old collagen and synthesis of new collagen fibrils

(Lundborg, 1976; Manske, Gelberman, Vande Berg and others, 1984; Lundborg, Rank, and Heinau, 1985). Nevertheless, a histological study has demonstrated that the connective tissue cells present in healing equine tendon had an appearance which is similar to that of myofibroblasts (Williams and others, 1980). In that study, based on morphology alone, it was not possible to determine if these cells originated from the existing tenocyte population (Williams and others, 1980). However, the demonstration of collagen type by immunofluoresence methods indicated that the healing tendon contained large quantities of type III collagen, which is normally present in muscle and not in tendon (Williams and others, 1980). These authors concluded that these findings supported the theory that the cells producing collagen in equine tendon injury were derived from smooth muscle of the blood vessels or from primitive mesenchymal cells. The frequency of peritendinous adhesions associated with tendon injury may provide further evidence that extrinsic healing predominates (Silver and others, 1983). Collagen typing by immunofluoresence was not attempted in this study and, therefore, no conclusions may be drawn as to the origin of the fibroblastic response. However, the cells which were observed in the early tendon lesions (Fig. 3.9) were similar to those described by Williams and colleagues (1980) and extensive endotendinous and peritendinous proliferation was apparent in the majority of both subacute and chronic tendon lesions (Figs. 3.21, 3.28, 3.36, 3.37 and 3.38).

Remodelling of the lesions within tendons occurs over a period of months: six months after the injury in Silver's study the scar tissue was becoming more similar to normal tendon although the scar was still hypercellular and little subdivision into bundles was apparent, and abnormalities in both histological and biochemical characteristics were detected fourteen months after injury (Silver and others, 1983). In a mild injury of six months' duration (3.10, right; Fig. 3.39), there was a slight increase in the size and roundness of the tenocytes and their distribution was patchy but remodelling of this tendon was almost complete but in the remaining cases, varying degrees of chronic fibrosis were present, characterised by increased numbers of cells with rounded nuclei, irregular arrangement of collagen widespread scar formation and prominent endotendinous tissue, (Cases 3.10, left and 3.11 - 3.14; Figs. 3.37, 3.38, 3.42 and 3.44). However, a localised area of granulation tissue was detected in a lesion in a tendon injury of more than twelve months' duration (Case 3.14, right).

The ultrasonographic features of superficial digital flexor tendon injury have also been reported (Rantanen and others, 1983; Hauser and others, 1984; Spaulding, 1984; Genovese and others, 1985; Rantanen and others, 1985; Genovese and others, 1986; Genovese and others, 1987; Reef and others, 1988). It has frequently been stated that the ultrasonographic features are a reliable indicator of the state of healing of a tendon lesion, but this claim has not yet been substantiated by comparative studies (Rantanen and others, 1983; Hauser and others, 1984; Genovese and others, 1985; Rantanen and others, 1985; Genovese and others, 1986; Genovese and others, 1987; Reef and others, 1988). Equally, in human sports medicine, ultrasonographic imaging of tendon lesions has been increasingly well-documented in recent years but there are no reports which relate the ultrasonographic and pathologic findings in either animal models or clinical cases (Fornage and Rifkin, 1988a; Fornage and Rifkin, 1988b; Fornage, 1989b).

The ability of ultrasonography to distinguish between acute and chronic lesions has been based on the increase in echogenicity which is observed in association with chronic lesions (Hauser and others, 1984; Genovese and others, 1986; Hauser, 1986; Genovese and others, 1987; Reef and others, 1988). But, there is only one report in the literature of a study which compares ultrasonographic and histopathologic findings in superficial digital flexor tendon injury in which surgically created, transverse lesions were monitored for a maximum of twenty-five weeks (Henry and others, 1986). The authors concluded that the decreased echogenicity observed in acute lesions was due to haemorrhage, oedema and early granulation tissue within the lesion, and that echogenicity increased as the lesion progressed. The increase in echo intensity was proportional to the amount of collagen within the defect rather than the number of cells. However, the authors do not indicate how they were able to quantify the amount of collagen present within the lesion (Henry and others, 1986). Preliminary results in another study and this published report have indicated that there is a strong relationship between the ultrasonographic and histological features of tendon and ligament injuries (Henry and others, 1986; Reef, personal communication).

Acute tendon injuries have typically been associated with a focal, central decrease in echogenicity as was observed in the less severe injuries (Cases 3.1, 3.2, left, 3.3, right and 3.4; Figs. 3.1, 3.5, 3.8, 3.13; Rantanen and others, 1983; Hauser and others, 1984; Genovese and others, 1985; Rantanen and others, 1985; Genovese and others, 1986; Genovese and others, 1987; Reef and others, 1988). Two other distinct ultrasonographic patterns were associated with severe, acute lesions in these cases: a diffuse decrease in echogenicity (Case 3.3, right, Fig. 3.7) and a complex mixture of anechoic and hypoechoic areas filling the majority of the tendon (Case 3.2, right, 3.4, left, 3.12) In Case 3.4, the distal portion of the tendon was completely anechoic in the area which corresponded to the complete rupture observed post-mortem (Fig. 3.14).

Previous authors have suggested that

ultrasonography can be used to detect lesions in the absence of clinical signs (Rantanen and others, 1985; Genovese and others, 1987). Some degree of clinical signs was apparent in all these cases and thus, no conclusion can be drawn as to this ability from these results. However, ultrasonographic imaging was able to identify extremely small lesions which were subsequently confirmed (Cases 3.1 and 3.4, right; Figs, 3.1 and 3.13).

A number of parameters were used to describe the ultrasonographic appearance of the subacute and chronic lesions and these were: the location and echogenicity of the lesion, the distinctness of the border between the lesion and the surrounding tendon, the presence of hyperechoic foci and peritendinous echogenic structures and the presence, length and arrangement of the linear echoes which could be detected on longitudinal images. Grades were allocated to describe the distinctness of the borders. These grades were allocated to simplify description of the lesions and are subjective and therefore limited in value. Similarly, the echogenicity of the lesion was allocated a number for descriptive purposes and these grades do not correspond to those proposed previously (Genovese and others, 1986).

Hypoechoic areas with varying degrees of definition and linear echo arrangement were the hallmarks of chronic tendon lesions. In those cases in which areas of haemorrhage or granulation tissue were detected in the subacute or chronic lesion, anechoic or hypoechoic foci were detected (Cases 3.5, left; 3.6, 3.7, 3.14, right: Figs. 3.19, 3.24, 3.25, 3.27, 3.45). The lesions which were typified by widespread fibroplasia, generally had areas which were less echogenic, but well-defined, with minimal or no linear echoes (Cases 3.5 - 3.7; Table 3.3; Figs. 3.19, 3.20, 3.22, 3.23, 3.24, 3.27). Whereas chronic fibrosis was represented by areas which were less well-defined producing an overall heterogeneous echogenicity, with greater numbers of, longer and more regularly-arranged linear echoes (Cases 3.8 - 3.14; Table 3.3; Figs 3.31 - 3.46). However, there was overlap in the ultrasonographic appearances with anechoic areas representing both haemorrhagic and necrotic areas and early granulation tissue and hypoechoic areas representing both granulation tissue, immature fibroplasia and more chronic fibrosis (Table 3.3).

Pinpoint, hyperechoic foci were detected in all cases with widespread scar formation except 3.3, right,(Cases 3.6, 3.7, 3.9 - 3.14; Table 3.3; Figs. 3.24, 3.26, 3.27, 3.33 - 3.46), and comparison of the gross postmortem specimen and the ultrasonographic findings in Case 3.10 (Figs. 3.35 and 3.36; Table 3.3), illustrates that these hyperechoic foci appeared to be located in similar positions as the white, dense scars. Assessment of the peritendinous tissues was less consistent: for example, in Case 3.5, fibrous adhesions were found between the flexor tendons but there was little ultrasonographic evidence of this. Previous reports have indicated that indistinctness of the flexor tendons is a feature of peritendinous adhesions, but it would seem that this is a subjective and not a sensitive feature (Genovese and others, 1985; Rantanen and others, 1985; Genovese and others, 1986; Genovese and others, 1987). In contrast, the presence of a hypoechoic areas between the skin and the superficial digital flexor tendon was noted in association with peritendinous haemorrhage and oedema (Cases 3.2, left and 3.4, left; Table 3.3; Figs. 3.4 and 3.12), and in all cases with extensive proliferation of the paratenon and subcutaneous tissue (Cases 3.8, left, 3.9, left, 3.10, right, 3.11, left and right, 3.13, left and 3.14, right; Figs. 3.35, 3.36, 3.38, 3.40, 3.43 and 3.45).

The major limitations of the study are that a small number of horses were studied and, on the whole, their tendon injuries were severe. Nevertheless, a good spectrum of durations of injuries was obtained and the fact that bilateral injuries were present in all cases produced some material from mildly-affected limbs. The study serves to compare the ultrasonographic findings with only gross pathological and histological findings. Thus, it is simply a morphological study and no conclusions can be drawn as to the relationship between the ultrasonographic findings and the tendon's functional capacity. However, the results indicate that small lesions can be detected by ultrasonographic examination, and their presence is indicative of pathological processes in the tendon.

The conclusions of this study were that, as is to be expected, the ultrasonographic and histological features varied with the age of the lesions. The ultrasonographic findings did appear to reflect the underlying histology of the lesions but the range of abnormalities which were detected ultrasonographically was limited and at different stages of healing a particular ultrasonographic pattern could represent different pathological processes. Nevertheless, there appeared to be a consistent relationship between the ultrasonographic, macroscopic and histological findings.