MOVEMENTS OF THE CERVICAL SPINE OBSERVED BY DIAGNOSTIC ULTRASOUND.

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ABSTRACT

An investigation was undertaken to ascertain if standard diagnostic ultrasound equipment was capable of imaging the cervical spine and observing intersegmental motion.

Cervical spine anatomy was reviewed with particular attention paid to the location and structure of the ligaments, fascia and articular structures of the region.

A real-time B-scanner and 5MHz probe was selected for the project. Using a model spine within a waterbath, experience in image collection and interpretation was gained. The axial and lateral resolution of the scanner was tested. The ability of the scanner to measure a known distance using its caliper function was tested against other methods of measurement.

Peripheral joints were scanned with ultrasound and were X-rayed. A set distance on both of the images was measured to see if the two methods were comparable.

In vivo scanning of the neck revealed two positions for the probe which were the most useful. The body type of the patient was important to the quality of the scan achieved. Muscular or necks with much adipose tissue would produce poor quality scans. It was possible to image the laminae and the vertebra in transverse section. The motion between laminae and the motion of the vertebra as seen in the transverse view was possible to observe. The quantification of motion still requires attention.

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CONTENTS

CHAPTER 1 INTRODUCTION

There is a wealth of literature available on the epidemiology and sequelae of low back pain, both from the pathological and the economic view point. The same degree of enthusiasm is not present for the cervical spine if the literature is any indication. This may reflect the economics of the problem, with the belief that probably fewer working days are lost because of pain of cervical origin than from low back pain.

Hult (1971) reviewed his 1954 study of 1137 patients with cervical pain. Patients in his sample were employed in both heavy and light industry and were aged from 25 - 54 years. His findings reinforced the belief that cervical pain is infrequently the cause of inability to work, yet the frequency of the complaints were approximately equal to that of low back pain. His study sample showed, that over 50% of the workers over 45 years of age had suffered bouts of neck symptoms, with little difference between the workers in heavy and light industry. Gore et al, (1986) also reinforced the idea, that despite the lack of strongly documented figures, the number of patients who have cervical pain, is in fact numerous.

Vith interest focused on the lumbar spine by medicine and science, there is much information on the anatomy and biomechanics of the back and the causes of low back pain. Often this infomation is simply extrapolated to the neck with seeming disregard to the differences in structure and function of the cervical spine.

The lack of scientific approach in the examination and treatment of patients with cervical pain has been recognised and strongly condemned by Bogduk (1985). This lack of a scientific base and the problems of conducting good clinical trials has made it difficult to evaluate the effectiveness of patient care, which today is vitally important both from a professional and an economic stand.

The cervical spine, or more specifically the lower cervical spine is the area of interest for this work. Details of the upper cervical spine are given elsewhere (Verne, 1957; Romanes, 1981; Penning, 1988). The lower cervical spine is considered to be the vertebrae from the second cervical vertebra (C2) to the seventh vertebra (C7) inclusive.

The cranium is attached to the cervical spine and the spine allows passage of major arteries veins and neurological organs from the thorax, via the neck up to the head. The spinal cord and vertebral arteries are probably the most important structures lying within the spine.

Whilst the neck is the most mobile region of the spine, it is stabilised through its attachments to the shoulder girdle by ligaments and muscles. Therefore any movements of the arms or shoulder girdle will be reflected in small movements in the cervical spine (Harms-Ringdahl et al, 1986). This will also occur with movements of the rest of the axial skeleton, pelvis and lower limbs.

The cervical spine has a complex musculature which is extremely effective in allowing and controlling movement yet is difficult to model mathematically (Helleur et al, 1982). The problems of making assumptions and extrapolating data from the basic kinematic information, is again present. This may be one reason why there is a relative dearth of information on the biomechanical nature of the cervical spine. With the advent of such groups as the Cervical Spine Research Society promoting investigations into specific structures of the spine then more new information should be forthcoming.

The tissues and skeletal system of the neck are commonly subject to degenerative processes and to both direct and indirect injury. Indirect injury, as in the case of muscle tension leading to fatigue is very common. This is often the result of poor postural habits or the occupation of the patient. The young (Pennecot et al, 1984 a,b) may also be subject to the problems of a painful cervical spine. These are usually the result of direct injury or facet joint subluxation. Degenerative changes can affect the neck greatly giving the patient much discomfort and dysfunction.

The motor segment (Schmorl & Junghanns, 1952) or as White and Panjabi (1978) termed it, the functional spinal unit (FSU), is the basic anatomical unit, at which movement can be demonstrated and measured. Early work on the analysis of spinal motion has been well documented by Lysell (1969). Observation of whole or gross spinal movement has been gradually succeeded by the observation of the functional spinal unit. However, isolated spinal segment studies usually ignore the interactions of the soft tissues which are an integral part of the structure of the neck.

Gross spinal motion may be described as the summation of movement of all FSUs throughout the region of the spine. Consideration of gross spinal motion will not allow the investigator to identify specific levels of dysfunction. However observation of segmental motion would detect the small movements usually in the order of 0° - 12°, and then demonstrate if dysfunction was present.

To observe segmental motion, various methods have been used depending upon the experimental protocols. X-ray techniques havs been used in particular with the overlay method (Penning 1978), using vertebral body outlines as guides and measuring various constructed angles to determine range of motion. Cineradiography has also been used to monitor the cervical spine (Fielding 1964).

Stereoradiography involves the use of orthogonal X-rays and will give the 3-Dimensional range of motion of a structure with respect to its neighbour. Pearcy (1979) used this technique to observe the lumbar spine. Computed Tomography, Magnetic resonance imaging and myelography are some of the techniques availablefor spinal imaging but have great drawbacks in that they are expensive, invasive or expose the patient to ionising radiation and they require static positioning to acquire the images.

The possible and novel use of standard diagnostic ultrasound to image the cervical spine was to be investigated. The main types of scanners would be tested to select the equipment fitting the requirements of the study.

Diagnostic Ultrasound has to date no known detrimental effects to humans at the recommended intensities and exposure times. Scanning is a relatively easy technique to perform although the interpretation of the images is at times difficult and does require practice.

Diagnostic ultrasound has primarily been used for scanning soft tissues where the presence of bone causes problems of acoustic shadows blocking the images. More recently its value for imaging bony structures which may be implicated in spinal conditions, such as spinal stenosis, has received much attention (Porter et al, 1978). Ultrasound has also been used for the scanning of joints to demonstrate the presence of effusion (Egund et al, 1986) or damage to ligaments or tendinous structures (Middleton et al, 1985).

It was therefore important to ascertain if standard diagnostic ultrasound would be capable of imaging an in vitro model of the cervical spine, made up of dried human vertebrae suitably mounted for scanning. If in fact images were possible then the identification of vertebral landmarks was the next stage and to test the ability of the scanner to measure distances between structures of the spine or from a calibration system.

The possibility of using a standoff medium to facilitate focusing of the ultrasound beam for the superficial vertebral structures might be required. The gel substance used should be tested to see if it facilitate or impede scanning.

As X-rays are the standard method of imaging the spine for patient examination and judgements are often made on the state of joints by observing X-rays, it would be useful to see if a difference exists between the two methods of scanning. A comparison of the results between the two methods of measuring would also be of interest. With the expansion of ultrasound into the field of orthopaedics this measurement could be attempted on the scans of peripheral joints.

Diagnostic ultrasound would then be used on in vivo spines to identify spinal structures. The optimum position for the ultrasound probe to achieve the best images would be investigated. Realtime diagnostic ultrasound equipment is capable of observing structures whilst they are moving. This ability is unique in scanning methods and should be optimised during spinal scanning of the neck. Positional changes of the vertebrae should also be observed and if possible measured in light of current knowledge.

It was hoped that the novel use of ultrasound scanning would allow the imaging of the cervical spine and the visualisation of intersegmental motion. With such a imaging system it might be possible, in future, to determine levels of dysfunction in the cervical spine and so determine the possible effects of treatment. Realtime imaging of the cervical spine during movement would allow the direct observation of the type and direction of segmental movement that occurs in the cervical spine.

CHAPTER 2 ANATOMICAL REVIEW OF THE LOWER CERVICAL SPINE

2.1 INTRODUCTION

The vertebral column, or spine forms a firm but pliant axis for the skeleton. The shoulder girdle with upper limbs and the pelvic girdle with lower limbs, are attached to this axis. Most of the vertebral column consists of bony vertebrae alternating with cartilaginous discs, but the sacrum is composed of vertebrae which are fused together. This arrangement allows the spine to withstand compressive loading yet have a wide range of movement. The development of the spine and its regional variations has probably resulted from the evolutionary demands made for the survival of man. Thus the human vertebral column has a relatively small number of large rugged vertebrae, adapted to give support for the vertical position.

The spine has four main regions, the cervical with 7 vertebrae, thoracic with 12, lumbar with 5, then 5 fused sacral and 4 coccygeal vertebrae. Vertebrae from each region may be easily identified by their size and shape, which also varies slightly between individuals. The adult spine is usually about 60-70 cm in length. The occipital bone, which probably represents a rostral vertebra may be known as "C0", with the first cervical vertebra as C1, and thereafter the others are C2 - C7. The "lower" cervical spine is usually considered as C2 - C7 and the "upper" cervical spine C0 - C2. The lower cervical spine is the region of primary interest for this work.

This chapter constitutes only a review of the anatomy of the cervical spine, with emphasis on the bones, joints and muscles of the region. Greater detail may be found in specialised texts (Wilkinson, 1971; Grant, 1978; White & Panjabi, 1978; Warwick & Williams, 1980; Rothman & Simeone, 1982; Sherk & Parke, 1983).

2.2 CERVICAL CURVATURE

The normal adult spine when viewed from the side, is convex forward in the cervical region. The curve is called the cervical lordosis, which is most prominent at C4 - 5. Development of the curve has been thought to result from the gradual weight bearing of the head on the neck and the need to raise and balance the head for vision and feeding. Bagnall et al, (1976) demonstrated that in a large series of foetuses, the cervical lordosis could be identified in many cases, at 9½ weeks. Their study puts in some doubt the traditional explanation for the formation of the cervical curve.

2.3 TYPICAL CERVICAL VERTEBRAL BODY

There are two main elements in the structure of vertebrae, the vertebral body in front and the vertebral arch behind.

The cervical vertebral body has a frontal diameter approximately twice that of the sagittal diameter (Jackson, 1977). The body of the vertebra is smaller than the arch (Fig.2.1). This makes the cervical spine sufficiently strong to withstand the load of the head and neck, also allows great mobility.

There are two small but important projections on the upper edge of the body, which are called uncinate processes, these take part in the uncovertebral joints. The caudal surface of the body is usually saddle shaped for its attachment to the disc. On the posterior surface of the body, there are several small foramina for the basivertebral veins.

The vertebral body is essentially a mass of cancellous bone contained in a shell of dense cortical bone. Cortical bone thickness has been described in the lumbar vertebrae as uniform, approximately 0.025 - 0.1 mm (Short, 1986), no value has been found for the cervical region, but it is probably less than the value for the lumbar spine. The cylindrical or drum shape of the body would poorly withstand axial loading without buckling. It is the presence and the structure of the internal cancellous bone which assist the thin cortical shell to withstand loads. Short (1986), demonstrated with his finite element model (FEM) of a lumbar vertebra, that the cortical bone would take only 5.1 N. of a load applied to the vertebra of 53.8 N. Lakes and Katz (1977) implied that the viscoelastic properties of the tissue they tested was temperature dependent, which would have important implications for the testing of spinal segments, which are usually frozen at dissection then thawed to room temperature for testing.

Another function of the cortical shell is that it contains the

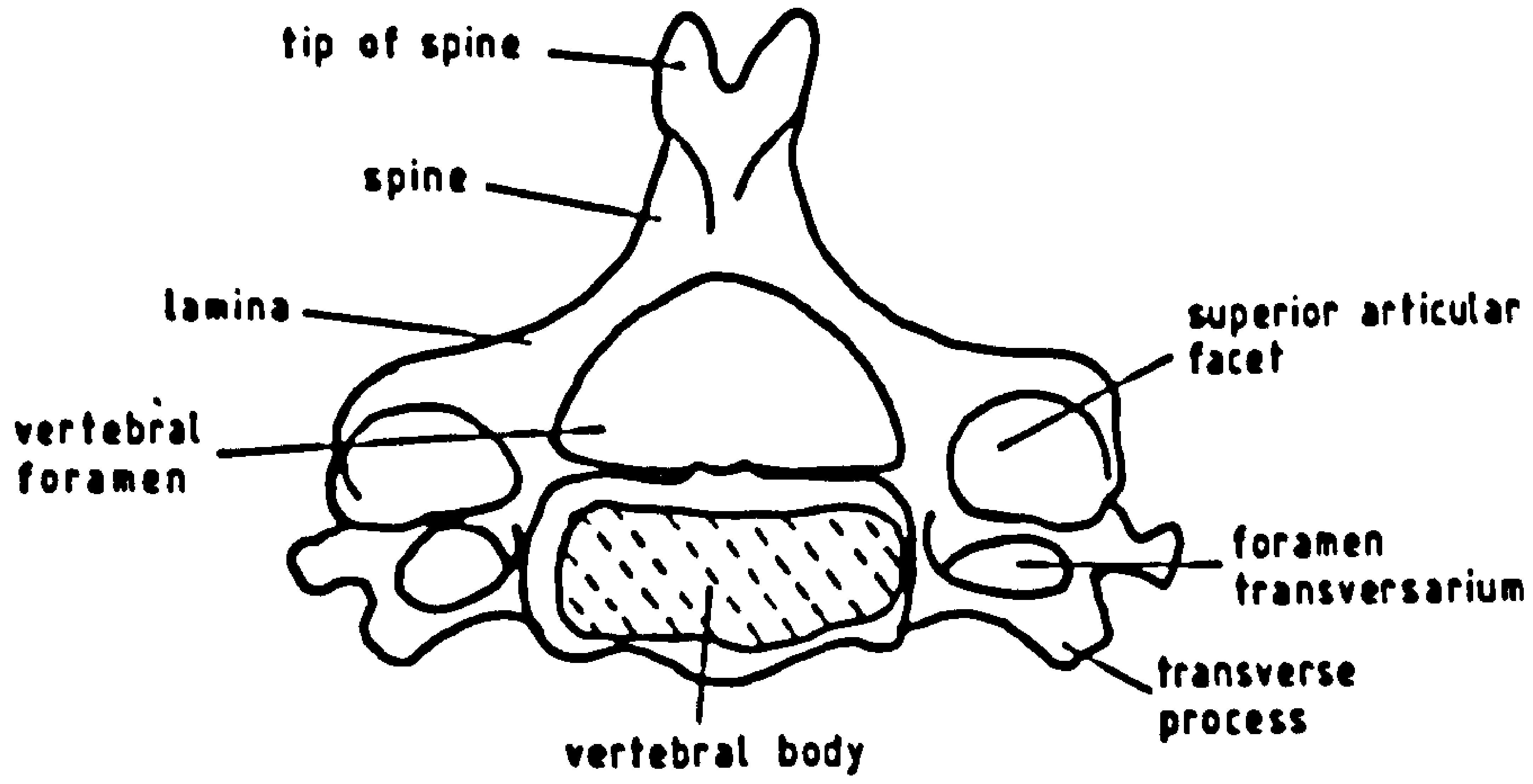


Fig. 2·1 Characteristic features of a typical cervical vertebra

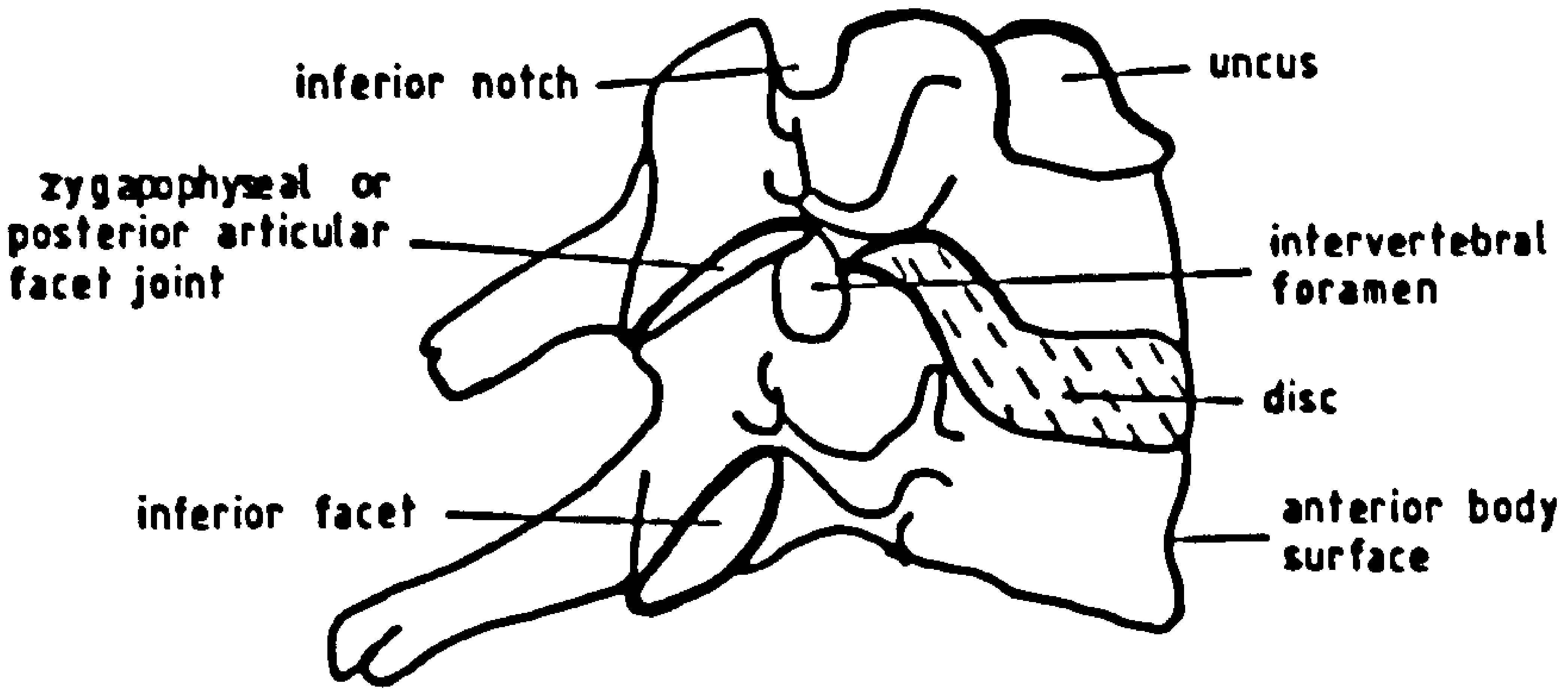


Fig. 2·2 Cervical mobile segment

highly vascular bone marrow. In the cervical spine the bone marrow is a site for the manufacture of red blood cells (haemopoiesis). White and Panjabi (1978) quote Lindhal (1976) and Hayes and Carter (1976) for their work on the relationship of vascular marrow and hydrostatic pressure and the ability of the body to withstand loading.

Cancellous bone has trabeculae forming an open network of orthogonal "struts". Their distribution in other parts of the body has been described (Currey, 1982) as following the direction of loading, however in the spine loading is predominantly axially. This does not seem to affect the position of the trabeculae. Injury, or micro trauma to the trabeculae would cause realignment of the "struts", which might then alter the mechanical response of the tissue in the area to stress.

2.4 TYPICAL CERVICAL VERTEBRAL ARCH

The arch or posterior element of the vertebra is larger than the body and has several characteristic features.

The pedicles are short strong bars of bone projecting posterior-laterally from the body, on either side. The curved superior and inferior surfaces of the pedicles form the floor and roof of the intervertebral foramen or canal which may be 0.5cm - 1.0cm in length. The disc and the posterior longitudinal ligament help to form the anterior borders of the canal. The canal contains the dorsal and ventral nerve roots of the spinal nerve and often the ganglion. Neural tissue can make up 50% of the canal contents (Fig, 2.1 & 2.2).

The laminae in the cervical region are long, narrow and have sharp superior margins adjacent to the ligamentum flavum.

Cervical transverse processes have a typical shape. The process is formed by the anterior costal element and the posterior, or true costal element. The two connect by a costo-transverse lamella grooved by the emerging spinal nerve. Through the transverse processes on either side are the foramen transversaria, for the passage of the vertebral artery through the neck to the brain.

Spinous processes are also characteristic in the cervical spine. The processes of C3-6 are similar and can be described together. They are short, stout spines projecting dorsally from the junction of the lamellae, each ending in a small tubercle. Assymetrical development of bony structures is common in the spine, so individual variations are frequent. The tip of the spinous process is level with the inferior margin of the corresponding posterior facet joint eg, C4 spine tip lies level with the inferior margin of the C4-5 facet joint (Grieve, 1981). The C2 and C7 spinous processes are considerably larger than the others and may be used for surface landmarks in most people. The tip of the spines are usually bifid.

The vertebral canal formed by the posterior wall of the vertebral body and the ventral surface of the arch is, in the cervical spine relatively large and triangular in shape, to accommodate the cervical enlargement of the spinal cord The spinal cord, meninges vascular plexuses and connective tissue all lie within the canal.

2.5 JOINTS OF THE VERTEBRAL BODY

The bodies of adjacent vertebrae are bound together by the strong and extremely important intervertebral discs. The discs are united to the vertebral bodies by a thin plate of hyaline cartilage, the cartilage or vertebral end plate.

2.5.1 Cartilage end plate

The cartilage end plates (CEP) are found on the cranial and caudal surfaces of adjacent vertebrae. Inoue (1981), using scanning electron microscopy (SEM), demonstrated the possible collagen fibre connections between the CEP and the vertebral body. Under polarised light he showed there were poor fibre connections between the CEP and the subchondral bone. The inner one third fibres of the annulus fibrosus were connected into the CEP and the outer fibres connected straight to the vertebral body.

During the second decade, the CEP has gradually sealed off the vertebral body from the disc. However small protrusions or herniations of disc material may occur into the body (Schmorl's nodes). These may be developmental or occur as a result of sudden increased loads on the spine. Bony changes in the trabeculae may follow this micro trauma, to cause alteration in the structure of the bone (sclerosis) and its mechanical properties. The aging processes will also lead to changes in the CEP. The cartilage would gradually becoming calcified, which alters its mechanical properties, so making it more vunerable to injury.

2.5.2 Intervertebral Disc

Discs in the cervical spine contribute approximately ¼ the height of the neck. Cervical discs are 'kidney' shaped with the anterior margin slightly convex and slightly longer than the posterior aspect, thus contributing to the cervical lordosis.

The annulus fibrosus is the outer part of the disc. It consists of concentric lamellae of collagen fibres which are opposite inclined to one another at approximately 60°. The annulus has a collagen fibre content of 15% as compared to tendon at 30% (Hickey & Hukins 1980). The inner collagen fibres of the annulus are attached to the CEP and the outer fibres are attached into the vertebral body directly. The lamellae arrangement of the fibres can easily be seen on dissection. Fibres in the posterior lateral corners of older discs can show evidence of degeneration, as a break down in the order of lamellae.

The nucleus pulposus is a hydrophylic gel-like substance, described by Inoue (1981) as an irregular mass of collagen fibres of 0.1μm-1.5μm, chondrocyte type cells and small particles of mucopolysaccharide protiens held together in a network of collagen fibres. The structure of the nucleus is known to change with age until it more resembles the annulus fibrosus. This occurs as the water content of the nucleus is reduced and there is a small increase in collagen.

The disc is said to be the largest avascular structure in the body. It depends upon the surrounding structures, which are well vascularised, for its nutrition. This is believed to occur by passive diffusion (Urban et al, 1977), through the nucleus pulposus and also the periphery of the disc. Simon et al, (1985) mathematically modelled the possible method of fluid flow between the disc and the vertebral body. They concluded that the disc, the CEP and the cancellous bone could all be considered as poroelastic structures. This fluid flow for nutrition maintains the slow metabolism of the disc.

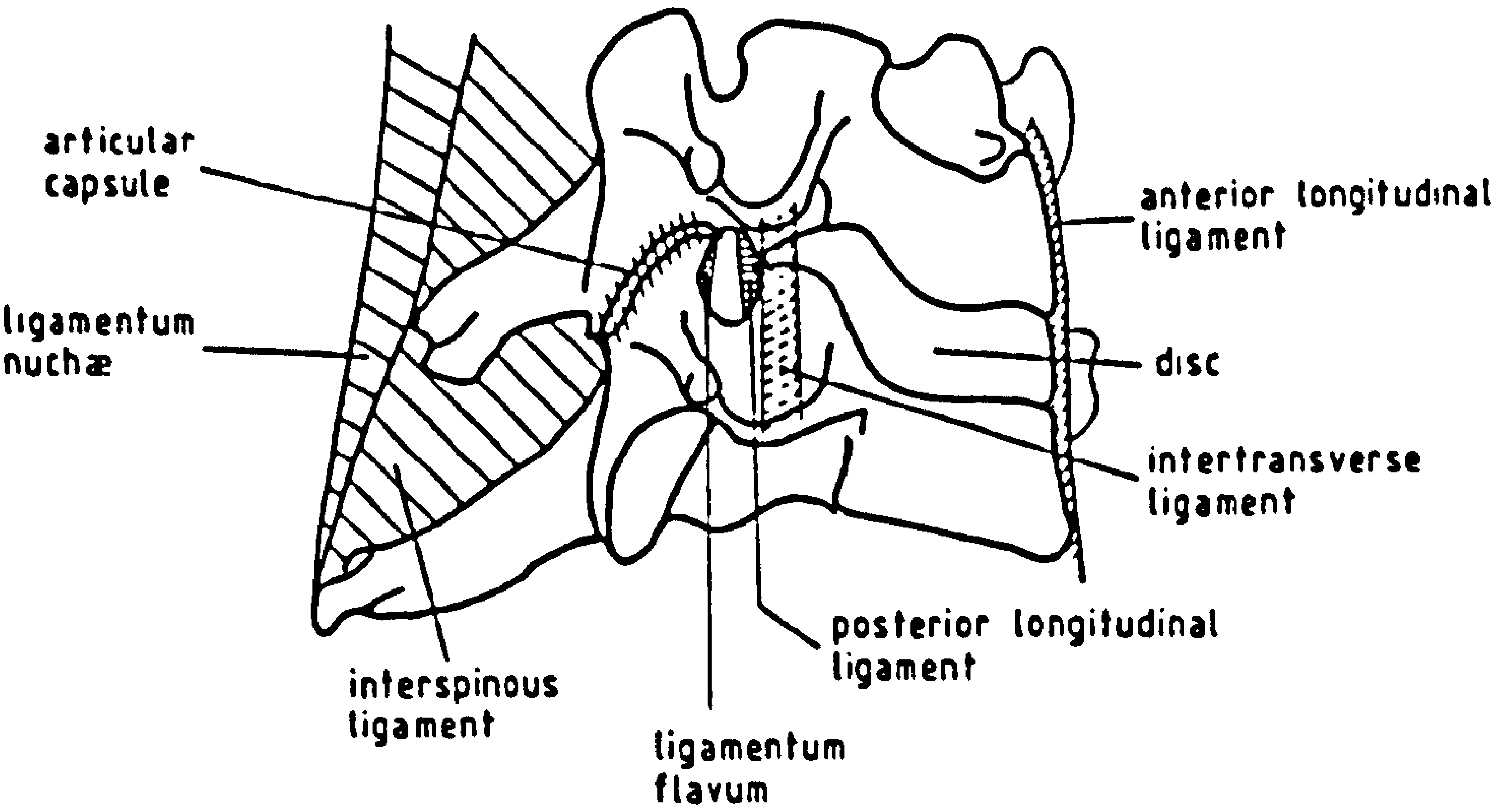


Fig. 2·3 Ligaments at a cervical mobile segment

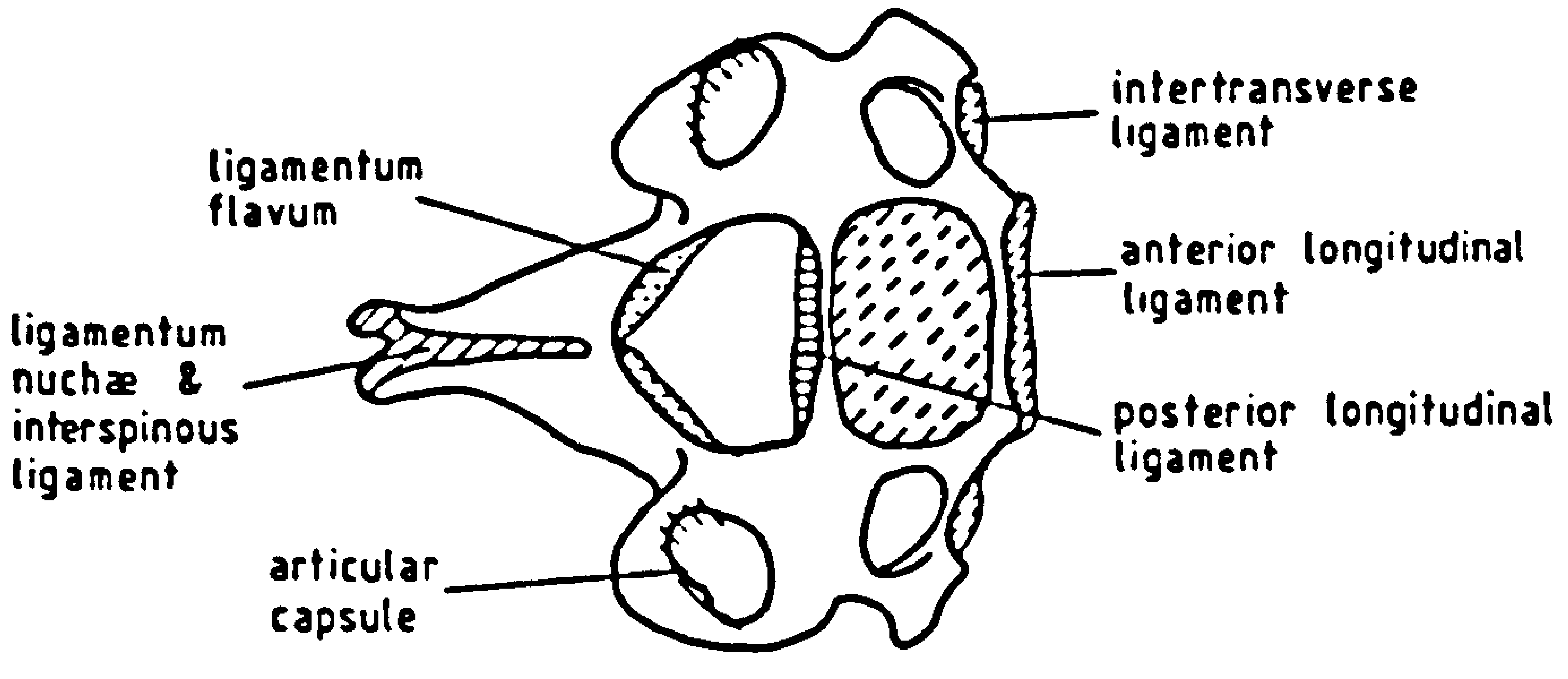


Fig. 2·4 Cross-section of Fig. 2·3

2.5.3 Uncovertebral joints

These joints have been described since the 19 th century. Von Lushka gave his name to them, but later they were called uncovertebral joints. There has been controversy as to whether or not they are true joints. They do have some features of true synovial joints, but Hirsch et al, (1967) and Tondury (1971 a) agree that as there is no synovial membrane, they are not true synovial joints.

At birth a triangular area of connective tissue is present in the area where the joint will develop. By 14 months, collagen fibres are present and by the 7th to 10th year, the uncus is visible as a raised lip on the body of the vertebra. The uncus is present on all vertebrae from C3 to T1 (thoracic) and is fully developed by the second decade.

The uncus is matched by a similar raised area on the inferior surface of the cranial vertebra. Small fissures may occur in the annulus in the region of the uncus and the cells that surround the fissures change and become more like chondrocytes. Tondury (1971 b) described the fissuring as a functional adaptation to changes in the tissue and functions of the spine during spinal development. The small clefts may extend to bisect the disc, these are normal changes but may be extreme in some pathologies. Joint motion is described in more detail later, but the uncovertebral joints allow a degree of translation and some angulation between adjacent vertebrae.

2.5.4 Ligaments of Vertebral body joints

Ligaments play an important part in maintaining the stability of the spine throughout its whole length (Fig. 2.3 & 2.4). They act because of their position, with the bony structures of the spine to guide and control spine motion. Penning (1968) has expresed this idea as having "active" and "passive" ligaments. The anterior and posterior longitudinal ligaments of the body are described as "active" ligaments as they are always under a degree of tension whereas "passive" ligaments are not under tension and are called into action only at the limit of their excursion when they restrict motion.

The anterior longitudinal ligament is a wide band extending from the occiput to the sacrum. It is composed of layers of fibres, the deepest of which span adjacent vertebrae. Superficial fibres span 3 or 4 vertebrae. Fibres are attached to the body and the disc, making a smooth anterior surface to the vetebrae. Stillwell's (1956) dissections give the nerve supply as arising from the vertebral plexus, being supplied segmentally, with some adjacent overlap. The anterior longitudinal ligament primarily assists in the control of extension of the spine. It is in Penning's definition an active ligament, being under a degree of tension, which increases when it is restricting dorsal motion.

The posterior longitudinal ligament extends from C1 to the sacrum within the vertebral canal. The ligament has a layered construction similar to the anterior longitudinal ligament. The ligament has a greater proportion of elastin fibres than the anterior ligament and is slightly thicker. It is attached to the bodies and the discs, allowing space for the underlying basivertebral veins to leave the vertebral body. The segmental nerve supply (Stillwell, 1956) is suggested as being visceral and somatic in origin and arising from more than one recurrent branch.

The inter-transverse ligaments are poorly formed in the cervical region and are easily removed at dissection. Because of their position, their action is most likely complementary to the deep muscles of the neck which have origin or attachments near the transverse processes.

2.6 JOINTS OF THE VERTEBRAL ARCH

2.6.1 Zygapophyseal joints

These are synovial joints with a capacity for translation and angular motion. Each vertebra has four articular facets, two on the superior surface facing posteriorly and two on the inferior surface facing anteriorly. The average angle of inclination is 45° to the horizontal, with a range of 30-60°. The C2-3 zygapophyseal joint also inclines at 10-20° laterally.

Facet are usually oval in shape but are not congruent (Tondury, 1971 a). Congruency, in the cervical spine joints, is thought to be achieved by small inclusions, as described by Mercer (1985). These inclusions were defined as intra-capsular or intra-articular and were of differing types of tissue. The shape of the inclusions also depended upon the shape of the joint and the surfaces involved.

Putz (1985) indicated that lumbar articular processes act with the small segmental muscles of the back and the joint capsule, as a 'tie-beam' for the intervertebral discs to help reduce the load on the disc at the completion of spinal rotation. This action may also occur in the cervical spine, as the discs are not as well adapted to taking heavy loads.

2.6.2 Joint capsule

The joint capsules of the zygapophyseal joints are lax around the joints, though they do contain elastic fibres especially where they are in close proximity to the ligamentum flavum. The elasticity of the capsule may help to maintain approximation of the joint surfaces after movement. Joint capsules will assist in the stabilising of the spinal joint. The lateral aspect of the joint does tend to be more lax than the other areas. On dissection it was noted that the capsule also lies in close proximity to the origin and insertion of the deep muscles of the neck and may well may be affected by their action. It was noted subjectively at dissection, that laceration of the capsule allowed increased range of motion in the neck. This may be a reason for instability of the cervical spine if the neck has had severe trauma.

2.6.3 Ligaments of the Zygapophysaeal joints

The ligamenta flava connect the laminae (Fig. 2.3 & 2.4). The fibres of the ligament are orientated caudio-cranially being attached from the anterior surface of the lamina above to the posterior surface of the lamina below. The ligament is broader but thinner in the cervical region, but is still composed of two lateral sections thus allowing a small central opening for vessels. This ligament contains a larger percentage of elastin fibres than any other spinal ligament.

In the lumbar spine studies on the L3 ligamentum flavum (Nachemson & Evans, 1968) have shown that, because of its elastic content it is able to pre-stress the disc to a small degree. The ligamenta flava assist in the control of spinal motion by resisting

Fig. 2.5 Ligamentum Nuchae in midline dividing muscle

Fig. 2.6 Ligamentum Nuchae at dissection

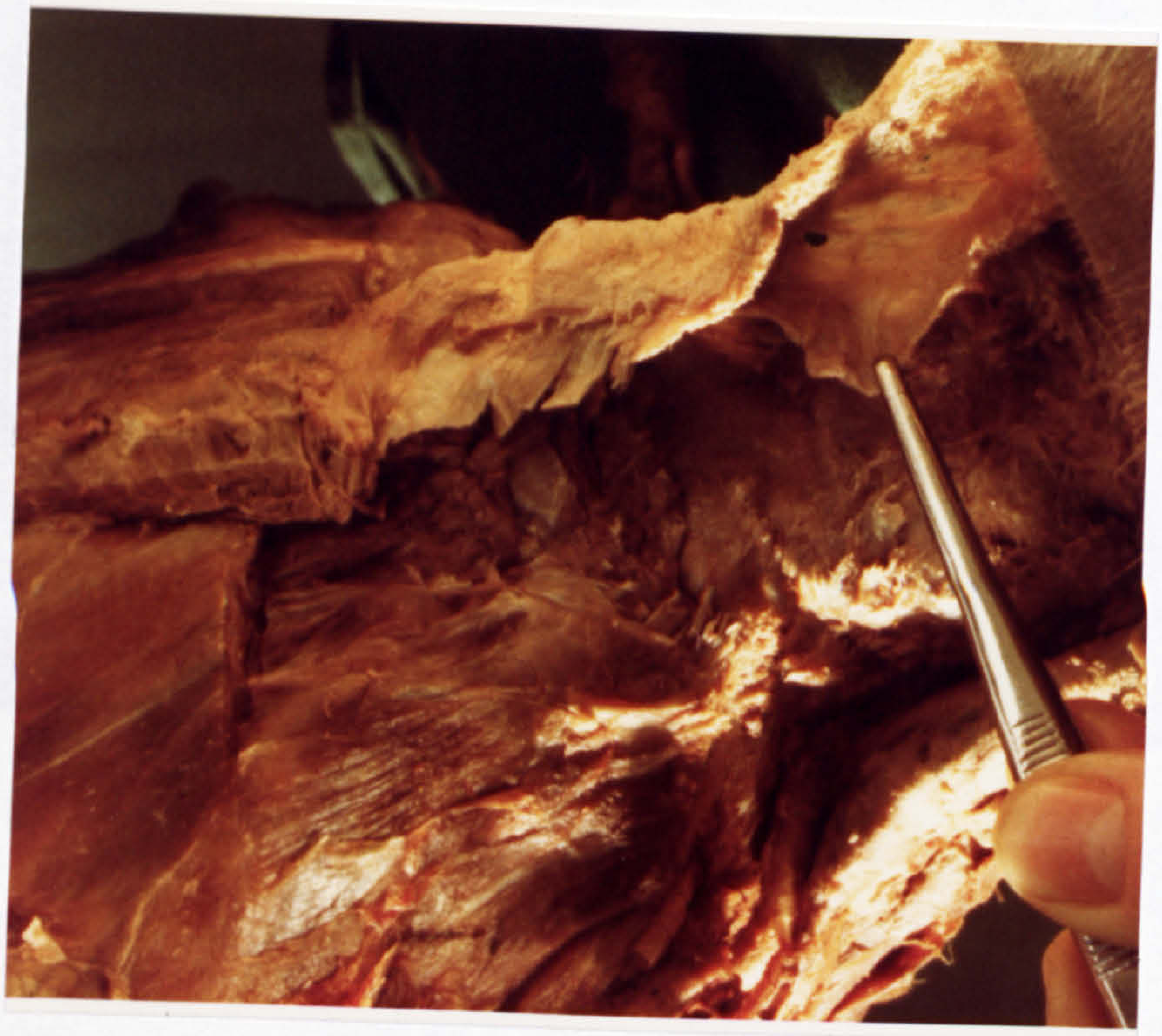


Fig. 2.7 Lateral fascial attachments to the Ligamentum Nuchae

excessive flexion movements of the spine. The elastic qualities of the ligament also prevent it from buckling into the spinal canal when extension occurs, which is extremely important in the neck, to avoid cord damage.

Intertransverse ligaments are not well developed in the cervical region and are closely related to or replaced by the intertransverse muscles.

Cadaver dissections of the cervical spine were undertaken to observe the anatomy and the inter-relationships of musculo-skeletal structures of the neck (Zuckerman, 1981). Attention was paid to the nature of the ligamentum nuchae and interspinous ligaments.

The ligamentum nuchae is a large structure in the sagittal plane on the dorsum of the neck. It spans the cervical lordosis from the external occipital protruberance to the spinous tip of C7 dividing the posterior muscle groups on either side (Fig 2.5). The ligament is traditionally described in two parts (Warwick & Williams, 1980), the lamella, or deep section and the funicular or superficial band.

The lamella portion of the ligament lies primarily between the spinous processes. Anteriorly it is in very close proximity to the ligamentum flavum, posteriorly, beyond the spinous processes, it blends with the funicular band. Fibre direction of the lamella portion, was seen (Fig 2.6) on dissection to pass in a posterior caudal direction. The direction of the fibres is different from the direction of the interspinous ligament of the lumbar spine. Heylings (1978) described the fibre direction for the lumbar spine, as posterior-cranial. This is contrary to that given in some older texts. Because of the close proximity to these ligaments, the interspinous ligament would most likely have a higher than normal elastin fibre content. Cranially, the lamella portion extends to the midline of the occiput. The fibres arched over and were not attached to the tubercle of the arch of the atlas. They then were continuous between the spines down to C7. At the apex of the cervical lordosis the lamella section of the ligament extended dorsally, 3 - 4cm beyond the spinous processes.

The lamella portion of the ligament became thickened along the dorsal margin of the ligament, to form the funicular band. On dissection, this band was found to be approximately 1cm wide and

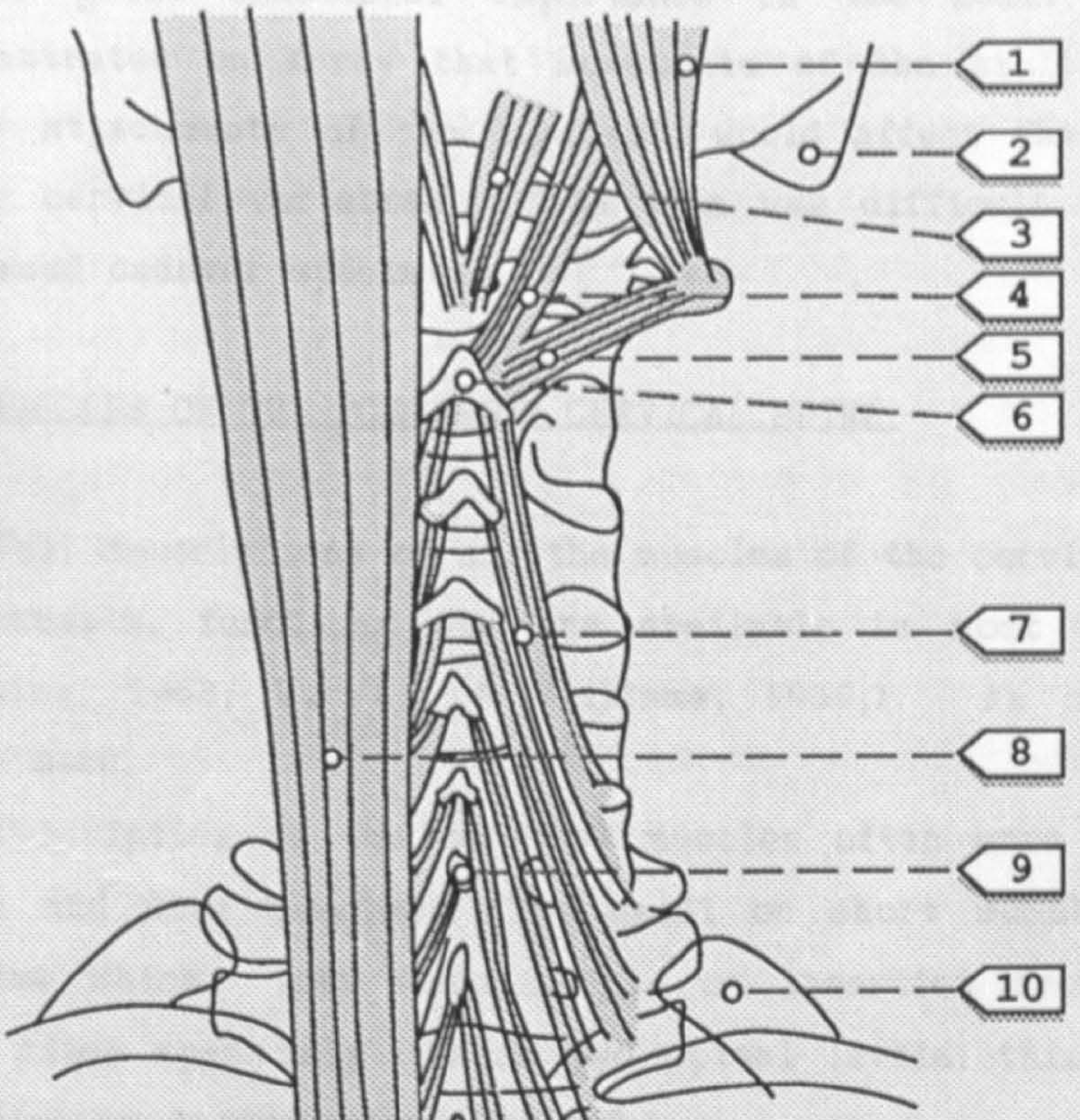


Table 2.1 .

Muscles covering the posterior aspect of the cervical spine. (After Penning 1968)

1. Obliquus capitis superior.
2. Mastoid process.
3. Rectus capitis posterior minor.
4. Rectus capitis posterior major.
5. Obliquus capitis inferior.
6. Spinous process of the axis.
7. Semispinalis cervicis.
8. Semispinalis capitis.
9. Vertebra prominens.
10. First rib.

several milimeters thick. The thickness of the band appeared to reflect the attachment of the extensive fascial planes (Fig 2.7) which lay laterally separating, or give origin to the lateral muscles of the neck. The funicular band was attached proximately to the external occipital protuberance and distally to the spine tip of C7.

Because of the size, construction and postion of the ligament, it is of great functional importance in the neck. Jirout (1974) demonstrated on X-ray that movements of the skull, because of the upper attachments of the ligament, would affect the position of the lower cervical vertebrae. This idea was difficult to appreciate on emblamed cadaver specimens.

2.7 MUSCLES OF THE POSTERIOR CERVICAL SPINE.

Full descriptions of all the muscles of the cervivcal spine, their attachments, functions etc are available in most anatomical texts (Penning, 1968; Warwick & Williams, 1980;). An overview only is given here.

Description of the cervical muscles often uses the headings of short and long muscles. The small or short muscles are the deep muscles which take their origin or insertion from the vertebrae. They often span only one or two spinal levels, this can be seen on the diagram accommpaning Table 2.1.

One function of these muscles, because of their position is to work with the ligaments of the cervical spine, to assist in providing stability for the spine, working at each spinal level. The long cervical muscles usually span several levels, some arising in the upper thoracic spine. The long posterior cervical muscles are attached in midline to the ligamentum nuchae and to the fascial planes radiating laterally from mid line.

The interactions of the various muscles of the neck with postures and movements has been found to be extremely complicated. Mathematical modeling (Helleur et al 1982) has often had to simplify the action of muscles. Interpretation of the results if over-simplification occurs may be difficult. The effect of posture and movements have been studied in relation to work situations using surface electromyographic activity (Harms-Ringdahl, 1986).

2.8 THE SPINAL CORD & SPINAL NERVES IN RELATION TO THE CERVICAL SPINE

Full descriptions of the spinal cord and spinal nerves in relation to the cervical spine are given in good anatomical texts (Breig, 1978; Vyke, 1979; Warwick & Williams, 1980; Bogduk, 1982). The subject area is varied and vast and only an outline can given in this text.

The soft mass of the spinal cord is probably the most important structure in the neck. It lies protected within the bony vertebral canal. The canal, in the cervical region is triangular in shape and is larger than other regions of the spine, to accommodate the enlarged spinal cord. The cord continues proximally up to the brain and distally is attached to the coccyx via the filum terminale. Despite being tethered, the cord, because of its structure, is capable of adapting its shape and length to movements of the spine. (Breig, 1978).

Eight pairs of cervical spinal nerve roots emerge from the cervical spine. Each leaves via the intervertebral foramen, and passes out towards the root of the neck and upper limb. The nerve roots lie in close proximity to the posterior lateral aspect of the disc and the zygapophyseal joints. They are susceptible to pressure from these structures. The nerve supply to specific tissues and zygapophyseal joints is given in great detail by Bogduk (1982) and Vyke (1979). Elvey (1985) has shown that in certain positions of the neck or upper limb, tension and movement occur in the lower cervical nerve roots at the intervertebral foramen level.

2.9 FUNCTIONAL SPINAL UNIT

To facilitate the descriptions of spinal anatomy, kinematics or biomechanics, the term 'motion segment', mobile segment or functional spinal unit (FSU) (White & Panjabi, 1978) has been adopted. Schmorl and Junghann (1971), used the phrase, 'motor segment' to describe the tissues and structures affected by movement at one spinal level. The FSU, consists of two adjacent vertebrae, the intervening disc and the soft tissues connecting them. Kinematics of the spine have used the system of the FSU in the analysis of motion and centres of rotation.

Movements of the cervical spine are considered in more detail in later specific chapters.

2.10 SURFACE ANATOMY

The bony landmarks of the neck are the spinous processes of C2, C7 and T1. These bony prominences are easily found on the dorsal mid line. The tips of the spines are bifid and may be large. The spinous processes of the other cervical vertebrae can be palpated in most people, but as they are smaller, they are more difficult to feel.

The zygapophyseal joints form the "articular pillar", which may be palpated 3 - 4 cm lateral to the dorsal midline of the spine. The transverse processes are then located just lateral and anterior to the articular pillar. A poor posture of the neck or a large amount of adipose tissue in the area will make the locating, palpation and imaging of structures more difficult.

The composition, position, function and integration of all the bony and soft tissue structures of the neck, demonstrate that the cervical spine is probably the most complex region of the spine.

CHAPTER 3. MOVEMENTS OF THE LOWER CERVICAL SPINE

3.1 REFERENCE SYSTEM

In 1970 an attempt was made to co-ordinate the use of referencing systems in biomedical engineering and biomechanical problems. It was agreed to adopt the "Right Hand Axis" System, (Task Force on Standardisation of Gait Analysis Parameters and Data Reduction Techniques, 1979).

For this system the co-ordinates are described as:-

Y - vertical and positive upwards.
X - parallel to the floor, in the direction of progress or anterior if there is no motion and positive in this direction.
Z - parallel to the floor and positive in the left to right directions.

This system is used at the Bioengineering Unit at the University of Strathclyde. White and Panjabi, who are major contributors in the field of spinal biomechanics, use the "Right Hand Axis" system, but have rotated the system through 90°. In their system, Z axis is in the direction of motion and X axis is at right angles to the Z axis. The three axes provide 6 degrees of freedom of movement (Fig 3.1) which Grieve (1981) has described in clinical terms as:-

1. compression - traction = movement along the Y axis
2. anterior - posterior glide = movement along the X axis
3. medial - lateral glide = movement along the Z axis
4. axial rotation = rotation about the Y axis
5. lateral flexion = rotation about the X axis
6. flexion - extension = rotation about the Z axis

The functional spinal unit (FSU) has the ability to rotate about an axis, to glide or translate along an axis or to use combinations of these two types of movement. The surrounding soft tissue and the shape of the articular facets will to a great extent, determine the resultant movement.

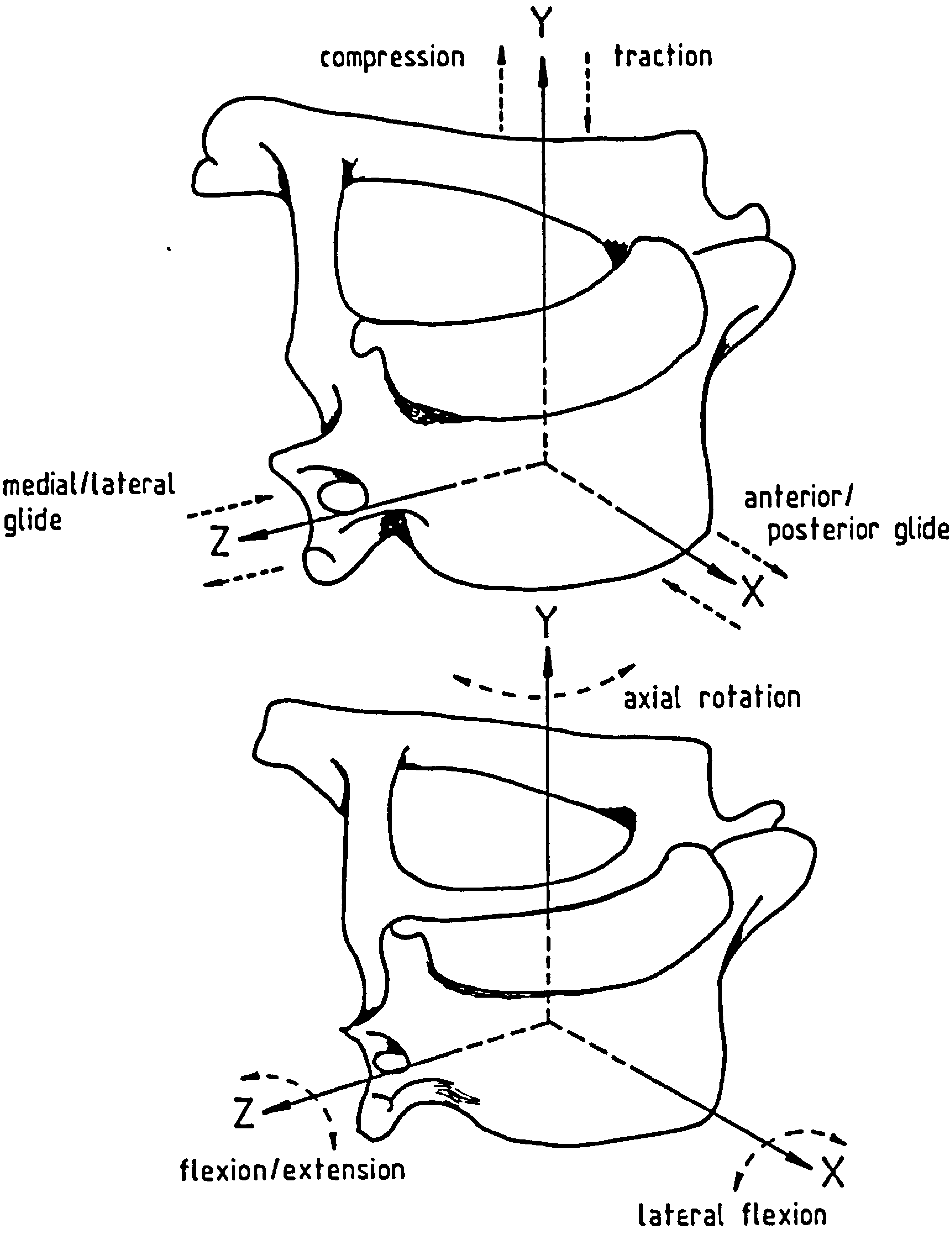


Fig. 3·1 The six degrees of freedom of movement for the cervical spine

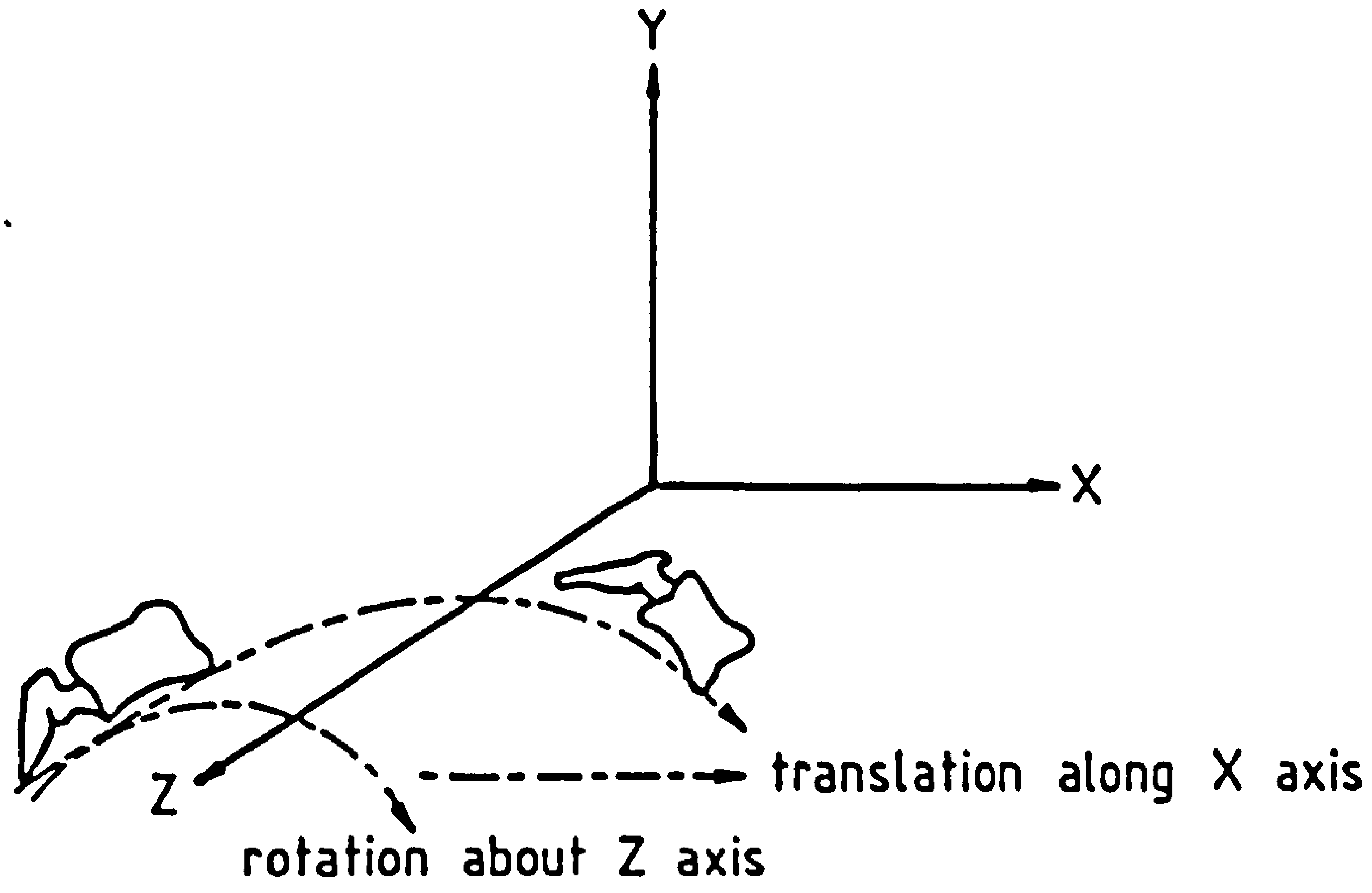


Fig. 3·2 In-plane movement

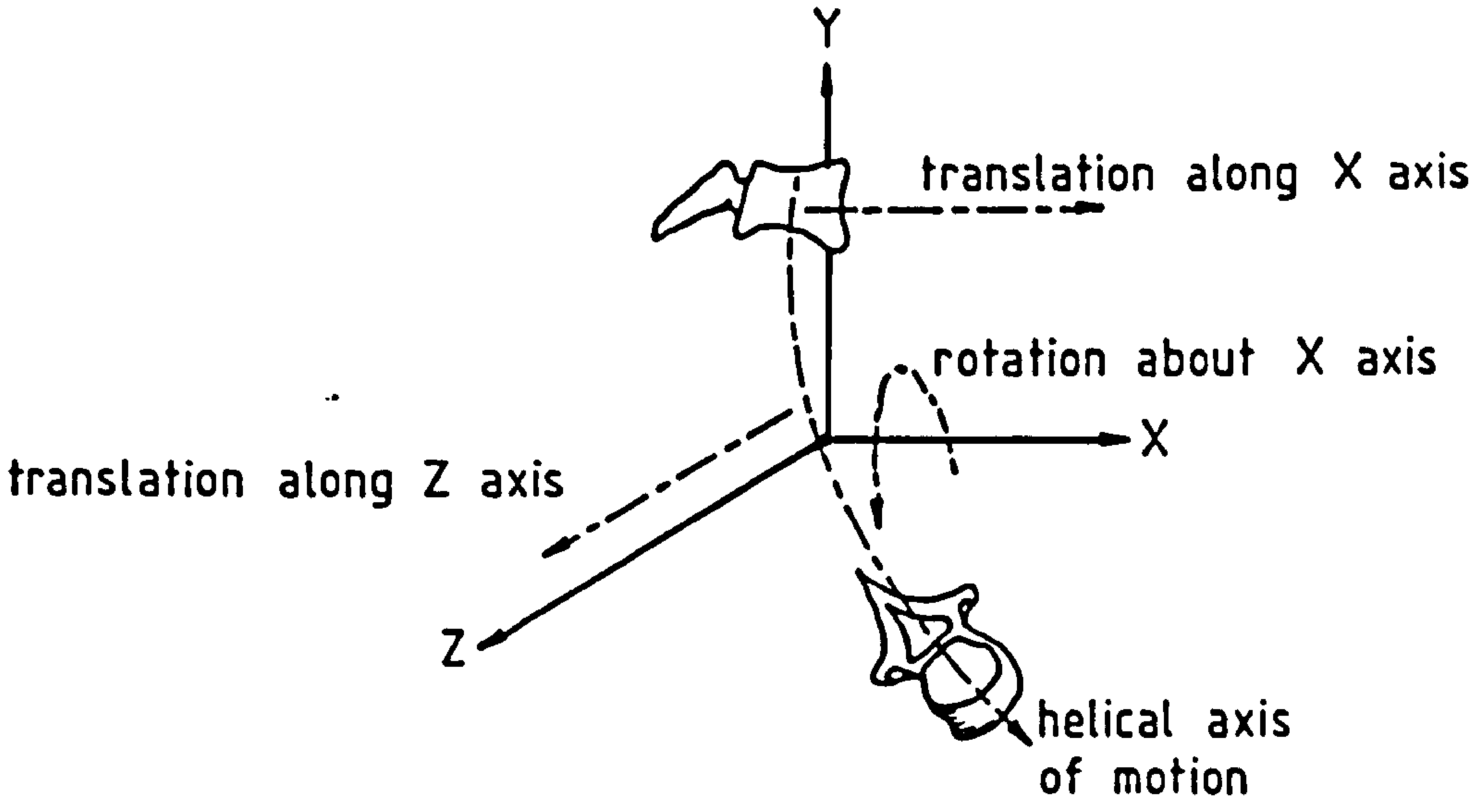


Fig. 3·3 Out-of-plane movement

3.2 MOVEMENT IN PLANES AND CENTRES OF ROTATION

3.2.1 Plane Motion

White and Panjabi (1978) define plane motion as movement in which all points in a rigid body, here, considering the vertebral body to be rigid, move parallel to a fixed plane. Movement may occur within the plane as a combination of rotation about and translation along a perpendicular axis. This combining of rotation and translation is extremely important for full functional motion at zygapophyseal and uncovertebral joints. A loss of one component can affect the type and range of movement left at the joint. Spinal flexion and extension are examples of this type of motion (Fig 3.2).

3.2.2 Out-of-Plane Movement

This describes the motion of a rigid body which does not stay within one plane. It is a complex motion which could, for example involve rotation occurring about two axes and translation along a perpendicular axis. Almost all functional movements of the spine are simple or complex out-of-plane movements (Fig 3.3).

3.2.3 Instantaneous Axis of Rotation

The centre of rotation is the axis about which rotation will occur. Due to the complex nature of the FSU, this centre of rotation will vary. When considering the motion of one vertebra to its adjacent vertebra, then the small movements that occur are said to be about the instantaneous axis of rotation (IAR) for that movement. Movements in other directions at the segment are said to occur about other, new IAR's. White and Panjabi (1978) describe the moving centres along the 'axis' as following a helical path. The IAR will change during movement, but the spinal segment's 3-dimentional position and motion can be described. The area described by the path of extremes of movement is called an 'envelope'. Three approximate positions for the IAR for flexion & extension, lateral flexion and rotation have been described.

The centre of rotation for flexion / extension and rotation is within the subadjacent vertebra (Fig 3.4), in the sagittal plane (Lysell, 1969). The centre of rotation for lateral flexion has not

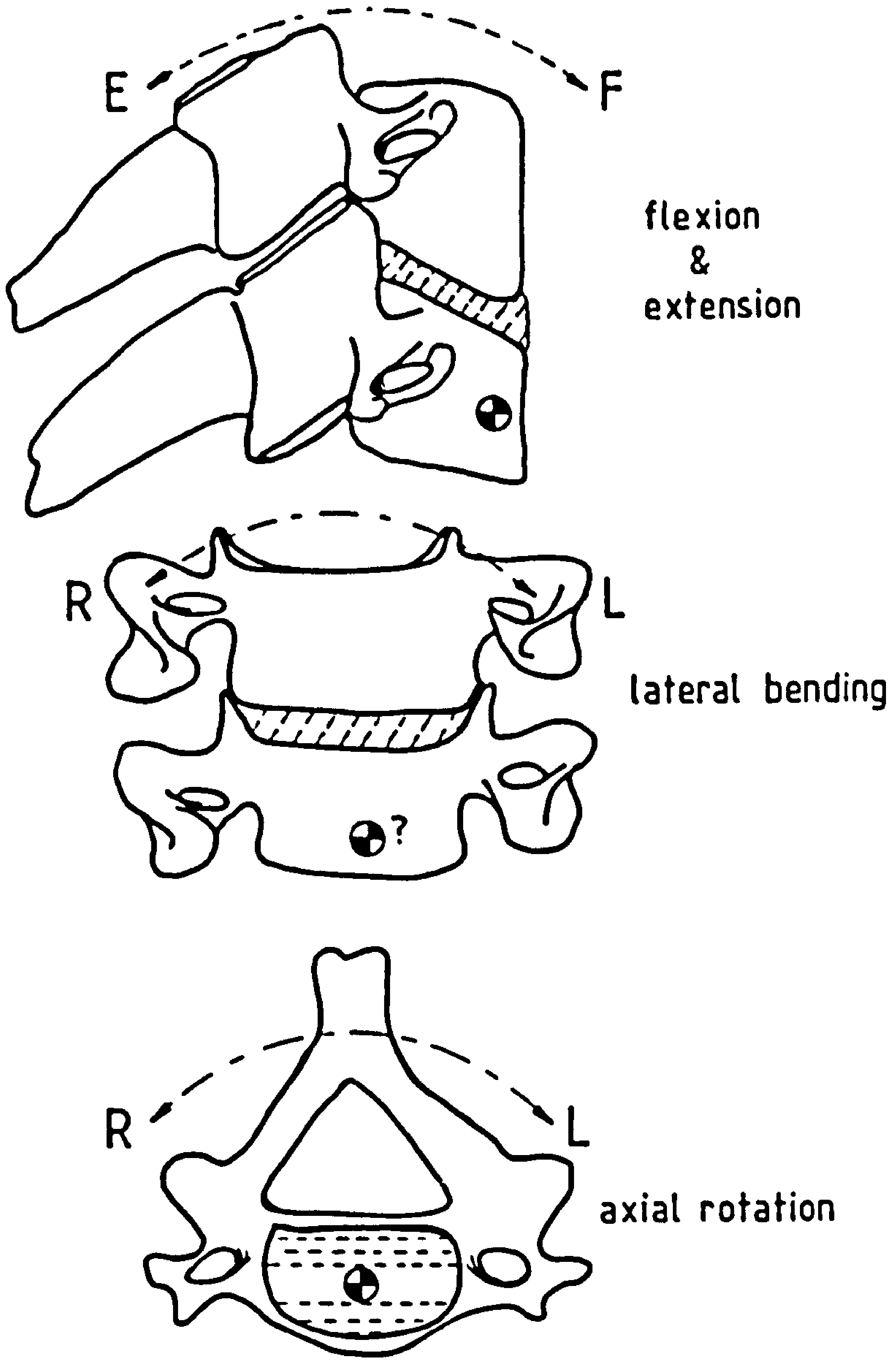


Fig. 3·4 Movement in 3 planes around the estimated instantaneous centre of rotation (⊕)

yet been definitely agreed upon. Lysell used Von Euler's principle to locate the centre of rotation for his spinal sections and quotes "If a rigid body moves in one plane the centre of motion can be determined as the intersection between the mean centre proportionals of two lines, connecting the respective positions of two random selected points in two phases of the motion". Lysell constructed lines from outlines of the vertebrae to the axis. The distance or radius would be an indication to the degree of rotation or translation which would occur. The angle constructed was called the 'T' angle.

3.3 NECK MOVEMENTS AND THE EFFECTS OF PATHOLOGY ON MOVEMENTS.

Movement will depend upon the soft tissues and joint geometry of an articulation, both of which can be affected by degenerative changes. Osteoarthrosis should refer to the degenerative changes which take place at the synovial joints and spondylosis that which takes place at the vertebral body joints and neurocentral joints. The disc itself is subject to degeneration and the whole spine may be affected by trauma.

There is no correlation between X-ray changes and the degree of functional loss. Hirsch, (1971), Bogduk, (1985) and Lysell (1969) found no correlation between articular and disc degeneration at specific levels. However, pathological changes at joints and in discs frequently produce restriction and pain causing the patient to seek help.

3.3.1 Neutral

There is difficulty in defining the neutral position for the neck. Penning (1968) referred to the ortho-optic position for the head, the lower margin of the orbit level with the external auditory meatus. American osteopaths often refer to the term 'easy normal' (Mitchell et al, 1979), with no tension to act as a pivot in the ligaments and capsules.

The cervical spine has a natural anterior curve, or lordosis, which increase from infancy as the child learns to raise the head. The lordosis may increase in adults as a response to poor posture or occupational strain. Maximum curvature is usually at the C3-4 level.

Lordosis will vary depending upon whether or not the chin is protracted or retracted. It can also be affected if there is muscle spasm, joint or vertebral subluxation which could happen for example as a result of an acceleration / deceleration injury. Pennecot et al, (1984,b) described ligament injuries in children, where immediate diagnosis was difficult but where pain and loss of lordosis were constant symptoms with no bony injuries present. Neutral for lateral flexion and rotation would be such that the body would point anteriorly with the horizontal and vertical axes of the vertebral body at right angles to one another and the sagittal plane.

3.3.2 Flexion

Flexion may be considered as a rotation in the sagittal plane about a horizontal medio-lateral axis. Clinically, flexion is the approximation of the head, or chin to the chest. Lysell (1969) noted a greater loss of flexion than extension in the neck and generally a loss of range with increasing age. In vivo, further flexion is achieved by compensating movements. There is more anterior glide of the lower cervical - upper thoracic vertebrae and extension of the upper cervical spine.

Flexion is guided by the position of the uncus on either side of the vertebral bodies. During flexion there is an upward and forward glide of the inferior facet of one vertebra on the superior facet of the vertebra below. The amount of glide is dependent on the obliquity of the facet joints which in the cervical spine is approximately 45°. Glide may be between 3.5mm and 6mm. White and Panjabi feel that 3.5mm is the upper limit of normal. There may also be some anterior glide or joint compression during flexion. Facet joint asymmetry may cause a rotational effect. The vertebral body tilts forward and there is some shearing of the disc, which becomes more wedge shaped with the anterior compression.

Any degenerative changes within the disc causing loss of height or integrity because of clefting, is bound to affect the range of motion available at that level. The interspinous ligament, ligamentum nuchae, posterior disc, posterior longitudinal ligament and facet capsules, will assist in limiting flexion

3.3.3 Extension

Extension is the reverse of flexion, the movement again being guided by the uncus. The superior vertebra will slide or tilt caudally on the inferior vertebra. Extension is limited by apposition of the articular facets, the capsule and the capsular ligament and the the anterior disc and anterior longitudinal ligament.

After trauma any ligamentous or bony damage, causing instability or subluxation may be demonstrated on X-ray (Penning, 1968). Mechanical and clinical instability are different. Mechanical instability implies that a toppling or buckling of the spine would occur if loads were excessive. Clinically, the term refers to excessive motion within the mobile segment, usually the glide motion. The degree of instability relates to the amount of excess motion found, which has ,in the lumbar spine been graded (Newman, 1974).

Attempts have been made to show which ligaments are responsible for the stability of the mobile segment, by serial sectioning of ligaments (White et al, 1975). The rational of this method may be queried, because by sectioning a ligament, altered stress is placed on other ligaments in the system which may not resemble the in vivo situation.

White and Panjabi (1978) give the greatest range of flexion - extension in the neck at the C5-C6 level as a representative angle of 17° (Table 3.1).

3.3.4 Lateral Flexion

This movement occurs simultaneously with some rotation. The spinous process may be felt to move in the opposite direction to the lateral flexion, the body, will move in the direction of lateral flexion. The inferior facet of the superior vertebra will move as a glide, downwards and medially, as a result of the facet shape and angulation (Fig 3.5 & 3.6). Work by Schneider and Pardoe (1985) demonstrated that the translation or glide movement was also a result of the location of the centre of rotation being in the anterior part of the vertebral body.

Lateral flexion is a movement which is dependent upon the integrity of joints and soft tissue of the functional spinal unit.

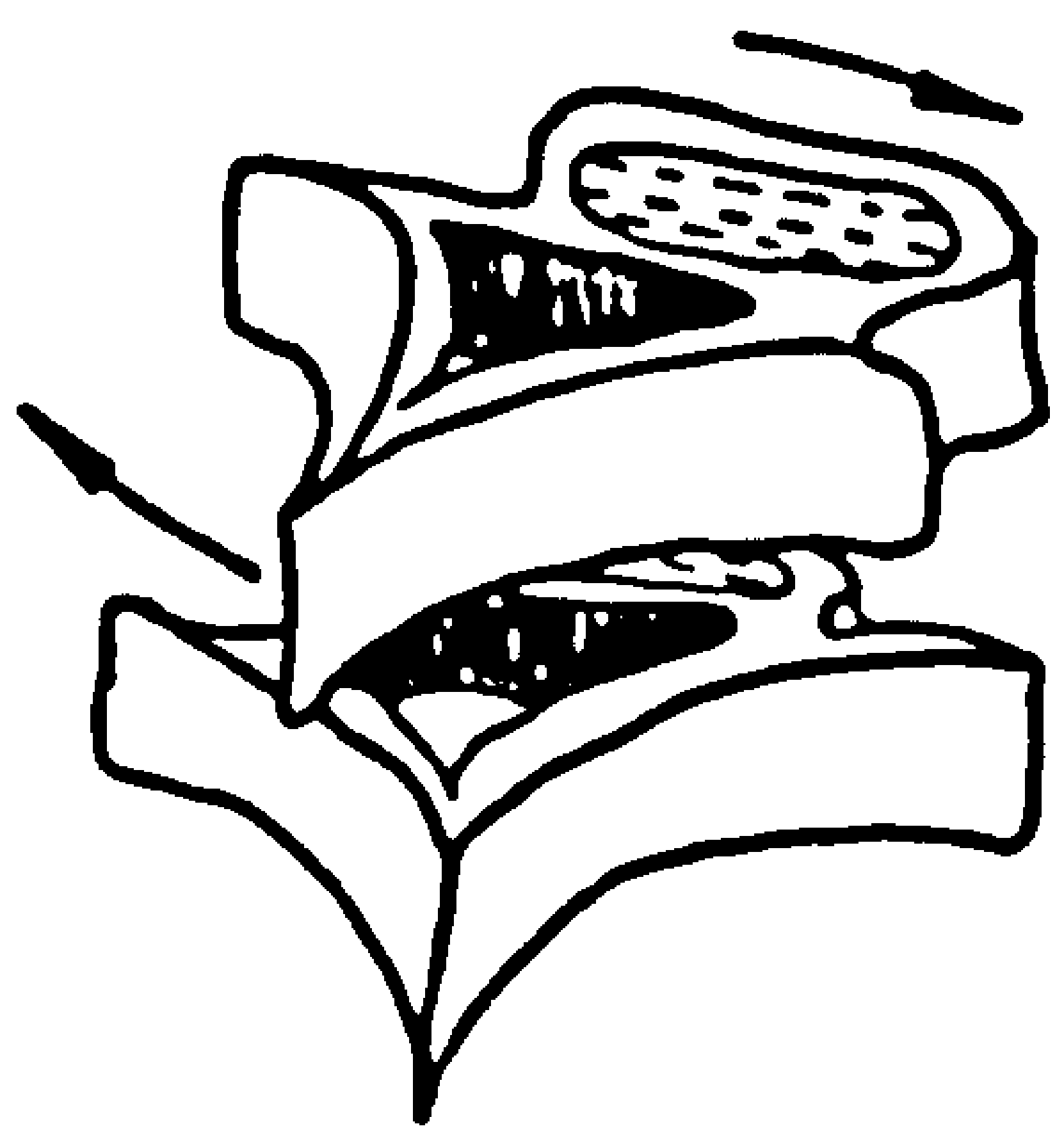


Fig. 3·5 Direction of the spinous process and vertebral body during lateral flexion or rotation to the right.

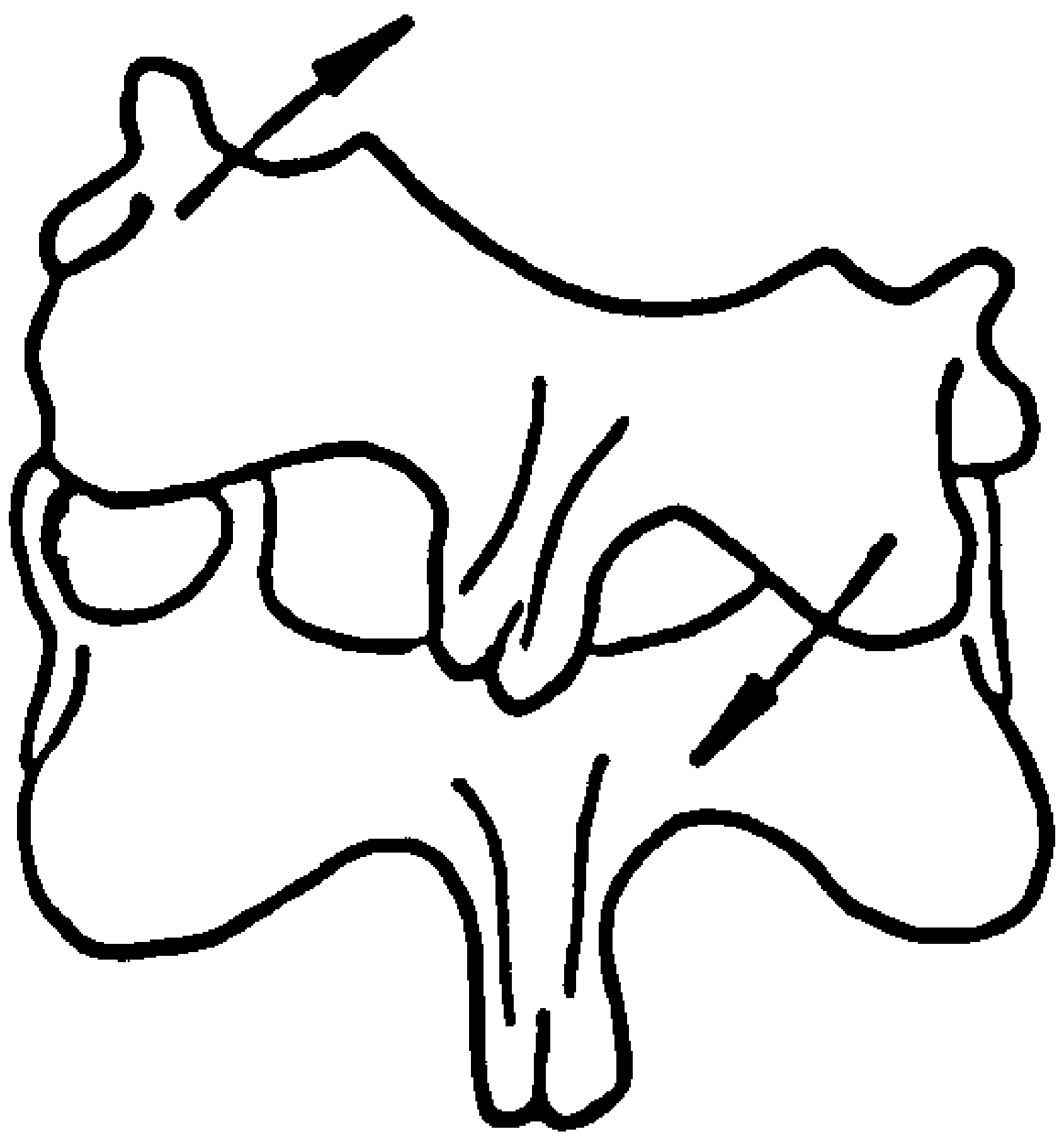


Fig. 3·6 Movement of the articular facets during lateral flexion or rotation to the right.

The posterior facet joints are synovial joints and are therefore subject to degenerative processes. The synovium can become thickened and small joint inclusions have been found in these joints (Töndury, 1971a, Mercer, 1985), they are not meniscii. The articular cartilage,whose function is to assist withstanding loads and facilitate joint lubrication is also very susceptable to degeneration (Grieve, 1981).

Disc degeneration occurs frequently in the neck and Lysell showed changes in the uncal area in the disc of a 14 year old cadaver. Most authors agree that the level to show most degeneration for discs is the C5-C6 level (Payne & Spillane, 1957; Hirsch et al 1967). The cervical spine also demonstrates characteristic clefting which may or may not be a response to wear and tear, as it can be found in the young (Bowden, 1971). The stability of motion segments has not been linked to the severity of these clefts, however some clefts can bisect the disc. Lateral flexion combines with rotation, causing a 'screw' motion. If there is loss of height from the discs, then both physiological and accessory movements would be affected. This in turn increases the load bearing of the posterior joints.

In the lower cervical spine the segmental range of lateral flexion is small. However, if it is missing, then rotation too is affected. There is usually less movement in the lower levels of the neck.

C2 has 2° rotation for each 3° of lateral flexion.
C7 has 1° rotation for each 7.5° of lateral flexion.
(Jofe et al, 1983).

3.3.5 Rotation

Rotation can only occur with some lateral flexion. Penning and Wilmink (1987) used computed tomography (CT) for the analysis of rotation in the lower cervical spine. They found that rotation and lateral flexion are greatly dependent upon the presence of the uncovertebral joints.

The amount of rotation will vary upon the spinal level and starting position for the movement. If the joints are already in a position where they are under some compression or stress, then the articular surfaces will not have the natural excursion for the joint and the soft tissues will come under tension far sooner to restrict motion. Therefore neck position is important when clinically examining the cervical spine for movement. The C3-C4 and C4-C5 levels have the greatest range for rotation.

3.4 SUMMARY OF MOVEMENTS

sagittal movements:-	flexion	40°
	extension	24°
	C2 the least movement,C3 and C7 the most.	
frontal movements:-	lateral flexion	49°
	combined rotation	28°
	no difference between left and right rotation.	
horizontal movements:-	rotation	45°
	combined lateral flexion	24°
	C7 the least,C4 the largest range of motion.	

Movements have been described with reference to the 'right-handed axes' system. The terms, plane motion, out-of-plane motion and instantaneous axis of rotation have been defined. The usual physiological movements performed at clinical examination are described along with some of the common pathological changes which can affect the cervical spine structures.

	FLEXION/EXTENSION		LATERAL FLEXION		AXIAL ROTATION	
LEVEL	range(°)	rep. angle(°)	range(°)	rep. angle(°)	range(°)	rep. angle(°)
C2-3	5-23	8	11-20	10	6-28	9
C3-4	7-38	13	9-15	11	10-28	11
C4-5	8-39	12	0-16	11	10-26	12
C5-6	4-34	17	0-16	8	8-34	10
C6-7	1-29	16	0-17	7	6-15	9
C7-T1	4-17	9	0-17	4	5-13	8

Table. 3.1.

Limits and representative values of movements of the lower cervical spine, [White,A.A., Panjabi,M.M: The Basic Kinematics of the Human Spine. SPINE., 3:12, 1978].

CHAPTER 4 CLINICAL ASSESSMENT OF THE LOWER CERVICAL SPINE

4.1 INTRODUCTION

The examination of a patient presenting with a spinal musculo-skeletal problem, will at some point require the assessment of spinal joint motion. Each medical and para medical profession has their own approach to the examination of a patient and each would elicit the necessary information upon which to base their treatment.

There are common elements in almost all examination procedures, which may be described under the following headings.

Subjective history.
Objective clinical examination.
Standard view X-ray films.
Specialised investigations.

All of the above would lead to the formation of a possible
Diagnosis,

followed by an appropriate
Treatment.

For efficient and effective patient care, good examination technique is vital. The lack of scientific inquiry into the treatment of patients with musculo-skeletal problems has been acknowledged (Bogduk, 1985; B.M.A.,1986). Bogduk (1985) indicated one possible reason for the problem, -- "because patients with neck pain do not die of their disease, traditional post mortem studies have not been possible."

The requirement to validate treatments, be cost-responsible and cost-effective, is now, more than ever before, part of the health care philosophy. It is therefore vital that basic research on cervical spine musculo-skeletal problems and their treatment is carried out.

This chapter concentrates particularly upon those sections of the examination procedure which relate specifically to musculo-skeletal structures of the neck, whilst realising that neurological, or vascular tissue can also be involved.

4.2 HISTORY

A subjective history i.e. information elicited from the patient or other sources, would form the basis of the whole examination. Questions usually follow a set pattern, thereby making a sequential picture of events (Maitland, 1986). The patients' presenting problem, be it weakness, pain, loss of movement, would be discussed. The area and behaviour of the signs and symptoms are then defined. Other questions releating to the current status of the problem, general health, levels of medication, X-rays or other tests, other treatment etc are all recorded. The history of the present condition and past related episodes are also recorded as well as any other relevant medical and social history. Information gathered in this section will determine what objective examination procedures will be required.

4.3 OBJECTIVE CLINICAL EXAMINATION

4.3.1 Observation.

Visual inspection of the cervical spine would determine the presence of swelling, bruising, deformity, neck and thoracic posture and movement of the neck. The measuring of cervical spine motion presents a unique problem to the investigator. Motion in the spine may be considered as either gross spinal motion or as intersegmental motion occuring at the mobile segment or functional spinal unit. The method of investigation would depend upon the requirements of the investigator. Lysell (1969) and Tucci et al, (1986) review methods of measuring spinal motion. Visual inspection, probably the most common method described by the American Association of Orthopaedic Surgeons (1965).

Visual inspection of movement is very subjective and the range of motion recorded will depend to a great extent upon the starting position of the joints and the experience of the examiner.

4.3.2 Goniometry

The underlying problem of having no standard method of measuring gross spinal motion was emphasised by Vorth (1985) in his

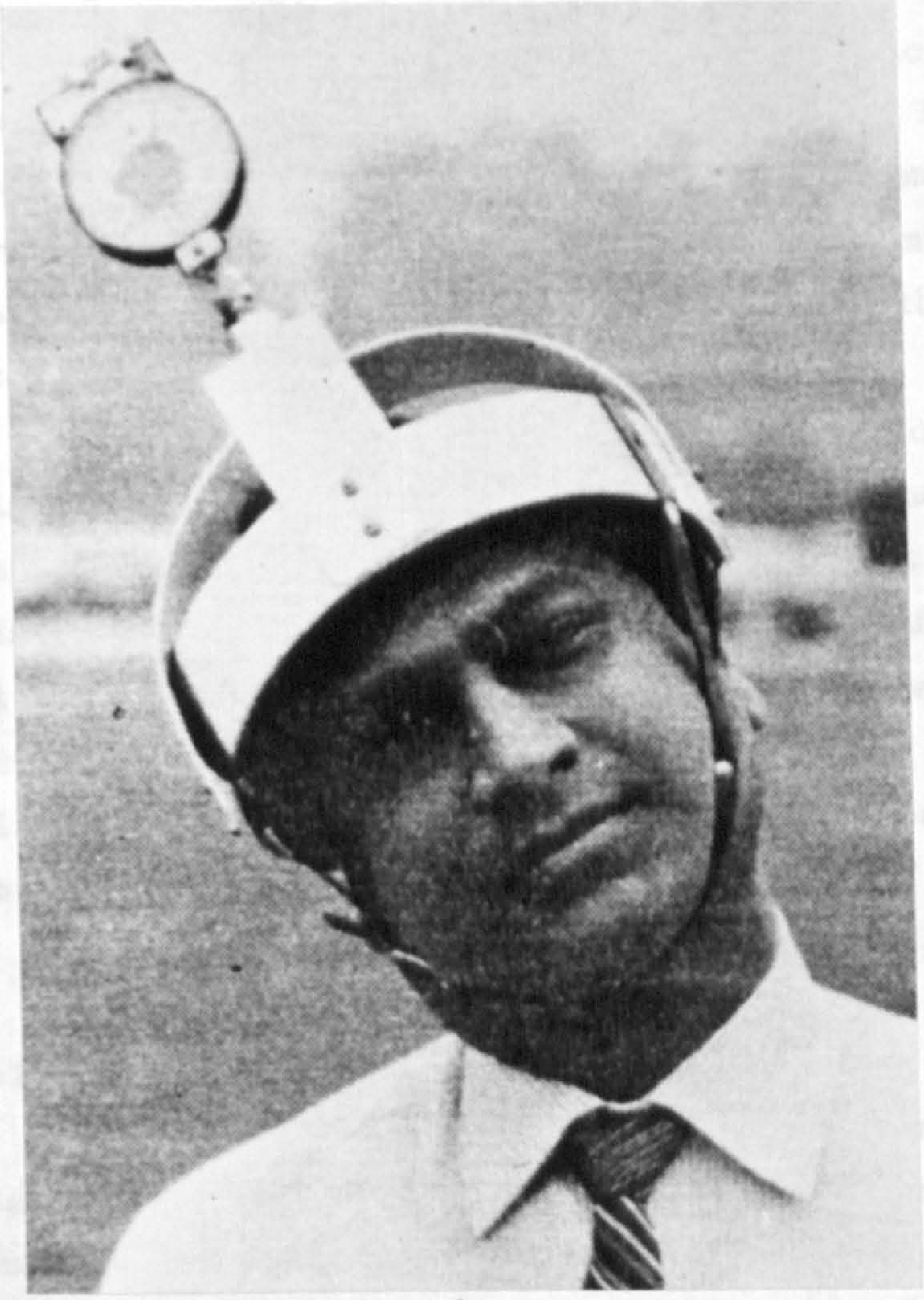


Fig. 4.1 Cervical goniometer

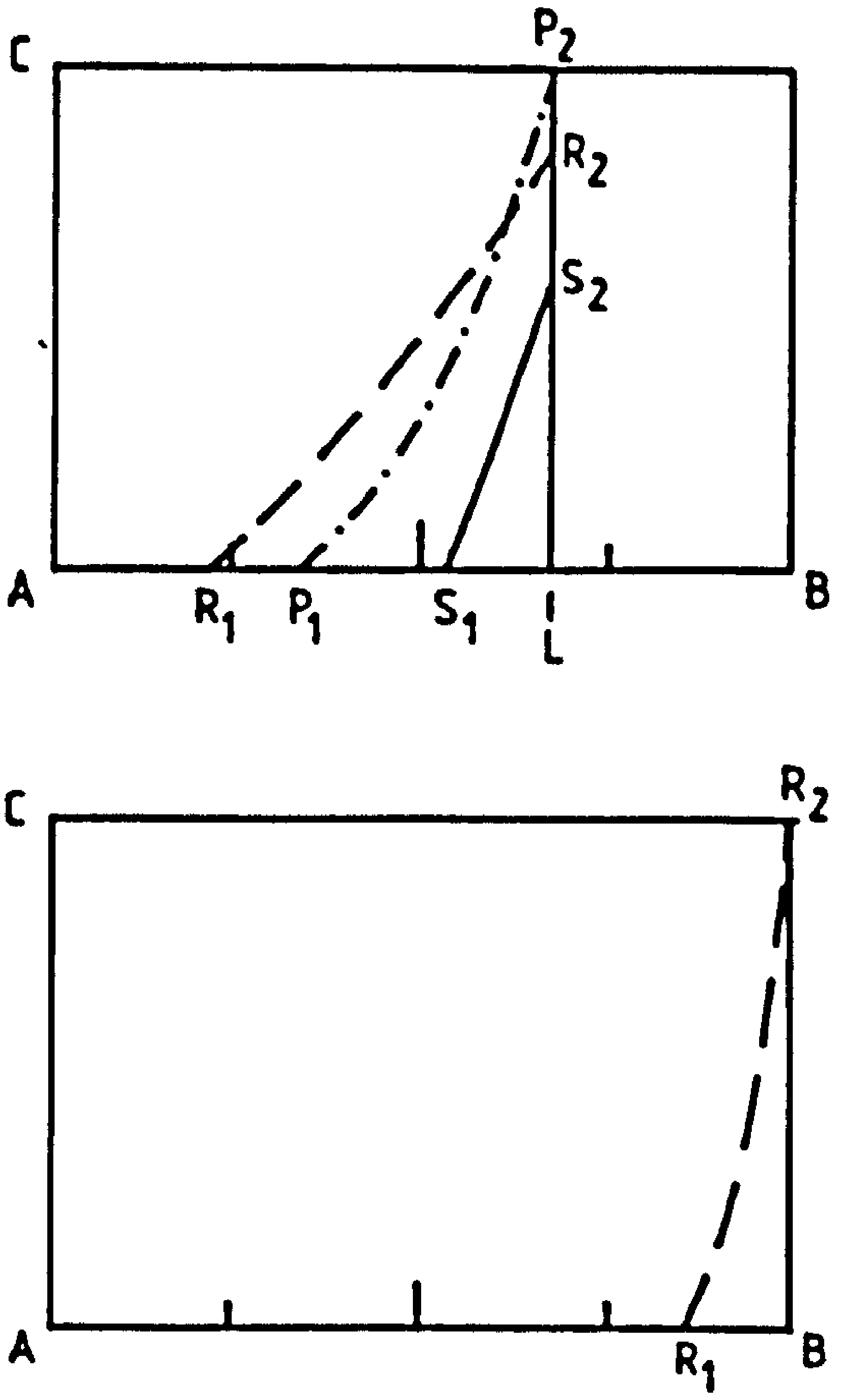
comparitive study of patients post "whiplash" and patients with "normal" necks. Vorth used a 3-D spirit goniometer to detect changes in postition away from midline.

Using a similar goniometer, O'Driscoll and Tomsen (1982) and Tucci et al, (1986) measured gross spinal motion in all directions by repositioning the goniometer on the head as required. Both sets of authors felt that the apparatus was useful as it was cheap, easy to apply and easy to use. They found that accuracy using the equipment was acceptable between the experienced staff. Low (1976) found good intra-observer reliability when studying the goniometric measuring of peripheral joints, however he did note that almost all observers had the tendancy to round-off measurements to the nearest 5°,(15°,20° etc.) which would be a source of error.

Head halter fixation of the goniometer could be difficult as movement between the goniometer and the head might affect the results of the movement measured. Placement of the goniometer is also important as that too will affect the results (Fig 4.1). Rankin et al, (1983) had developed an electro-goniometer to record spatial head and neck postitions and neck motion. Their apparatus also allowed the determining of the prefered position into which a patient would move.

4.3.3 Manual Examination of the Cervical Spine

There is no definitive manual examination procedure. It will vary according to the professional bias and experience of the examiner. However, within the last few decades, there has more agreement between disciplines than ever before, regarding the manual examination of the spine. Orthopaedic medicine specialists and manual therapists (Cyriax, 1975; Stoddard, 1977; Maitland, 1986) have refined the examination processes. However the interpretation of findings is still an area of contention. The principal method of examination would be by the palpation of the soft tissues and the superficial bony landmarks. Palpation would allow clinical judgements to be made as to the alingment of the spine, abnormal tension in muscles and resistance to movement of the zygapophyseal joints. Percussion of the spinous processes is another manual



(a) Severe joint

AC : intensity

AB : normal passive (movement) range

AL : limited passive range

(b) Normal joint

Fig. 4·2 Intensity of pain (P), resistance (R) and spasm (S) with movement.

technique which may be used when examining the spine. Excessive tenderness or pain at the site of percussion might indicate infection or serious pathology in the vertebra or spinal segment.

The manual examination of the spine would include the use of active movements through physiological range, passive movement through physiological range and the testing of accessory movements of the zygapophyseal joints. The accessory movements of the vertebrae when subjected to a centrally applied pressure would also be tested. Accessory movements of the vertebrae are produced and tested by applying small rhythmical alternating pressure in a vertical or angulated manner (Maitland, 1986).

Joints are normally tested in or from the neutral position, when the soft tissue of the functional spinal unit is not in tension. The neutral position of the neck, from which range of motion is estimated is difficult to define. Neutral will vary depending upon whether or not the whole cervical spine is to be considered or if it is the segmental level of motion that is of interest. Because of the cervical lordosis, the neutral position of the segmental levels will vary.

The range of passive available motion, the relationship of resistance to movement to the presence of pain or muscle spasm, can all be noted in diagramatic form. These "movement diagrams" are useful recording and teaching tools (Fig 4.2).

In an attempt to ascertain the accuracy of manual examination techniques, Jull and Bogduk (1985) compared standard palpation techniques, to anaesthetic nerve blocks for the locating of levels of 'symptomatic' dysfunction in the neck. Their results demonstrated that manual testing techniques, performed by an experienced clinician, were as sensitve as the use of nerve blocking techniques.

There is considerable controversy about the validity and reliability of commonly used manual techniques. The problems of attempting to measure spinal motion are fraught with difficulties. The rigour that Matyas & Bach (1986) applied in their critisism of some commonly used techniques could be seen as being overly critical in the light of the problems for all clinical manual techniques. Their critisim should be balanced by the defence made by Stoelwinder et al, (1986) and the work of Jull and Bogduk (1985).

4.4 X-RAY EXAMINATION OF THE NECK

Patients who are referred to Orthopaedic clinics because of musculo-skeletal problems with their cervical spine, may have x-rays of the neck taken to assist the diagnostic process. However it is well understood that there may be discrepances between X-ray evidence and clinical findings (Matthews,1979; Prantl, 1985; Gore et al, 1987). Degenerative changes are common, yet may be asymptomatic, while some pathologies e.g. osteoporosis, may be well established before there is radiological evidence of the disease or process being present..

Common abnormalities seen on cervical X-rays are the degenerative changes at the level of the discs and the sclerotic and osteophytic changes at the zygapophseal joints and uncovertebral joints. Soft tissue are not usually well defined on X-ray unless there are other inclusions, for example a haematoma, or areas of calcification, which would be demonstrated as opacities on the film.

There are standard views of the cervical spine which are taken for routine investigations and there are specialised views which allow inspection of specific structures e.g. the oblique view for the intervertebral foramen.

4.4.1 Lateral View

The lateral view allows good visualisation of the cervical spine (Fig 4.3). The size and shape of the disc spaces can be noted, as well as the condition of the vertebral bodies and canals. From this view it is possible to detect if there is subluxation of the zygapophyseal joints. The outline of the vertebral bodies, when viewed from the side form smooth longitudinal curves. If there is any degree of anterior of posterior subluxation of one vertebra on another the disruption of the smooth curve would be visable on X-ray. Ideally, good X-rays should allow imaging from the upper cervical spine down to at least C7, so care is required in the positioning of the patient. The lowest levels (C7 - T1) are often difficult to image as the clavicle and ribs can obscure the cervical spine and special views are required to visualise the area.

Fig.4.3 Cervical Spine, lateral x-ray

Fig.4.4 Oblique view, Cervical Spine

4.4.2 Anterior - Posterior View

This view offers the images of the uncovertebral joints and the lateral masses of the articular pillar which are superimposed on the pedicles. Any lateral flexion or translation of the vertebrae would be noted in this view.

4.4.3 Oblique View

This view of the cervical spine is not routinely taken. The view (Fig 4.4) is used to image clearly the intervertebral foramen. If bony encroachment into the canal was suspected then this view would be taken.

4.5 MYELOGRAPHY, COMPUTED TOMOGRAPHY AND MAGNETIC RESONANCE IMAGING

These are three very powerful, widely known imaging techniques used for conditions affecting the spinal musculo-skeletal system. An outline of each is given.

Each technique would have its own drawbacks either of cost, which may be considerable, ionising radiation especially if several sets of images have to be taken, or if they are invasive. There are other scanning procedures available for the example isotope scanning, but these are outwith the scope of this work.

4.5.1 Myelography

Of the three techniques myelography is probably the most widely uesd. Contrast scanning of the meningeal spaces and ventricles has been on going for the last 60 years (Perovitch, 1981 a). With the discovery and use of improved contrast media (the water soluble chemicals) and the improved scanning techniques, better images are obtained at a reduced risk to the patient.

The risks include the damage to the meninges from the injection of medium under excessive pressure, the risk of headache if the patient raises the head from supine to soon after injection, anaphalactic shock, or the risk of adhesions forming about the injection site. With any invasive technique there would always be

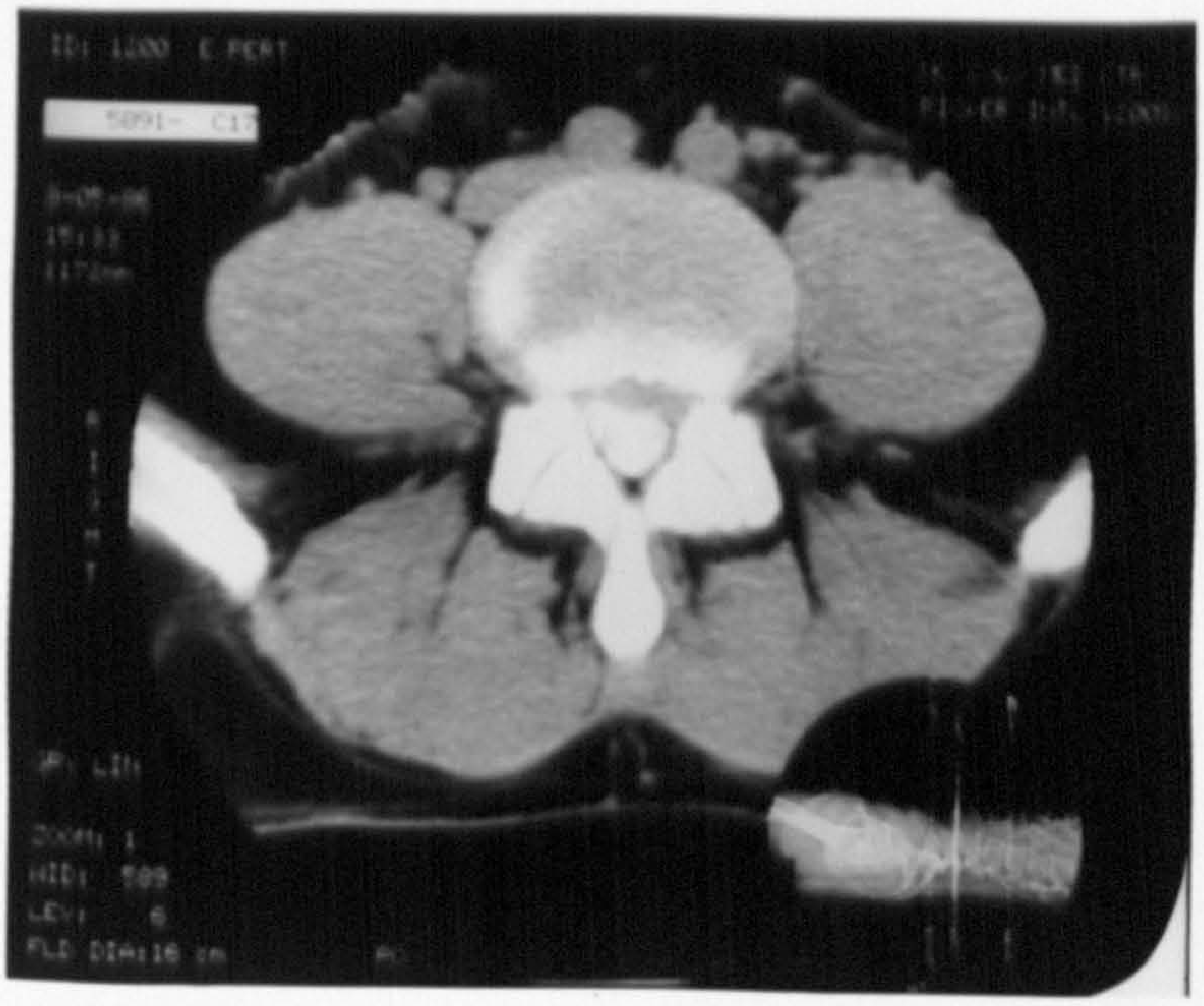


Fig 4.5a C.T Scan Lumbar spine

Fig,4.5a MRI Scan Lumbar spine

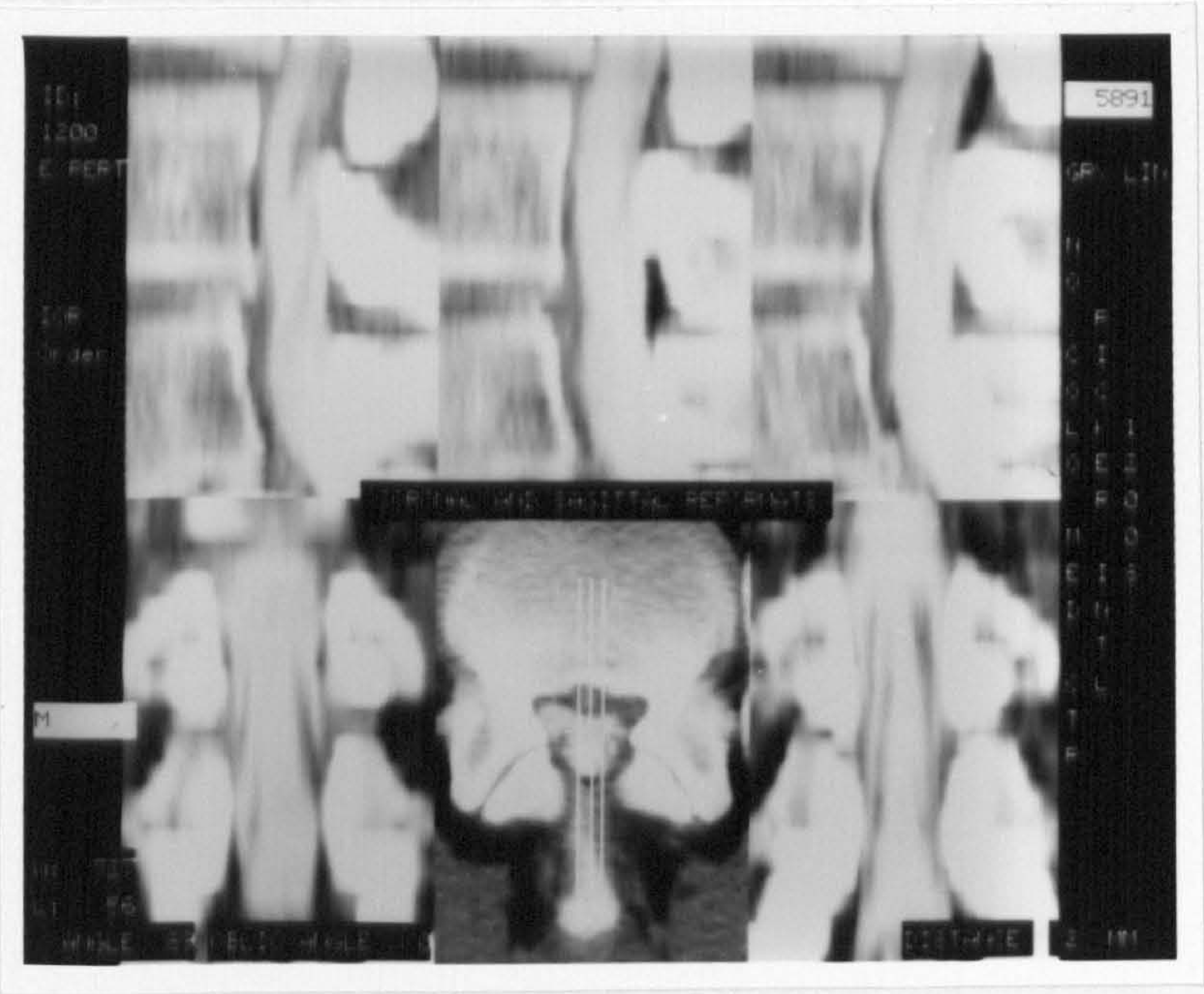


Fig.4.5b C.T. Scan of Lumbar Spine in sagittal section

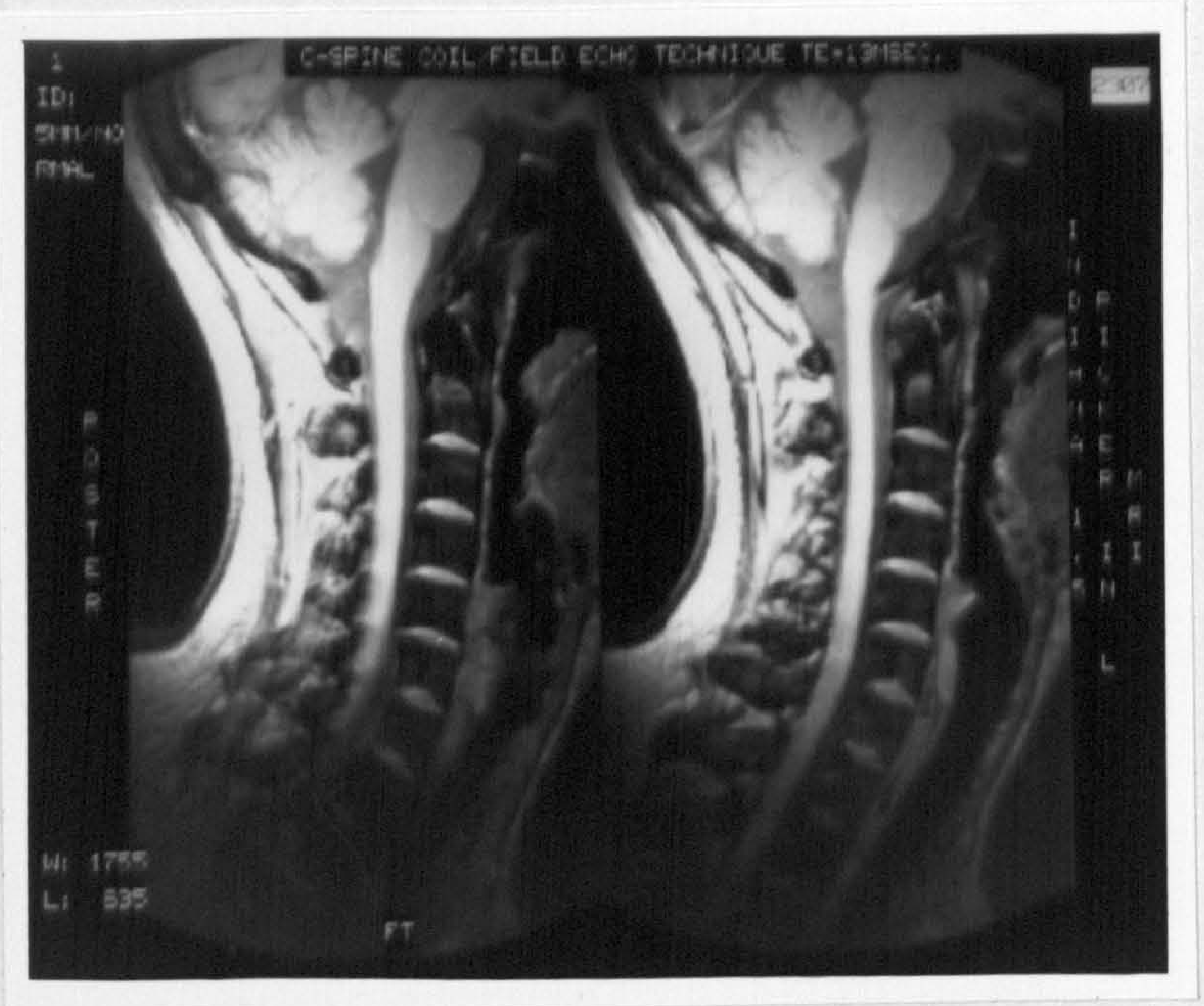


Fig.4.6b M.R.I. Scan of Cervical Vertebra (Picker Intn.)

the risk of infection being introduced at the site of the injection. In the case of myelography the consequences of infection being introduced into the vertebral canal would be severe, so all steps possible would be taken to reduce the risks.

The contrast medium once into the subarachniod space, is able to infiltrate the whole area of the space and the nerve root sheaths. Any constriction or blockage to the flow of the contrast medium would be visible as such on the X-ray film of the scan. Grubb et al (1987) when comparing the diagnostic sensitivity of myelograms and X-rays with discography, implied that discography was the more sensitive technique in the screening of patients with low back pain. Their work questions the frequent use of myelography and the problems of obtaining good results if the reliability of the technique is in doubt. Myelography using gas in the meningeal space can also be used. Perovitch (1981 b) has implied that the choice of technique would depend upon the equipment available, the experience and the preference of the investigator

4.5.2 Computed Tomography

Computerised tomography uses the principles of a basic X-ray source, the X-ray beam and receiver. Tomography was first introduced in the 1920's (Mackay, 1984), but since the advent of high performance computers and advanced data handling techniques, tomography has been succeeded by computed or computerised tomography (CT) has been very useful in medicine.

New third and fourth generation scanners have been developed to allow faster and safer scanning of the body. There are various types of scanners. The basic principle is that a section of the body is scanned by multiple "X-rays" as the X-ray source and receiver are rotated around the body segment. The multiple images then require complicated analysis to reconstruct the many angled images into a series of specific views of the body segment of interest (Fig 4.5). Virapongse et al (1986) demonstrated the possiblitity of further improvements in the production of images from 2-Dimensional systems such as CT. Their work demonstrates the 3-D reconstruction of 2-D images. Computed tomography also used grey scale for imaging tissue, the levels of grey reflect the different degrees of attenuation of X-rays through the tissue and hence the density of the tissue (Wegner,1983).

4.5.3 Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI), or as it was previously termed nuclear magnetic resonance imaging, is one of the few scanning techniques which is more effective scanning soft tissue than bony structures (Fig 4.6). The visual effects which are achieved on the scans are the result of the stimulation of the nuclei of some atoms in the body by a very strong magnetic field surrounding the body. The effect of this strong magnetic field will cause the lining up of protons of the nucleus. MRI detects easily tissue with a high water or fat content so tissues in the cervical spine are imaged clearly. The scans of some machines may be colour coded as a function of density but the majority of scanners are at present only the monochrome black and white models.

M^{c}Afee et al,(1986) have compared he use of MRI to CT scans in the upper cervical spine. They suggest that MRI, at the frequencies and intensities recommended should be safe and that producing superior images to CT scans they should be used more frequently.

MRI scans are still not as rapid as the CT scanners. The newer CT scanners have to some extent improved and can now scan a complete body in 1 - 4 s or just 3 - 8 s for the fourth generation scanners. The slightly longer times require the patient to remain very still to avoid movement artifact.

All of these methods require the use of sophisticated and very expensive equipment and computer image enhancing. They also require trained personnel with the expertise in producing the images and their interpretation. Yet another considerable drawback is that all the images have to be achieved with the patient lying still. Movement would cause poor image quality.

4.6 ANALYSIS OF MOTION USING X-RAY FILMS

The comparison of X-Ray films of the cervical spine in various

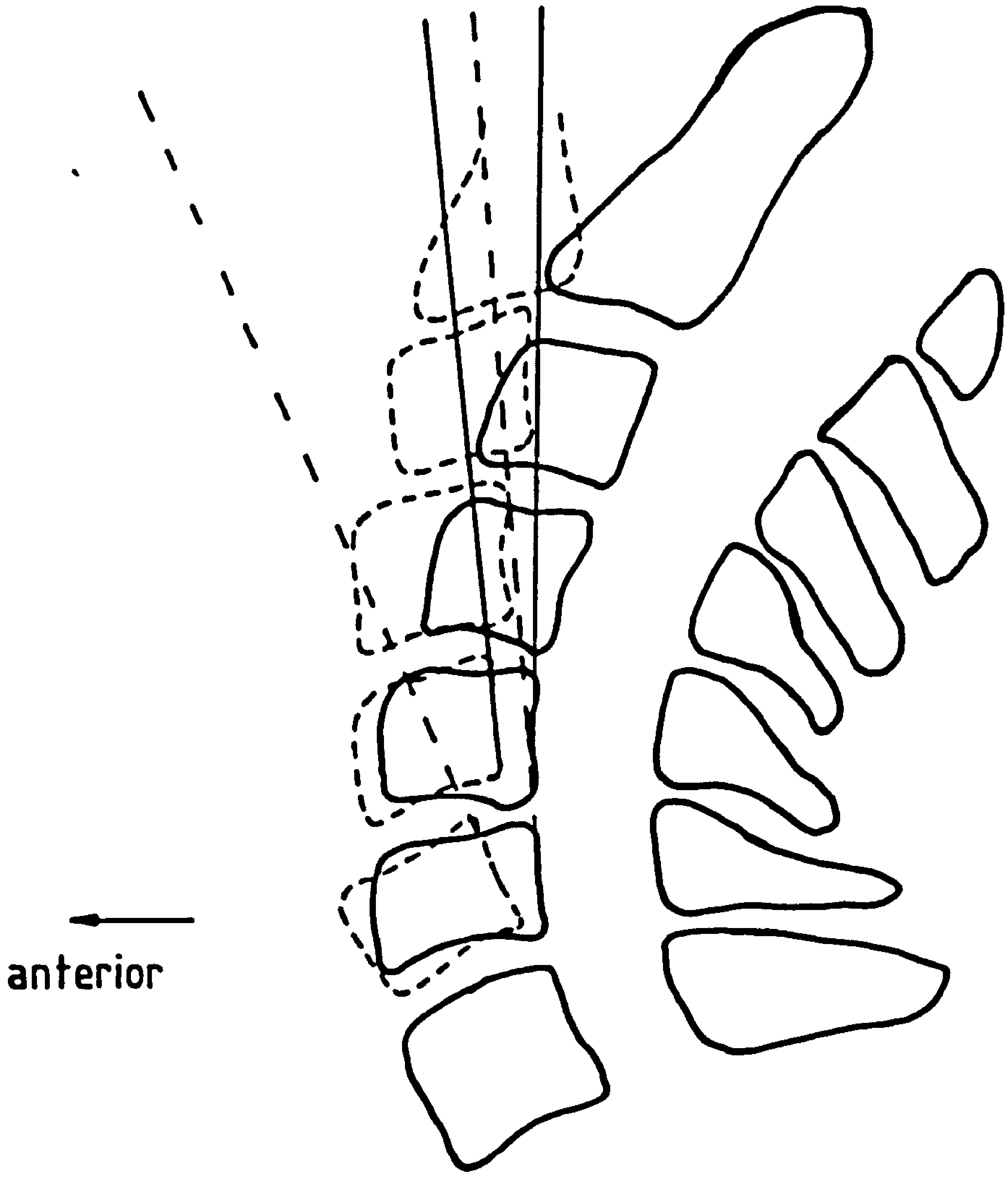


Fig. 4·7 Overlay method to compare flexion/extension X-Ray :- lateral views positions has been used for a long time. Bhalla and Simmons (1969) used the plain film overlay method in their work measuring segmental motion in the cervical spine. Penning (1978) implied that it was the best method to determine the degree of mobility between vertebrae (Fig 4.7).

The method requires a system of overlaid film images. These could be either plane films taken in flexion and extension as standard films (Penning, 1983), or from frames of cine film (Fielding, 1964).

There is however no standard method of measuring relative motion from X-ray films. Most authors use methods based on that described by Penning (1978), where a vertebra is selected as the fixed point e.g. C7 and the images of C7 from both films are superimposed. Angles are constructed by tangents to various vertebral surfaces to demonstrate segmental motion (Fig, 4.7). A comparison of similar X-ray measuring methods was made by Prantl (1985). Dimnet et al (1982) used serial lateral X-rays to measure centres of rotation of movement and to observe "patterns of curvature" of the spine during movement. Their method was found to detect 'functional abnormalities' in patients presenting with cervical pain but normal X-rays. They did not define 'functional abnormalities' and they acknowledged the problems they encountered with data collection and handling.

Comparing results from serial X-rays of cadaver specimen cervical spines, was also used by Ball and Meijers (1964). They used pins inserted in the vertebrae as markers to measure motion of the cervical spine against a measuring scale.

4.7 3-D ANALYSIS OF MOTION FROM X-RAY FILMS

The introduction of techniques looking at the 3-dimensional position of vertebrae in space, results from the need to know what is happening to the vertebrae at the segmental level and the recognition that movement is in three dimension and not as seen on an X-ray film. The movement which occurs at the local level is to a great extent dependent upon the state of the soft tissues and the geometry of the joint.

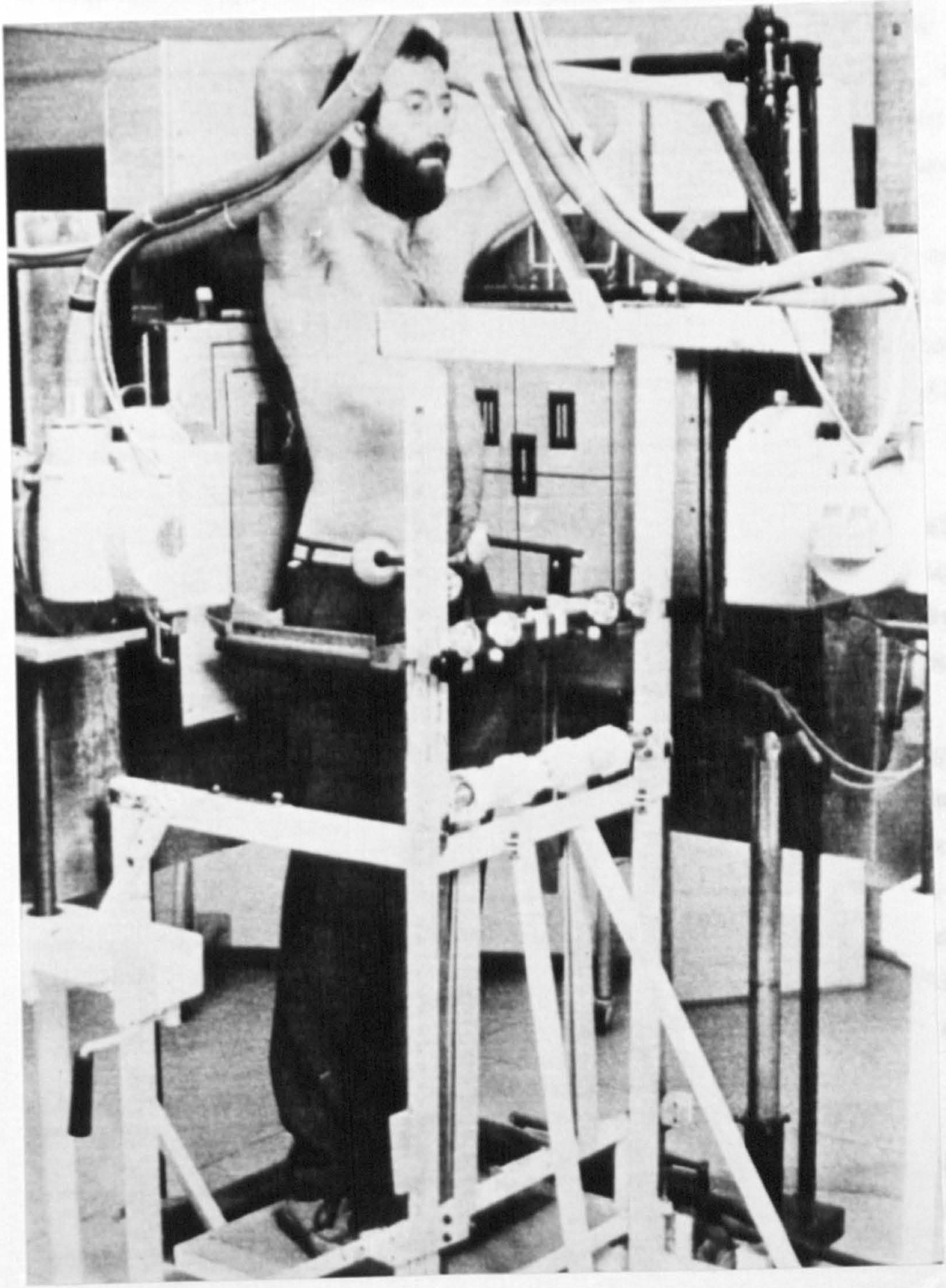


Fig. 4.8 Stereo-radiography - Lumbar Spine

The monitoring of implanted markers in cadaver spine by orthogonal X-rays has meant that 3-dimensional measurement of the in vitro functional spinal unit is possible. Selvik in 1977 used this method for measuring movement in the lumbar spine using small Tantalum balls injected into the vertebrae. A similar method was used by Worth et al,(1978) for the upper cervical spine cadaver studies.

For in vivo studies the use of anatomical marker points on the vertebrae was required for biplanar radiography. Stokes et al (1980) and Pearcy and Whittle (1982) have used this method both on normals subjects (Fig 4.8) and on specifically targeted groups of patients. The accuracy of measurements was detected to 0.3 - 0.5 mm using marker balls compared to 1 - 2 mm with anatomical landmarks.

It is recognised that although the use of X-rays allows internal imaging of the spine, it also incurs the problem of the exposure to radiation. For each view, two radiographs are required and to demonstrate a change of motion, two or more sets of X-rays would be necessary.

Another considerable problem with using X-rays to image the spine is that it may be necessary to construct a standing frame in which to place the patient to achieve standardised films (Pearcy and Whittle, 1982). The cost of X-rays is another factor which has to be considered. Orthogonal X-rays require two films at a time and several sets of films. Radiographers are also required to take the films, as the filming technique is important to the outcome of the image.

The development of 3-dimensional scanning has meant that there is now software which will enable the investigator to digitise the data from the radiographs and to link this directly to a computer. The amount of data that is available and the information required would be impossible to handle without computer assistance. This in itself may be a constraint for clinical research.

4.8 ADVERSE EFFECTS OF RADIATION

X-rays are a source of high frequency electromagnetic radiation.

They pass through tissue releasing energy by their interactions with cells and their contents. The results of this may be the release of ions and even chemical changes in the tissue (Mackay, 1984).

Radiation is measured in three units. The unit of exposure is the Roentgen (R), the unit of absorbed dose is the Rad (radiation absorbed dose) and the Rem, which has been defined (Dorland, 1977) as "the amount of any ionising radition which has the same biological effectiveness of 1 RAD of X-rays".

The main effects of exposure to X-rays have been well documented and are summarised by Drummond et al,(1983). Their work was in connection with the monitoring of patients with scoliosis who required frequent X-rays. The main factors they indicated were the possibility of direct tissue damage from radiation, pre-natal defective development, chromosomal damage and cancer induction. Strict guide lines should be followed during the taking of X-rays to minimise the hazzards to staff and patients.

4.9. THE USE OF BIPLANAR PHOTOGRAPHY TO MEASURE JOINT MOTION

The use of stereo or biplanar photogrammetry in medicine and biomechanics has probably developed from its use in such areas as mapping and surveying. Here the ability to observe and record shapes and surface contours is required to a very high degree of accuracy.

The use of this technique to monitor spinal motion and tissue deformation is well documented (Hindmarsh et al,1980; Stokes and Greenapple, 1985). As in biplanar radiography, an orthogonal camera or source system is required. The use of cameras implies that one can only images a surface marker on the skin. This may be why this method has been used more successfully in the monitoring of large joints such as the knee and less successful in the small joints of the spine.

The identification of joints by skin markers, is a common method of locating a joint for measuring or observation. The position of the marker should be recognised as only a representation of joint position. For the single or larger joints there is less problem to locate the joint site. In the spine this method is less successful. Accuracy would be difficult to achieve.

This system also has the problem that it is vital that equipment used is of a high calibre and that it is placed with a high degree of accuracy or errors in the data and data collection would be to great. Cameras need to be placed orthogonally to the markers and to be placed on firm bases. The films needed to be simultaneously exposed as the data from each would be combined to give the marker co-ordinates. The co-ordinates are derived from the positions of the markers on the film as recorded on the digitiser screen or tablet. At each stage there is scope for the introduction of errors which would jeopardise results.

Biplanar photogrammetry was used by Stokes and Greenapple (1985) to observe the surface shape and deformation in the soft tissues of the intervertebral disc. They also looked at the strain in the annular fibres of the disc. To overcome one of the problems of accuracy, they reduced the size of the markers to 0.8mm in diameter. They used two regular 35mm SLR cameras with 50mm lenses. These authors were looking directly at the effect of position and stress on tissues and their system might not be applicable to the skin markers used over joints in the in vivo situation.

The problem of identifying spinal intersegmental motion cannot really be addressed by observing skin markers. It was therefore decided to use the method of stereo-photogrammetry, externally visible markers and fresh cadavers to ascertain if one could measure intersegmental motion and to see the effects that position and manipulation would have on segmental motion. This work is described in Chapter 5.

4.10 MATHEMATICAL MODELS

Mathematical modelling of the lumbar spine has been carried out for some time, but only recently has the same approach been applied to the neck as the movements and soft tissue constraints make this method difficult (Merril et al, 1984; Helleur et al, 1986; Vanderby et al, 1986). Basic mechanical parameters can be modelled, but at present there is little information available on the way the various body systems interact, so that improved mathematical models may be used. Huelke & Nusholtz (1986) have reviewed much of the literature on biomechanical studies of the cervical spine and their review has illustrated how difficult mathematical modelling can be when applied to the neck. Miller et al,(1987) also indicated the problems of modelling soft tissue in their study on cervical spine distraction with weights. Work on quantifying the activity in neck muscles has recently been tackled by Harms-Ringdahl et al (1986). The further experimental work in this area should assist the analysis of cervical movement.

CHAPTER 5. CERVICAL SEGMENTAL MOTION MEASURED WITH BIPLANAR PHOTOGRAMMETRY

5.1 INTRODUCTION

Lumbar segmental motion has been demonstrated both in vivo and in vitro under several experimental conditions. Three dimentional motion of the lumbar FSU's has been observed and measured in vivo using biplanar radiography by Pearcy and Whittle (1982). The upper cervical spine has also been examined in cadavers using biplanar radiography (Worth et al, (1978), however neither of these groups of workers have looked at the lower cervical spine.

In view of the relative lack of information on the 3-Dimentional motion of the lower cervical spine, it was considered appropriate to attempt to use a similar stereo imaging system to observe the lower neck. The system might demonstrate by another method the available range of motion of cervical vertebrae to compare with amounts given by other authors (Table 3.1).

The system of biplanar photogrametry was to be combined with in situ pins using fresh, pre post - mortem cadavers. This combination would allow tests in the cadaver, with the neck and shoulder girdle tissue tension similar to that found in the in vivo situation matched for age and weight.

The movements and manipulation of the neck would be produced with manually applied forces. These would be transmitted via the soft tissues to the vertebrae to result in positional changes. Therefore it was important to consider the effect the forces might have on the deformation of the vertebra itself, which might alter the results.

5.1.1 Effect of torque on cervical spinous processes

Farfan et al (1970) had shown that in the lumbar spine, that vertebrae can and do deform with axial and rotational forces. He demonstrated joint capsular stretching of 0.25in (0.6cm) and bony deformation with 10° or more rotation at a segmental level. Due to the great difference in size and shape of the cervical and lumbar vertebrae, it was felt necessary to test the cervical vertebrae under rotational loads to see the extent to which they would deform. Deformation of more than 0.22mm caused by a simulated manipulation would have to be taken into account in analysis of data, otherwise the vertebrae may be considered as rigid bodies.

The type of bone, its site of harvest, the state it is in at testing and the direction of the test will all affect the results for mechanical tests. The variations in the results quoted in the literature reflects the lack of standardisation of testing procedures (Farfan et al 1970; Evans, 1978; Short,1986). Goldstein (1987) has comprehensively reviewed the literature on mechanical testing of bone. Results for unspecified vertebral bone (cortical or trabeculae) strength under uniaxial testing situations,varies between 0.34 M Pa and 15.0 M Pa . The modulus for vertebral (unspecified) bone also has a wide range from 1.1 to 151.7 M Pa.

A ligamentous preparation of the neck was prepared from a 66 year old female cadaver. A steel pin with a dial gauge (Mercer type 72) attached, was inserted into the posterior aspect of the C6 vertebral body. The thorax was fixed to prevent rotation of the trunk, and a torque was applied to the skull and neck of the cadaver, and readings were taken. Gauge deflection indicated that less than 0.22mm bony deformation had occured. This indicated that cervical vertebrae when subjected to rotational forces will show minimal deformation. It was decided that the small amount of deformation would not be a source of error in future calculations.

A trial was also carried out to find the approximate forces that would be applied in a therapeutic rotation technique. No information was available in the literature, so a test was carried out on a fit volunteer (female, 22 years, no known pathology). The subject was seated on a chair, on the force plate. Her neck rotated in a manner identical to that given in a clinical situation, where cervical rotation mobilisations (Maitland, 1986) would be given. A force of 0.97 Nm was found to be the average torque given. It was acknowledged that this is an area which needing futher attention, however at the time it was out with the remit of the main project.

5.2 BIPLANAR PHOTOGRAMMETRY SYSTEM FOR POST-MORTEM CERVICAL SPINES

A biplanar photogrammetry system was devised to track and record the position of markers placed in cervical spinous processes

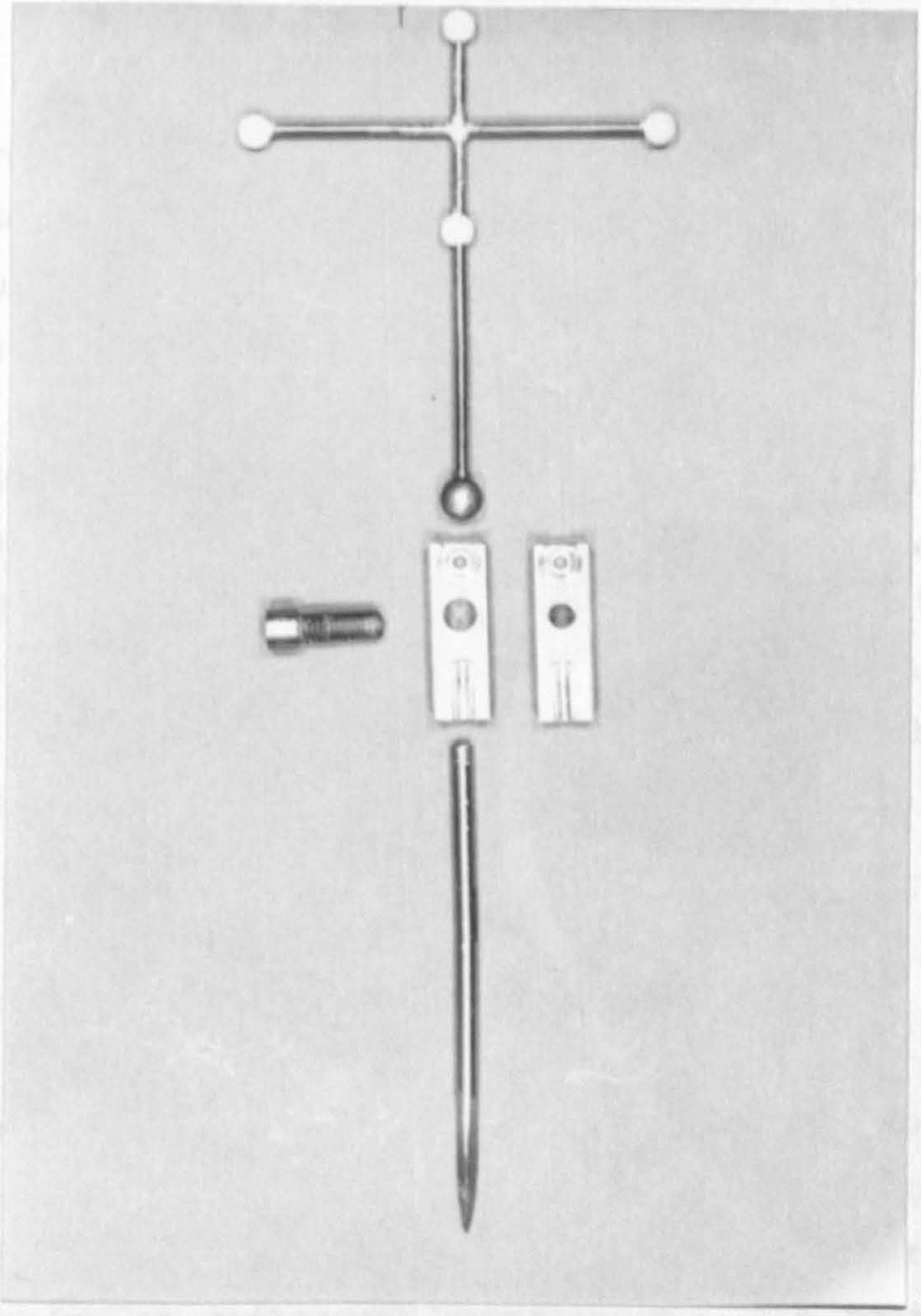


Fig. 5·1 Marker system showing crosswires with spherical markers, holding block and steel pins of post-mortem specimens. The system was designed to be portable, compact and as optically accurate as possible. X-ray techniques were not used at this time due to difficulties of providing the required X-ray sources (orthogonal), within the post-mortem room.

5.2.1 Marker System

A set of 60-100mm long, 3-4mm diameter, sharpened steel pins were made. Pins of graduated length were found to be ideal to accommodate the curvature of the neck. Modification of the pin tip would be recommended for future work to improve 'holding' ability of the pin in the bone (Fig 5.1).

Four marker balls were used on each pin. The four balls were attached to a cross wire in the same plane and this was checked for accuracy. The cross wire was held in a casing, like a modified 'ball and socket' joint, which allowed the marker to be aligned in the vertical plane. Three markers and pins were used for each patient. To facilitate identification of the markers, they were painted with fluorescent paint.

5.2.2 Camera and Base Equipment

Two Nikon "F" series, 35mm SLR cameras were used with 55mm Mikronikon lenses and motor drive attachment for synchronised firing.

A horizontal base beam was made and the cameras were bolted to their support brackets on the beam. The cameras were angled at 45° to give an orthogonal arrangement. The pentaprisms were removed once the equipment was ready to allow easy access to view without disturbing the cameras (Fig. 5.2a, 5.2b).

After a trial, it was found that the best results were achieved with a speed of 1/60s. and an aperture of f8, using a 160 ASA Tungsten Ektachrome colour transparency film.

Two 500 watt halogen photographic lights were used. The optimum position to reduce shadowing to a minimum was found. The lights could be bolted to the sides of the beam ends.

A referencing guide was constructed. This was a length of rod with three small vertical markers. This was made to fit the central

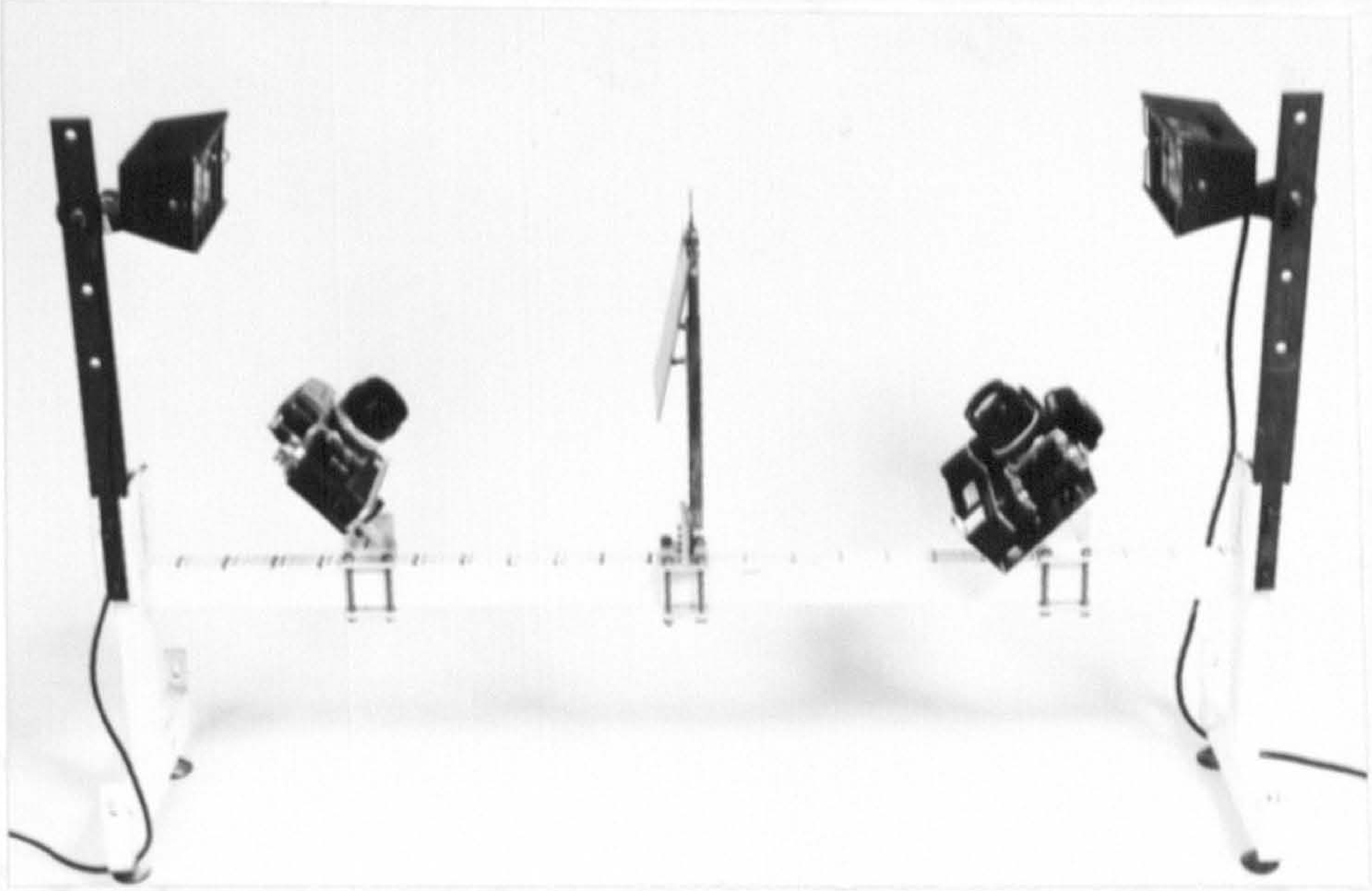


Fig. 5·2(a) Base assembly showing position of lights, cameras and calibration rod in holder

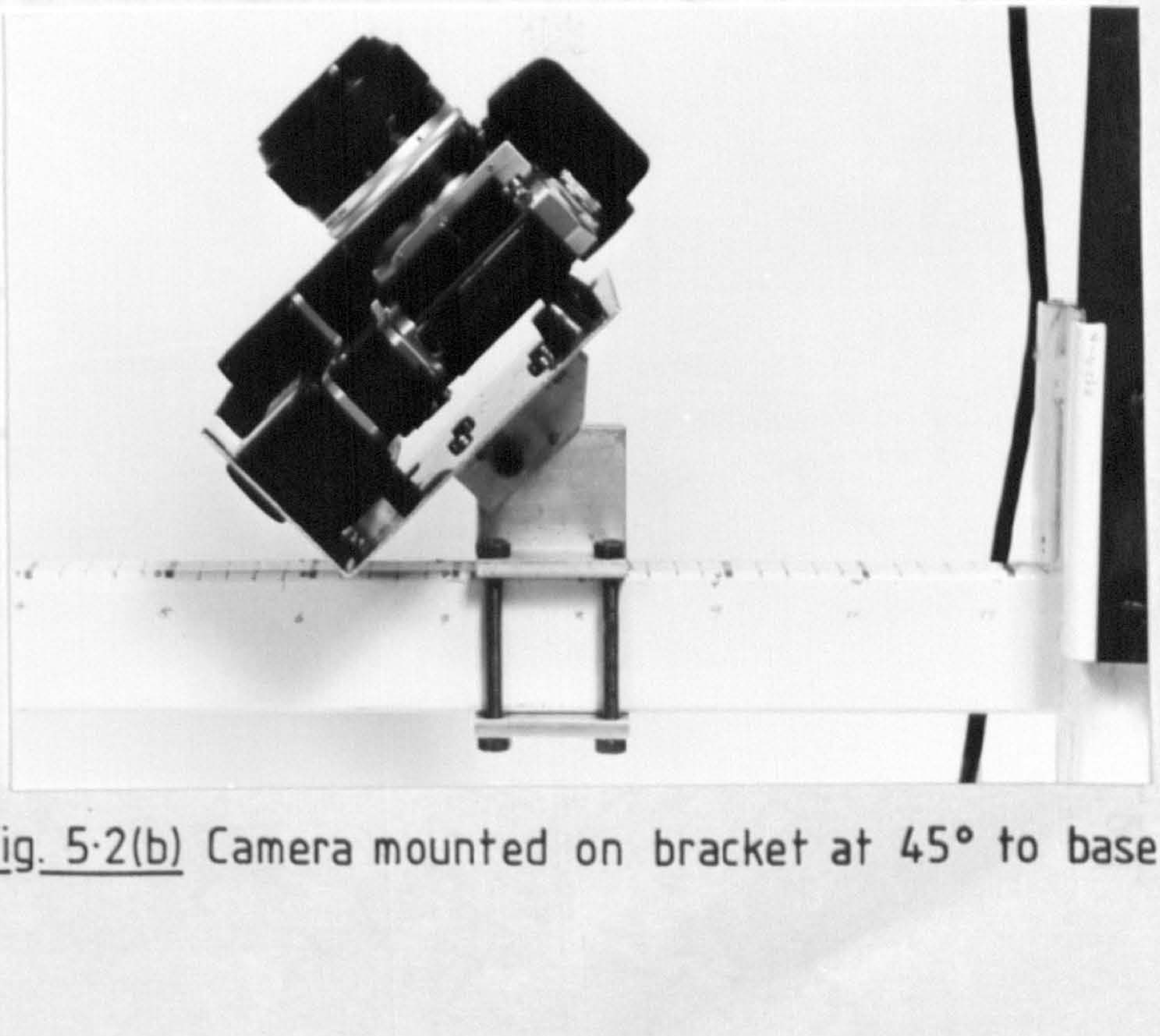


Fig. 5·2(b) Camera mounted on bracket at 45° to base

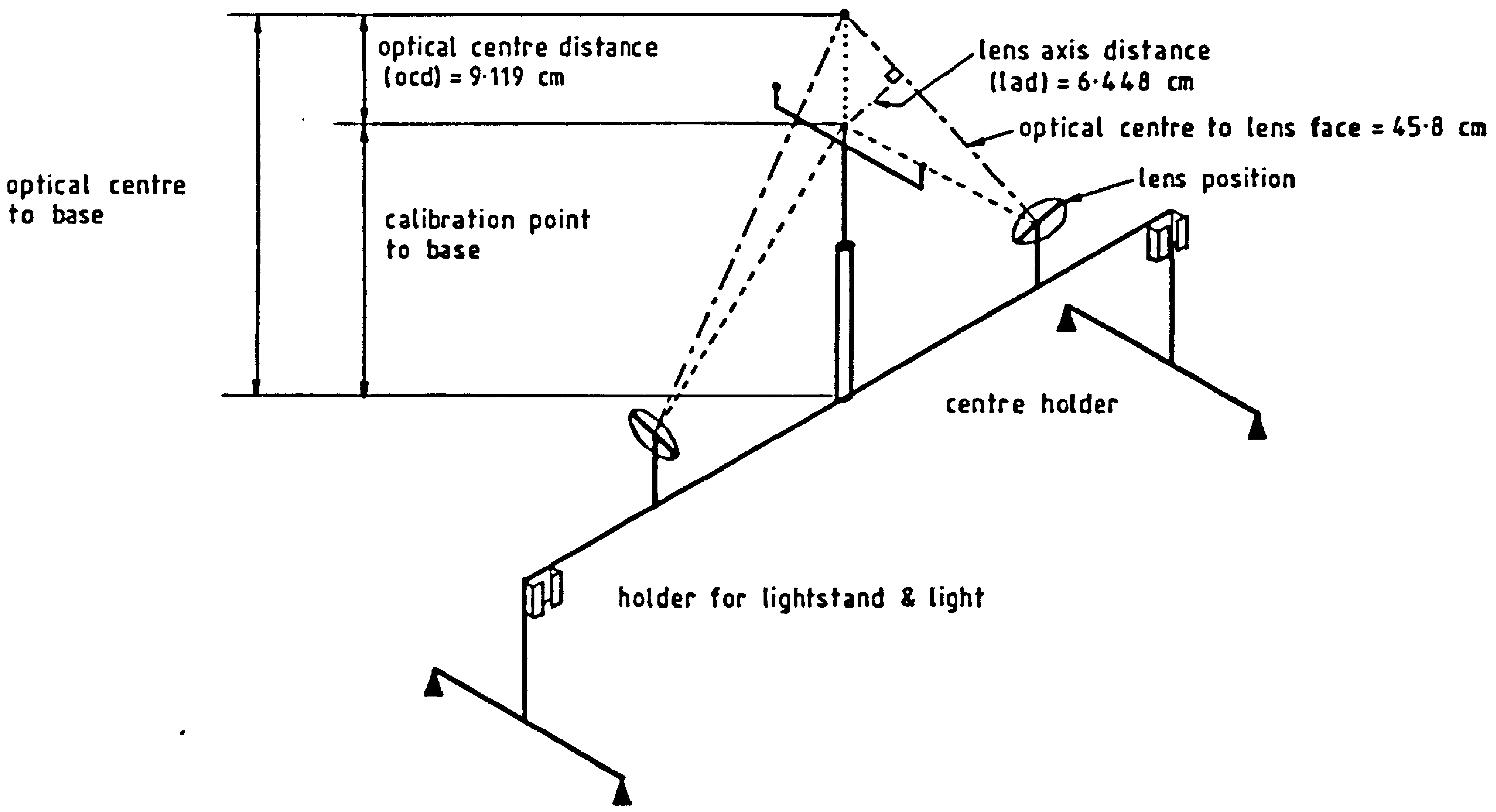


Fig. 5·3 Distances required in calibrating optical centre origin from calibration rod origin (pt.2) holder of the base assembly (Fig 5.3). The axis of the markers 2 and 3 were checked by mirror reflection to be normal to the vertical plane in which the camera lay and not horizontal. The distance between points 2 and 3 was measured by travelling microscope and found to be 7.734cm, this was called the physical distance (PD). It was required for calculations of co-ordinates.

5.2.3 The Physical System for Biplanar Photogrammetry

It was necessary to find the intersection of the axes of the cameras. A rod with a marker ball on top was placed in the central holder of the base. Both cameras were focused onto the marker, using the 'horizontal' of the split-image focusing guide (Fig. 5.3). The height from the marker to the base was recorded. The distance from the calibration rod point 2, to the base was measured, the difference in height = 9.119cm = optical centre distance (OCD). The distance from the calibration rod, point 2, to the optical lens axis was calibrated as 6.448cm = lens axis distance (LAD).

When the initial referencing guide was in the holder, the distance from the marker point to the film plane was measured by ruler as 51.7cm and was then checked against manufacturers specifications. The lens axis distance was taken to represent the distance from the marker to the focal point of the lens, as measured by the experiment. The lens face distance was measured as 45.8cm = (LFD).

By lining up 2 pins as markers on a bench in line with 2 set points, the projections from these two points would intersect in an area of lens focal point. Each lens was found to have 'focal area'.

5.2.4 Post-mortem Specimens

Post-mortem specimens were stored at 4°C. The tissue temperature rose after exposure for 1½ to 2 hours. Room temperature was recorded at each experiment and was between 20° and 25°C. The temperature of each body was measured with platinum wire electrodes and digital thermometer through a skin incision in the neck. It was between 21 and 23°C.

Rigor mortis was expected to be a problem. However the timing of the testing allowed the post mortem bodies to warm to 21° and 23° C and no strong rigor was found in the upper limbs, shoulder girdle or cervical spine. The resistance to motion ot the neck was similar to that of an intact,in vivo neck of similar sex and age.

5.3 PROTOCOL FOR BIPLANAR PHOTOGRAMMETRY

The body was turned prone and through a midline incision, the spinous processes of C5-6-7 were identified. Pins were inserted into the spines. X-rays were taken to ensure pin placement and that no unsuspected pathology was present. A cap was used to avoid hair obscuring the cervical markers. The body was then turned supine and was positioned so that the head, neck and shoulders were off the end of the post-mortem table. The cross wire markers were then attached to the pins and aligned with those of the calibration rod positioned on the base assembly beneath the cadaver's neck (Fig. 5.4).

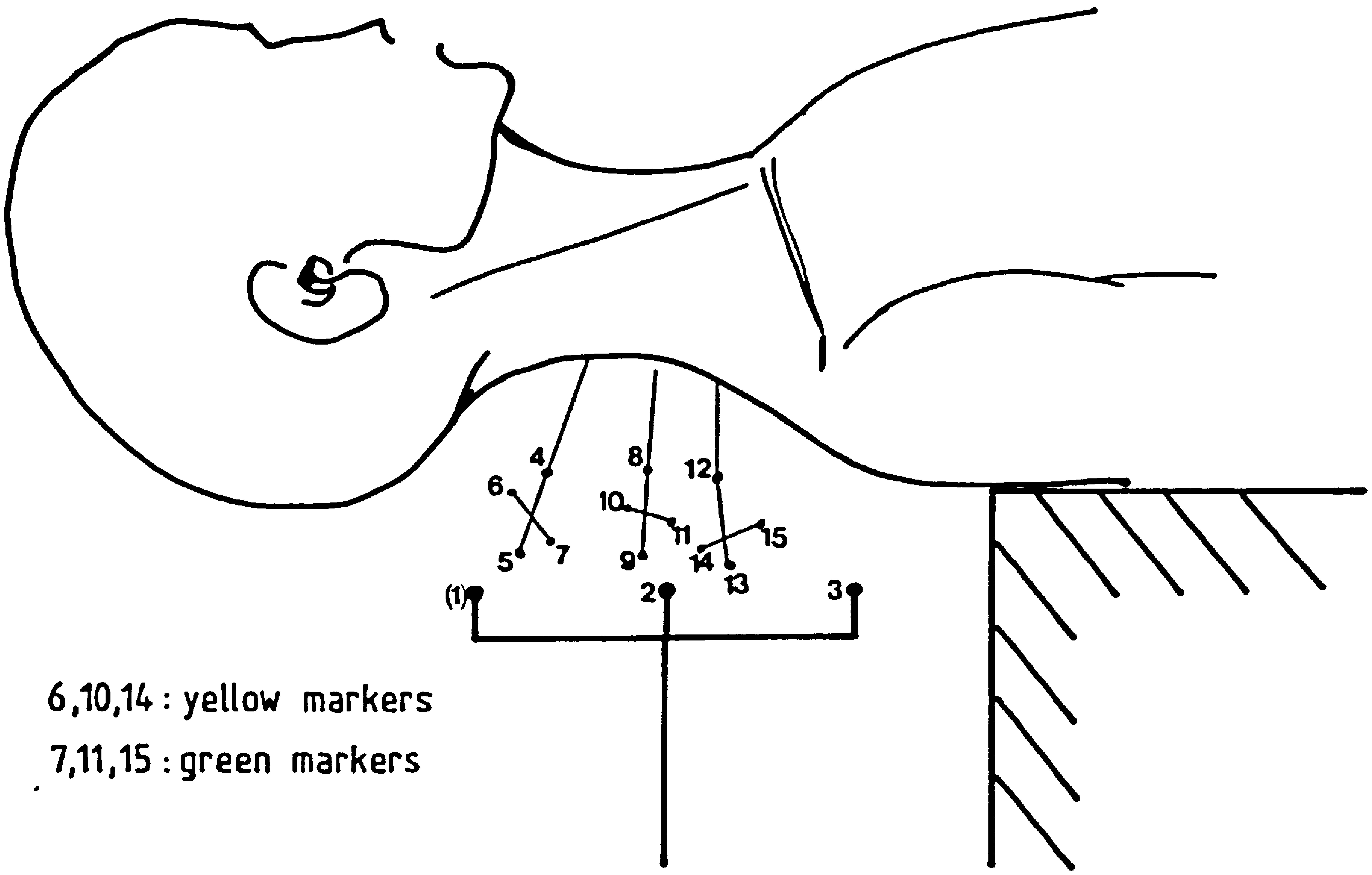
A series of movements were made with the neck, while synchronised firing of each camera recorded each movement. The sequence was;

full left rotation, full right rotation,
neutral mid position, flexion,
lateral flexion to the left,
lateral flexion to the left plus rotation to the left,
rotational manipulation to the left.

The sequence was repeated three times for each of the bodies tested. The changes in the marker positions may be seen in Fig. 5.5a and in Fig. 5.5b.

5.4 DATA COLLECTION AND PROCESSING

The slides were glass mounted and projected (Leitz Pradovit Projector) onto a digitising table (Calcomp 9000 series). For each film, every frame of the film was digitised in the same order, also



6,10,14 : yellow markers

7,11,15 : green markers

Fig. 5·4 Sequence for taking marker points from digitising table each of the marker balls on the three marker pins were digitised in the same sequence. This was facilitated by the colour coding of the balls.

A series of mathematical calculations were required to compensate for factors which were known could affect the results, and these were:-

1. Any tilt of the slide in the projector:

   x frame (f) = x dig. pt. 3 - x dig. pt. 2
   y frame (f) = y dig. pt. 3 - x dig. pt. 2

2. Tilt of the calibration rod from the horizontal:

   $$\theta^\circ = \tan^{-1}\frac{(yf)}{xf}$$

   The value was used to give new co-ordinates to the markers, where for the right camera

   z is equivalent to -y
   x is equivalent to -z

3. The scaling factor was the physical distance between points 2-3, measured by the light microscope, divided by the digitised distance, then converted to centimetres.

4. The parallax problem of the system was resolved by adding -6.448cm to the y and + 6.448 cm to the z values, this value was the lens axis distance (LAD),which was described in the previous section.

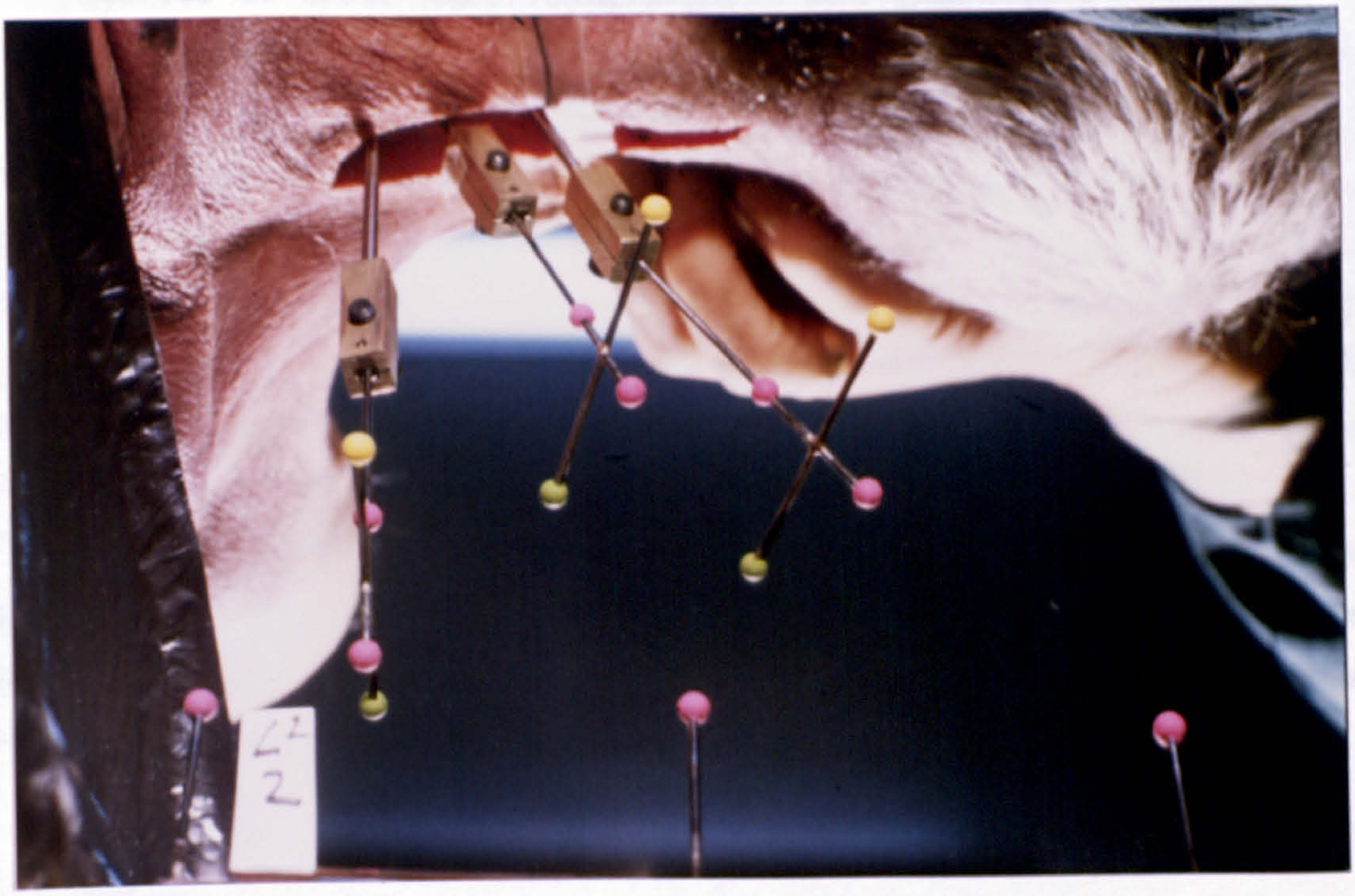


Fig.5.5a

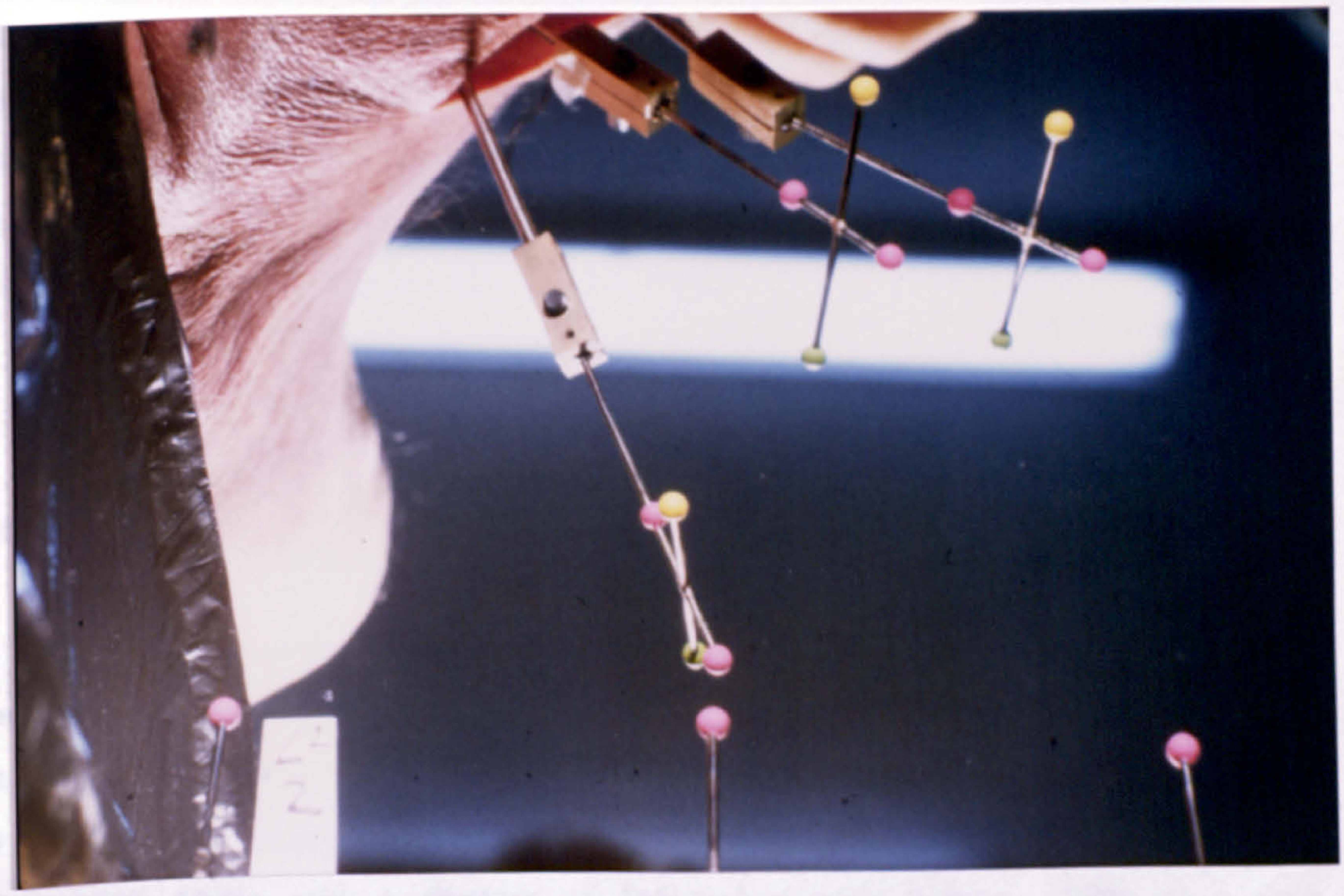


Fig.5.5b Movement of marker pin when Cervical Spine is moved Position a (5.5a) to Position b (5.5b)

Sources of error were recognised in the experiment and attempts were made to reduce them to the minimum. The equipment was constructed so that once assembled under the cadaver, no handling was necessary. Results from all the experiments were collected using the DIGCOL programme (Appendix I) and a PDP11/44 computer. A second programme was required to calculate the adjustments for the physical system and the optical system (APPENDIX I DIGSAL) to calculate all the new co-ordinates. A further programme was designed to plot out all the positions of the markers in each of the planes (Fig.5.6.). The marker in the C7 spinous process, with the neck was in the neutral position, was chosen as the reference marker, against whose position, all other marker positions would be compared. Angles were measured directly from the plots of the marker pins.

5.5 RESULTS

The results of the experiment look primarily at rotation about the X axis in the Y Z (-Y,-Z) plane (Fig 5.7). Results for the movement in the YZ plane are given in Table 5.1. The range of segmental motion falls within the ranges offered by other workers. The increase of movement at the level of the local manipulation (C6) is also noted. Data on movements in the other planes were collected, but not analysed at the time.

5.6 DISCUSSION

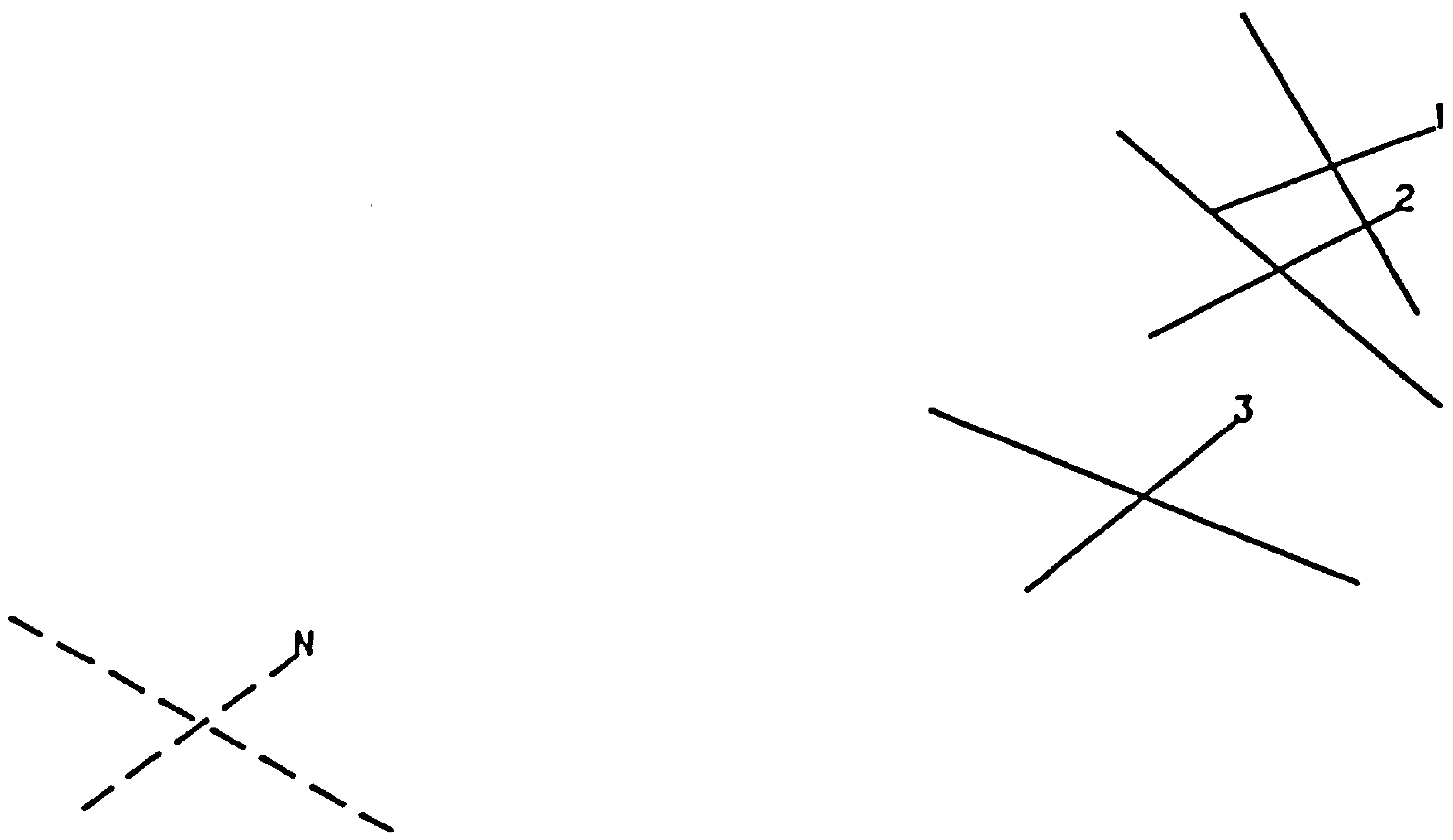
It was interesting to note that for positioning the head in the neutral and in flexion, the markers stayed in the sagittal plane. This is important for therapeutics, that positioning of body segments by visual discrimination can be accurate. In some of the combined movements there was a degree of lateral displacement. This was felt to be a result of patient handling and could be reduced with more experience in the experimental situation.

In the cervical spine, the movements of lateral flexion and rotation are always to a degree combined, due to the shape of the

Fig 5·6 Y-Z PLANE　FRAME NO... 1

1 of 7

GRAPHICAL PLOT OF DIGTISED DATA
RESEARCH - S.RUSTON
PROGRAM - K.SHORT



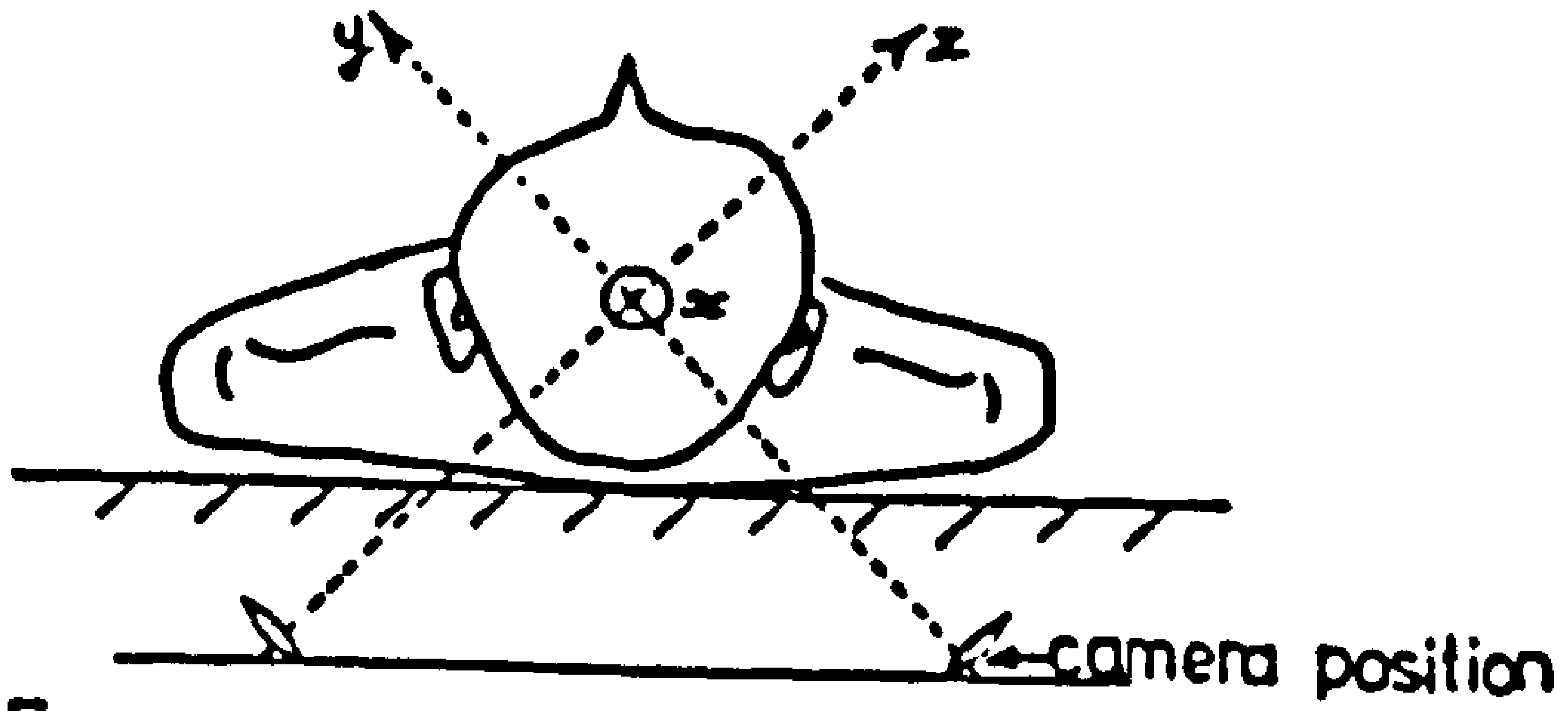


Fig 5·7
To show axes used in data analysis & calculations.

Table 5·1
Angle of rotation of markers from "Neutral marker" through movement sequence.
(IN YZ PLANE)

Movement Sequence	marker 1.	marker 2.	marker 3.
left rotation	degrees 15	degrees 9	degrees 4
right rotation	12	22	19
neutral	4	0	0
flexion	2	2	0
left lateral flexion	0	1	0
" " " + left rotation	16	10	6
" " " +" "+ manip	20	14	10

joints and the soft tissue. There was less rotation in these combined movements than expected. It also appeared that the amount of lateral flexion did not have much effect on the amount of rotation possible. The lateral flexion component was visible on the plots as a shift away from the other markers. A localised rotational manipulation was performed at the level of one of the markers (C6) .It altered the range of motion at the targeted level and also of the segments above and below.

This experiment set out to test the feasibility of measuring intersegmental motion in the cervical spine using biplanar photogrammetry and intact pre post-mortem specimens. The method was found to be possible and results were obtained of motion in one plane (YZ). The system could be improved, if further work was to be carried out. There would need even greater emphasis on accuracy of equipment especially that constructed for the experiment. Marker balls could be made smaller, for improved digitising technique. Marker pins would have a different shape to facilitate their retention in the spinous process, lastly more experience in the experimental situation would improve body handling and so assist by removing artifact movement.

Another area that would deserve attention is that of the forces applied to the spinal joints during a manipulative technique, and the direction of the forces. No information is available on this subject.

This technique used a situation as close as possible mimicking the structure and tension of the intact in vivo neck. To progress the work, a system for observation of the vertebrae which was safe, and non invasive was required. From the current available methods of body scanning, diagnostic ultrasound appeared to offer the best opportunity to observe the neck. The system does not currently have a high profile use in the orthopaedic situation. A review of the principles of ultrasound and its use in orthopaedic situations will be given.

CHAPTER 6. PHYSICAL PRINCIPLES OF DIAGNOSTIC ULTRASOUND

6.1 INTRODUCTION

Ultrasound (US) was primarily developed for military, navigational and detection purposes. Subsequently, it has been used to a great degree in engineering for measuring thickness of materials and for detecting flaws in materials. In medicine, ultrasound has been used as a diagnostic tool since the 1950s. It is used regularly for abdominal, foetal and obstetric scanning and more recently for the scanning of cardiac patients. With the advent of high performance computers and improved ultrasound technology, manufacturers are now able to offer the investigator a wide range of facilities, both hard and software, from which to chose for their specific requirements or specialty.

Diagnostic ultrasound has some major advantages over other diagnostic scanning techniques;-

a. It is non-ionising
b. It is non invasive
c. There are no known long or short term side effects
d. Scanning is relatively comfortable for the patient
e. Dynamic imaging is possible
f. It is relatively cheap, considering staff, equipment and scanning time.
g. Machines are often portable to allow scanning in the ward or clinic situation

It is precisely these qualities that make diagnostic ultrasound such a popular tool in clinical practice and one whose use may be more useful to orthopaedics.

6.2 BASIC PHYSICS OF ULTRASOUND

A review of the basic principles of ultrasound is given. For more complete technical information, several texts are available covering all aspects of the technology (Ensminger, 1973; Wells, 1979; Woodcock, 1979; Carpenter,1980; Wells, 1980; Dreijer, 1983; Hussey, 1985).

Sound is the result of a mechanical disturbance of the particles of matter or air. The particles of matter whilst remaining in place, vibrate and it is this disturbance which causes the formation of pressure wave fronts which travel forward through the various media. Sound requires a source or generator also a medium through which to pass and an adequate receiver to receive and interpret the signals or pulses. The waves of sound are often described as alternating pressure fronts of low (rarefaction) and high (compression) pressure.

6.2.1 Piezoelectricy

In the 1880's the Curie brothers discovered that certain crystalline materials had the ability to be distorted when an electrical current was placed across them. The distortion would cause the material to vibrate at a frequency particular to that crystalline material. The vibration caused a compression / rarefaction wave in front of the crystal. This effect or piezoelectric effect was noted for natural materials such as quartz and later has been produced in synthetic ceramics, for example, barium titanate and lead zirconate titanate (PZT) which are now used in the manufacturer of ultrasound equipment. High DC voltages are required to produce these effects and these materials are now called ferroelectric materials.

6.2.2 Wavelength, Frequency, Velocity & Impedance

As the crystal, the mechanical source of the sound waves is set vibrating, pulses of altered pressure are formed in front of the crystal. There is a periodicy in the waves, of compression and rarefaction, so that a distance may be measured between indentical phases of the pressure wave. This distance or cycle is called the wavelength (λ).

The next unit which is important in ultrasound technology is the frequency of the sound waves. Frequency (f) is defined as the number of cycles per second. It is measured in Hertz (Hz) or for ultrasound in MHz. Human ear has a capacity to detect sound in the range of about 20-20,000 Hz. Diagnostic ultrasound however use much higher frequency band, from about 1-20 MHz. However the principles of sound still apply.

Velocity (c) of sound waves is the speed at which sound passes through the medium. This will depend upon the density of the medium (ρ) and the compressibility or bulk modulus (K) of the medium, and can be expressed by the formula;

$$c = \frac{1}{\sqrt{K\rho}}$$

The relationship of wavelength to velocity and frequency is usually expressed by the formula

$$\lambda = \frac{c}{f}$$

Each tissue or material has its own characteristic impedance (Z) to the passage of sound. This is determined by the ration of the pressure of the sound waves (p) in the tissue and the velocity of the particles (v) as they are set into movement.

Impedance (Z) may also be defined as the product of velocity (c) and tissue density (ρ), where the tissue bulk modulus is (K).

Formula commonly used to find the impedance of tissue are given (Hussey, 1985)

$$Z = p \quad \text{or} \quad Z = \rho c$$

$$\therefore \quad Z = \frac{\sqrt{\rho}}{K}$$

6.2.3 Intensity Scale

Diagnostic ultrasound requires both a emitter and a receiver of sound signals. However with the passage of sound through tissue there is usually loss of signal intensity and it would be difficult to try comparing the intensities of the signals from the two directions.

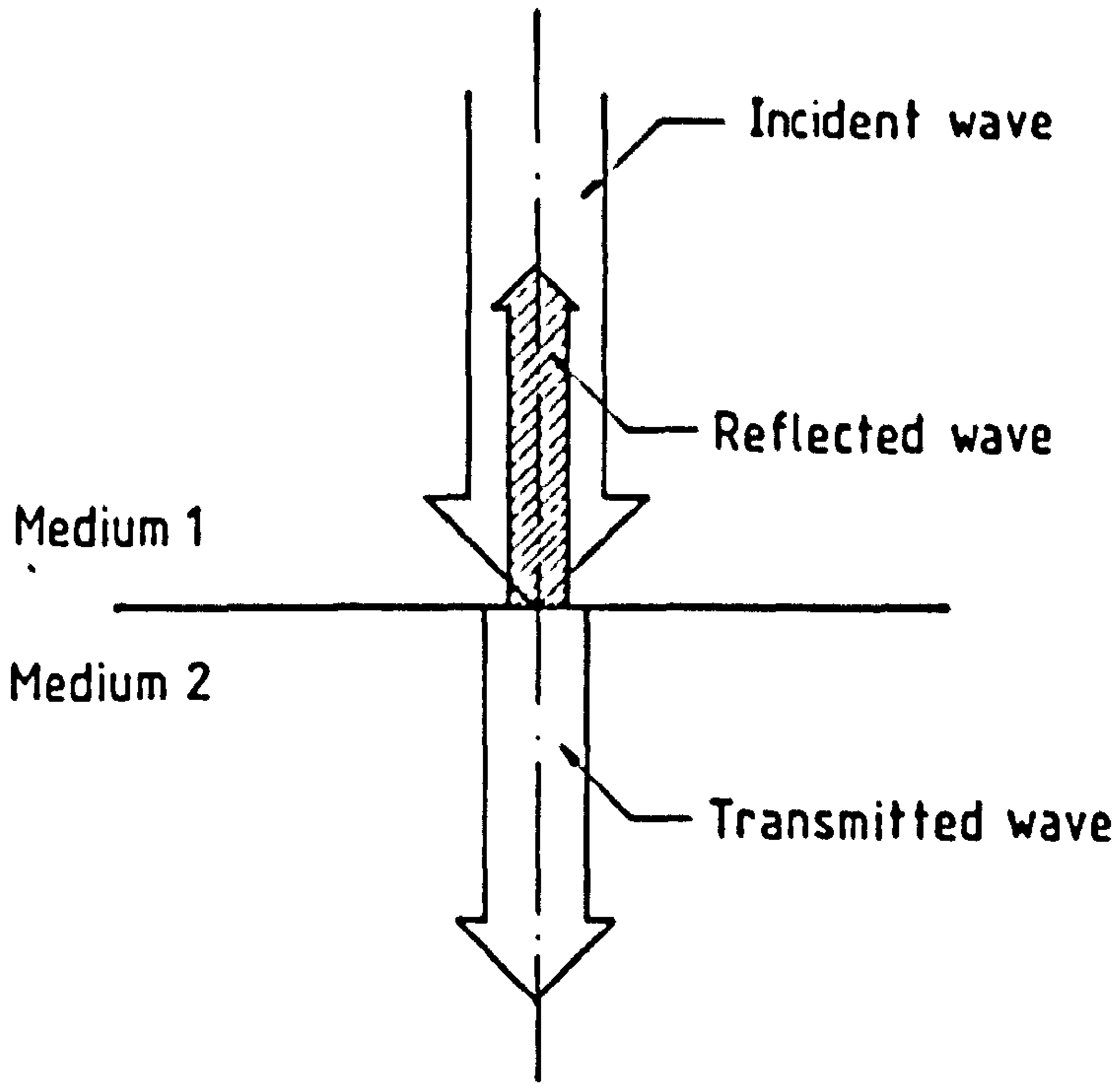


Fig. 6·1 Behaviour of ultrasound normal to tissue boundary (after Wells & Ziskin 1980)

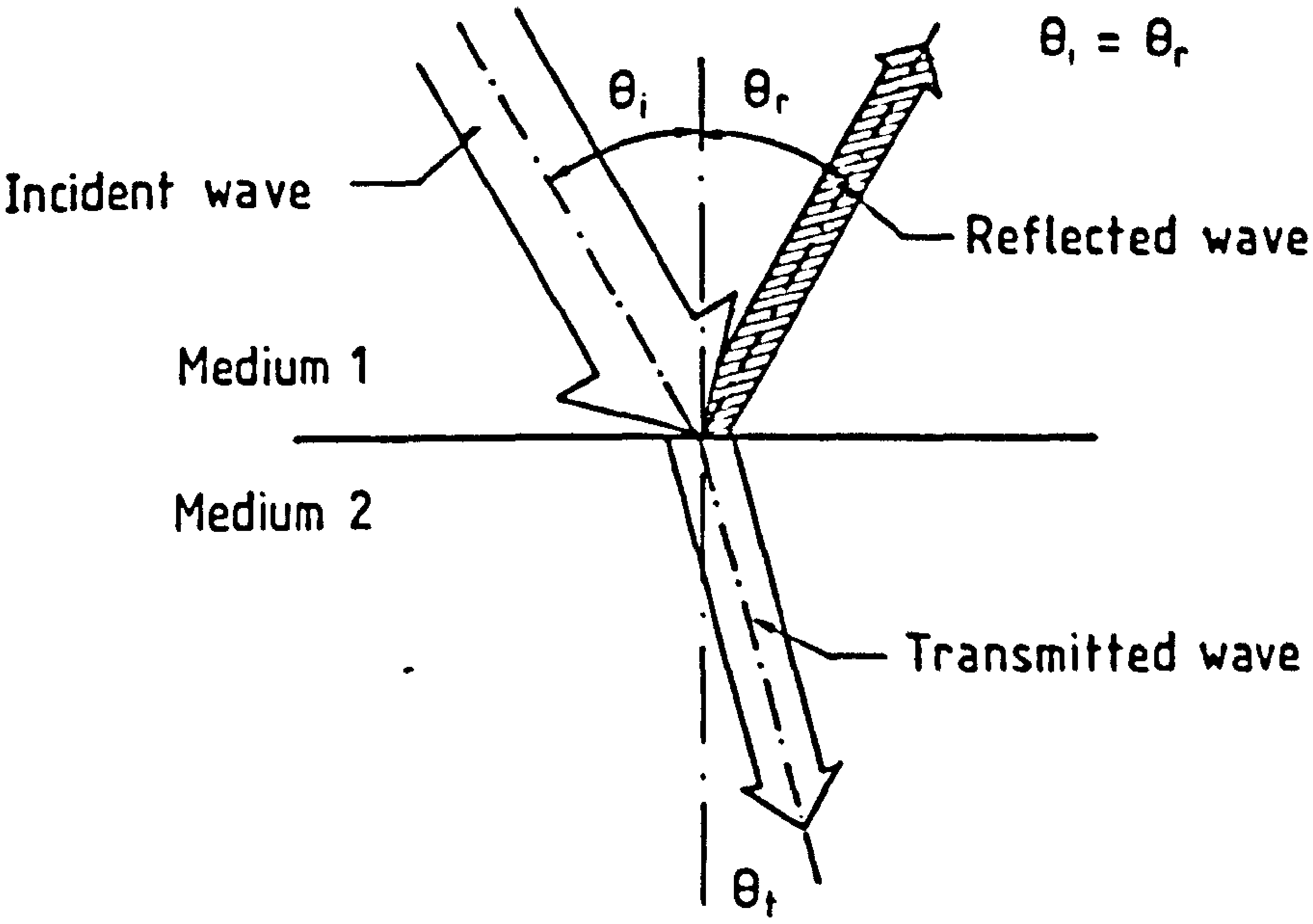


Fig. 6·2 Behaviour of wave striking boundary at an angle (after Wells & Ziskin 1980)

By applying a logarithmic scale called the decibel scale (dB) the comparison of values of greatly differing magnitude is then possible.

The ratio (dB) or intensity = $10 \log_{10} \frac{I_2}{I_1}$

Where I_1 is the intensity of a tissue used for reference, and I_2 is the intensity of the signal of interest.

Negative results imply that the sound has been reduced or attenuated with its passage through tissue.

6.3. REFLECTION, REFRACTION, SCATTER & ABSORPTION

As sound passes through human tissue it crosses many different tissue boundaries, skin and fat, fat and muscle etc. Sound, like light will be subject to the laws of reflection and refraction (Fig. 6.1). Reflection will occur if two media have different acoustic properties or impedances.

With a transducer at 90° to the surface of the skin, there will be reflection (I_r) of the incident ray (I_i) and the rest of the beam will be transmitted into the medium (I_t).

If however, as often happens in the body, the transducer is not able to lie on the surface at 90°, then there will be reflection of the incident rays and refraction of the transmitted rays (Fig. 6.2).

The angle of incidence = the angle of reflection and the two are related to the angle of refraction (Snell's law);

$$\frac{\sin\theta_t}{\sin\theta_i} = \frac{c_2}{c_1}$$

The amount by which sound is reflected (intensity reflection coefficient [R]) is dependent upon the angle at which sound is transmitted to the medium and the amount of sound transmitted (intensity transmission coefficient [T]) depends upon the acoustic impedance properties of the two media.

$$R = \frac{I_r}{I_i}$$

$$R = \left(\frac{Z_1/\cos\theta_i - Z_2/\cos\theta_t}{Z_1/\cos\theta_i + Z_2/\cos\theta_t}\right)^2$$

and $T = \frac{I_t}{I_i}$

$$T = \frac{4\,(Z_1/\cos\theta_i)\ (Z_2/\cos\theta_t)}{(Z_1/\cos\theta_i + Z_2/\cos\theta_t)^2}$$

(Hussey, 1985).

Scattering of sound waves occurs at the irregular boundary surfaces. If the irregularities on the surfaces are small or less than one wavelength, scattering will be in all directions and the transmitted wave is reduced greatly. Scatter will reduce the intensity of available ultrasound for signals and may cause 'backscatter' or interference which reduces the clarity of the images.

As sound passes through tissue a small proportion of sound is lost or absorbed. This usually occurs in the form of heat generated as a consequence of the vibration of particle matter.

6.4. ATTENUATION

Attenuation refers to the loss of strength or intensity of the sound signal as it passes through the tissue, rather than the total loss of signals. When intensity (dB) of signal is plotted against distance to be travelled by the signal (m), a linear relationship for attenuation of biological tissue is found and is usually given in unit, μ(dB/m). What is also important to realise is that the absorption of sound is also dependent upon the frequency of the signal. As the frequency of the signal increases then so too will the attenuation of the tissue.

Attenuation has an exponential decline when intensity is plotted against distance travelled by the sound signal. Attenuation may be caused by reflection, scattering, refraction and general divergence of the wave front. The tissue of interest may be at considerable depth for example 3 - 10 cm. Consequently, signals received back from these tissues will be weaker than those emitted from the source.

Most modern scanners will now offer a range of transducers so the operator can scan both deep or superficial structures with a probe suitable for function and thereby giving the best images possible. Deep structures may require a probe with a frequency of 1-5 MHz, or superficical structures, for example the eyes 5-20 MHz. As the frequency increases, then the possibility of losing signals by attenuation from distant structures is increased.

Tissue	Propagation speed (c) $m.s^{-1}$	Impedance (Z) $10^{-6} kg.m^{2}.s^{-1}$	Overall coefficient at 1 MHz μ(dB/m)
Air (lung)	331.000	0.40×10^{3}	4100.000
Water	1.53×10^{3}	1.53×10^{3}	0.002
Blood	1.57×10^{3}	1.66×10^{6}	9.000
Fat	1.45×10^{3}	1.33×10^{6}	60.000
Muscle	1.59×10^{3}	1.70×10^{6}	350.000
Bone	$2.5-4.70 \times 10^{3}$	5.00×10^{6}	870.000

Table 6.1

Values for propagation of sound, impedance and attenuation at 1 MHz for some common biological tissues.

(Based on data from, Dreijer, (1983); Hussey, (1985)).

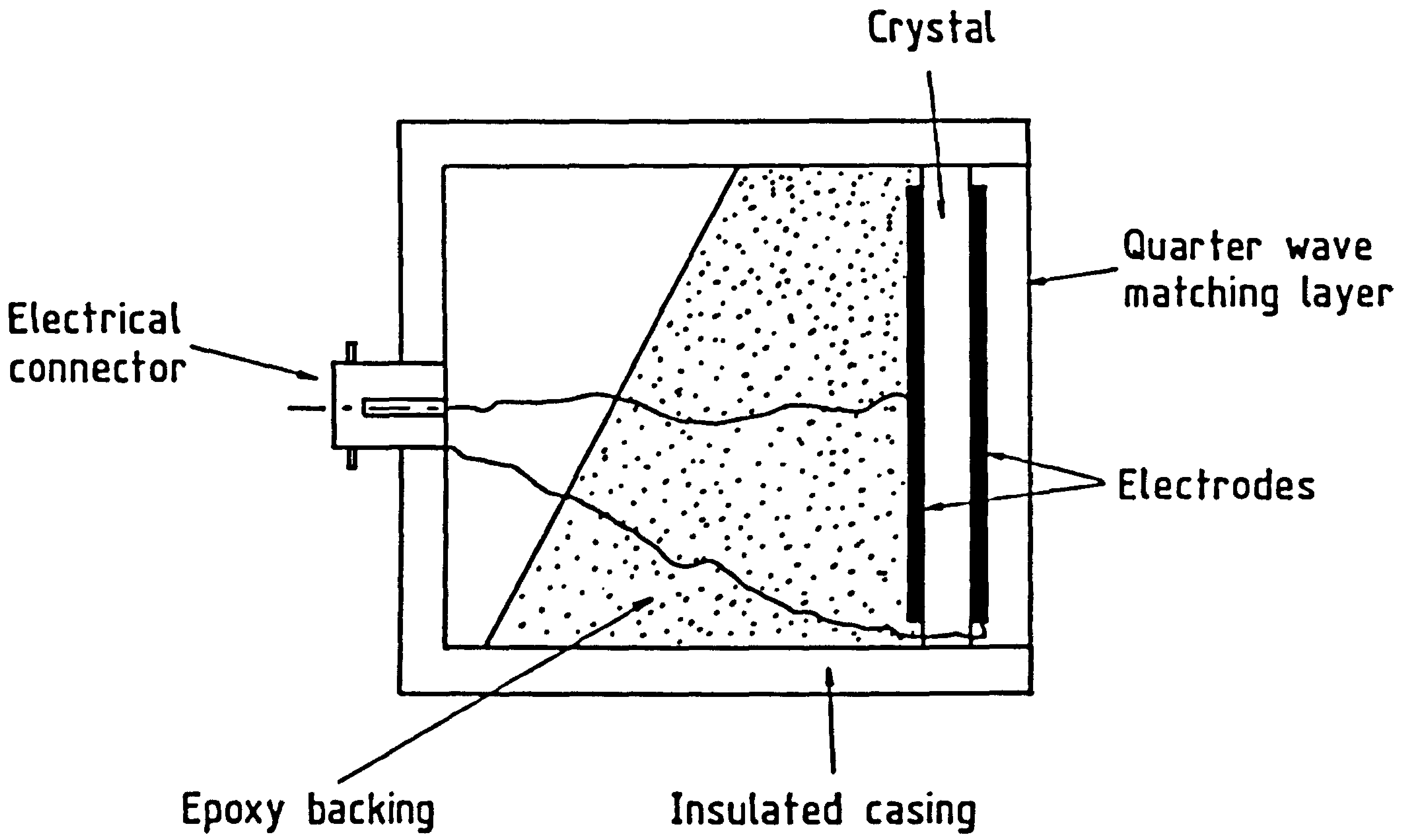


Fig. 6·3 Construction of basic pulse echo transducer (Wells & Ziskin, 1980)

6.5 BASIC TRANDUCER

The transducer is an integral part of the total ultrasound system and is the component which accumulates power from one source and supplies it to a second system. In ultrasonics, the pulses of electrical energy are converted to mechanical energy and then to sound (Ensminger, 1973).

A transducer element or crystal, either natural or synthetic is shaped for the purpose for which it is required. Both the size, thickness and the curvature can be adjusted to facilitate the use of the crystal. An crystal of 1mm will resonate at 2 MHz. The transducer is made to both transmit and receive signals It is located within the casing of the probe head (Fig. 6.3).

For ultrasound to be useful it will require high resolution both axially and laterally. Axial resolution is the ability to distinguish between two objects in the path of the beam, one behind the other. This requires a short pulse length. To achieve this, it has been found that by placing a ¼ wavelength 'lens' in front of the transducer it does increase sensitivity or focusing of the beam to improve image quality. Most transducers have some backing material (epoxy resin and metal powder) behind the transducer head, which helps prevent the "ringing" of the signal which distorts the main signal. However it has been found that any futher additions have not improved the image quality significantly (Wells, 1980).

6.6 ULTRASOUND BEAM

The beam of sound energy emitted from the transducer head will vary depending upon the size and shape of the 'crystal' of the transducer. This to a great extent can be controlled by the manufacturer. A circular flat element will emit a beam of sound the shape of an inverted funnel. The beam can be divided into near and far regions which is in part dependent upon the size of the crystal. If the diameter is too small, then the far zone will be troubled by the presence of 'side lobes' on the main beam, which are areas or pockets of energy extranous to the main beam which then waste energy.

Focusing of the beam is important and can be achieved in various ways:-

a. By placing a lens infront of the flat crystal.

b. Shaping the crystal directly in its manufacture, into a lens.

c. By placing a reflecting surface behind the crystal to catch backwardly directed waves and project them forward.

Focusing will improve the lateral resolution of the beam. There would be less sideways distortion and it would allow greater accuracy in the detection of objects at the edge of the beam. By altering the curvature of the lens the focusing will be weak or strong. By altering the diameter of the lens, the actual beam width will also be altered. Therefore by using focusing, or increasing the frequency of the waveband a compromise is reached. Weak focusing allows a relatively wide beam to penetrate to a reasonable depth, moderate focusing will reduce the beam width but often has only about half the penetration of a weakly focused beam and the strongly focused beam is most useful for imaging small superficial objects.

6.7 B-SCANS AND ARRAYS

There are several types of scans which can be offered by modern equipment, these are A-scans, doppler scans, static B-scans and realtime B-scans. Recently there has been interest in the use of A-scans to measure the the properties especially the mechanical properties of bone before and after exercise (Rubin et al, 1987). However only the real-time B-scans will be discussed here. Good descriptions of the other types are to be found in standard texts on ultrasound (Wells and Ziskin,1980, Hussey, 1985).

Todays sophisticated scanning equipment is capable of the rapid production of good quality images (Fig. 6.4). There has however always to be the acceptance that by increasing the speed of conduction, the overall resolution of the images may decrease.

The images acquired in diagnostic ultrasound are the result of many pulses of sound energy recorded passing through tissue. For the diagnostic scans the sound is pulsed at high frequency. The

Fig. 6.4. Ultrasound image

higher the frequency, the shorter is the pulse length and the better is the image quality. This is only so if the frequency correctly matches the scanning depth requirements.

6.7.1 Real time B-scanners

Real time B-Scans are a composite image of the relative density of the tissue and the impedance to the sound signal passing through. The signal is emitted, returned as an echo, stored and processed to form an image.

The collection of infomation and the building of the image is now so fast that there is no need for the gradual line by line build up of an image. Frequencies are in the order of 20 frames per second and at 100 lines per frame. This is called 'real time' scanning. The image one sees on the monitor is that which is occuring in that moment in time. This is very important if one is interested in monitoring movements or if there is likely to be movement in the area.

The images are produced as a series of light spots on a monitor. Each light spot is an echo of a structure and the brightness of the light spot is representative of the strength of the signal on return to the transducer. Most scanners have monitor screens with a pixel range of either 256 x 256 or 512 x 512. The larger the number of pixels, the finer the resolution of the image.

6.7.2 Arrays

There are two main types of transducers used in real time scanning, the mechanical scanner,then the multiple element linear array and the multiple element phased array. The mechanical scanner (Fig. 6.5) has either a single or multiple small standard type transducer which is caused to rotate at high speeds within a casing. Signals are captured each time the element faces a "window" in the direction of the body. These scans are usually sector scans. The angle of curvature may be adjusted on some makes of equipment.

The multiple element linear arrays have a series of small elements aligned in a row to make a "strip" of elements. There are

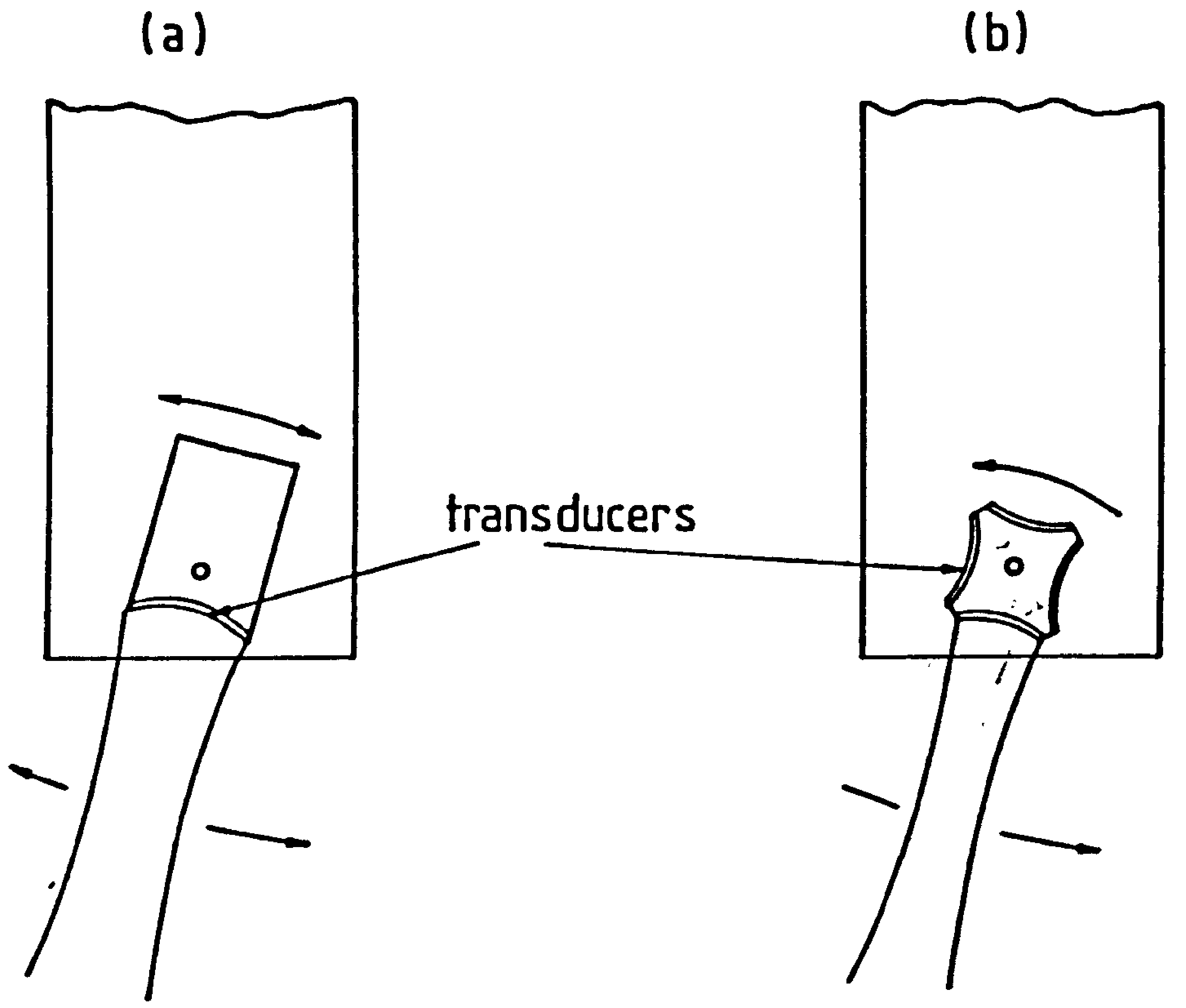


Fig.6·5 Two types of mechanical real-time scanners: (a) Rocking; (b) Spinning

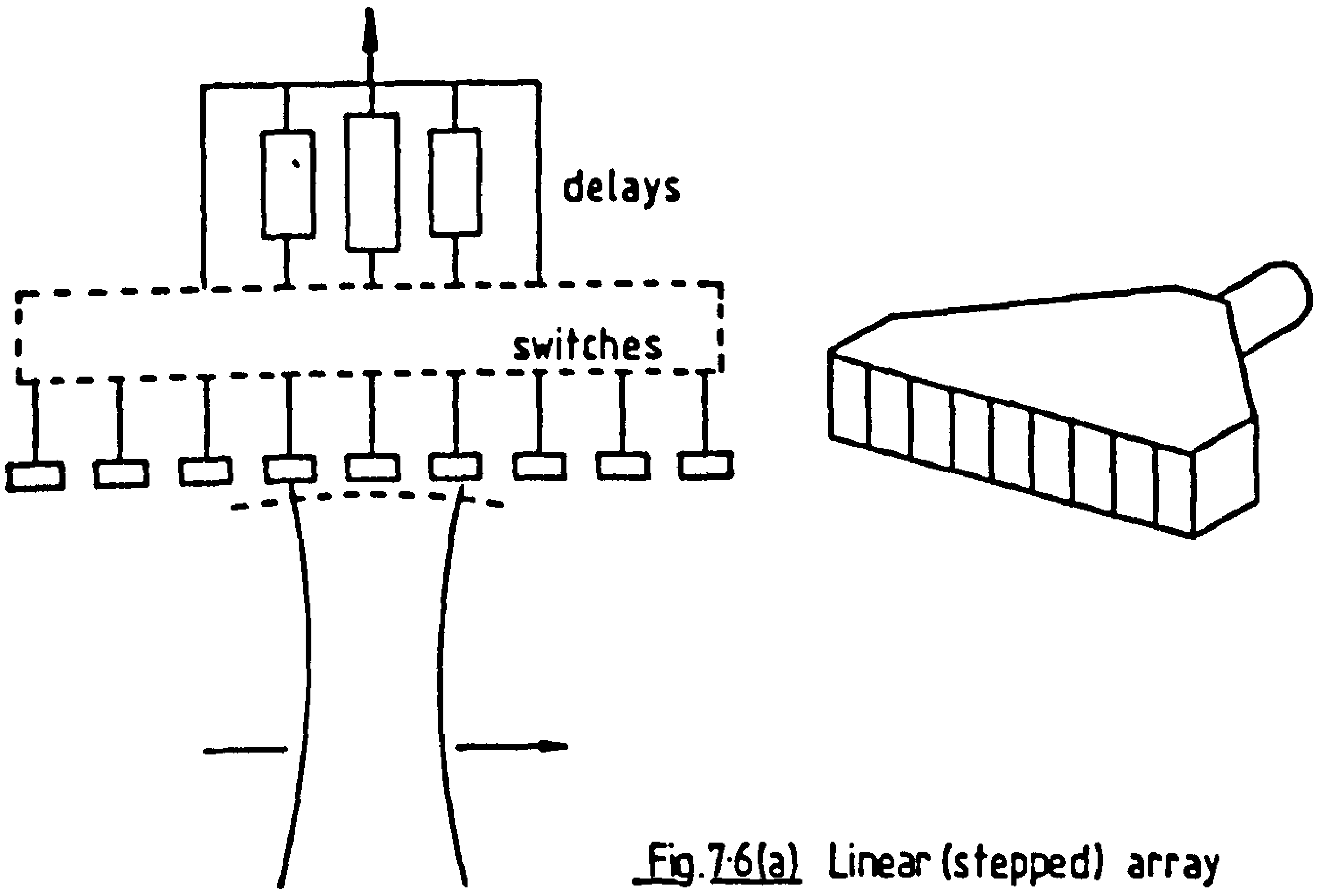


Fig.7·6(a) Linear (stepped) array

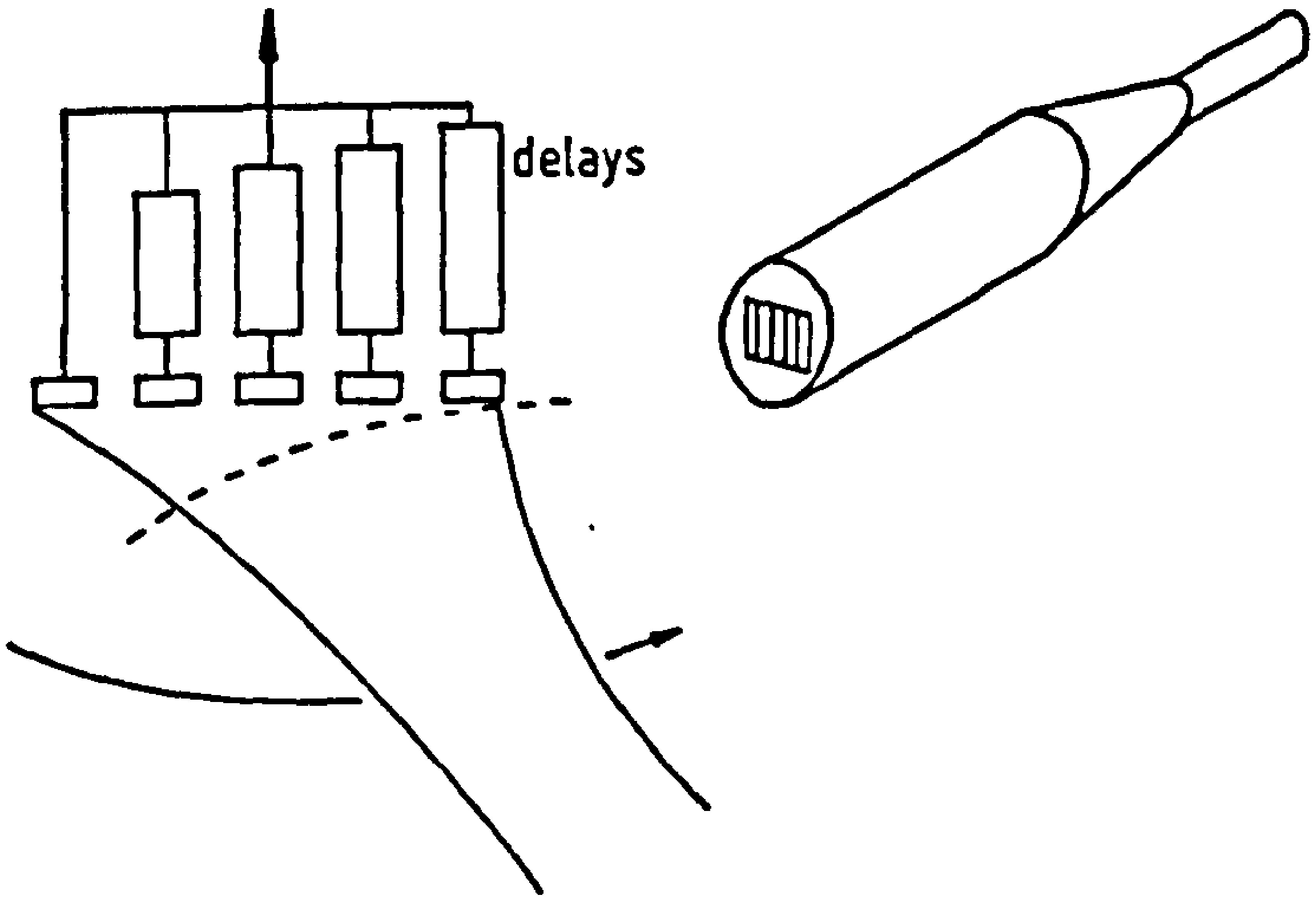


Fig.66(b) Steered (phased) array

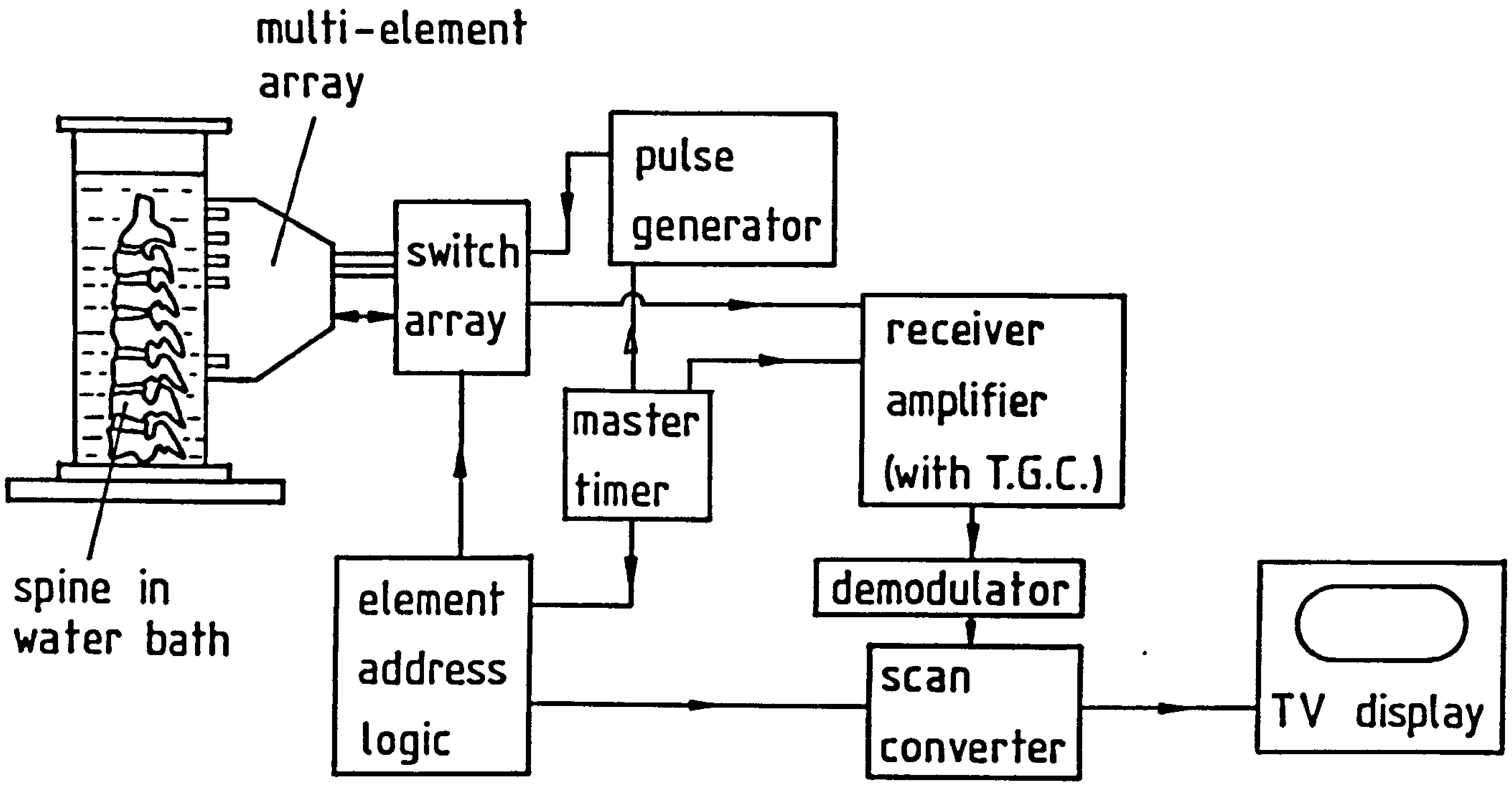


Fig. 6·7 Block diagram of multi-element array for real-time B-scanning often up to 64 elements which may be up to 170mm in length. The elements are electronically fired in blocks rather than individually which would be slower and so reduce the quality of the final image quality (Fig. 6.6a).

Multiple element phased arrays uses the line of elements, but they are clustered and triggered by cluster. This produces a strong wavefront from the transducer. The beam may also be focused by controlling the firing sequence of the element blocks (Fig. 6.6b). The signal on its return is also controlled, 'delayed'. The quality of the image output on monitor is greatly determined by the technique of image capture by transducer but mainly by the equipment hardware and digital processing of the signals (Fig.6.7).

6.8 SAFETY

It is acknowledged by most workers using ultrasound that the nature of ultrasound might mean that there is some danger of biological damage. Sound energy especially when it occurs in peaks can have a heating effect in tissues Spatial peaks of energy have been recorded up to $10^7 W/m^2$ but these peaks are for extememly short periods of time only. By using pulsed electrical energy these peaks are reduced.

Microstreaming of cellular fluid has been said to occur because of the unidirectional flow of energy. Cavitation will only happen if there are periods of very high intensities, when heating causes gas bubbles to appear which then collapse. This occurs less frequently in biological tissue than in aqueous solution. Tissue damage (heating) is dependent upon the intensity and the duration of the exposure to ultrasound. It is generally felt (Hussey, 1985: Wells, 1987) that with care and adherence to the current safety codes that diagnostic ultrasound is safe. However they do advocate continued investigation on diagnostic ultrasound.

CHAPTER 7 THE USE OF DIAGNOSTIC ULTRASOUND IN ORTHOPAEDICS.

7.1 INTRODUCTION

To observe the 3-Dimentional segmental motion of the lower cervical spine a non - invasive imaging technique was required which allowed the observation of deep cervical tissue and structures.

Although diagnostic ultrasound has been used in medicine, its primary area was not for the orthopaedic field, therefore relatively little information was available on the possible types of equipment and imaging techniques available. In order to gain experience in the acquisition and interpretation of ultrsasound images, some peripheral joints were to be scanned. At the same time the opportunity would be taken to X-ray the joints to allow both qualitative and quantitative comparisons to be made from the two types of images. Peripheral joints to be imaged were the hip, shoulder, elbow, patello-femoral, the sacro-iliac joint and also the fore foot and the cervical spine.

Clinical assessment of the patient's joints may sometimes involve the subjective judgments of the clinician on the evidence of such diagnostic tools as X-rays. It was felt to be of relevance, to compare the ability of these two scanning techniques to image similar structures both qualitatively and quantitatively by taking measurements from the to images.

Diagnostic ultrasound was primarily developed and used in the areas of obstetrics and gynaecology and internal medicine for abdominal scanning (Dreijer, 1983; Hussey, 1985). The possible application of ultrasound in orthopaedics was probably not thought to be as useful as for soft tissue scanning, as bone has a high attenuation to sound. However its ability to image internal structures without exposing the patient to ionising radiation or invasive techniques has always been recognised as extremely important.

The advantage that ultrasound has because of the lack of exposure to ionising radiation, has been recognisd for obstetric scanning. Ultrasound also will allow images of cartilage and other soft tissues, again an advantage over imaging methods such as X-ray films. For obstetric scanning, the ability to image the developing foetal skeleton, could be used for example, for the diagnosis of developmental abnomalities, or for estimating foetal age.

Traditionally, bone has always been a hindrance in the production of images by ultrasound. Soft tissue organs would be hidden by the overlying bony structures, for example, the ribs, or the bony elements would throw strong acoustic shadows and obliterate any information possible. Requirements of specialists, have led to improvements in equipment, both in the ultrasound hardware and the computer software which increasingly is being incorporated into the systems. It is anticipated that the current demands made of ultrasound systems will encourage the manufacturers to continue their development programmes, especially for the orthopaedic field.

The use of diagnostic ultrasound in the field of orthopaedics, is more recent than its application in other areas and new developments in equipment and techniques are assisting its use in this field. Progress has not been quite as rapid as has been in some areas, despite the fact it appears to have some definite advantages over some of the more conventional imaging techniques available in the general hospital. Barnett (1985) in a text on the clinical application of ultrasound appeared to give little importance to the use of ultrasound in orthopaedics. This is surprising considering the now common use of ultrasound scanning for such joints as the hip, the shoulder and the lumbar spine.

Much of the early and important work on the application of orthopaedic ultrasound was by Porter and co workers in their investigations on spinal canal diameters. Their techniques ans results have been used by other workers and a review of their work is given

7.2 ULTRASOUND SCANNING OF THE LUMBAR SPINE

In response to the need for more infomation on the size of the spinal canal for the diagnosis of spinal stenosis, Porter et al, (1978), used standard diagnostic ultrasound to image the spine and its components. They used a 1.5 MHz probe and static B-scanner to image the lumbar spine and canal when they attempted to measure the canal diameter. They identified a scanning plane which subsequently most other workers in the field have copied. They scanned the spine with the probe approximately 1cm from the midline and at an angle of 15° to the vertical. They use the A-scan facility of their scanner to identify the interfaces of the different tissues and structures. They believed that they could identify the anterior and posterior surfaces of the laminae and the posterior surface of the vertebral body.

Measurements were made from the peaks of the A-scan image, representing each tissue interface. This method of taking measurements was questioned by Finlay et al, (1981) and also by Kadziolka et al, (1981). These two groups of workers disagreed with the identification of the tissue images in the work of Porter et al, (1978). They also queried the selection of the trailing edge of the A-scan peak from which to make the measurements. They cite Mc Dicken's work (1976) in explaining that the measurements should be made fron the leading edge of the peak. Work by Hibbert et al, (1981) using the approach devised by Porter (1978), also looked at the measurements of the spinal canal. They identified the acoustic "window" through which the spinal canal could be imaged as being the ligamentum flavum. Findlay et al,(1981) also believed that the choice of the scanning plane would affect the measurements of the canal. This problem was not re-identified by Hibbert et al, (1981) and was discounted as a problem in later work, by Hammond (1984).

Hibbert et al, (1981) also looked at the inter and intra observer error for their measurements. They achieved a mean error of less than half a millimetre for the interobserver measurements. However, the accuracy of these measurements was questioned by Davies (1982). Davies again pointed out that any measurements taken from an A-scan should have been taken from the leading edge of the peak and this was not carried out by Hibbert and co workers. Legg and Gibbs (1984) have offered another method of taking measurements from the A-scan. They have suggested that the first of the two measuring caliper"pips" is placed on the descending edge of the first peak of interest and the second, on the tip of the second peak of interest. The first peak was a complex peak probably composed of several smaller peaks. It could be argued that until there is uniformity in the method of measuring, there will always be problems comparing results of various studies.

The problem of accuracy and reliability of measurements from ultrasound scans was noted by Howie et al,(1983). They had used diagnostic ultrasound to scan patients who had been referred for surgical treatment for their sciatica. They encountered problems with the quality of the image and the failure of the equipment to consistently image the spinal canal. This occurred especially with patients who had some or marked degenerative changes in the spine, where the interlaminae "window" was affected and the viewing angle was changed. They also attempted to image the posterior aspect of the intervertebral disc, to detect posterior bulges or sequestered material. The results they achieved for the succesful detection of these structures was considered by the authors to be poor. There are also problems comparing results from the work of various authors, when they have used different equipment. Battie et al, (1985), when looking to measure the spinal canal of the lumbar spine, took measurements from the Polaroid ® prints possible from their equipment (General Electric Dataline portable real-time scanner with a 3.5 MHz transducer and Polaroid Hadrcopy Imager). Although a magnification factor was taken into account, the method must still be open to error, especially from interpretation of shodow boundaries. They did not use the A-scan facility to take measurements, but went directly to the B-scan.

From the literature there seems to be a shift from using the static scanners which were traditionally maintained in the Departments of Radiography, to the real-time scanners. The static scanners were fixed pieces of equipment, so that experimenting by placing the patient in differing positions (Hammond, 1984), could prove difficult. The static scanners required that the picture was slowly "built-up" by passing the scanner head back and forth across the body, again some workers have found that subjects, particularly the young would not tolerate this procedure well (Hammond, 1984).

The availability of smaller, portable, real-time scanners has allowed the experimental use of diagnostic ultrasound in situations outside the usual radiography departments. Eismont et al,(1984) have used standard ultrasound equipment intraoperatively during laminectomies to image the contents of the spinal canal, with good results. They felt able to identify soft tissue structures within the canal reliably and to observe the effect of surgical intervention techniques upon the tissues for example surgical decompression of the cauda equina.

Since the work of Porter in 1978, most investigators have used the posterior approach, described by Porter, to image the spine. Portela (1985) described an anterior approach which he and his collegues used when scanning patients who had been referred for lumbar myelography. He found that visualisation of the spine was difficult in approximately one third of his patients. This he attributed to degenerative changes in the spine usually commensurate with age or to the obesity of the patient. Both of these facts caused poor images. Portela defended the case for using ultrasound imaging of the spine in conjunction with myelography, especially if the more costly computerised tomography (CT) was not available. He also recognised the fact that often personnel not trained in the interpretation of the images, will require time to acquire these skills.

The detection and monitoring of scoliosis is an area which to date has relied upon serial X-rays to demonstrate spinal curvatures. Ions et al,(1986) have incorporated ultrasound scanning with three dimensional imaging. The possibility of stereographic imaging of the spine without the exposure to radiation has to be of significance, especially for the monitoring of the adolescent spine. They scanned the spine in the supine position, but acknowledged that there could be differences in the position of the spine between the supine and weight bearing positions. This they were going to investigate in their future work.

The techniques developed by Porter in the scanning of the spine have been used by most of the other workers looking at spinal ultrasound imaging.

7.3 COMPARISON OF X-RAY AND US SCANNING OF PERIPHERAL JOINTS AND OTHER STRUCTURES

As X-rays are probably the most common method of imaging the musculo-skeletal system, the opportunity was taken to X-ray the targeted joints and structures so that comparisons might be made on the quality of the images and the ability to take measurements from the images.

Eight adult subjects were asked to participate and gave their consent after the procedure was explained to them. One joint only was used from each subject. For each of the structures of interest, the subject had had no history of pathology which had required them to seek medical attention of any sort. Peripheral joints used were the hip, patello-femoral joint, shoulder elbow (in two views) and the sacro-iliac joint. The fore foot was also scanned and X-rayed and the cervical spine of two subjects. Measurements were not taken from the sacro-iliac joint or the foot images as image quality was poor.

For the section of the work in which comparisons would be made of distances measured on the two images, a null hypothesis that there would be no significant difference between measurements taken by the two methods was set up and tested. Paired "t" tests were used, at a significance level of $p= 0.05$.

The null hypothesis was, that there was no significant difference between measurements taken from the ultrasound images or the X-ray images of the same joint or structure as measured by the digitising system.

7.3.1 Protocol for the collection of X-ray Images

When taking X-rays, the use of a calibration rod is the method most commonly used in Schools of Radiography and in Departments of Orthopaedics and Radiology. The calibration rod when placed alongside and in the plane of the joint is also imaged and the known distances on the rod are displayed on the developed film. The amount of magnification of that specific film can then be calculated. The magnification in an X-ray is the ratio of the focus-to-film distance and the focus-to-object distance (Jaundrell-Thompson & Ashworth, 1970, Meredith & Massey, 1972,).

Magnification factor for the Kontron Videoplan System = 4.2
Magnification factor for the digitiser tablet = 4.03

The magnification factors for the peripheral joints X-rayed were determined as ;-

the sum of the the distance measured from the X-ray on the digitising tablet (d) x the magnification factor of the tablet (4.03) x the magnification factor of the specific X-ray. Values are given below.

Shoulder & hip	x 0.87
Knee	x 0.95
Elbow	x 1.0
Cervical spine 1	x 0.87
Cervical spine 2	x 0.87

Table 7.1.
Magnification factors calculated from specific peripheral joint X-rays.

Both ultrasound scanning and X-rays involve a degree of magnification in the images they produce. The data digitising system also has a magnification factor which is important to include in the calculation of measurements

X-ray views of the joints and structures were taken in the standard positions for the structures. Great care was taken with the positioning of the subject, the film cassette and the placement of the calibration rod. This was placed as close as possible to the plane of the joint. One X-ray was taken for each structure and joint.

To obtain a measure of distance from identified structures on the X-ray, the X-ray was placed on the digitising tablet which was illuminated from beneath to facilitate measurements.

7.3.2 Protocol for the collection of the ultrasound images

For all of the joints and structures there was a standard method of collecting ultrasound images. The same equipment and operator were used throughout all the scanning collections.

The equipment used was a Toshiba Sonolayer SAL 32-B ® real time Scanner. A 5 MHz phased linear array probe was used for all scans. Contact gel (Sono jelly ®) was applied to the skin where the probe was to be placed. The probe was placed in position to image the structure of interest. Because of the orientation of the ultrasound beam, and the image of the X-Ray, it was difficult to always achieve matching orientations of the two images. On occassion, the images would be orthogonal e.g., the shoulder. However, great care was taken to locate the area of interest as clearly as possible. It was noted that the differences in orientation might affect the results from measurements taken from the two images.

A series of ten consecutive images were taken from each structure. Each time the probe was replaced on the skin and re-orientated prior to the recording of the images. All information or images were recorded directly onto VHS video tape on the recorder linked into the ultrasound scanner. Results from the video tape were later analysed using a digitising system (Kontron MOP Videoplan ®). All magnification factors were included in the final calculation of measurements.

Comments on the method of collection and analysis of the results from each X-rayed and scanned structure will be given in sections, followed by a discussion on the qualitative assessment on the techniques and results.

7.4 IMAGING OF THE HIP

7.4.1 Introduction and Literature Review

The adult hip joint would offer a large regular shaped articulation for attempting to image with ultrasound. The joint can be easily be X-rayed and the positions for standard views are well defined. It is also a joint which has had some previous background for ultrasound scanning.

Ultrasound scanning is non ionising and will allow the imaging of the developing skeletal system of the neonate and infant. Work by Graf in the early 1980's on the use of diagnostic ultrasound to image the hip of the neonate was reviewed by Berman et al (1986).

Diagnostic ultrasound has been found very useful in making or confirming the presence of effusion in the diagnosis of painful hip, especially in children (Adams et al 1986; Peck, 1986). Wilson et al (1984) used both the static B-scans and realtime scanners, with 5 MHz focused and 3.5 and 5 MHz linear array probes respectively, to look at 36 painful hips. It was not noted if these were children or adults. They were able to diagnose effusion in 16 hips and later confirmed their results with positive fluid aspiration in 13 of the 16 patients. No effusion was detected in 14 patients, and there were no false negative results. The distance between the femoral neck and the joint capsule on the ultrasound scan was measured by the caliper function of the scanner. A distance greater than 3mm was held to be suggestive of an effusion within the joint.

Egund et al (1986) attempted to compare the results for diagnosis of hip effusion in children, using CT scans and ultrasound scanning. They did not directly compare measurements, as the difference in positioning of the hip, would affect the fluid position. However, they felt that their results showed strong agreement between the two systems and felt that ultrasound scanning could be used with confidence when making diagnoses.

While the skeletal system is developing the hip joint can be imaged. The early detection and monitoring of neonates with suspected congenital dislocation of the hip (CDH) or hip dysplasias can be achieved quickly and with little apparent discomfort to the child. Harcke and Grisson (1986) emphasise that the incidence of

CDH is approximately 0.1% of neonates and the incidence of neonates with hip dysplasias, is 1.0%, and that early detection of these disorders promotes a more satisfactory outcome for the infant.

In a study scanning 1001 babies Berman and Klenerman (1986) found that paediatricians using the standard scanning methods for hip instability including the routine tests, e.g. Barlow's test (Barlow,1966), referred 45 infants compared to 5 referred by the ultrasonographers. Forty two of the 45 children referred by the paeditricians were then classified as normal by ultrasound scanning. Berman and Klenerman raise the point that current tests may diagnose children as having problem hips when in fact given time, they would develop normally, as had those followed up in their study. They also question the safety of the standard tests, as they have been put forward as a possible cause of hip dislocation at a later date.

Infants and children diagnosed with hip dysfunctions fall in the category of patients who require regular and frequent monitoring (Suzuki et al 1987). In view of the current concern about radiation exposure for any person, the use of ultrasound must be seen as advantageous.

7.4.2 Method - comments

As the method for all scanning was described in the previous sections, comments only are made here. The orientation of the ultrasound probe was over the anterior aspect of the right hip with the probe in the longitudinal position. A standard A-P view X-ray was taken. The two images are in fact set orthogonally to one another, a fact which must be remembered in the discussion of results. Good visualisation of the hip was achieved.

Measurements were taken across what appeared to be the "joint margins" from both types of image. Four groups of 10 scores were taken for both systems, using the X-ray and data from the sets of ultrasound images recorded.

Results - comments

The hip joint was clearly imaged on the ultrasound scan. Table 7.2 gives the Means (X), Standard Deviation (SD) and Coefficient of

Fig. 7-2a Right hip

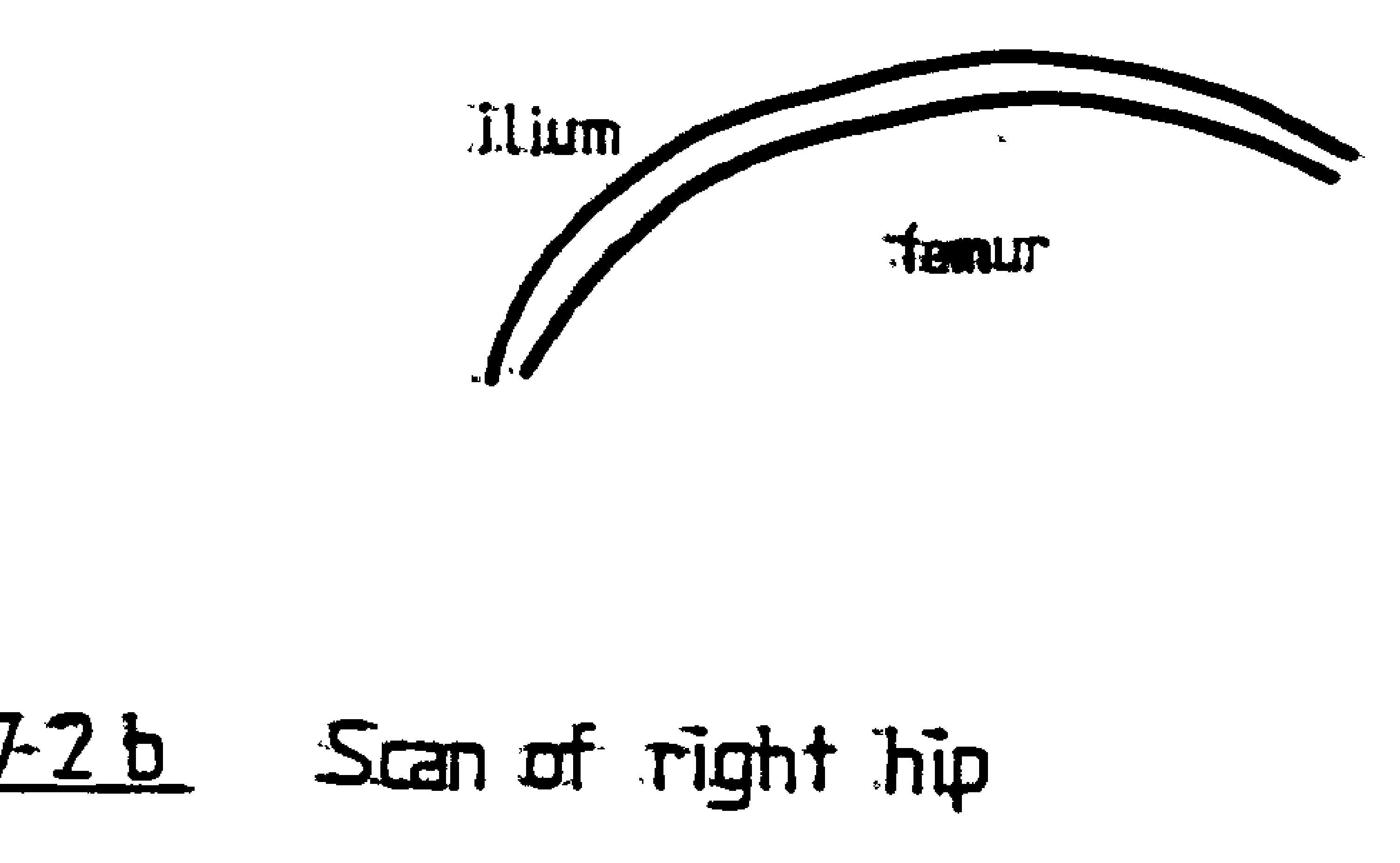


Fig. 7-2b Scan of right hip

Fig.7.2a Right hip

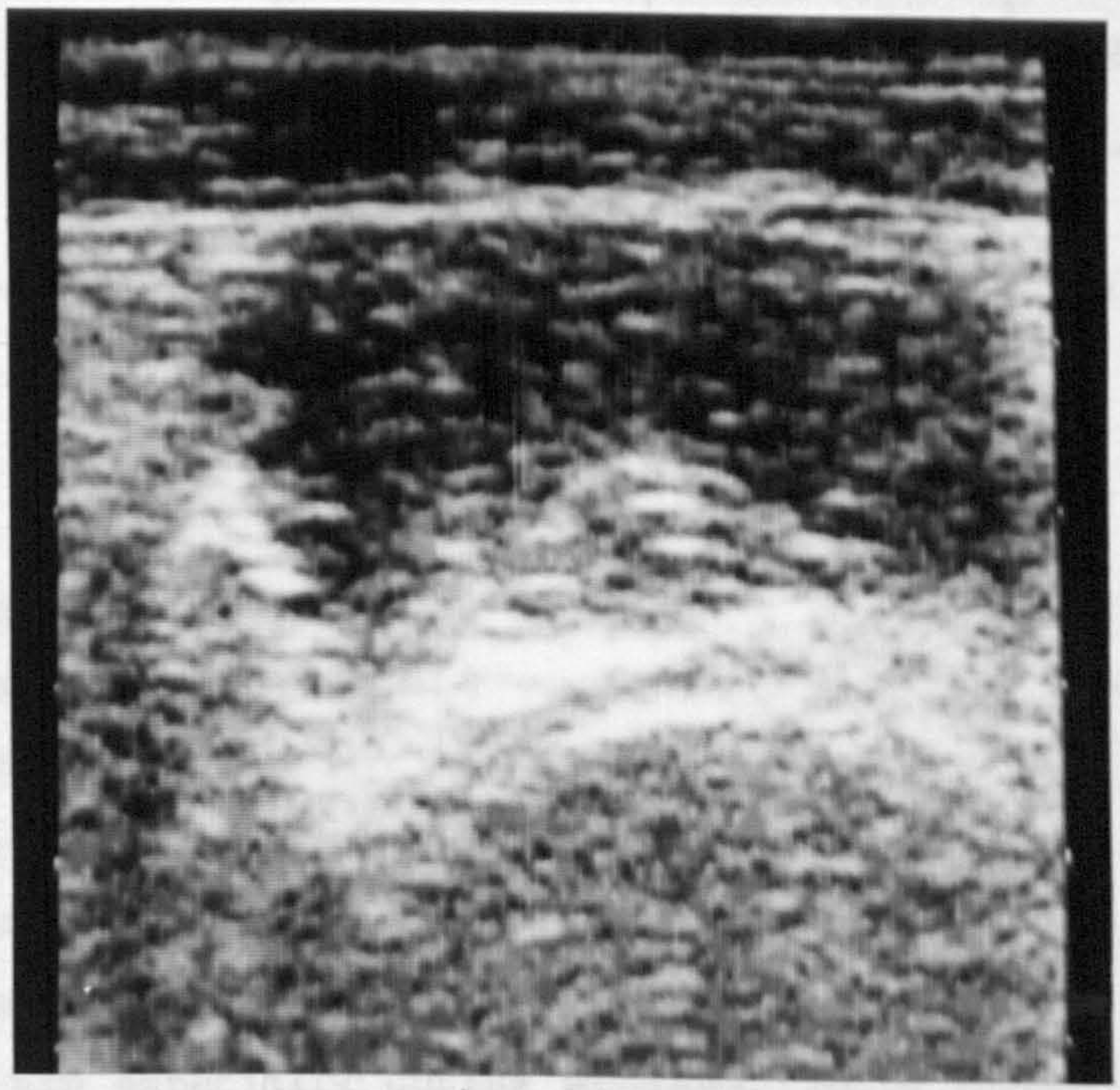


Fig.7.2b Scan of Right hip

Fig. 7.2a Right hip

Fig.7.2a Right hip

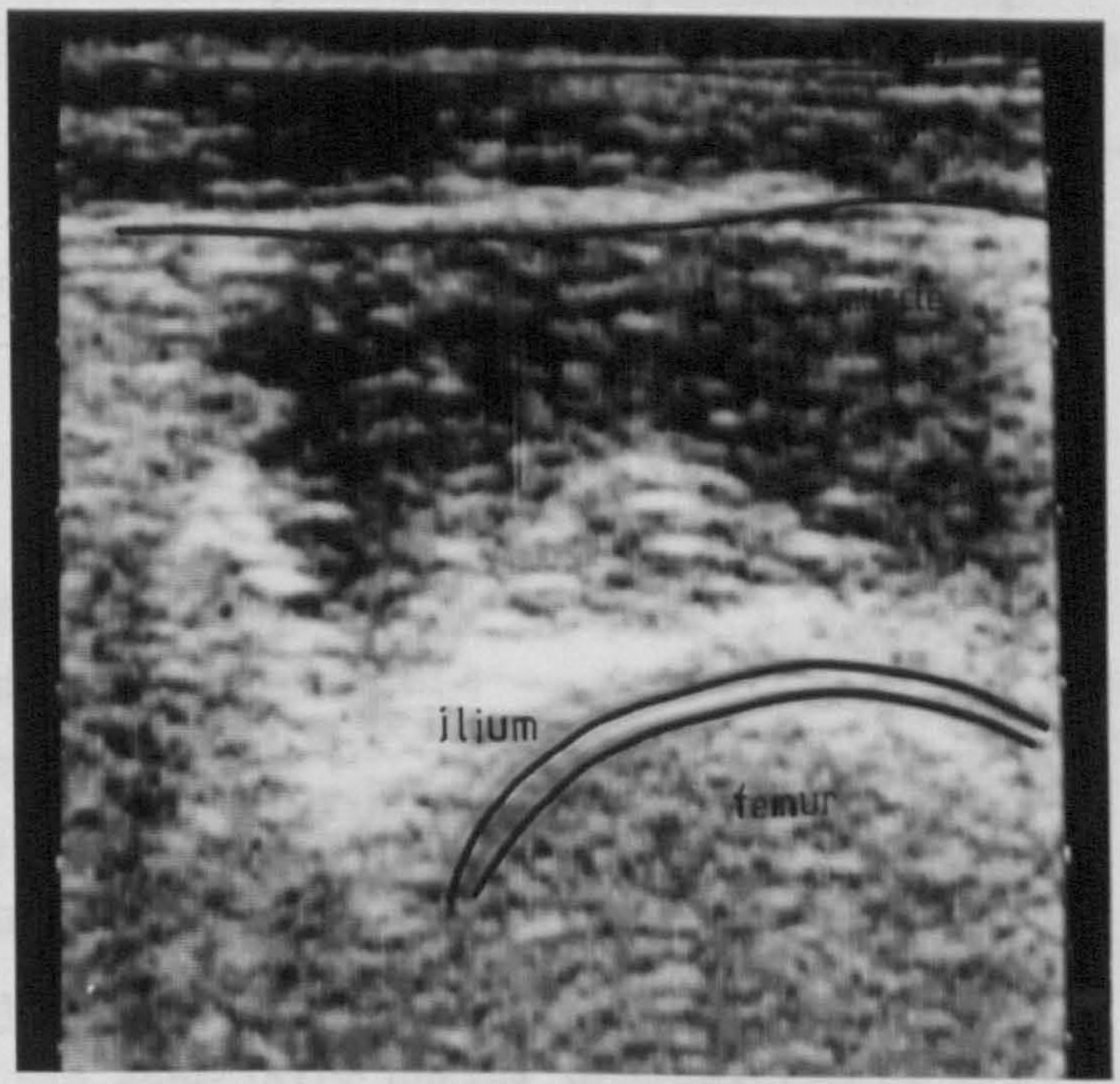


Fig. 7-2 b Scan of right hip

Fig.7.2b Scan of Right hip

Variance (CV%) for each of the 10 scores in each of the 4 groups.

To consider the mean scores for each of the 4 groups both in X-ray and ultrasound gives an indication of the range of the scores compared to one another. Some spread is evident between the 4 groups for the two systems.

All X-Ray scores were pooled as were the scores for the US and "t" test for two independent samples was used to test for significant difference between the two systems. Results of the test indicate that at the 0.05 level, the "t" value (1.833) was less than the "t" critical value (1.943) so the null hypothesis, that there is no significant difference between measures taken from the two images is held as true.

	1		II		III		IV	
	X-RAY	US	X-RAY	US	X-RAY	US	X-RAY	US
$\bar{x}$	3.780	2.170	3.514	2.485	3.540	3.740	3.409	3.200
SD	0.205	0.170	0.139	0.558	0.110	0.200	0.175	0.340
CV%	5.430	8.236	3.950	2.245	3.104	5.740	4.333	10.492

Table 7.2

Measurements across the [R] hip joint (adult male), comparing X-ray to US statistical results.

Conclusions

Both methods will image the hip joint. Despite the difference in orientation of the images structures could easily be identified. Measurements were taken across the "joint", and good agreement was achieved between the two methods of scanning.

The ease with which the scans were obtained and the ability to image the hip especially during movement could enhance the use of US for imaging the joint. Its further application in this area may be of clinical benefit.

7.5 IMAGING OF THE SHOULDER

7.5.1 Introduction and Literature Review

The ability of ultrasound to image the soft tissues around a joint has led to its application in the diagnosis of soft tissue problems at the shoulder joint (Middleton et al,1985a,b; Harland, 1987). X-ray diagnosis is important for the exclusion of frank bony disease or fractures, but the complex soft tissue structures at the joint are not visible, and are frequently at fault. Clinical diagnosis is often difficult. Arthrography has also been used for the diagnosis of soft tissue damage (Middleton et al,1985a), but it is invasive and requires serial radiographs to be taken.

Real-time scanning allows the immediate inspection of the joint and its surrounding soft tissues. Ultrasound scanning of the biceps tendon and the rotator cuff tendon complex (Middleton et al, 1985a;1985b;1986a;1986b.), has demonstrated that specific structures can be identified and observed during movement. The complex nature of the area was also noted . The echo characteristics of tissues were seen to change after surgical intervention (Crass et al,1986), making definitive diagnosis difficult. The method of joint scanning described by Middleton et al,(1986a), was used to observe 20 shoulders, and to compare measurements made on ultrasound video and standard X-ray film.

7.5.2 Method - Comments

The right shoulder of a female subject was X-rayed (Fig. 7.3a), with the joint in the standard position for an anterior posterior film. The scanning method followed that of Middleton et al,(1986a) (Fig. 7.3b). To gain experience in the interpretation and gathering of shoulder US images, video data was gathered on ultrasound images of the shoulder by scanning the shoulders of 20 volunteers. None of the subjects had had injuries or pathology of the joint requiring medical attention. The optimum view of the shoulder in these circumstances was with the probe on the posterior-lateral aspect of the shoulder in the horizontal position. Once again the two images would be orthogonal.

Fig. 7-3a Right shoulder

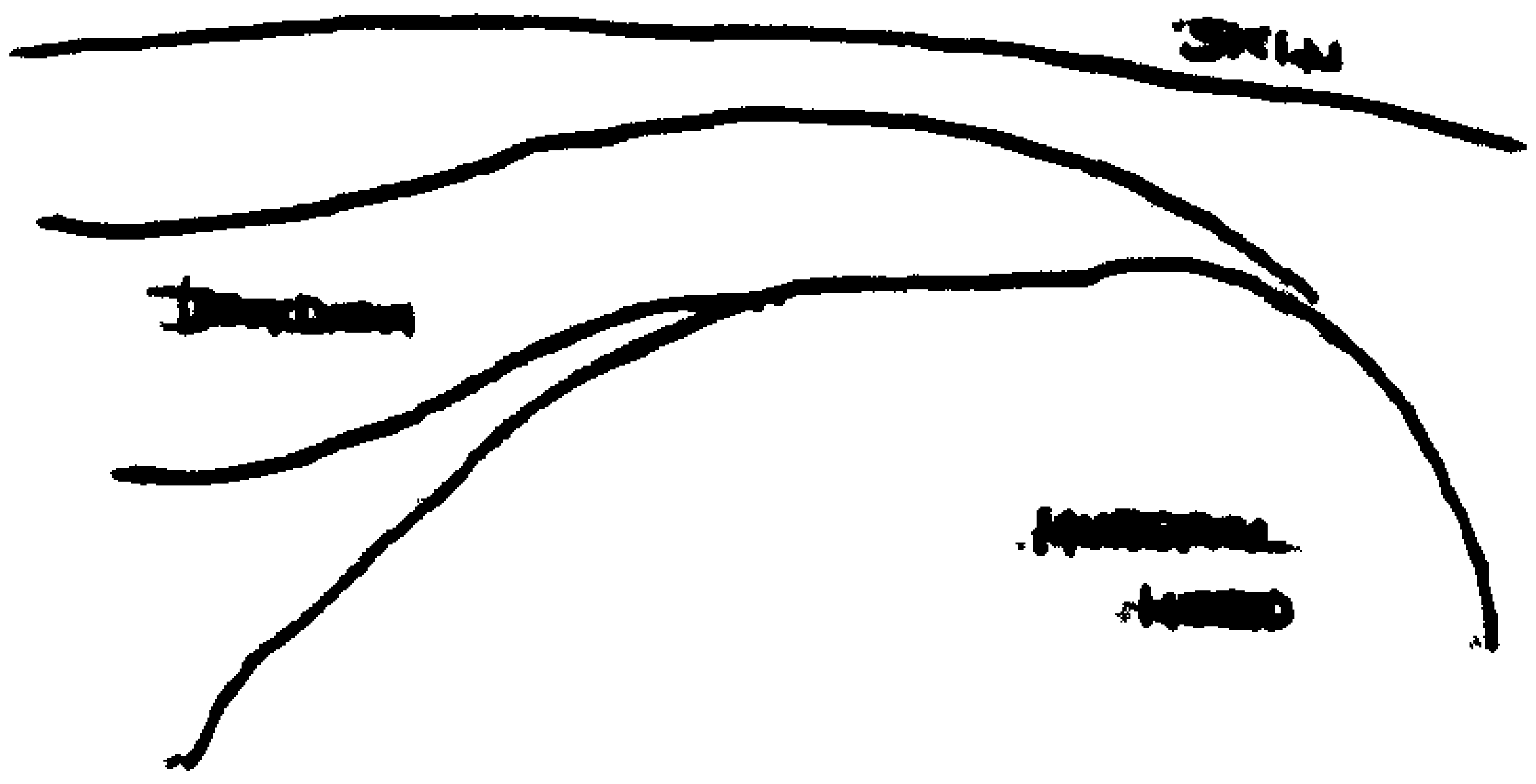


Fig. 7-3b Scan of right shoulder

Fig.7.3a Right shoulder

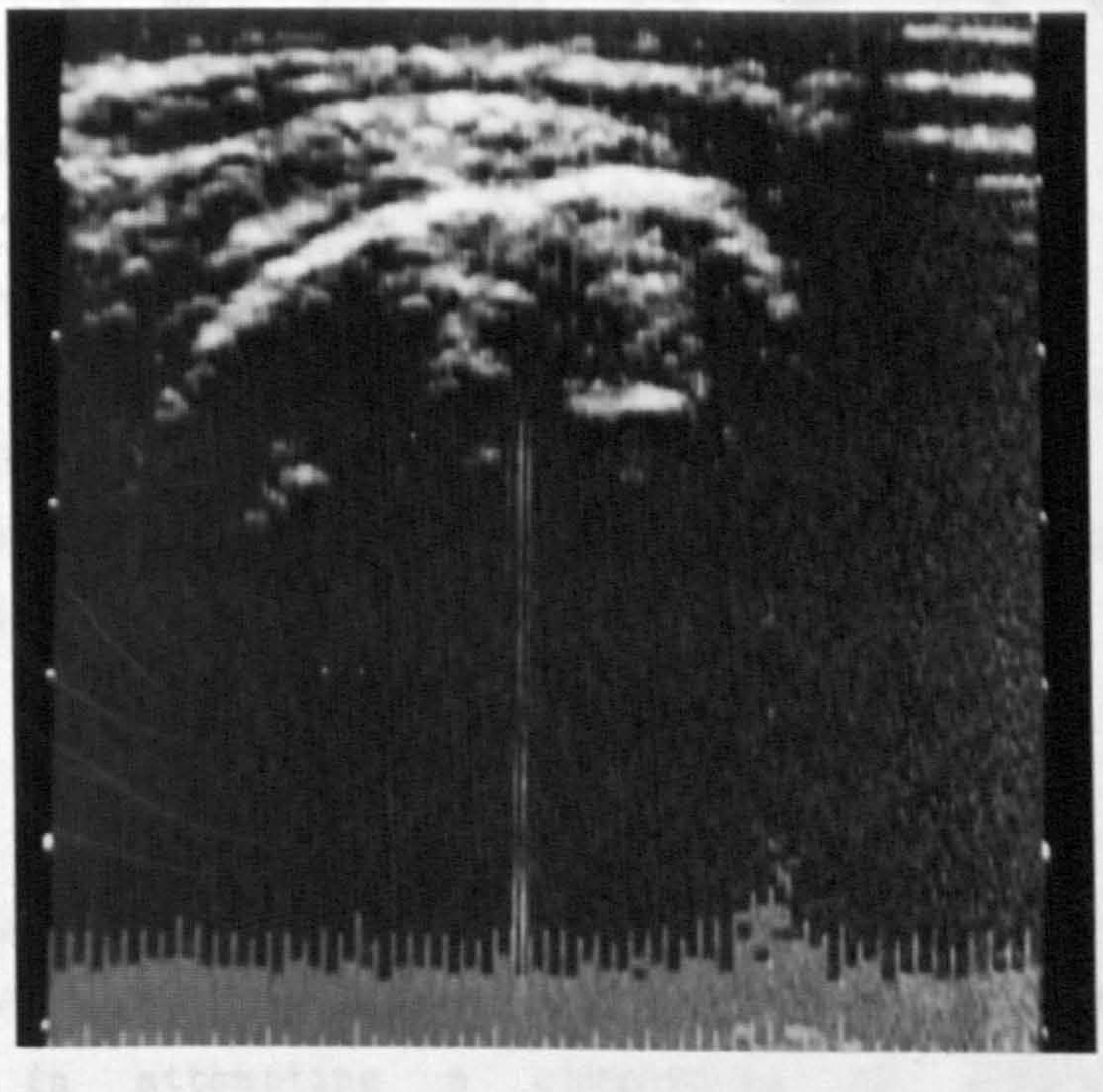


Fig.7.3b Scan of Right shoulder

Fig.7.3a Right shoulder

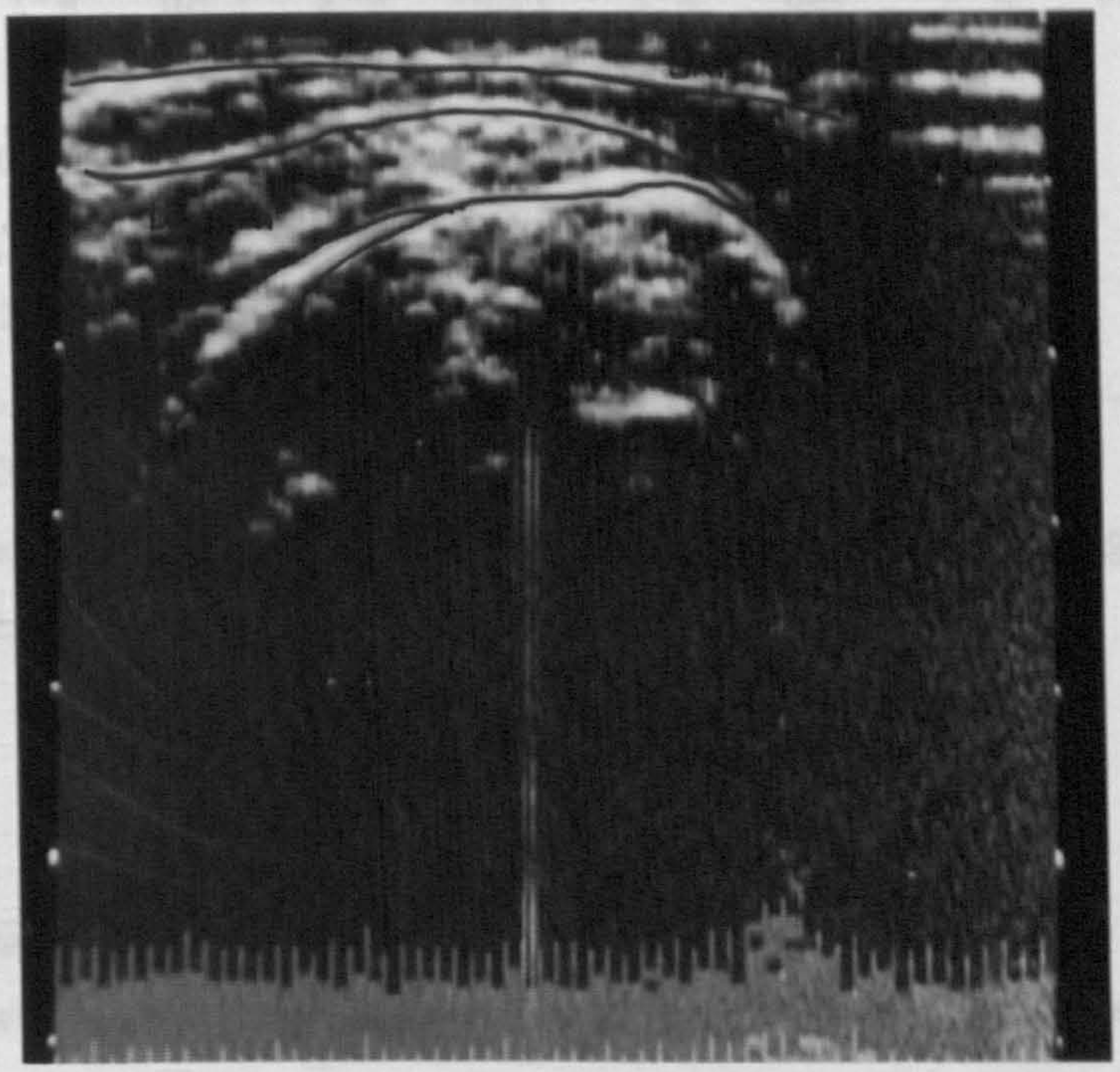


Fig. 7-3b Scan of right shoulder

Fig.7.3b Scan of Right shoulder

Results

An attempt was made to measure across the shoulder joint on the video and the X-ray. Ten readings were taken from the single X-ray and the series of scans. Five groups of ten scores were considered. .Results reflect the difficulty of determining the actual joint margins. The standard X-ray of the shoulder did not allow good visualisation of the joint or the glenoid labrum of the articulation.

Using the representative score (the mean of the 4 mean scores for each technique,(X-ray = 4.27 and US = 3.116) and the Means of the SD scores (0.201 and 0.276 respectively) "t" tests of independent samples,p= 0.05, detected a significant difference between results of the two methods of imaging the shoulder, the null hypothesis was rejected.

	I		II		III		IV		V	
	X-R	US	X-R	US	X-R	US	X-R	US	X-R	US
$\bar{X}$.	4.02	2.72	4.18	3.06	4.51	3.19	4.44	3.49	4.20	3.12
SD	0.33	0.49	0.31	0.44	0.19	0.36	0.36	0.40	0.35	0.49
CV%	8.18	17.80	7.52	14.41	4.28	11.32	8.07	11.32	8.27	15.72

Table 7.3.

Measurement across [R] shoulder joint, comparing X-ray to US statistical results.

Conclusions

The rotator cuff and biceps tendon could be seen as described by Middleton et al,(1986a), on the ultrasound scan. There was great difficulty in attempting a comparison of articular distance measurements from X-ray and ultrasound scan, using the conventional views. Both methods of imaging demonstrated high variability in their results.

Despite the rejection of the comparison of the two methods of measuring, interesting points were raised. The standard view (AP) of the shoulder may well be insufficient to make judgements on the joint condition or humeral head position. The use of US to image soft tissue at the shoulder could possibly be made use of in the assessment of soft tissue injuries. The ability to visualise the movement of soft tissues is of interest in some·shoulder conditions e.g.rotator cuff tears.

However, by using the more promising posterior approach to the joint, the measuring of intra-articular distances from ultrasound scans may be possible.

7.6 IMAGING OF THE KNEE

7.6.1 Introduction and Literature Review

Ultrasound scanning of the knee has primarily been undertaken to assist in the diagnosis of meniscal or ligament damage or to assess the state of the articular cartilage of the joint complex (Aisen et al,1984; Selby et al,1985).

Depending upon the tissue under investigation, the position of the probe would vary. One of the best views of the knee joint complex was found to be the "sky-line" view of the patello-femoral joint, with the knee in approximately 90° flexion, with the probe, horizontal, over the superior aspect of the patello-femoral joint. This view is similar to that used for X-rays of the patello-femoral joint. The patella is viewed lying over the femoral condyles.

The tibio-femoral joint was found difficult to image. Selby et al,(1985) used a posterior medial approach in an attempt to image the intra-articular structures. In this study little success was achieved from scanning the knee in any view but the "sky-line" view. This then was the view selected to ascertain if a comparison could be made between X-ray and ultrasound measurements.

Ultrasound scanning of the knee also allowed the imaging of the quadriceps muscle, patella tendon and lateral expansion and dynamic

Fig.7.4a Skyline view: right knee

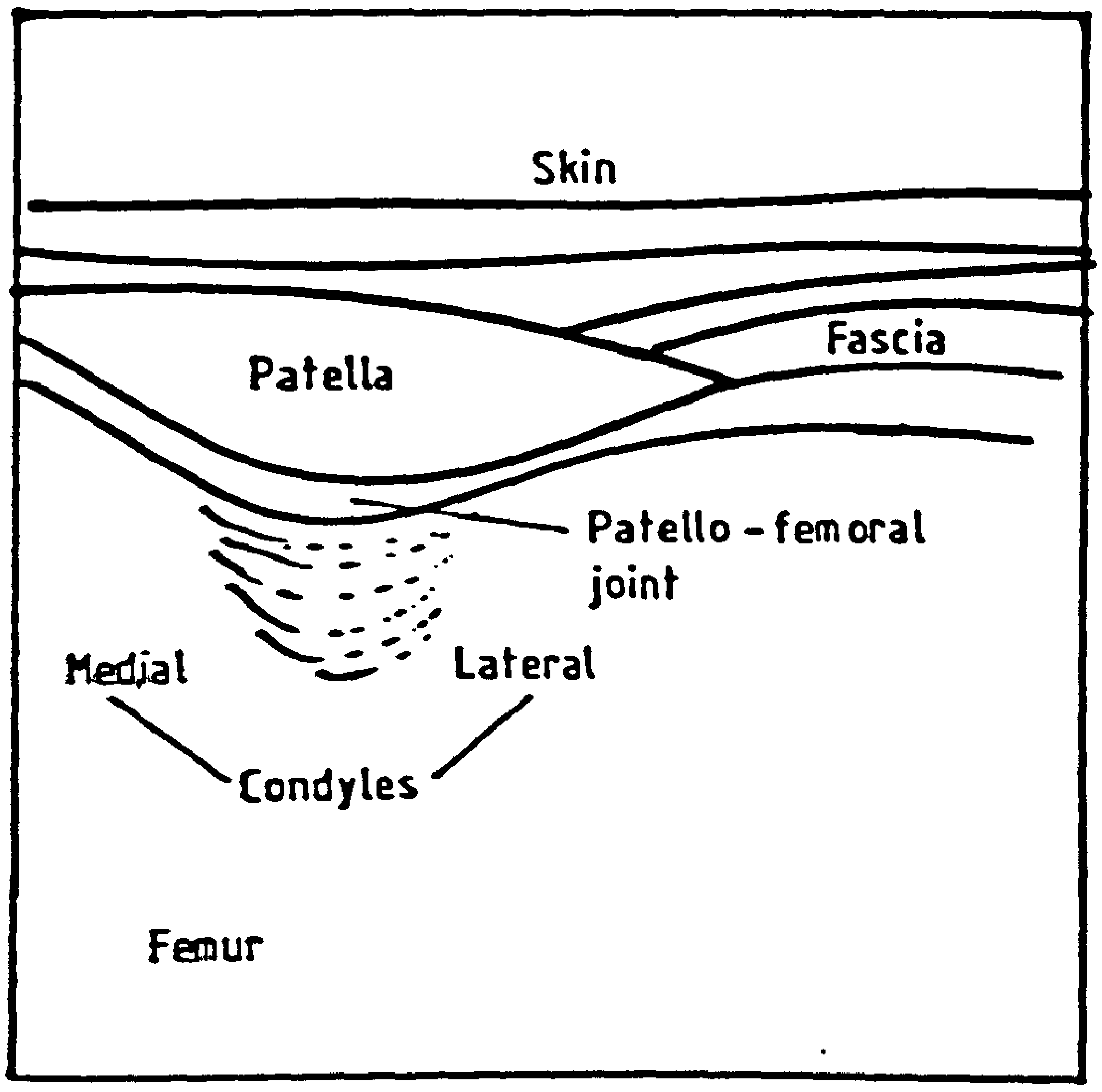


Fig.7.4.b Ultrasound scan right knee: skyline view

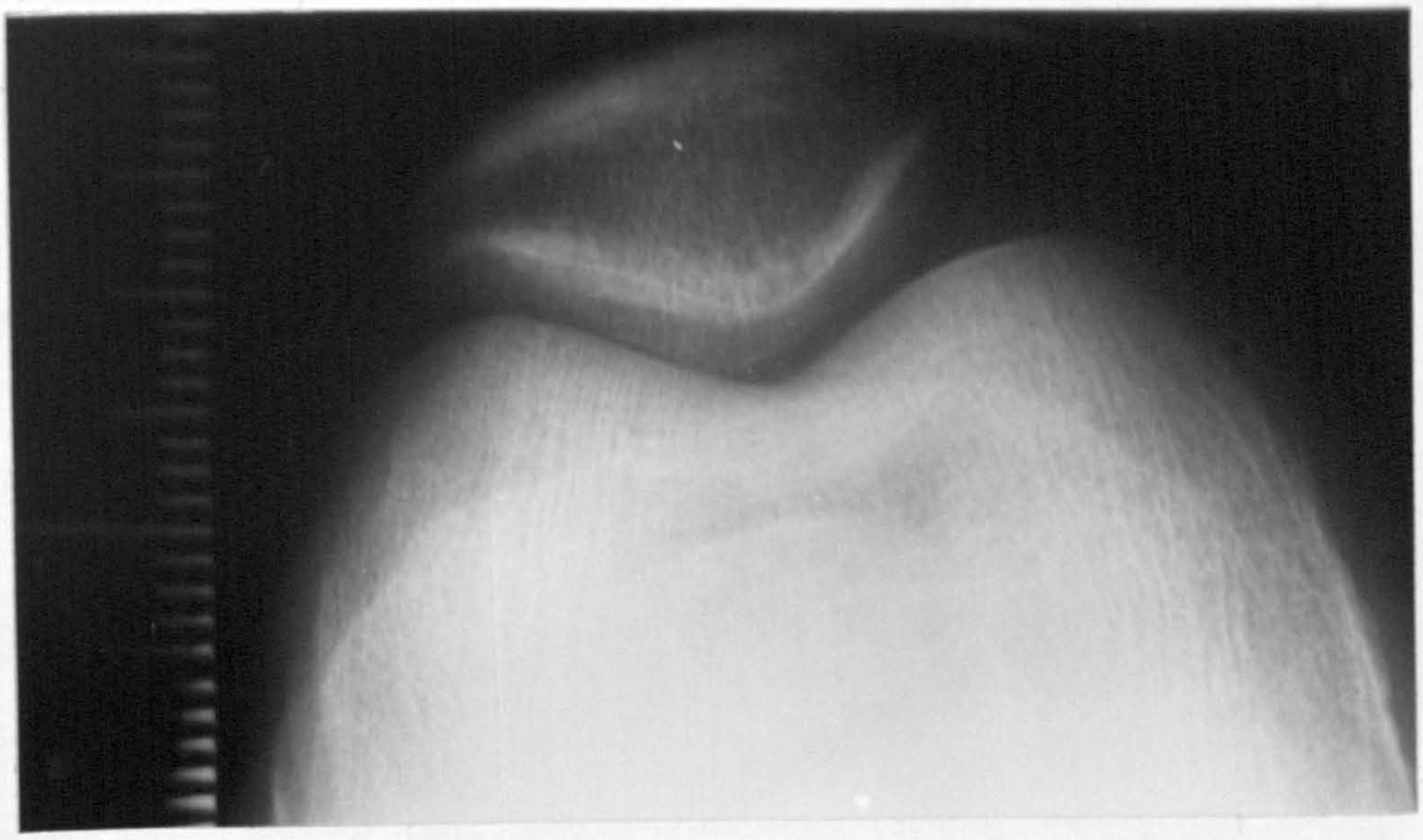


Fig.7.4 a Skyline view : right knee

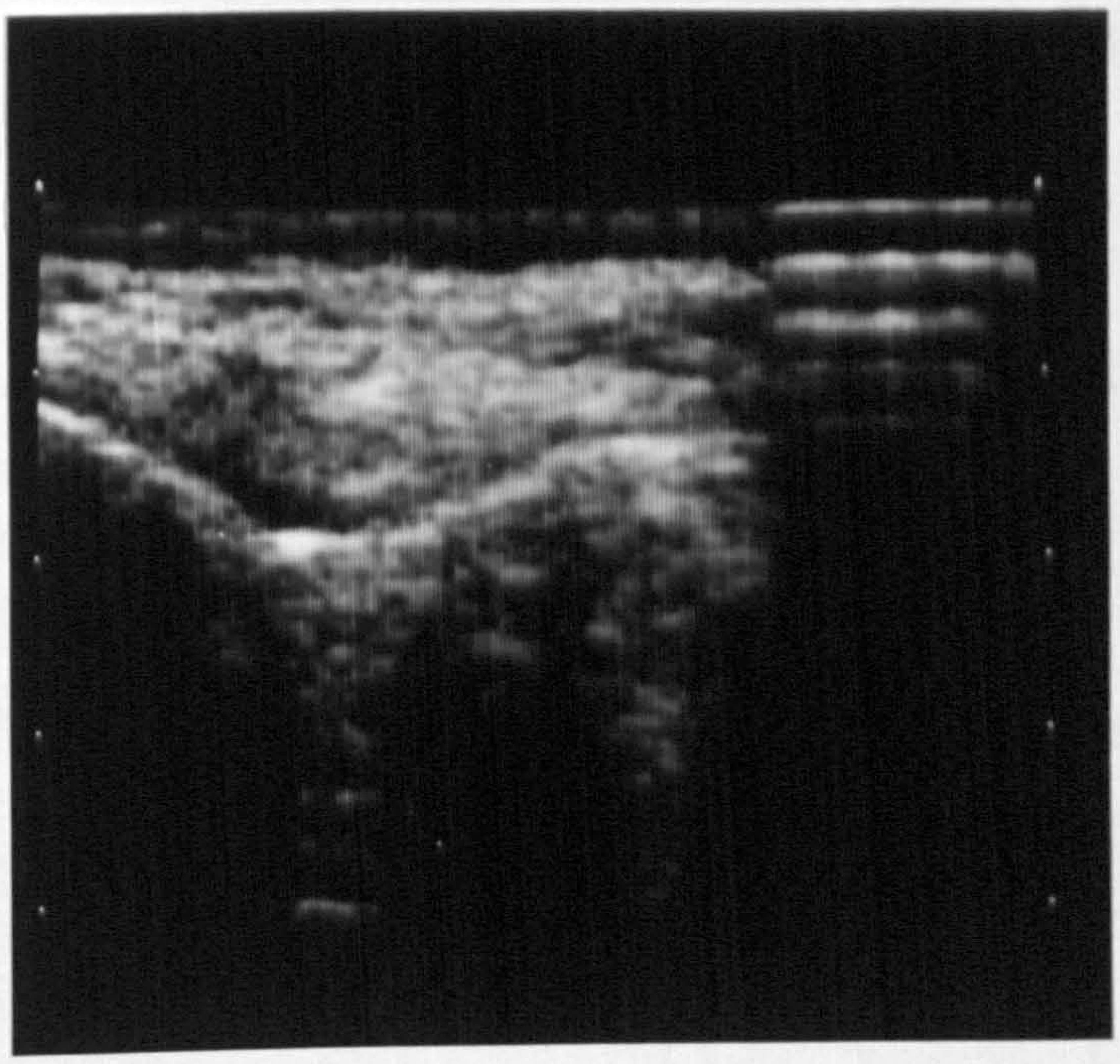


Fig.7.4b Ultrasound scan right knee : skyline view

Fig.7.4a Skyline view : right knee

Fig.7.4 a Skyline view : right knee

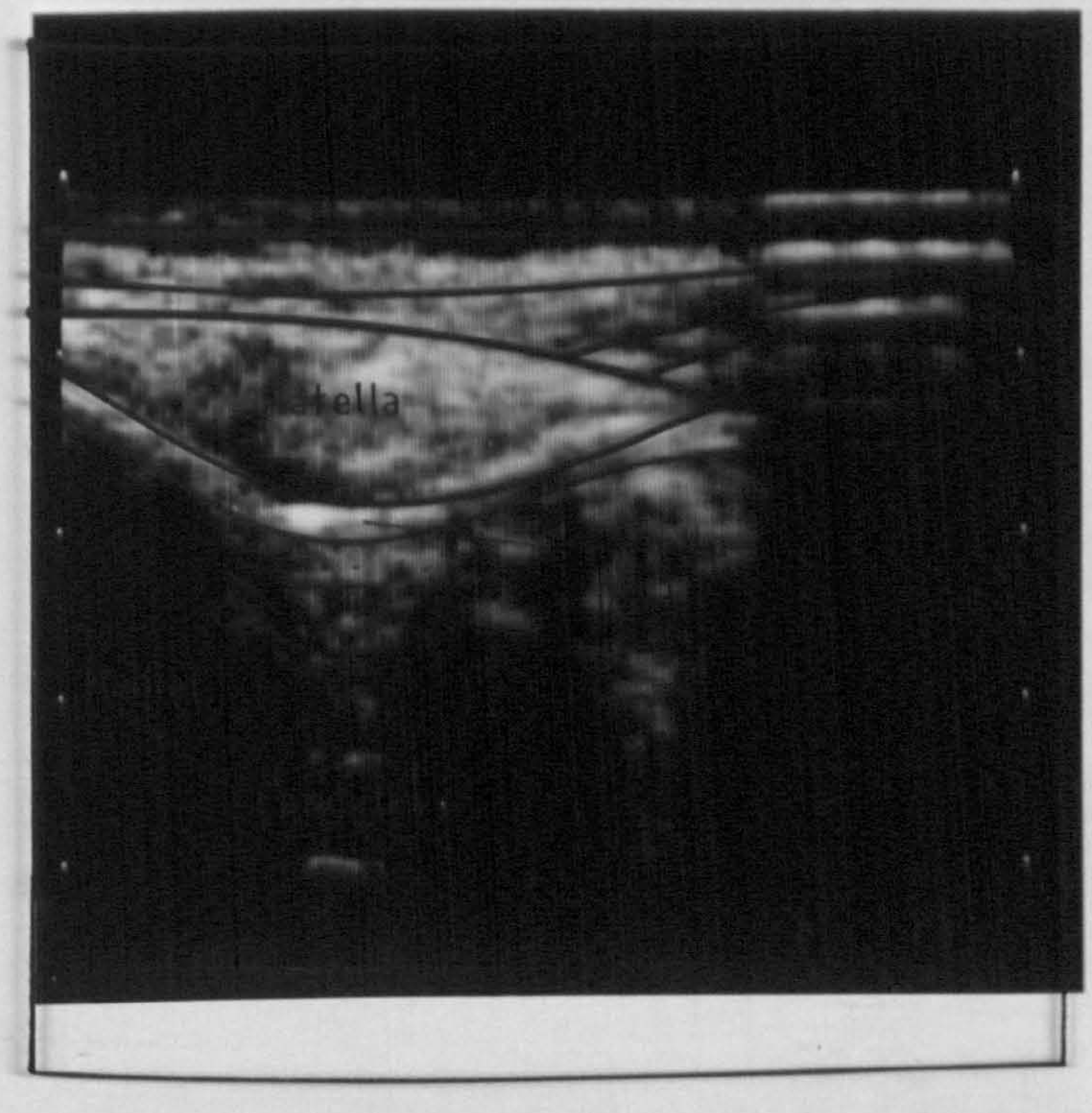


Fig.7.4.b Ultrasound scan right knee : skyline view

Fig.7.4b Ultrasound scan right knee : skyline view scanning of the patello-femoral joint with a static quadriceps action. Scanning at the the anterio-medial aspect of the joint line allowed visualisation of the articular fat pads. These at scanning, do resemble the menisci

7.6.2 Method - Comments

To achieve experience in knee scanning some 20 subjects had their right knee scanned in the manner described by Aisen et al,(1984) and Selby et al,(1985). No subject had any recent bony or soft tissue problems with the joint that had required surgical or medical intervention. One additional subject was scanned who presented with an acute effusion of the right knee following a sports injury.

Attempts were made to image the the joint line on the lateral and medial aspects of the knee. The "sky-line" view was also used for the patello-femoral joint. An attempt was made to image the menisci from the anterior and posterior aspects of the joint line. While scanning the knee, use was made of a propriety stand-off medium (3M Kitecho ®) and a waterbag, in an effort to improve the image quality of superficial structures. The amount of improvement did not warrant the continued use of any stand-off media. Contact gel only was used in the standard scanning procedures.

The right knee of an adult male was X-rayed in the sky-line position (Fig. 7.4a). After being X-rayed the knee was then scanned using the scanner described previously (Fig. 7.4b). Ten scans were taken of the joint. Measurements were taken from videos of the scans and also from the X-rays as described previously.

Results

Four groups of 10 readings were made using the two techniques. Comparing across the two techniques, and againg making use of the combined mean scores for Means (6.05 for X-ray and 3.77 for US) and combined scores for SD (0.256 and 1.42 respectively) a "t" test of two independent samples could be used to test the null hypothesis.At $p= 0.05$ level, the null hypothesis had to be rejected. For this joint, the difference in measurements gave the X-ray scores consistently higher than the ultrasound scores.

	I		II		III		IV	
	X-R	US	X-R	US	X-R	US	X-R	US
$\bar{X}$	6.20	2.91	6.26	5.90	6.06	3.26	5.69	3.02
SD	0.39	0.18	0.37	0.30	0.33	0.29	0.31	0.38
CV%	6.25	6.33	5.90	10.45	5.40	8.94	5.47	12.65

Table 7.4.

Measurements across the [R] knee patello-femoral joint (sky-line view), comparing X-ray to US statistical results.

Conclusions

Experience gained from scanning of the 20 subjects, suggested that the "sky-line" view of the patello-femoral joint was the easiest to obtain and the most informative. Views of the joint at the medial and lateral margins proved very difficult as acoustic shadows from the femoral condyles obscured the joint structures. At this stage imaging of the intra-articular structures was not the thrust of the study. The knee joint was not found as easy to investigate as had been anticipated.

One difference between results of the ultrasound scan and X-ray results may be due to the problem of selecting a definite articular line from which to make measurements. This is true for both types of images. The skyline view of the patella also has the problem of image overlap and therefore before making clinical judgements from this view on X-ray, the problem of boundary definition must be appreciated.

Whilst scanning the knee joint the opportunity was taken to image the quadriceps muscle and the soft tissues around the joint. All components of the quadriceps muscle were easily visible in longitudinal and cross section views. When the subject was asked to statically contract the muscle, the activity of the mucscle fibres could be seen in both views of the thigh. Different body types were noted to give different quality of scans. Adipose tissue

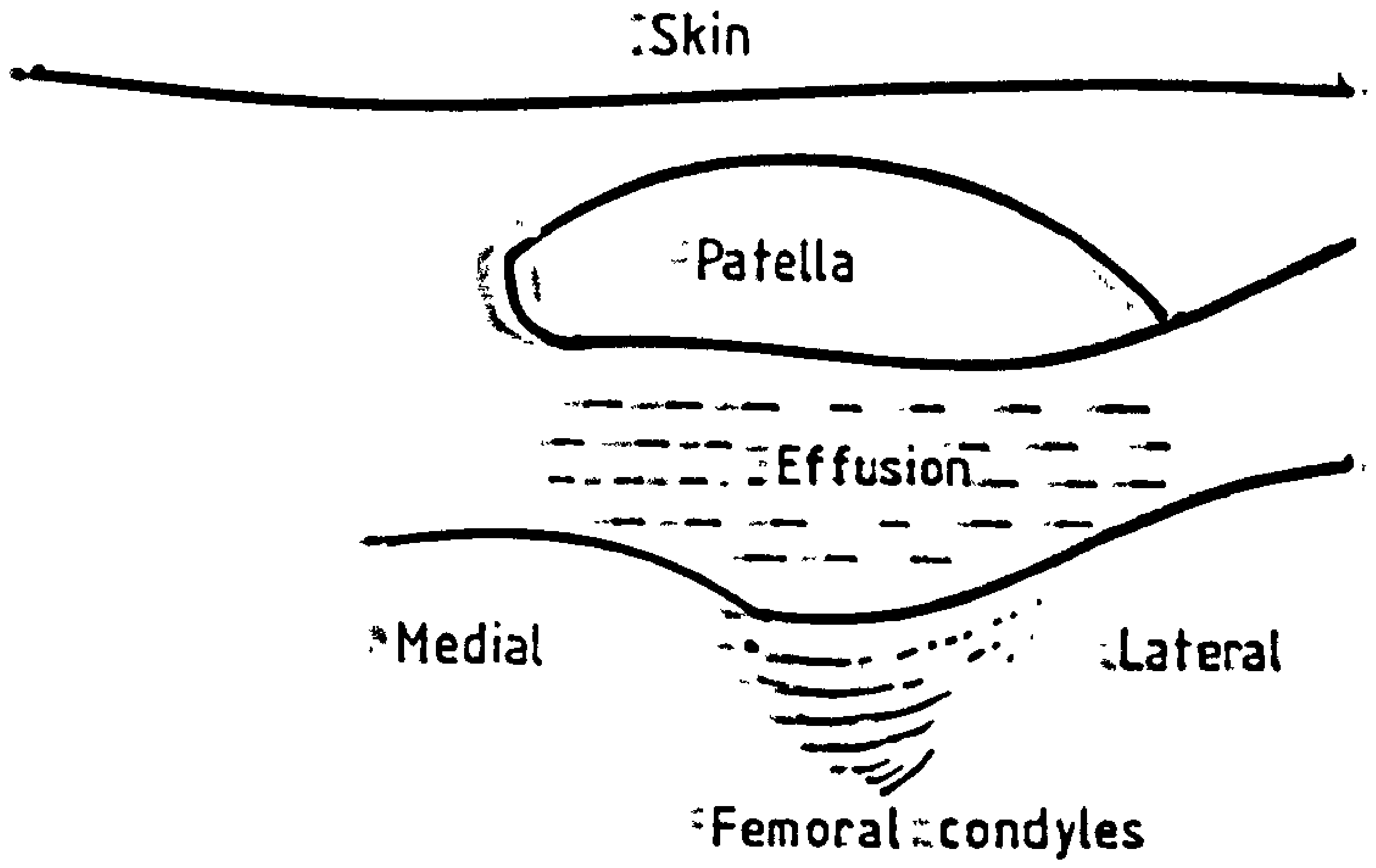


Fig.7.5.a Right knee with effusion

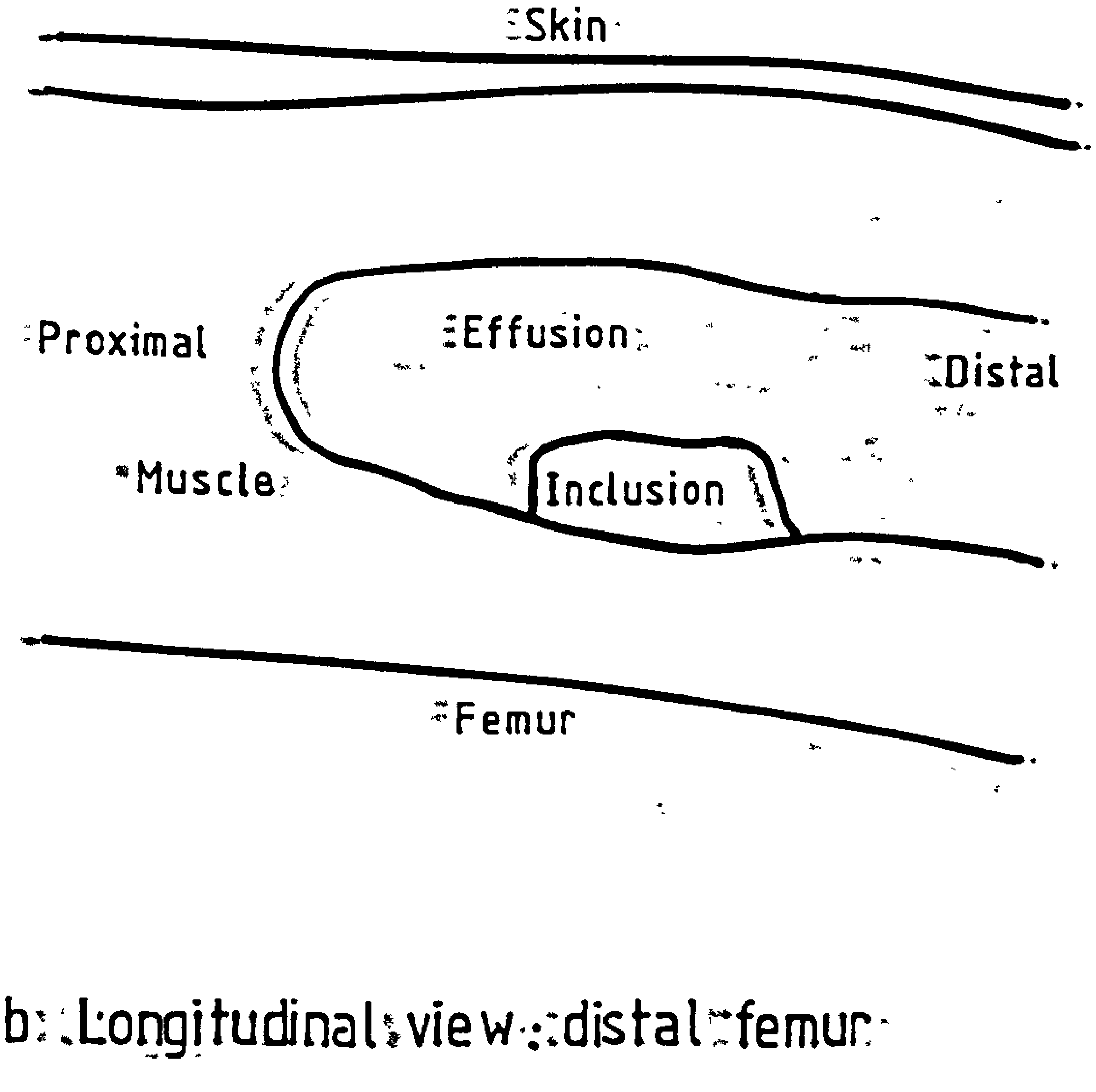


Fig.7.5.b Longitudinal view distal femur

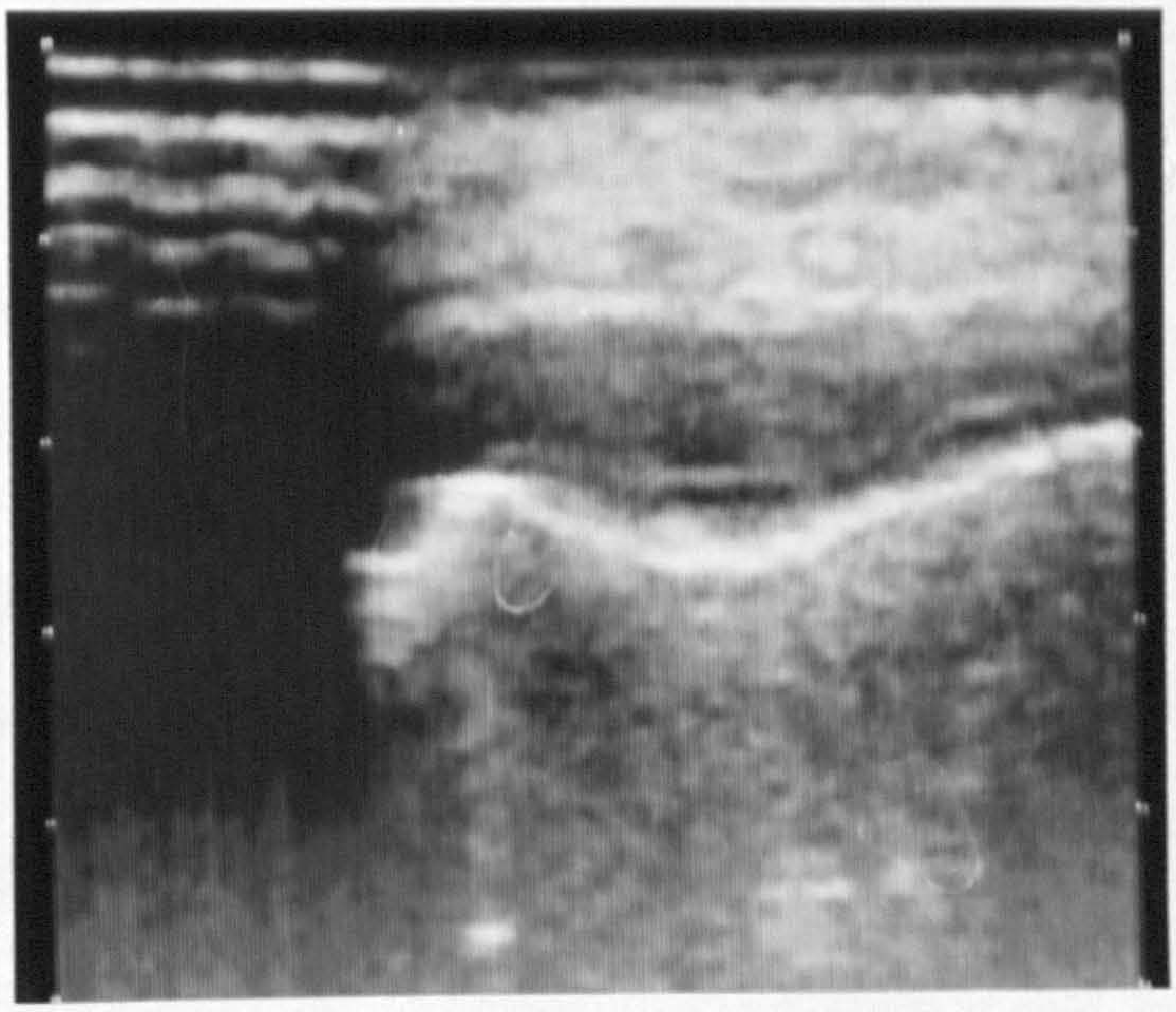


Fig.7.5 a Right knee with effusion

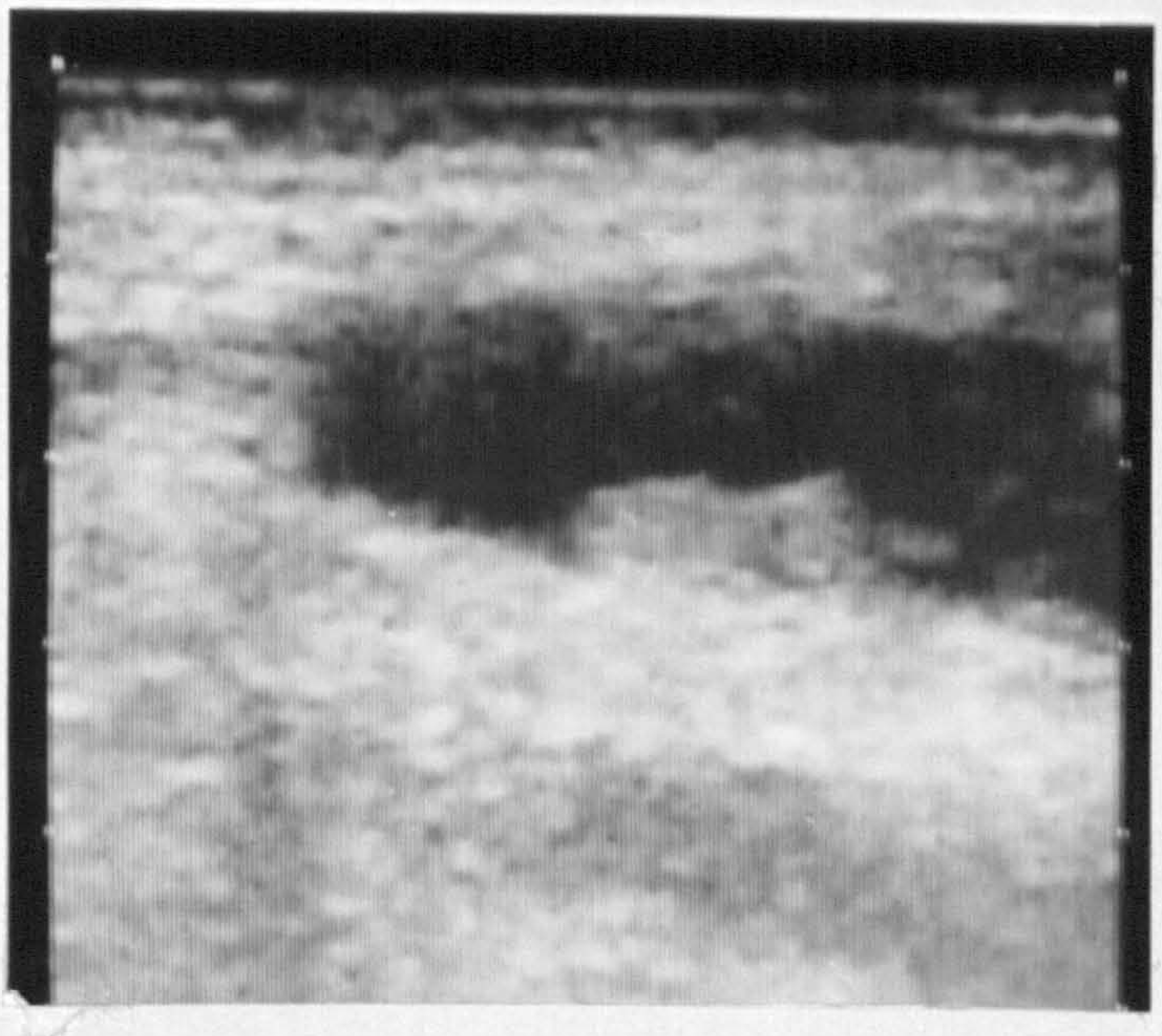


Fig. 7.5 b Longitudinal view : distal femur

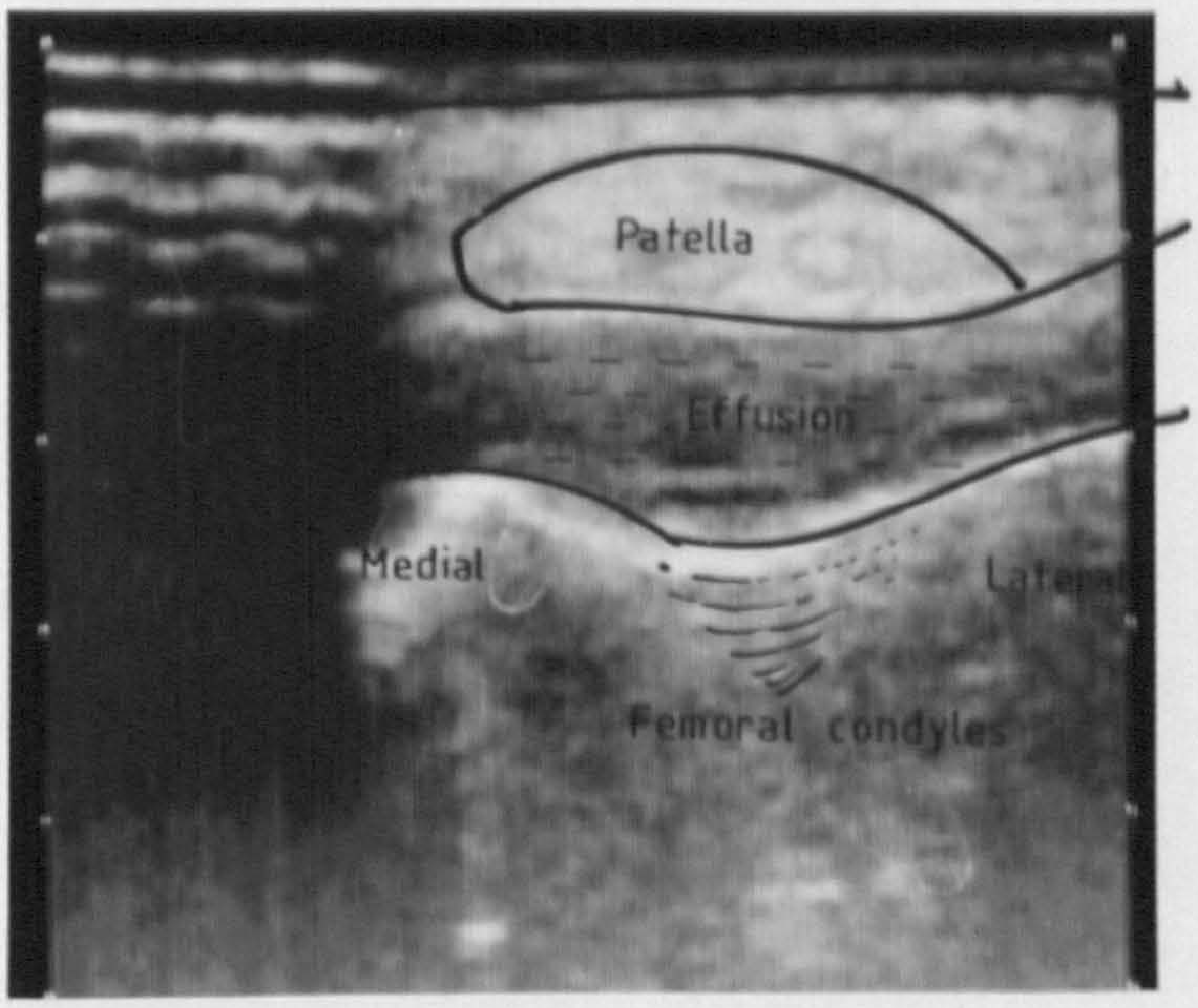


Fig.7.5.a Right knee with effusion

Fig.7.5 a Right knee with effusion

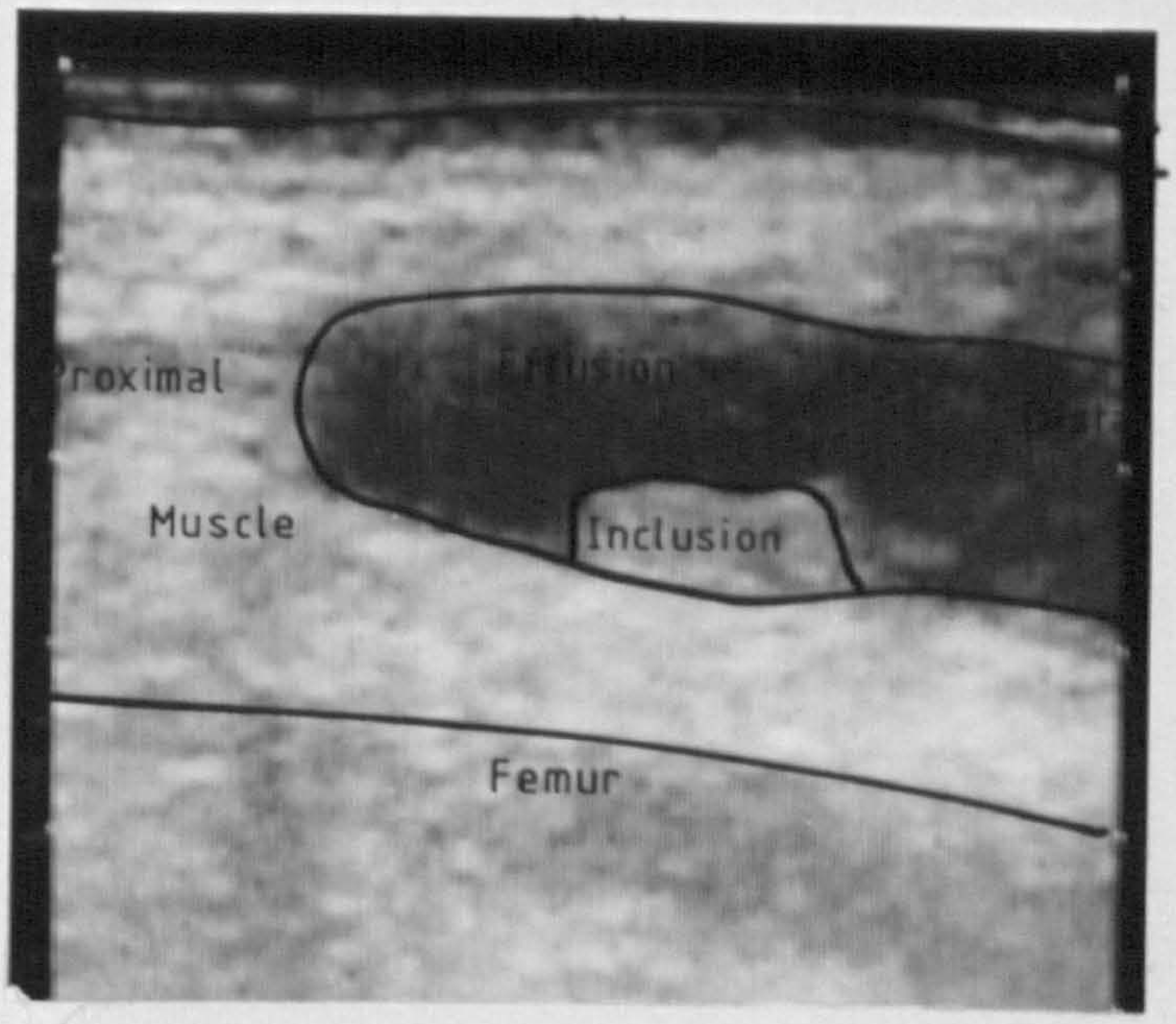


Fig.7.5.b Longitudinal view: distal femur

Fig.7.5 b Longitudinal view: distal femur

reduced the quality of the image. An example of knee joint with an effusion was also recorded (Fig. 7.5a). The effusion being demonstrated as a dense but well defined anechoic shadow (Fig. 7.5b) in a position consistent with the supra-patella pouch. Movement of fluid within the bursa was observed. The effusion was also visable on the scan when the knee was scanned from the posterior aspect.

With current equipment the patello-femoral joint of the knee was found to be the best for study. The articular margins of the joint were well defined. The quality of the echo as a possible indication of the state of the cartilage was not investigated in this study. Comparison between two methods (X-ray and US) of measuring across the patello-femoral joint, with the knee in 90° flexion, were made and significant differences were found between the scores.

7.7 IMAGING OF THE ELBOW

7.7.1 Introduction

There appears to have been little interest in the use of ultrasound for scanning the elbow joint, which, considering its accessibility, is unusual. The complex joint is susceptible to soft tissue damage and disease processes. The standard X-ray techniques would not always be able to demonstrate the presence of effusion or tissue disruption. The ability of ultrasound to scan a problem joint, in a comfortable, non invasive manner,would seem to be advantageous.

7.7.2 Method - Comments

The right elbows of 20 subjects were scanned for practice. All joints were normal. The joints were scanned with the probe in the longitudinal postion over the humero-radial joint, then in the transverse plane across the same joint and thirdly,transversely

Fig7.6a Anterior–posterior view - right elbow

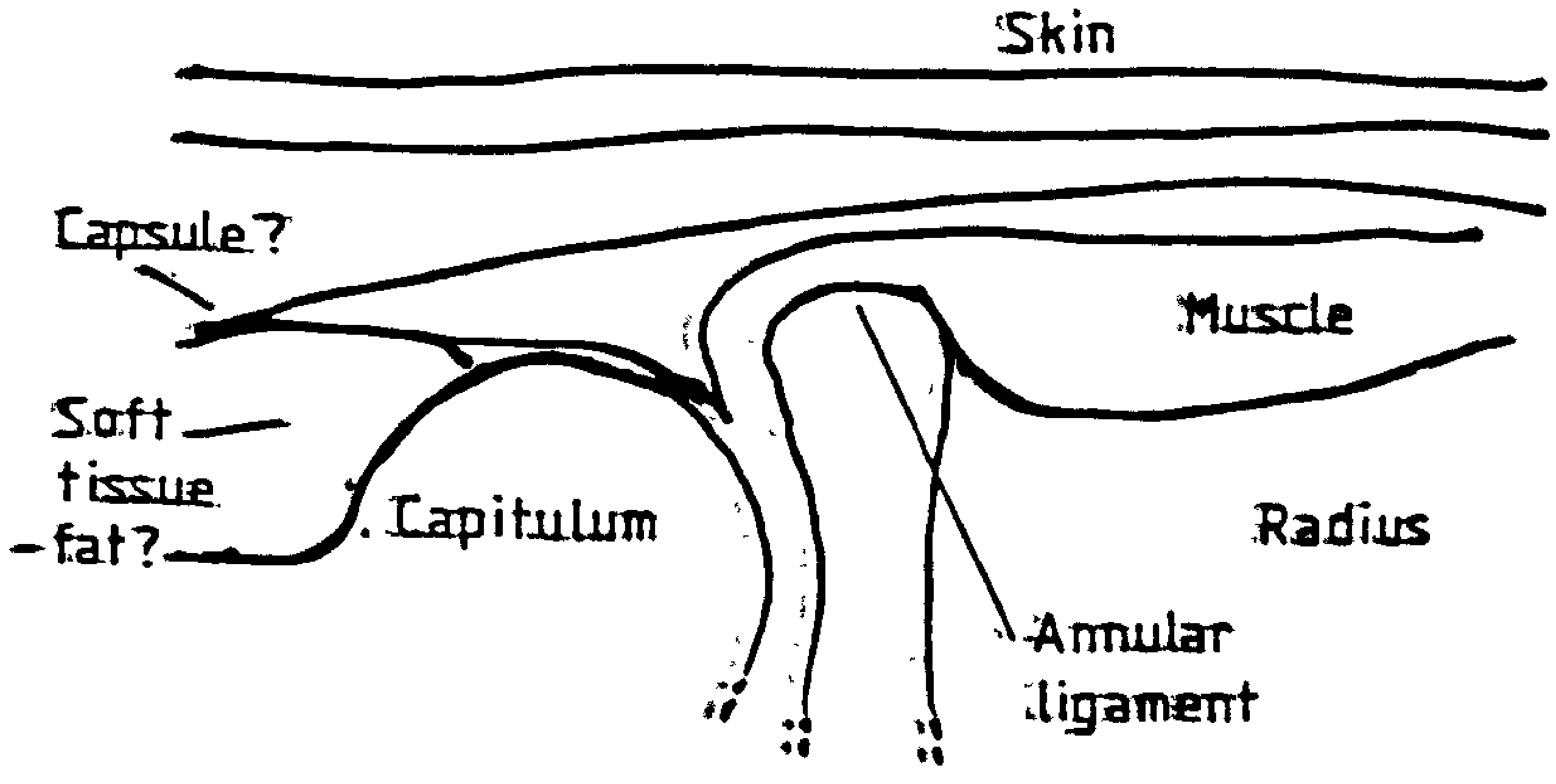


Fig7.6b Ultrasound scan right elbow

Fig.7. 6.a Anterior - posterior view : right elbow

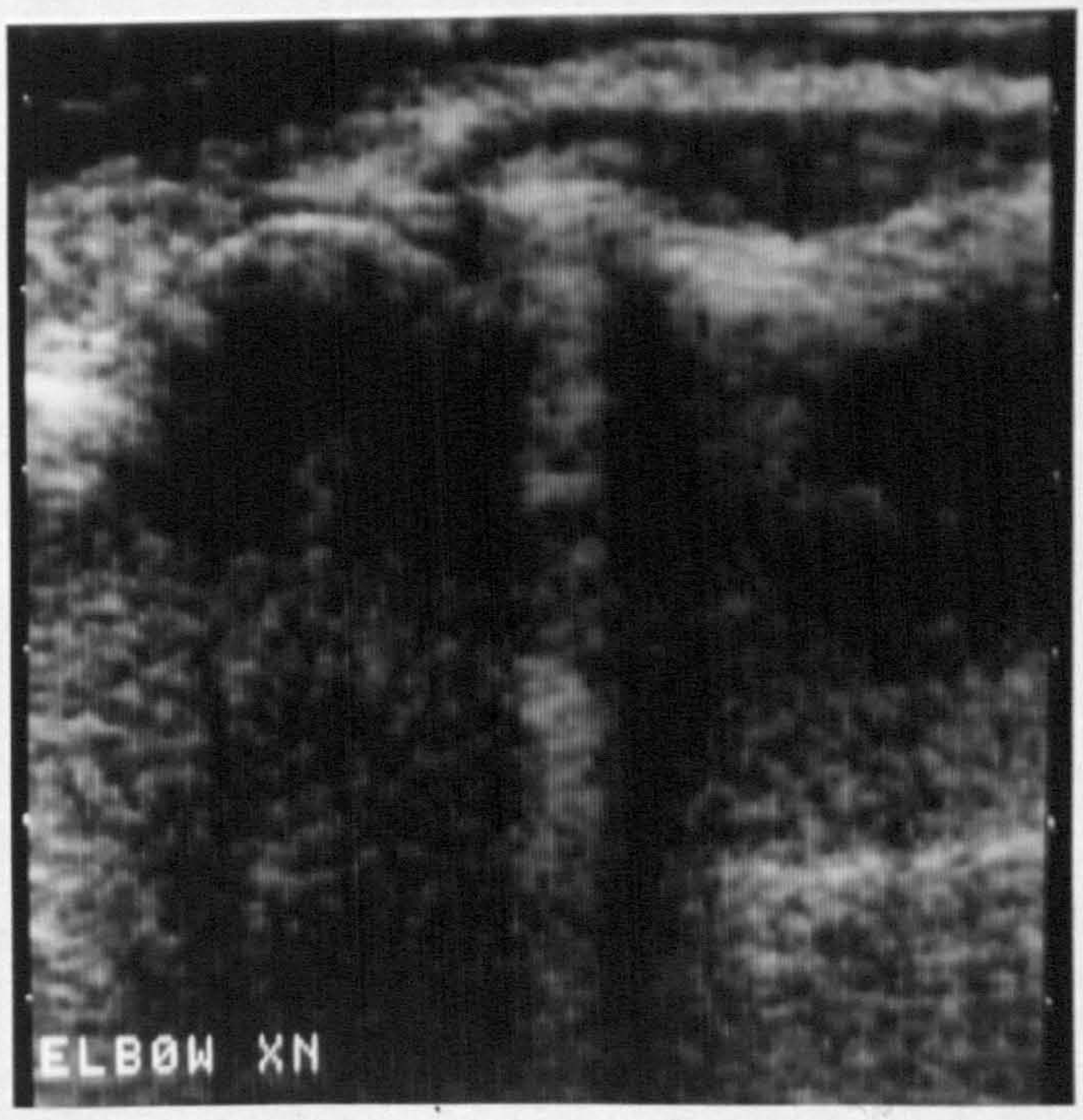


Fig.7. 6.b Ultrasound scan : right elbow

Fig.7.6.a Anterior - posterior view : right elbow

Fig.7. 6.a Anterior - posterior view : right elbow

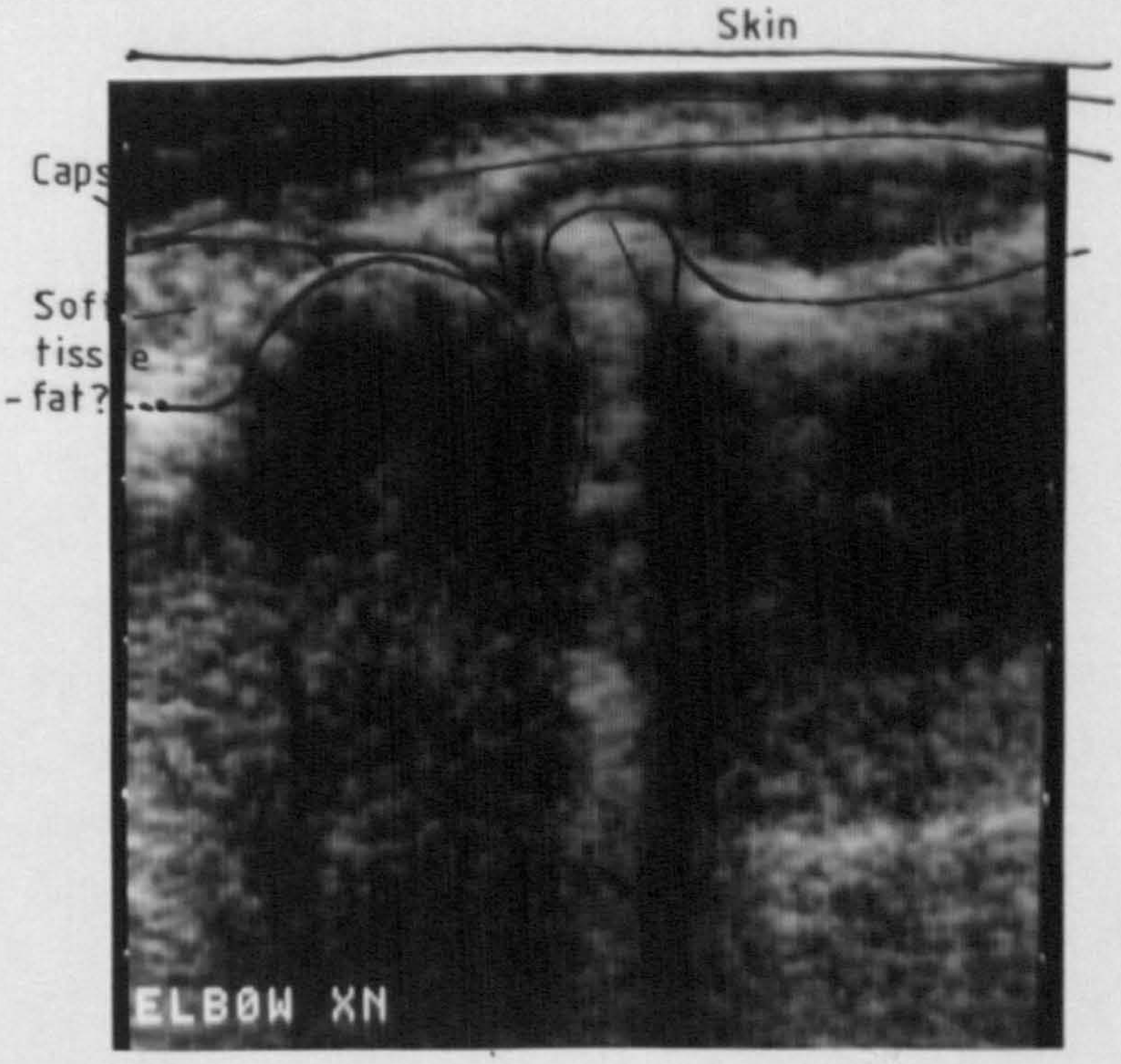


Fig.7.6.b Ultrasound scan right elbow

Fig.7. 6.b Ultrasound scan : right elbow

across the entire elbow joint, the arm in the supinated position. Results were recorded for later analysis.

One subject had the right elbow X-rayed in the standard position for an antero-posterior view of the joint (Fig. 7.6a). . The elbow was then scanned 10 times using both the longitudinal and horizontal views of the humero-radial joint (Fig. 7.6b). Measurements of the distance across the joint space were taken from the ultrasound scans and the X-ray. The elbow joint, radius, ulna and interosseous membrane were observed during pronation / supination (Fig. 7.7 a & b), however movements were not measured.

Results

Measurements from this joint, comparing ultrasound and the X-ray, demonstrated the most agreement of any of the peripheral joints scanned. When the radio-humeral joint was scanned in the longitudinal position, only one, of the four sets of 10 measurements, showed a significant difference at the p= 0.05 level. Therefore the null hypothesis, that there was no significant difference between the methods of measuring, was accepted in 3 of the 4 sets of results.

Using a "t" test on two independent samples at the same p= 0.05 significance level, the relationship between the two imaging methods was additionally tested. Combined mean scores for the 4 groups were ;- X-ray, 2.83 and US 2.703 and their respective SD combined mean scores were 0.041 and 0.241 .

When the joint was scanned in the horizontal plane then there was little agreement between the four sets of results. Three of the 4 rejected the null hypothesis. When re tested using the "t" test as before the same result was obtained that the null hypothesis was rejected, indicating a significant difference in the two methods of imaging. However even in these groups the SD was also low (0.12-0.36) but the CV% was higher than expected and cannot be explained(4.86-16.59).

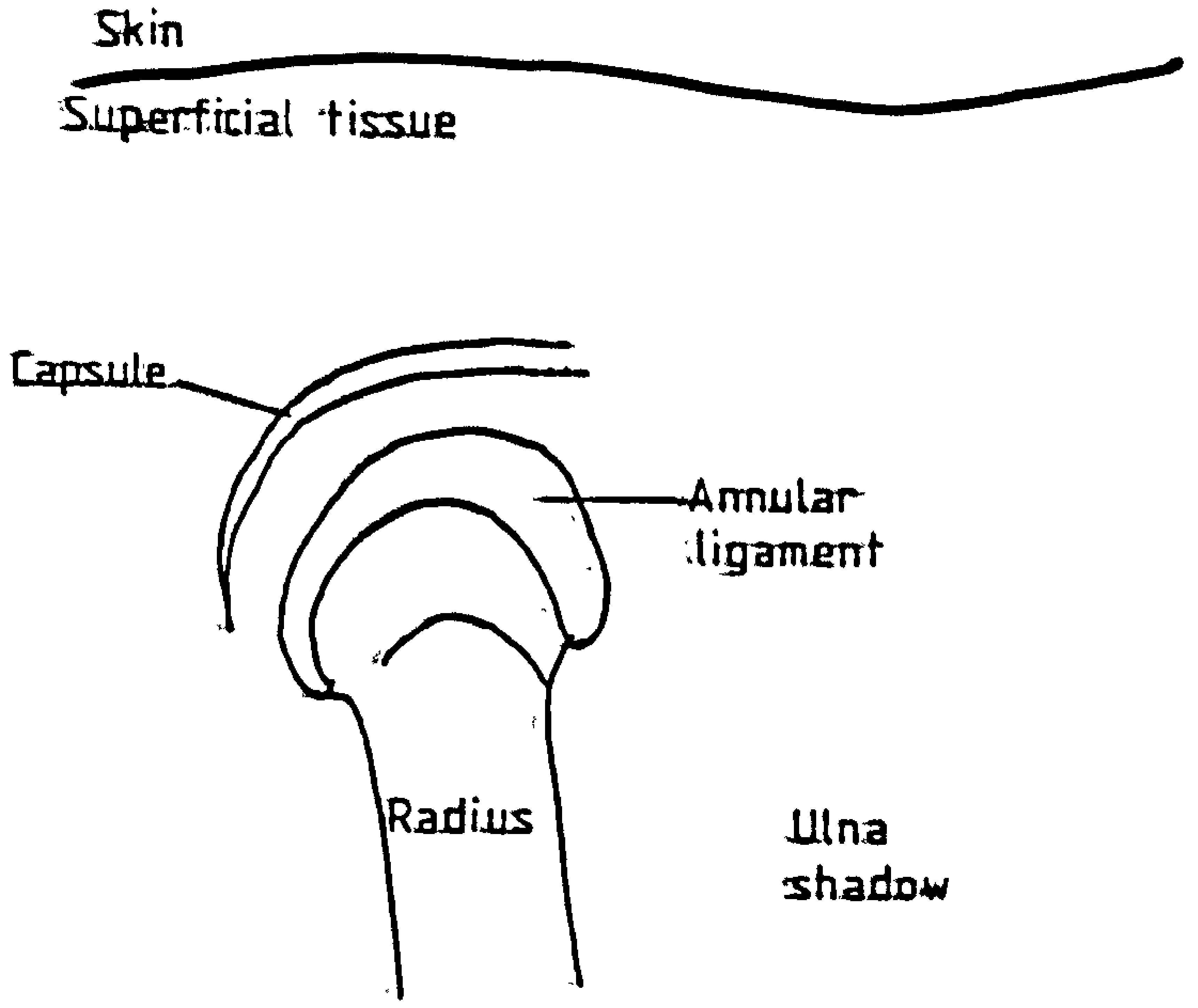


Fig7.7a Anterior aspect radial head – Supination

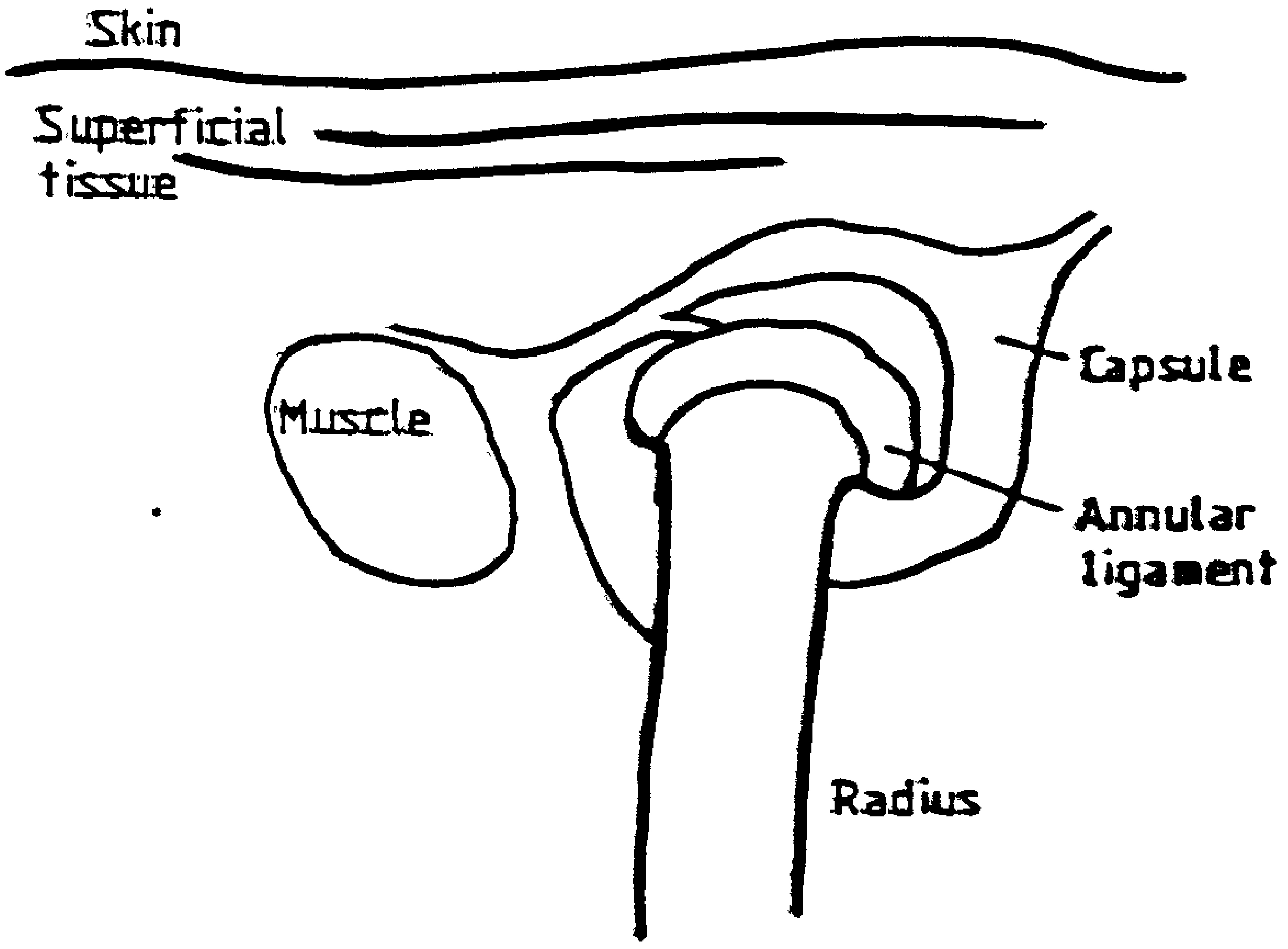


Fig7.7.b Radial head – Pronation

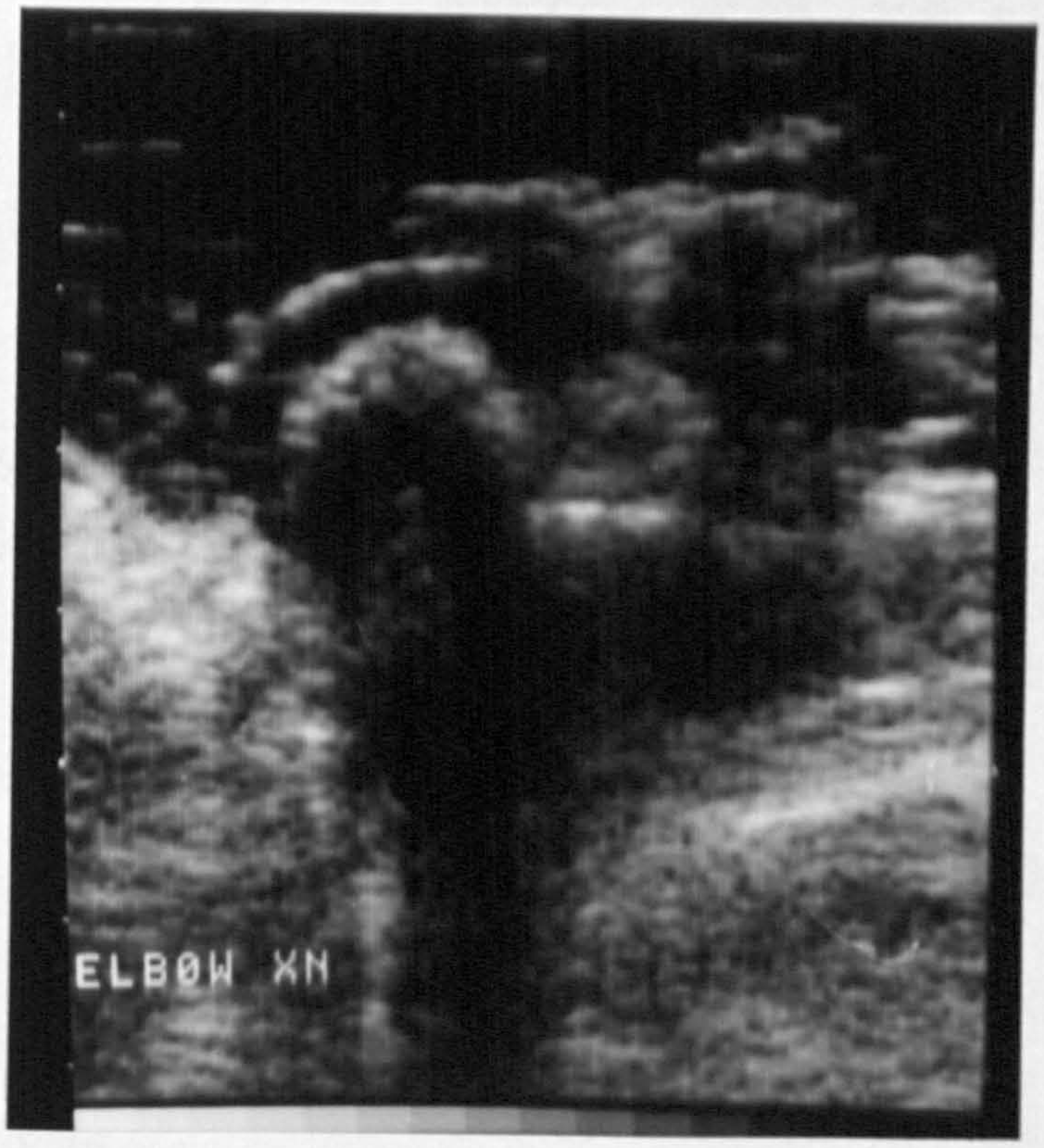


Fig.7.7 a Anterior aspect radial head - Supination

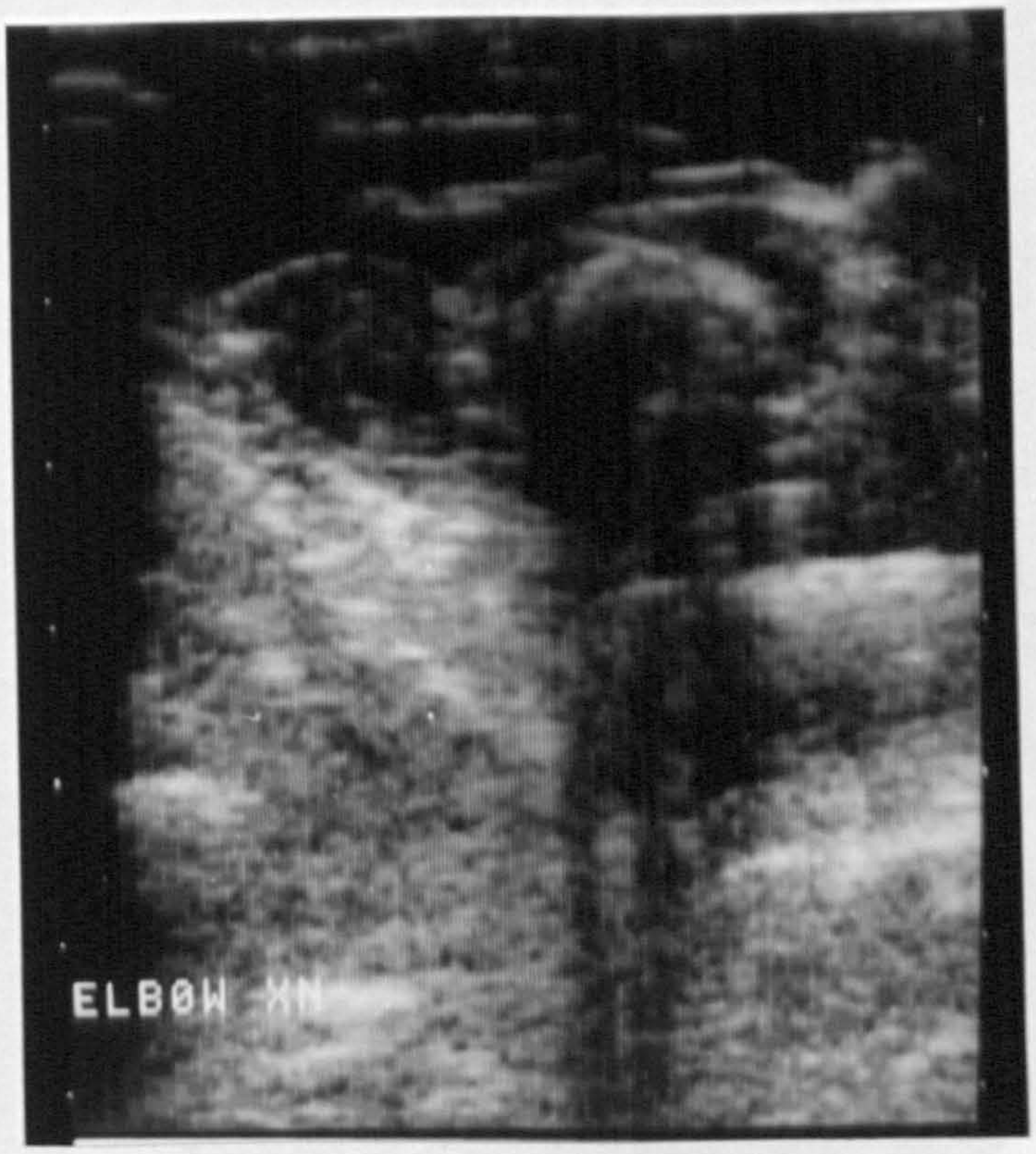


Fig.7.7 b Radial head - Pronation

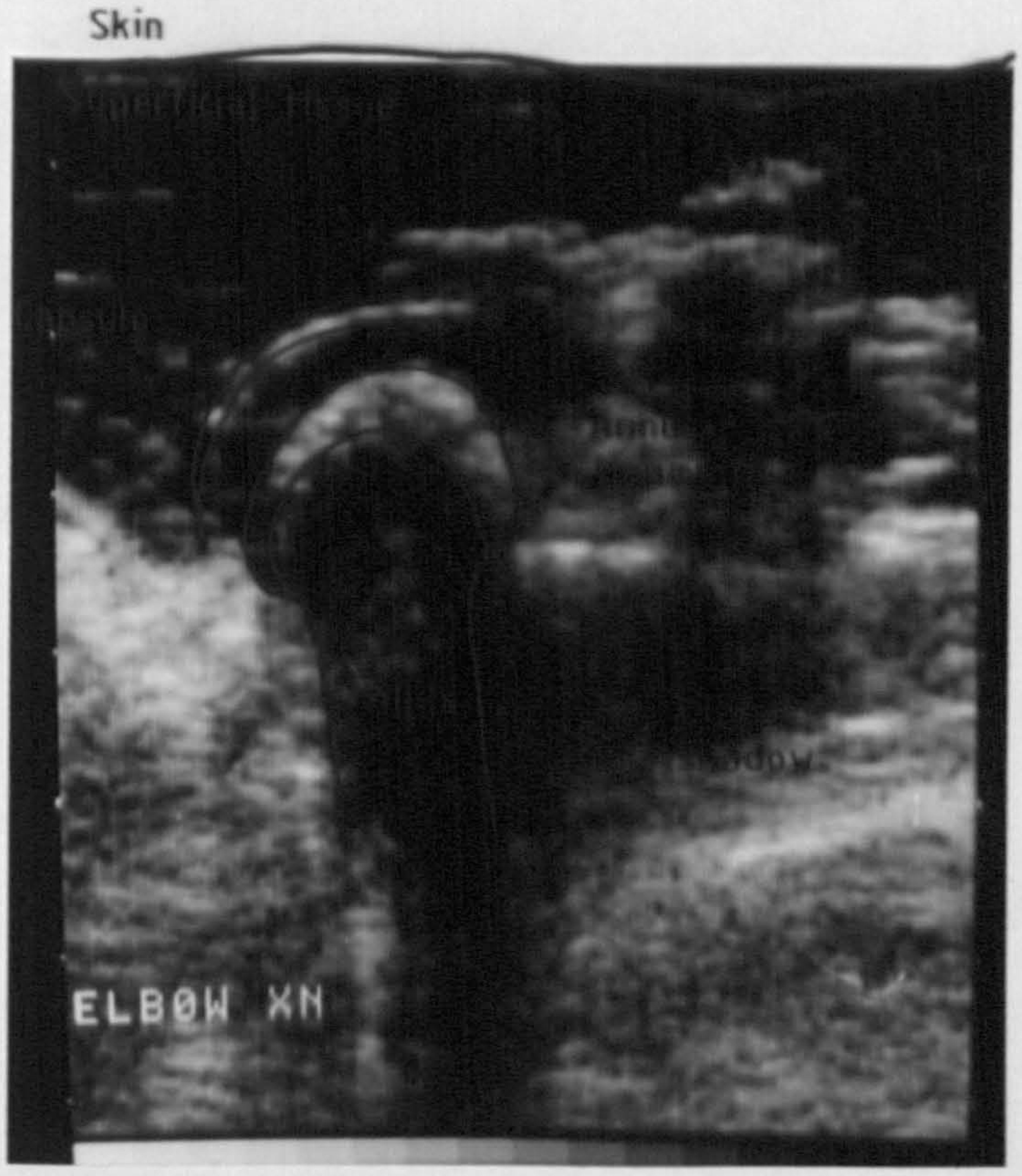


Fig.7.7a Anterior aspect radial head - Supination

Fig.7.7 a Anterior aspect radial head - Supination

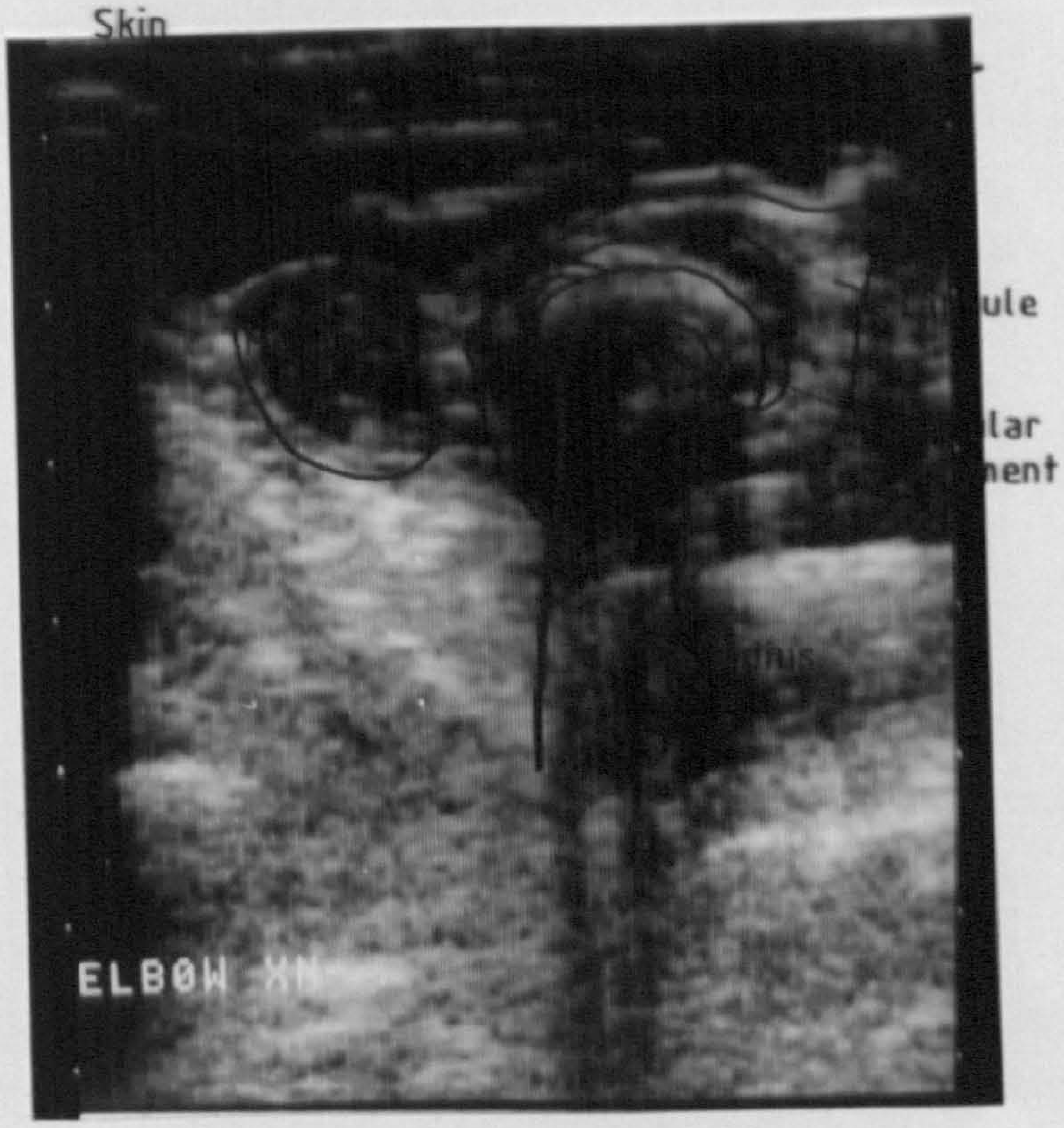


Fig.7.7.b Radial head - Pronation

Fig.7.7 b Radial head - Pronation

	I		II		III		IV	
	X-R	US	X-R	US	X-R	US	X-R	US
X	2.86	2.34	2.84	2.9	2.77	2.76	2.85	2.81
SD	0.20	0.22	0.19	0.19	0.19	0.31	0.18	0.8
CV%	8.60	9.6	6.70	22.12	6.80	11.34	6.25	30.74

Table 7.5.1.

Measurements across the [R] radio-humeral joint in longitudinal view, comparing X-ray to US statistical results.

	I		II		III		IV	
	X-R	US	X-R	US	X-R	US	X-R	US
X	2.42	2.5	2.51	2.80	2.21	2.80	2.44	2.75
SD	0.12	0.28	0.16	0.16	0.36	0.16	0.17	0.11
CV%	4.86	11.32	6.32	5.54	16.59	5.54	7.00	4.09

Table 7.5.2.

Measurements across the [R] radio-humeral joint in horizontal view,comparing statistical results.

Conclusions

The elbow joint proved technically an easy joint to scan. The soft tissue about the joint was visible and on dynamic scanning was demonstrated in action.

The three views of the joint complex were all useful for imaging the joint. An agreement was achieved between the measurements made across the humero-radial joint from the X-ray and the ultrasound scans with the probe in the longitudinal position.

Because of the aggrement in the two sets of results, there may be an implication for the use of US for the non invasive scanning of the elbow. The ability of the scanner to allow movement studies of the joint and soft tissues may also be of clinical interest.

7.8. IMAGING THE SACRO ILIAC JOINT

7.8.1 Introduction

A literature search failed to elicit much information on the use of ultrasound imaging of the sacro-iliac joint. Only one reference, a conference proceedings, was obtained. Vicks (1984) used both static and realtime scanners to image the sacro-iliac joint. She felt that real-time scanners were able to demonstrate the relative joint motion, but the static scanners gave larger and clearer images. Vicks's method for measuring joint motion was by the use of drawing overlays. She described changes in relationships between the sacrum and ilium as occurring only with abnormal sacro-iliac joints (Fig. 7.8a).

7.8.2 Method

Using a method similar to that described by Vicks (1984), for the real-time scanning, the right sacro-iliac joints of 10 subjects were scanned. The joint was scanned with the patient standing in the upright position and then with the right hip and knee flexed to 90° and the foot upon a stool. The probe was placed in the horizontal position across the joint. Movements of the bony complex and muscle activity in the area were noted. The information was recorded upon video tape for later analysis and comment.

Results

No measurements were taken for comparison between the X-ray and the US scans. The image quality was of interest to seeif in fact the joint could be imaged and observed for motion.

Vicks used an image overlay method to detect changes in position of the various structures around the sacro-iliac joint. This method was not possible with the equipment available, as images were stored directly onto video tape. Real-time scanning does allow the observer to watch the relative positional changes of joints and tissues, however in these circumstances it was too difficult to

Fig. 7·8a (R) Sacro-iliac joint

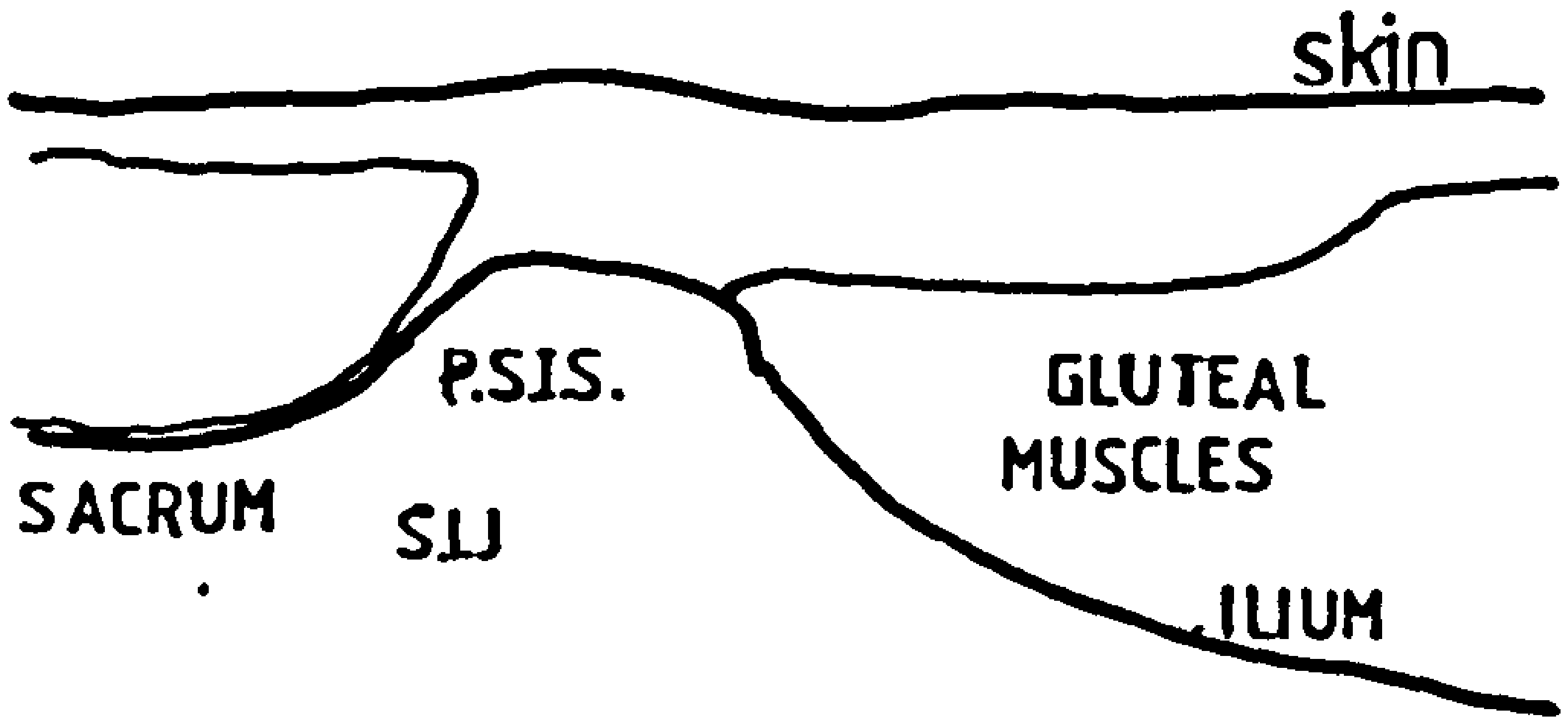


Fig. 7·8b Right Sacro-iliac joint

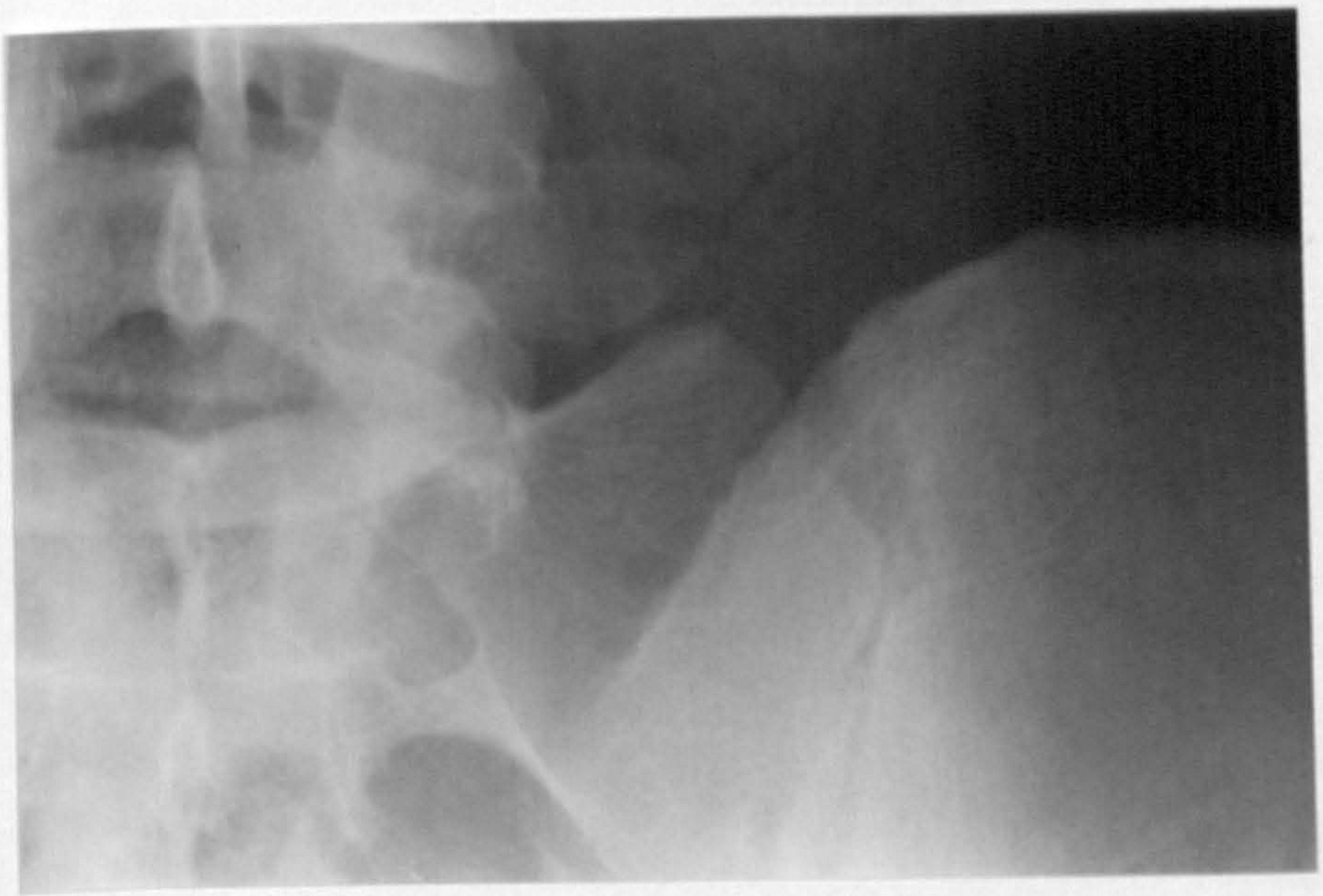


Fig.7.8a Sacro-iliac joint

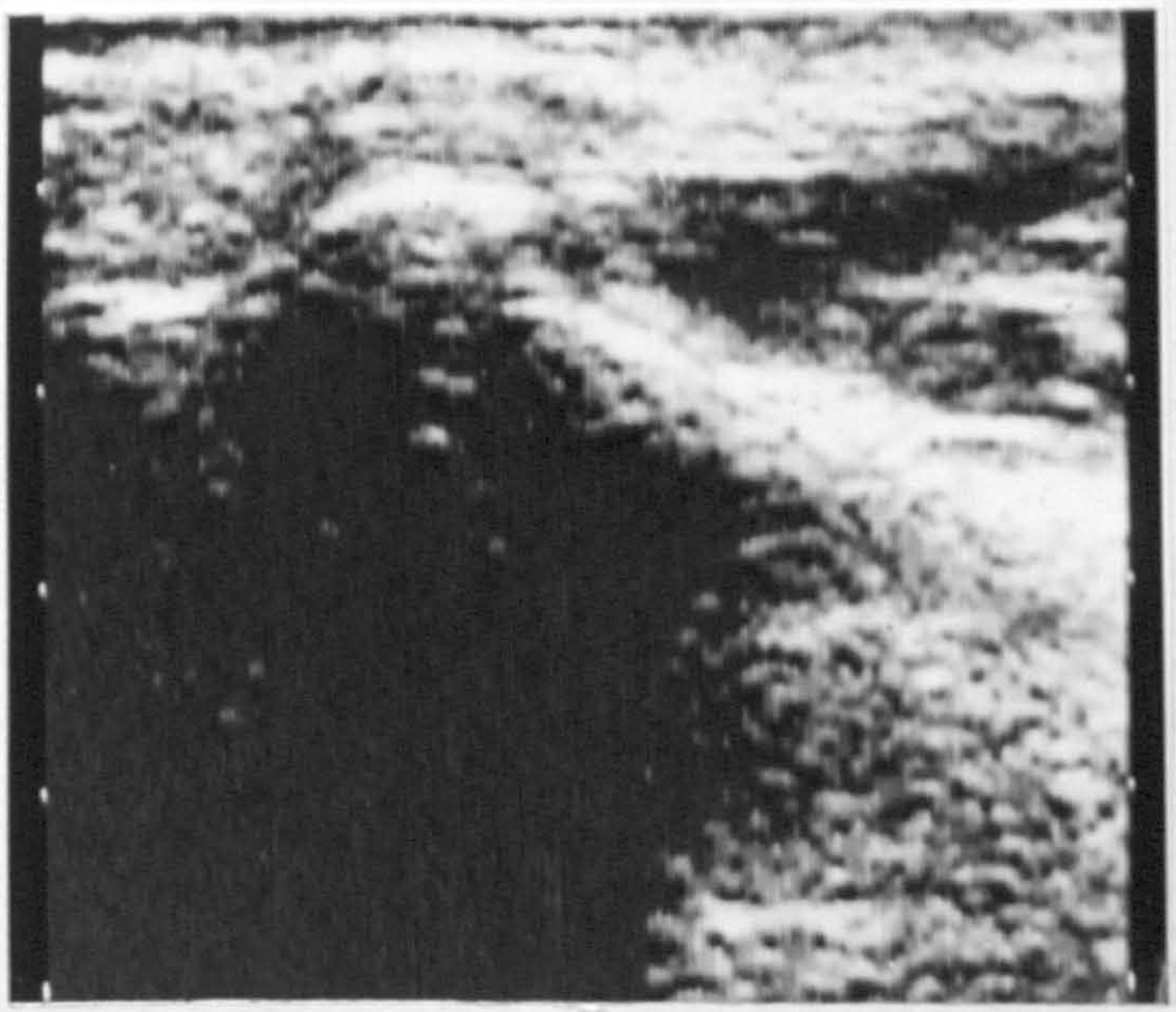


Fig.7.8b Right Sacro-iliac joint

Fig. 7·8a (R) Sacro-iliac joint

Fig.7.8a Sacro-iliac joint

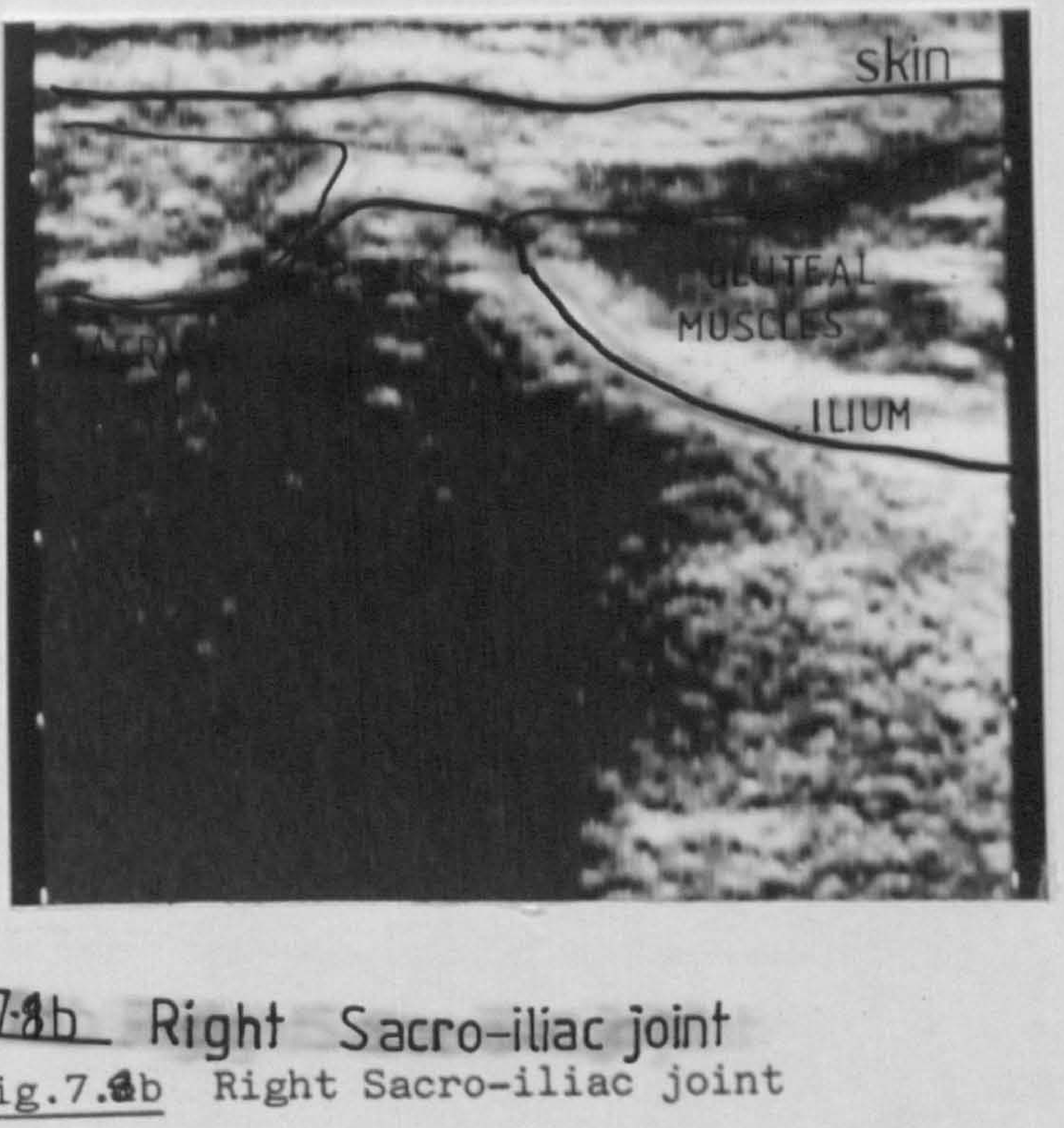


Fig. 7·8b Right Sacro-iliac joint

Fig.7.8b Right Sacro-iliac joint

measure relative joint motion with any degree of confidence, as the joint was so ill-defined.

Conclusions

Images achieved from scanning the area (Fig. 7.8b) were difficult to interpret. The ilium from the anterior superior iliac spine,the gluteal muscles and fascial layers, the sacrum and the L5-S1 joint space were all clearly defined. The sacro-iliac joint was represented as a dense acoustic shadow.The lack of published work on ultrasound scanning of the sacro-iliac joint may reflect the complex nature of the problems encountered by workers. Vicks herself acknowledged that several factors made scanning and interpretation of images difficult. Information on the muscular and bony structure of the sacrum and ilium was possible and interesting and may be useful in other orthopaedic conditions. Little useful information was gathered from the 10 scans made on movements of the sacro-iliac joint. This is an area which would benefit from further study to determine if motion at the sacro-iliac joint is indeed motion or artifact.

7.9 IMAGING THE FOOT

7.9 Introduction

The foot is a complex structure and is frequently subject to injury. A attempt was made to ascertain if ultrasound scanning could identify specific structures of the foot and observe joint motion. Bradley et al (1986), used real-time B-scans to observe the effect of metatarsal domes on the "transverse arch" of the foot, by imaging the foot with and without the arch support, and comparing drawings of the"arch" outline.

7.9.2 Method - Comments

Fig.7-9a Right foot

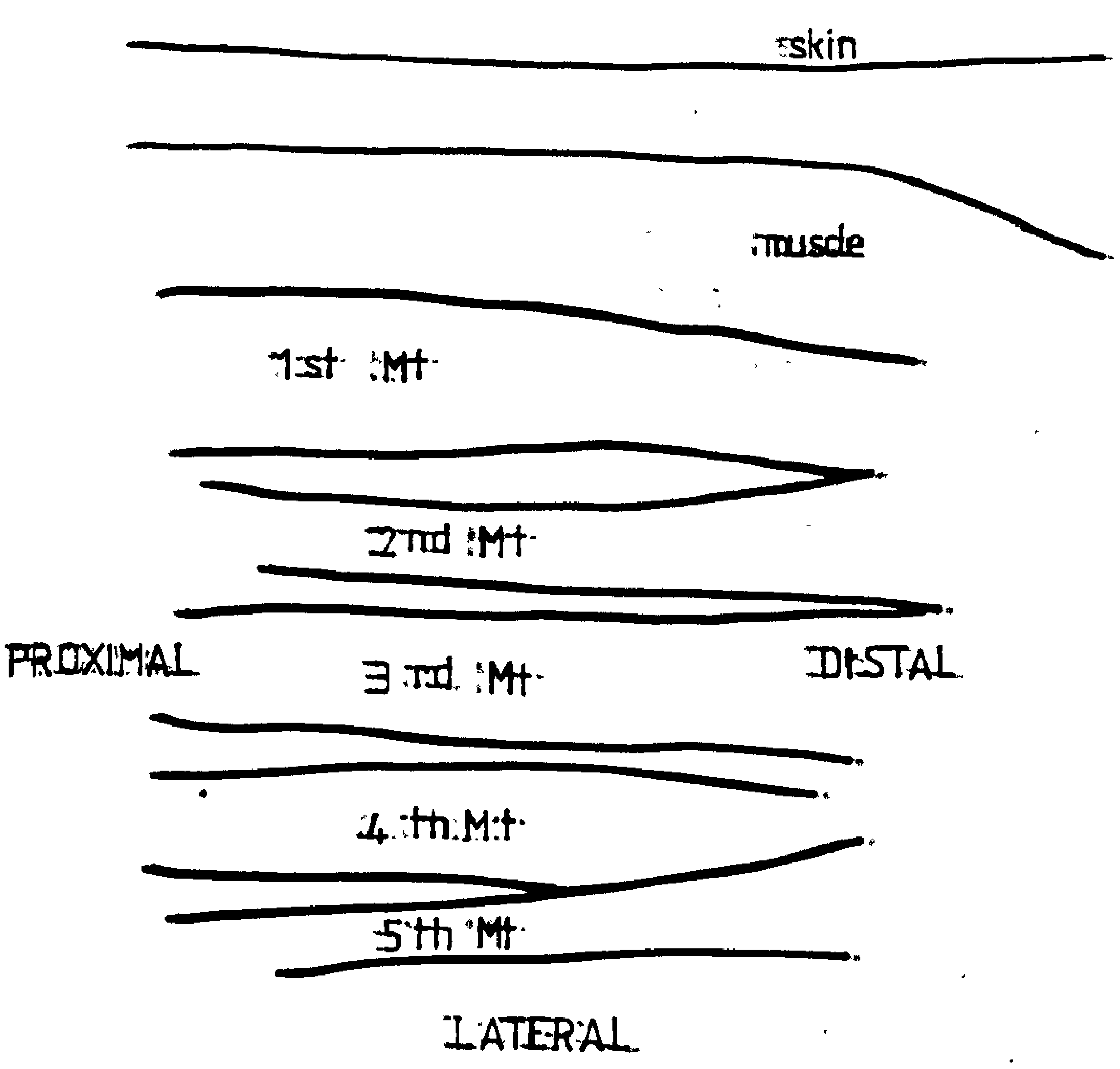


Fig.7-9b Scan of foot across metatarsals.

Fig.7.9a Right foot

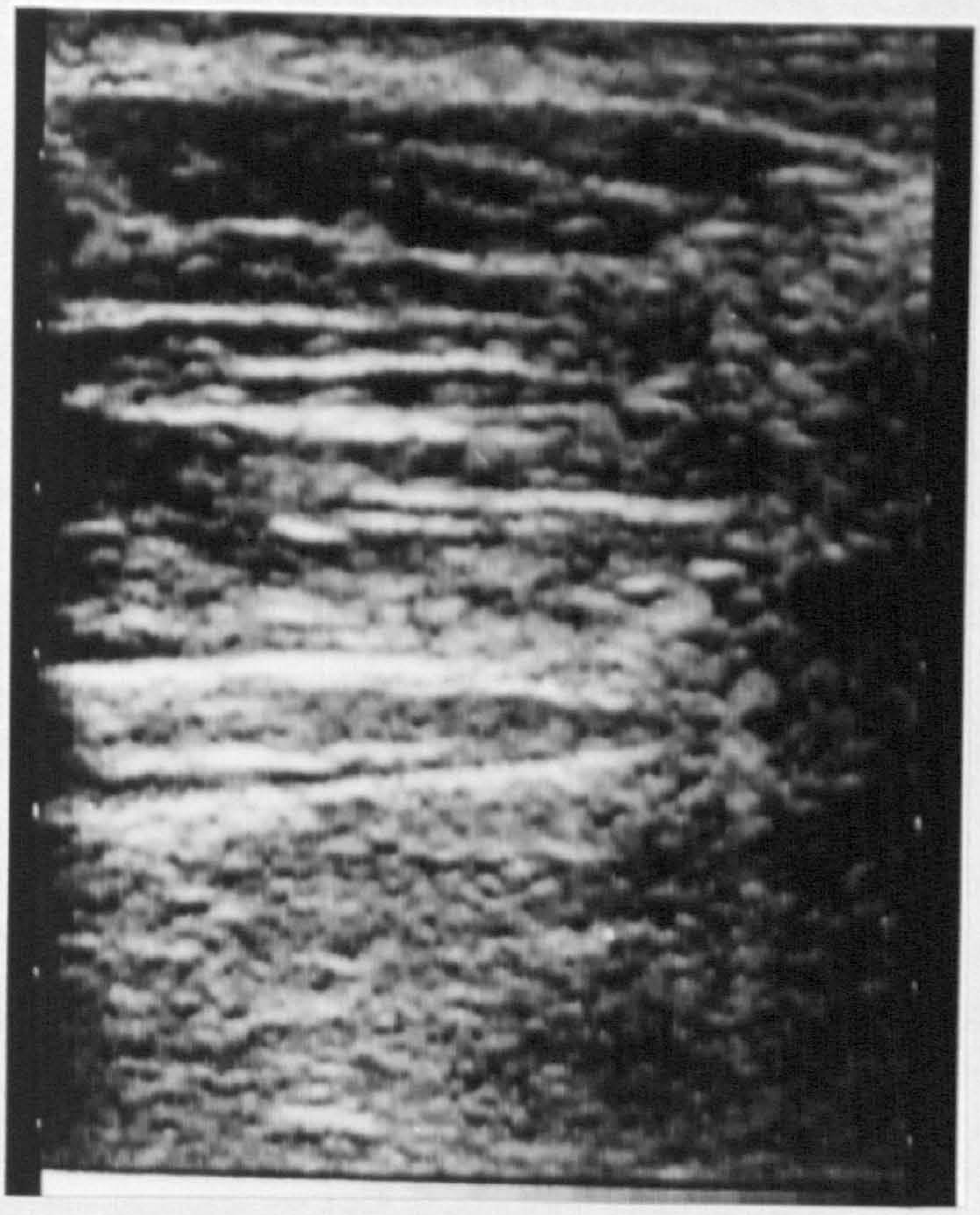


Fig.7.9b Scan of Right foot across metatarsal

Fig. 7-9a Right foot

Fig.7.9a Right foot

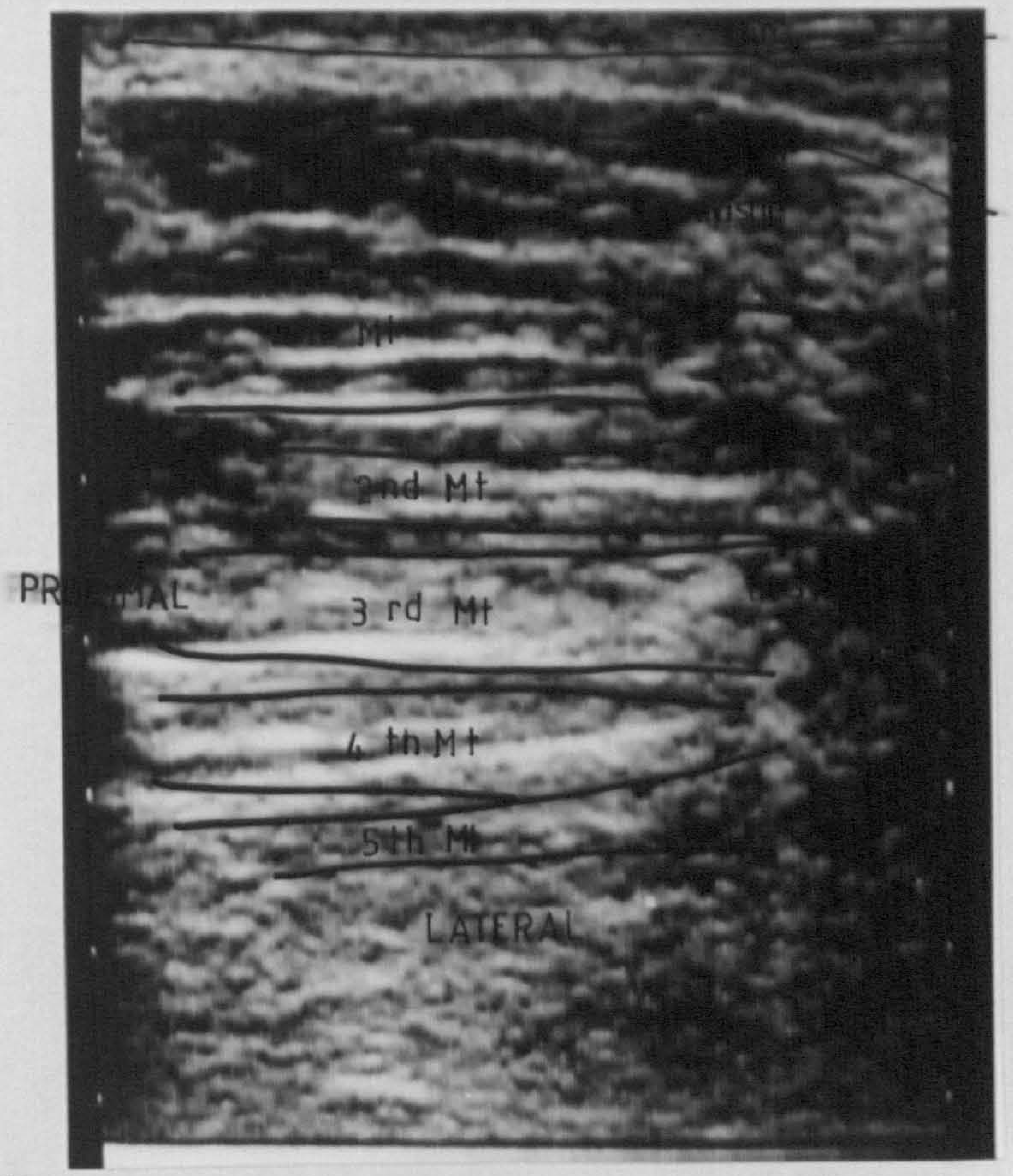


Fig. 7-9b Scan of foot across, metatarsals.

Fig.7.9b Scan of Right foot across metatarsal

No measurements were to be taken from the images. The ability to image structures in the foot was to be tested and the quality of image compared subjectively with that of the X-ray of the same region.One subject had the right foot X-rayed. The direction of the X-ray was medial to lateral through the foot in a standard view (Fig. 7.9a).The right foot of 5 subjects were scanned using the ultrasound scanner as previously described. Several scanning positions for the probe were tried:-

1. Longitudinally, on the sole of the foot over the 1st metatarso-phalangeal joint (Fig. 7.9b).
2. On the sole of the foot in the frontal plane,to image the metatarsals.
3. Along the medial aspect of the foot from calcaneum to phalanges.

Results were recorded on video tape for later observation.

Results

With the probe as in position 1 (as above),the tendon of flexor hallucis longus was clearly seen as the great toe was flexed and extended. The extent of the joint surface on the head of the 1st metatarsal was noted. With the probe against the medial surface of the fore foot, all 5 metatarsal rays could be identified by being individually moved. The joints of the midtarsal block and the calcaneo-navicular joint were not at all clear. With the probe on the sole of the foot, the transverse arch of the metatarsals could be seen in cross section. The use of a water bag to assist beam focusing was tried, but did not improve the image quality.

Conclusions

Results from a small sample showed that ultrasound scanning of the foot seemed unable to offer clear views of the talo-calcaneo-navicular joint or other joints in the mid tarsal block. This may be due partly to the very superficial nature of the joints, but also because of the mass of bony structures in the foot causing acoustic shadows and echoes. Ultrasound was able to demonstrate the dynamic nature of the 1st metatarso-phanangeal joint and the surrounding soft tissues. The metatarsals were also clearly seen when moved.

X-rays are currently used for the diagnosis of skeletal problems in the foot. Ultrasound would appear at present to offer the ability to image soft tissues of the foot working dynamically.

7.10. SUMMARY

From the literature, there appears to be a continued interest in the use of ultrasound for orthopaedics situations. This is probably due as much to the relative safety of ultrasound as to the accessibility of the equipment and its ease of use.

From the work in this chapter it was noted that much depends upon the quality of the image and the experience of the operator to achieve the desired image and then in the interpretation of that image.

Overall it was found to be difficult to directly compare measurements made from X-rays and US scans of the same object.

The planes of the images may well produce a slightly different aspect of the joint for measurement.

The other problem was the definition of the joint boundaries, which would still be a subjective decision and hence a place for error.

However, the quality of the image is much dependent upon the tissues to be scanned. Areas with large superficial continuous bony surfaces , for example the femoral condyles, are difficult to image. Soft tissue will also alter the image quality and this is discussed later. The type of equipment and the skill of the operator are all important to achieve quality images from which assessments can be made.

Technical advances to improved the quality of images available and the ease of obtaining body scans has helped this advance. It is hoped that the need for ultrasound scanning as another tool will will lead to the design of scanners aimed specifically at the musculo-skeletal specialities.

Ultrasound has two considerable advantages over conventional scanning, it is free from ionising radiation, and it permits dynamic scanning of tissues and joints. These two factors strengthen the argument for its use in orthopaedics.

CHAPTER 8 ULTRASOUND SCANNING OF THE CERVICAL SPINE TO OBSERVE SEGMENTAL MOTION

8.1 INTRODUCTION

In Chapter 7, the current and experimentally investigated use of ultrasound for orthopaedic situations was reviewed.

Clinical examination of a patient presenting with an spinal condition, will at some stage require the examiner to measure or estimate the range of motion of the spine or spinal region. This is usually done by visual estimation of range, or with the use of a measuring device. Such methods can only give the range of gross spinal motion and cannot indicate what occurs at the individual spinal levels.

Spinal studies have concentrated on the lumbar spine, primarily for the investigation of spinal canal size and canal content (Porter et al,1978; Eismont et al,1984). The biomechanical, structural and pathological aspects of the lumbar spine have been extensively examined. However, it appears that not the same intensity of interest has been applied to the cervical spine, yet the structure of the cervical spine and components is more complex than the lumbar spine.

It was anticipated that the neck might be difficult to image with standard ultrasound equipment. However, as a novel area of interest for the application of ultrasound and for the information to be gained from observing segmental motion, scanning of the cervical spine was undertaken using standard diagnostic ultrasound equipment. The interest was given to the identification of anatomical landmarks and the observation of individual spinal motion segments and relative motion at these segments was investigated. The detection of useful scanning plans would be a requirement of the work.

It would also be necessary to observe the effects of the position of the scanning probe on the ability to measure distances reliably, both in the vertical an inclined positions. Measurements could be taken from the US scanner and the ability of this measuring facility would be compared to another method of measuring, this could be undertaken in the "test" situation, in vitro and in vivo.

The cervical spine has not be scanned with standard diagnostic ultrasound. It has considerable soft tissue surrounding the spinal column and this was not expected to cause problems for imaging the spine. The vertebrae however, being superficial on the posterior and postero-lateral aspects of the neck were expected to be difficult to image because of the acoustic shadows the bone might cause.

8.2 EQUIPMENT

8.2.1 Spine

To enable the operator to gain experience in the collection and interpretation of the complex ultrasound images of the cervical spine, which could be repeatedly identified, a phantom spine was made. A second more successful design of spine and plinth was developed from the first model. The second design was found to improved the access for the transducer head to facilitate scanning.

Eight clean and dried human vertebrae (C2 - T2) were mounted on a length of silicone rubber tubing, which had been inserted to fill the spinal canal (Fig. 8.1). A length of thin lead rod was placed within the tube, which was then filled with silicone rubber (Dow Corning, Silastic 9161). This arrangement allowed movement of the spine but also gave the whole structure some stability. The same silastic was used to fill the intervertebral "disc" spaces. Care was taken to achieve realistic dimentions for the spine and to have the joints in correct alignment. The lowest vertebra (T2), was embedded in epoxy resin on the plinth. The spine could then be placed within a waterbath for scanning.

After early work using the first model spine, an attempt was made to image vertebrae with soft tissue attached. A sheep's cervical spine was used in the waterbath. However this arrangement was found to be impossible to scan as the release of soft tissue particles and fat globules from the specimen into the surrounding water made images difficult to achieve or interpret. Little information was gained from this investigation which subsequently

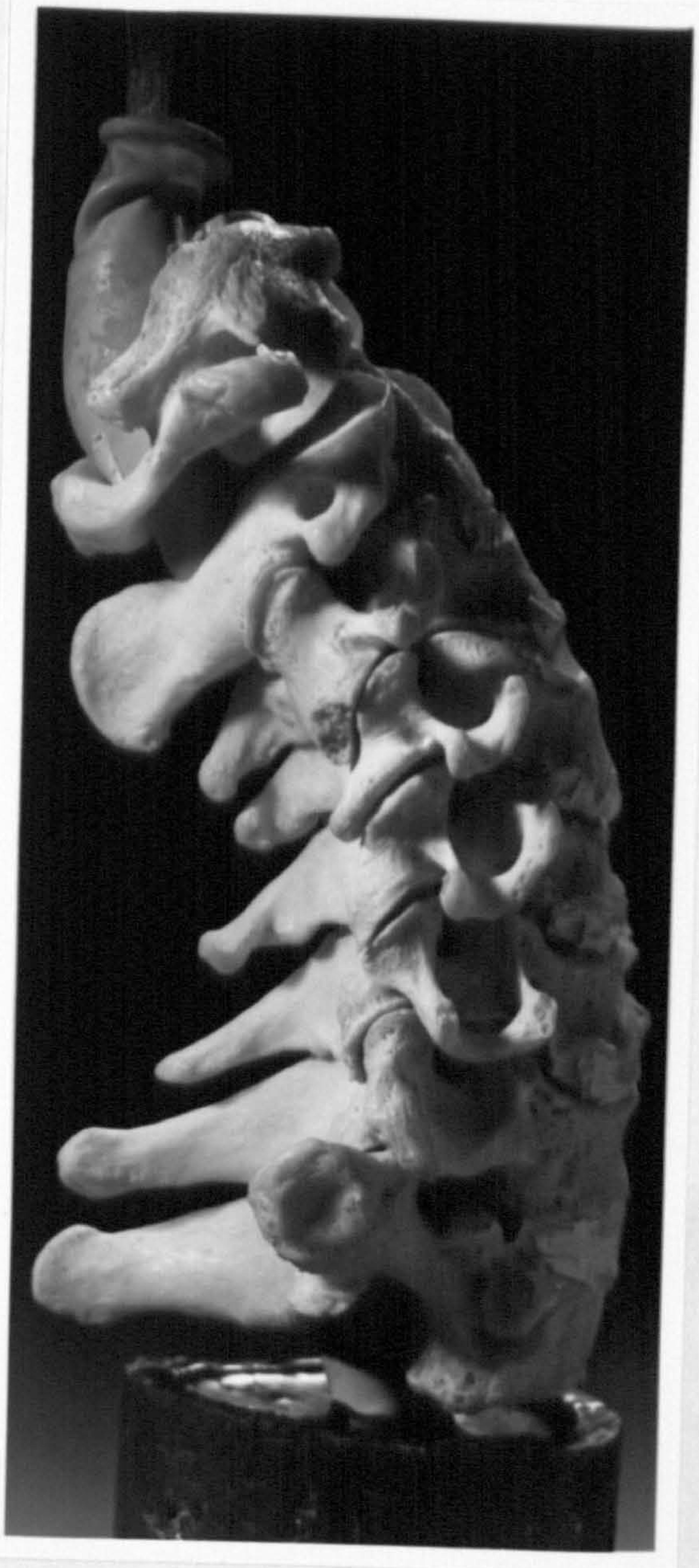


Fig.8.1 Model/Phantom Spine

Fig.8.2a Rigid Perspex/Silicone membrane waterbath

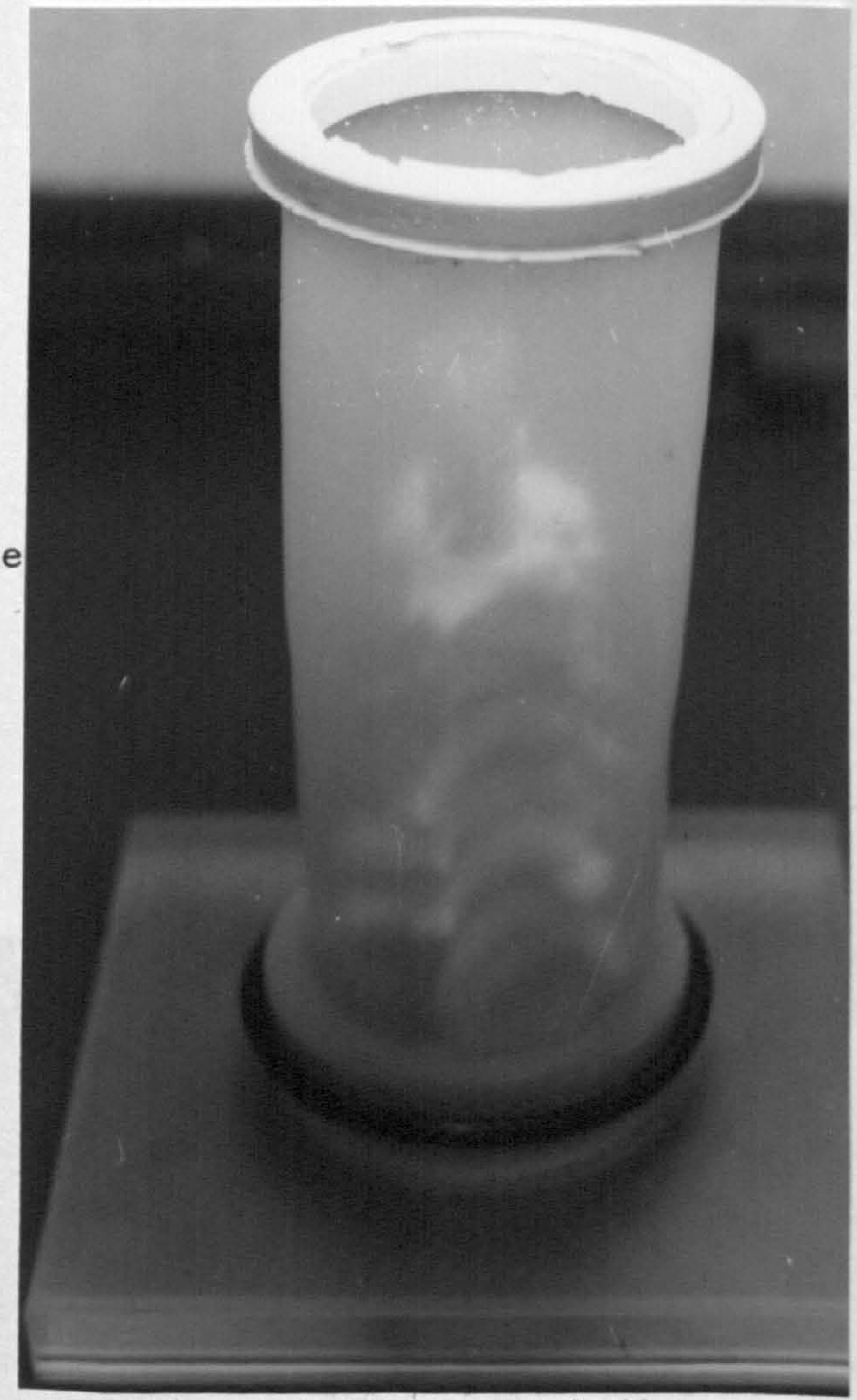


Fig.8.2b Silicone tubing waterbath

stopped.

8.2.2 Waterbath

A continuous medium is required for the transmission and receiving of signals from the US transducer head. Water is an ideal medium. The use of a waterpath to transmit sound has long been used in abdominal, obstetric and small part scanning.

To assist scanning of the model spine, small portable waterbaths were made (Fig. 8.2a). The second was the more useful as it allowed circumferential access to the spine and allowed more spinal motion within the waterbath (Fig. 8.2b). The tube and windows of the box waterbath were of silicone rubber, which did not hinder the transmission of sound. A rubber sealing ring formed a watertight seal at the base of the tube. By allowing the water to stand, at least 15 minutes before scanning the presence of bubbles in the water was reduced and room temperature was reached.

8.2.3 Contact Gel.

The ability to obtain an image by the transmission of sound, requires an airtight path between the sound source, the transmitter and the receiver or structure to be scanned. At each interface, for example, the skin, the airtight link must be present.

The most common method of maintaining the sound path is with the use of gel substances. The gel as well as providing the airtight seal, it allows the probe to be moved easily on the scanning surface. Any coupling medium used has to be non allergenic, non toxic, to have a low absorption coefficient to sound and to be relatively inexpensive (Williams, 1987). During all scanning procedures, a suitable gel was used (Toshiba ultrasound gel) to ensure good contact with the membrane wall of the waterbath and the skin of subjects. The gel was wiped away after scanning.

8.2.4 Ultrasound Scanner and Probe

In the literature on the use of ultrasound in orthopaedics,

Fig.8.3a U.S. Scanner, probe, spine and V.T. Recorder

Fig.8.3b 5 MH_z Probe for the Scanner

there is little or no consensus in the choice of scanner or transducer head (probe). Middleton et al,(1986a,b), describes the use a variety of scanners for imaging of the shoulder, likewise Clarke et al,(1985) and Adam et al,(1986), for imaging the hip. This study initially required the testing of various types of ultrasound scanners available from manufacturers and departments of radiology so ascertain which model suited the need of the project.

A mechanical sector scanner with a 2.5 MHz scanning probe was tried. It was able to give only an adequate image of the model spine , but a poor image of the in vivo neck. Both 7.5 and 10 MHz probes were also tried but they both failed to give good quality images for the structures of interest. The best image for both the model spine and the in vivo neck, after testing several machines, was a 5 MHz probe with a phased linear array.

The equipment chosen was the Toshiba Sonolayer - L, linear scanner, SAL-32B, with a compatible 5 MHz phased linear array probe (Fig. 8.3a & 8.3b). This scanner offered a measurement caliper function, identification characters, direct video output and 16 grey scale levels which was considered adequate. Lerski, (1981) believed that only four grey levels could be detected with any degree of accuracy. The probe head had a window of view 84mm wide. All images could be seen on the screen and could be recorded directly using a small portable video recorder onto video tape for later analysis. A freeze frame facility was useful while recording the image. This improved the ability to take still photographs from the video monitor without any movement artifact. The scanner and video system were portable which allowed it to be used without trouble, in the clinic, laboratory and other settings.

The axial and lateral resolution of the scanner was tested, using a U-shaped frame with two strands of fine (0.13mm) monofilament between the frame struts. The frame was lowered into the waterbath so that it could be scanned from the top (axial resolution) and from the side (lateral resolution).

Using a travelling light microscope to measure the separation between the strands, ten readings were taken. The distance at which the readings were taken were just as the two threads being imaged merged into one image. The same proceedure was undertaken for lateral resolution with the scanner against the side of the waterbath. Again ten readings were taken.

Results for the axial resolution gave a mean distance as 0.40mm, with a range of 0.38 - 0.45mm. Lateral resolution had a mean of 0.39mm, with a range of 0.37 - 0.44 mm.

These results would appear to be well within the range require to detect motion between a motion segment.

8.2.5 Digitiser

All images from scans were recorded directly from the scanner onto standard VHS video tape. This was later played back through a digitising system. This equipment (Kontron MOP Videoplan System ®), complete with its own software, allowed the video image to be screened and measurements, selected from a menu, taken using a digitising tablet and screen cursor. The software was designed so that the operator could imput the magnification factor as appropriate for the work and could also select from several measurement parameters, those of interest. The distance between two selected points and also the angle subtended between two intersecting lines were the parameters used for this project. The digitising tablet haa an accuracy of 0.1mm (Manufacturers specifications) and it was capable of being illuminated from beneath, when measurements from the X-rays were required.

8.3. USE OF A STANDOFF MEDIUM

8.3.1 Standoff Medium

To facilitate the focusing of the ultrasound beam to image superficial structures within the area of interest, a standoff medium could be used. There has been little reported information on the use of standoff media. It was anticipated that a focusing device might be required when scanning the cervical spine and also some of the peripheral joints, as the structures were quite superficial.

A sample of 3M Kitecko ® jelly was tested as it was used in some Radiography departments as a standoff for ultrasound scanning. The white opaque jelly was cut to 2 x 3 x 10 cm in size. The substance was quite conformable but was difficult to maintain in position on the neck, with the subject in the upright position. The jelly was also very friable. Cracks in the block caused distortions or loss of ultrasound image. The quality of the image was not enhanced by the use of this standoff medium and the problems with handling the jelly led to the decision not to use this standoff medium during scanning.

Some technical data on the Kitecko ® jelly (Lees & McDicken, 1984,) is given below. They found that the average velocity of sound in the the jelly was less than that for soft tissues (1540 m/s). At frequencies of 5MHz and above, the attenuation rose rapidly degrading the signal, however below 5MHz, the attenuation was similar to that of soft tissue.

Density	0.89 gm/ml
Acoustic impedance	1.23 x 10 gm/cm s
Average vel. of sound in jelly	1383+50 m/s at 18 'C
Attenuation at varying frequencies	1.5 MHz = 1.3+ 0.1 dB/cm
	3.0 MHz = 3.2+ 0.3 dB/cm
	5.0 MHz = 7.6+ 0.5 dB/cm
	7.5 MHz = 14.0+ 0.9 dB/cm

Table, 8.1.

Technical Data - 3M Kitecko ® jelly, Lees & McDicken, 1984).

8.3.2 Tests of Silicone Gel Standoff Medium

A two part silicone gel system (Dow Corning ® Q7-2218) was used.

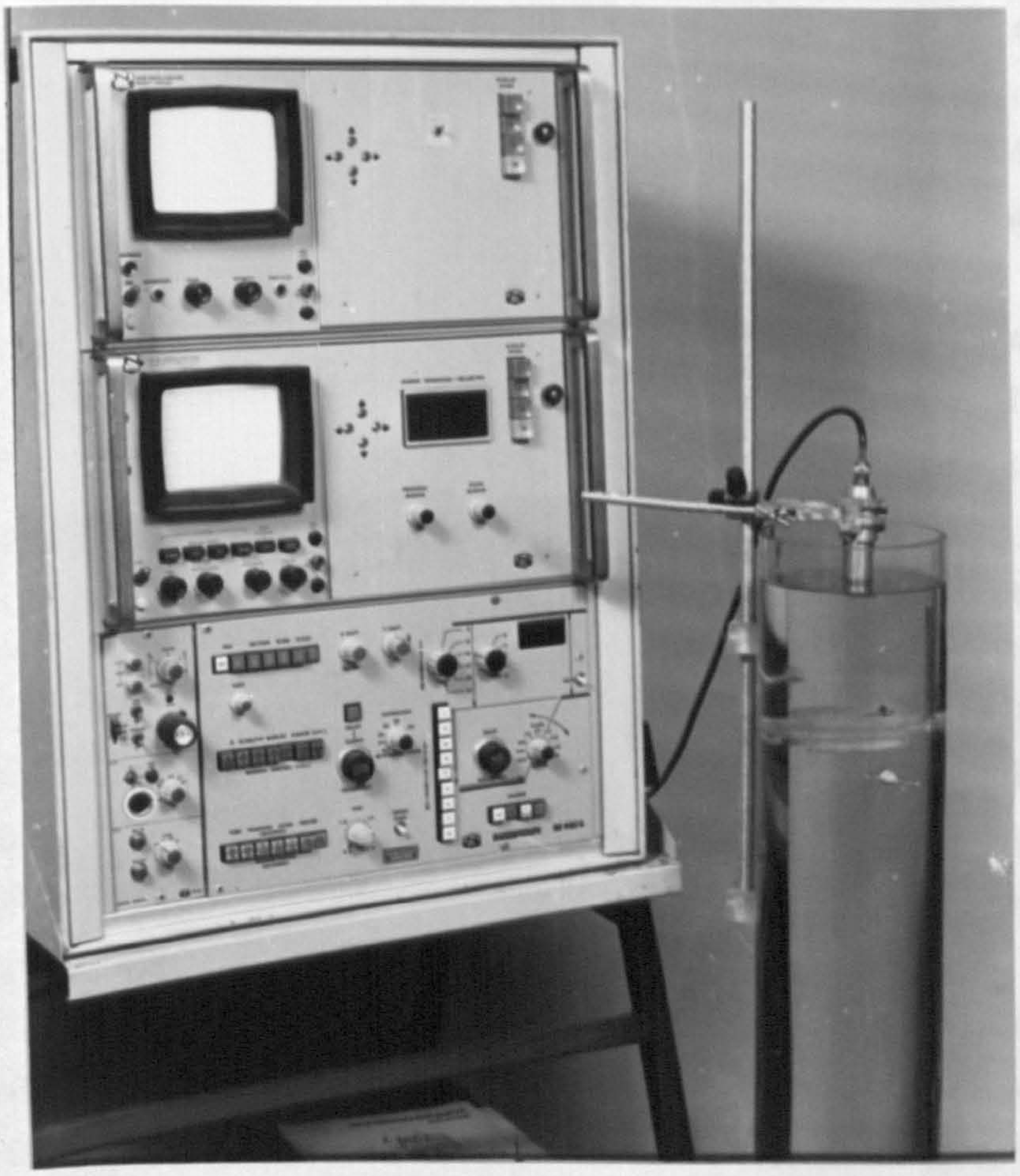


Fig.8.4 N.E.4102 Diasonograph, probe and water column, with gel ready for testing

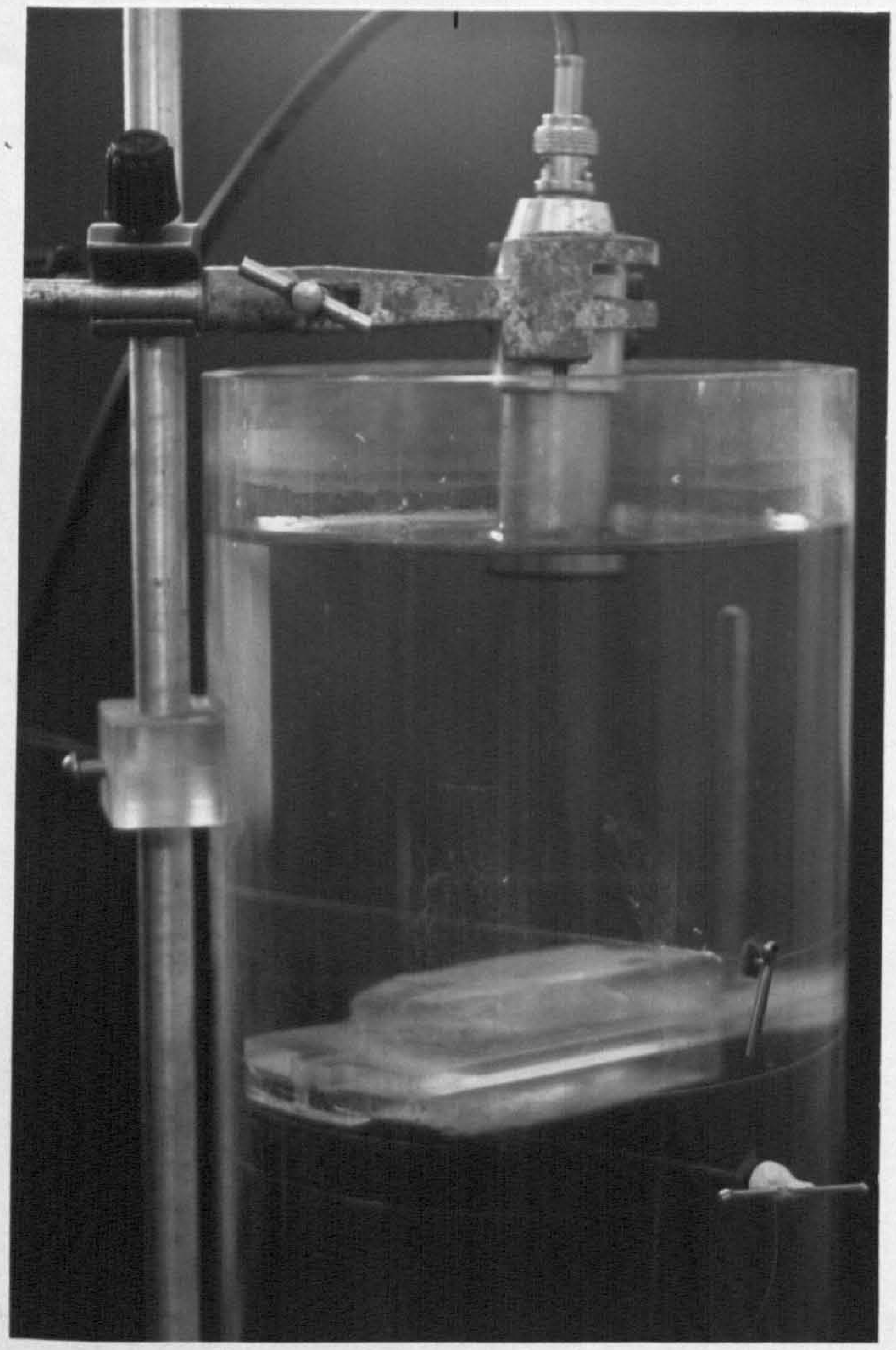


Fig.8.5 Gel in place in platform, threads above and below in line with probe

The gel was a polydimethylsiloxane. The two part compound gave the freedom to set any proportions of the A : B mixture to produce three gel blocks of slightly differing stiffness. The gel when cured was transparent.

Method

A perspex mould was made for casting a gel block 8 x 4 x 2.7cm. The proportions of the three gels were A : B = 50 : 50, 60 : 40, 65 : 35. The filled molds were placed under vacuum to reduce the possibility of air bubbles in the gel whilst being cured. Curing at 110°C was for approximately 20 minutes and then the gels were released from the mould when cold.

A perpsex tube, 1m high and 14 cm diameter, was made to hold water (Fig. 8.4). Washed sand was placed in the base of the tube to reduce acoustic standing waves which would interfere with the signal on the A-scan. The water was left to stand to reach 20°C. Two monofiliment threads 0.13mm diameter were placed diametrically across the tube, the upper thread being approximately 11cm below the water surface (Fig. 8.5). The threads were 5cm apart. In turn, each of the gel blocks was placed in a frame and was lowered onto a platform midway between the two threads. Using the A-scan facility of a NE 4102 Diasonograph and the 1MHz probe at 1cm depth the test was carried out.

Initially, the peaks representing the two threads were demonstrated on the scanner. The receiver amplifier was adjusted to equalise the distal signal to that of the proximal signal. The scanner was adjusted to give equal signal peaks at a frequency of 2 MHz, and the time / distance axis was set to the 5 cm distance. The gels, when in place, caused an alteration in the 'distance' reading and amplitude of the distal signal peak, and these alterations were noted for each of the three gels in turn.

Calculation for velocity of sound through gel (example gel 1)with respect to water

Real image distance = 5 cm water =5 cm on display.
" " " of 2.7 cm gel+ (5-2.7)cm of water =6.3 cm on display
∴ Image distance for 2.7 cm gel =6.3-(5-2.7)cm
=4.0 cm

∴ Speed of sound in gel(1) w.r.t. water $= \frac{2.7}{4.0} \times \frac{5.0}{5.0} = 0.675$cm

Calculation for attenuation of gel to sound (example gel 1)

$$\frac{\text{Amplitude of distal image signal}}{\text{" " Proximal " "}} \times \frac{1}{\text{thickness}} \times \frac{\text{object distance}}{\text{image distance}}$$

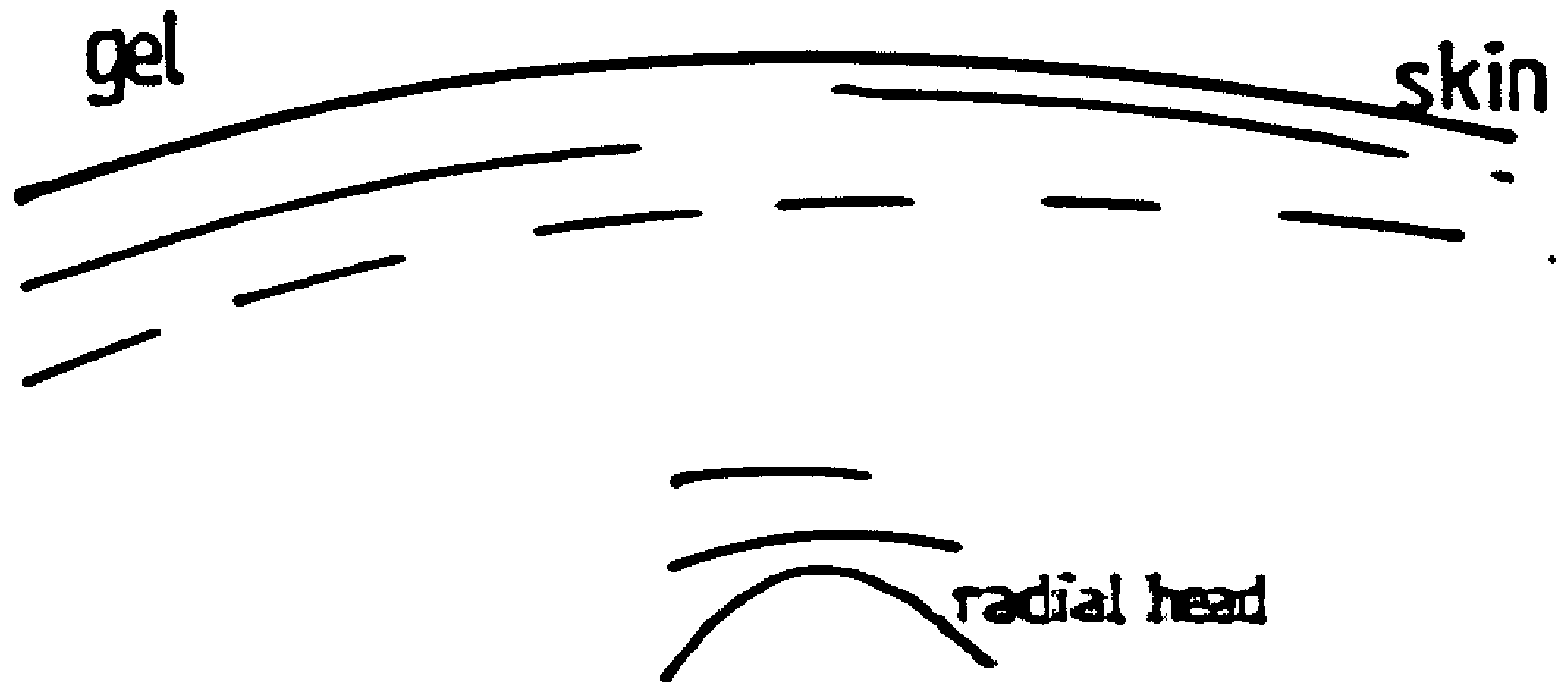
$$\frac{4.0}{5.7} \times \frac{1.0}{2.7} \times \frac{5.0}{6.3}$$

∴ Attenuation of gel w.r.t. water at 20°C, at 2 MHz = 0.206.

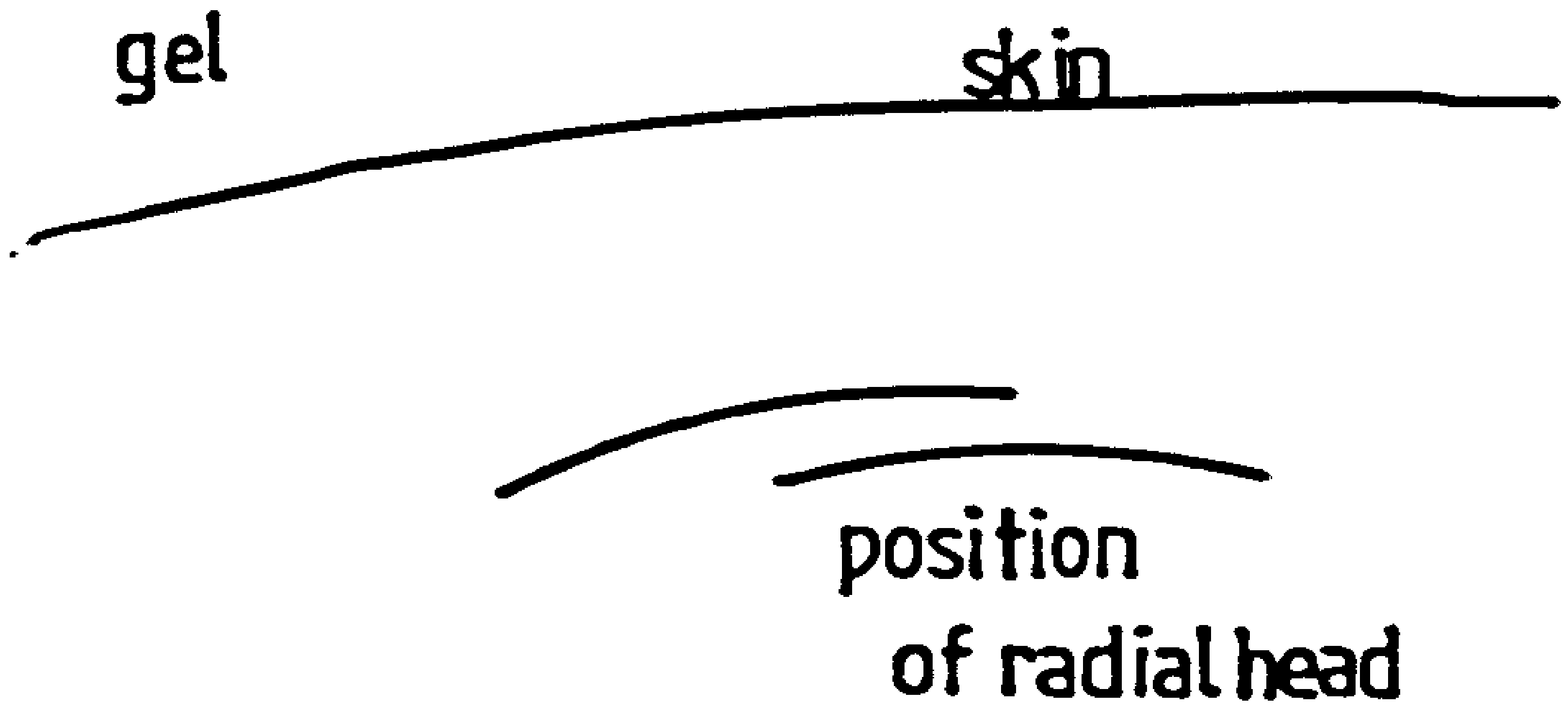
Gel block	Speed of sound w.r.t. water.	Attenuation at 2 MHz. w.r.t.water
1	0.675	0.206
2	0.701	0.181
3	0.700	0.187

Table, 8.2.

Test results for the speed of sound and attenuation w.r.t. water for three fabricated gel standoff blocks.



Test block 1



Test block 2

Test block 3

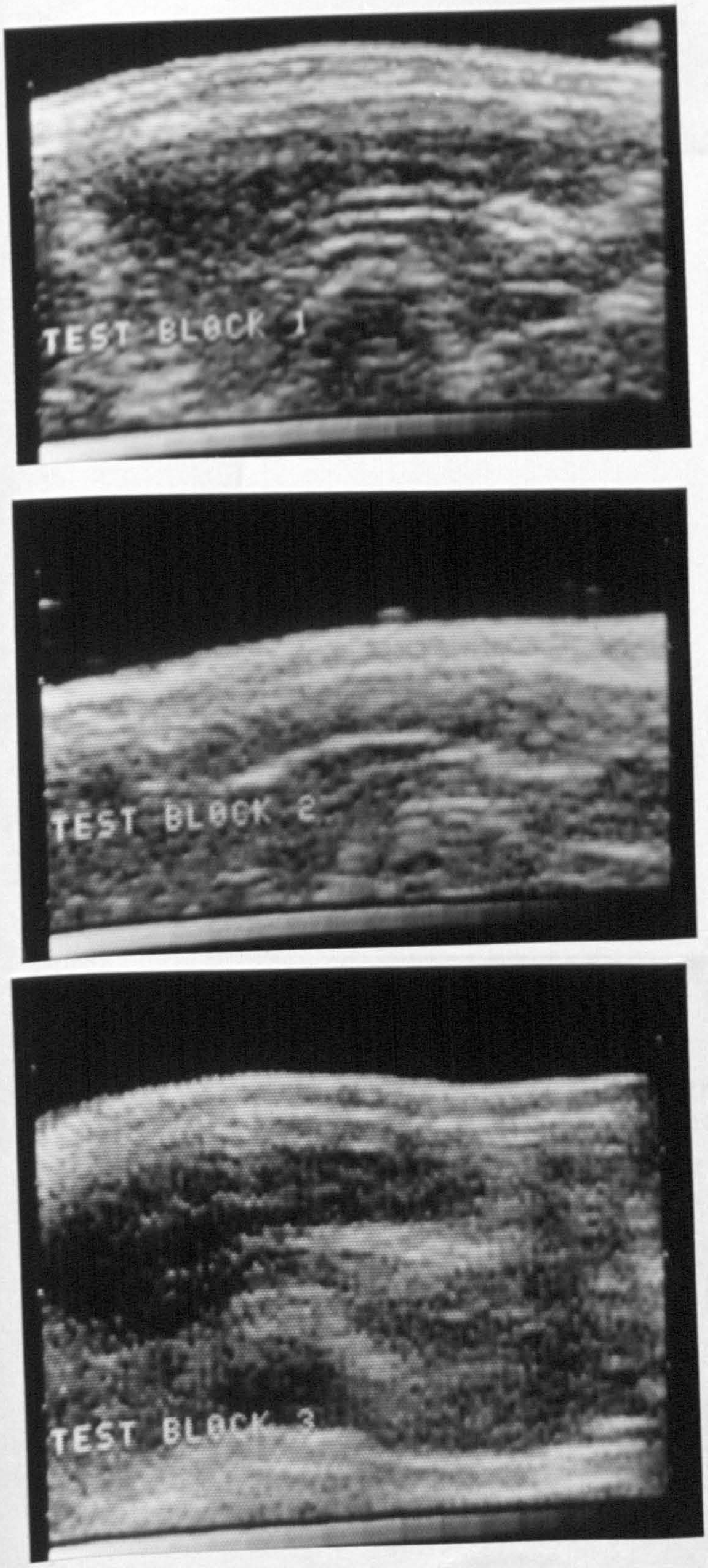
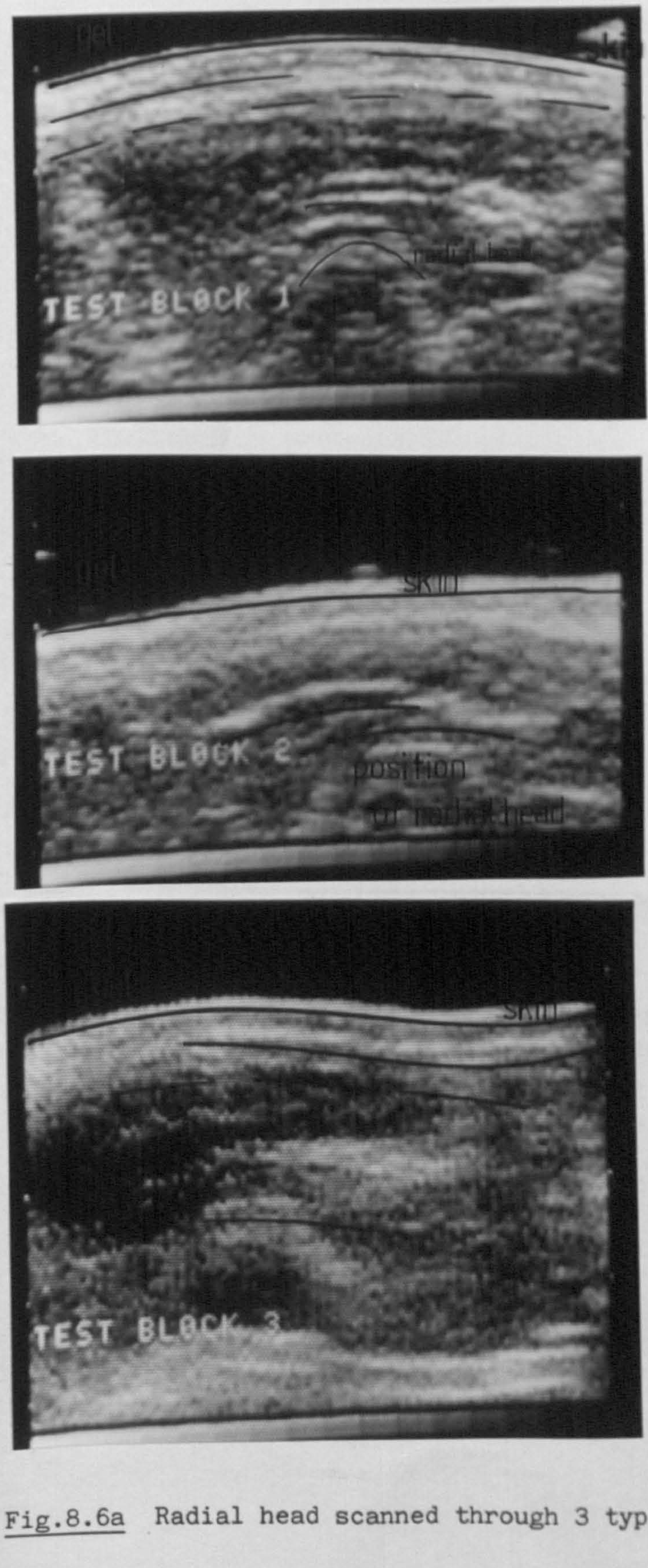


Fig.8.6a Radial head scanned through 3 types of silicone gel

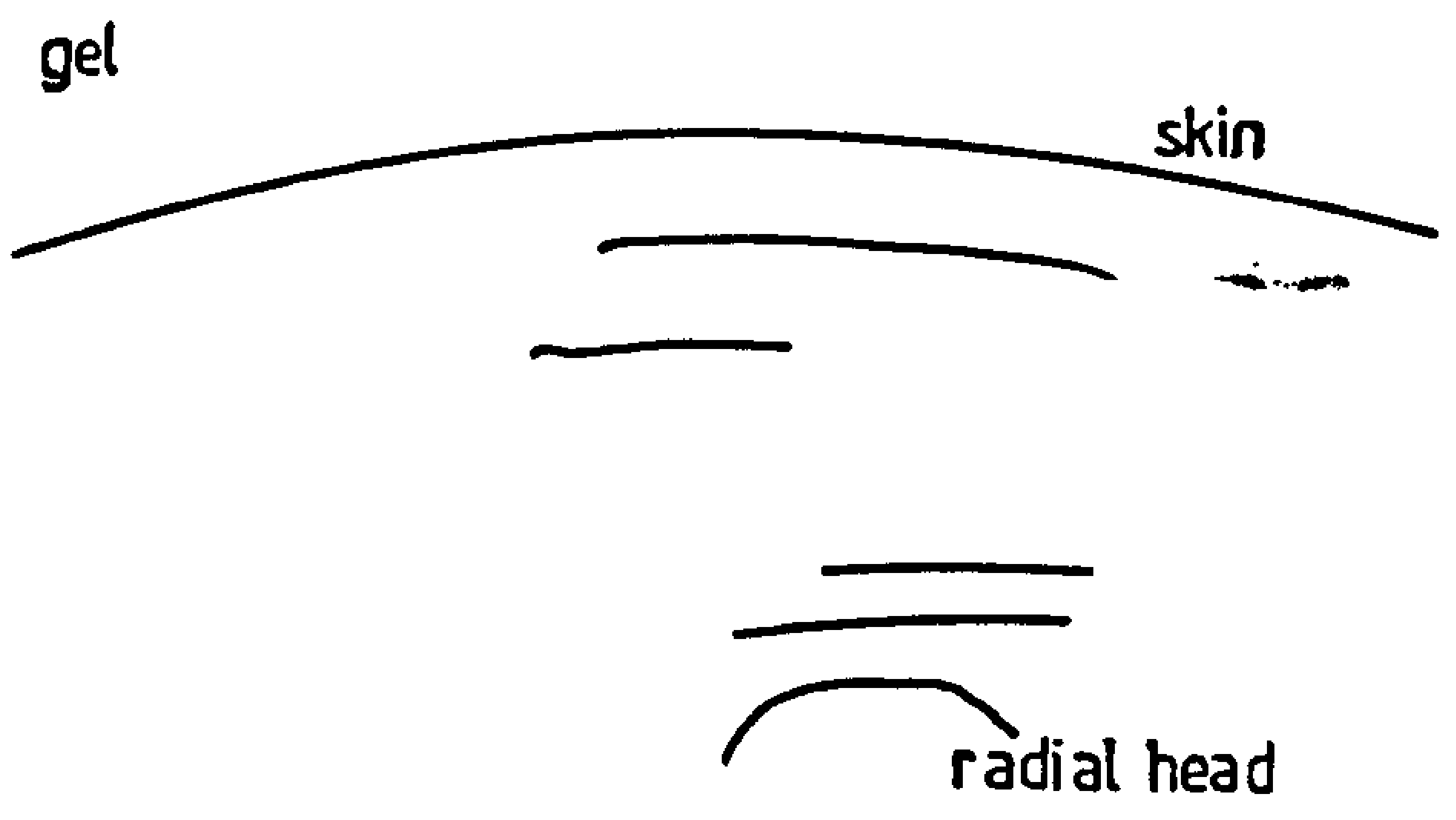


Test block 1

Test block 2

Test block 3

Fig.8.6a Radial head scanned through 3 types of silicone gel



Test block 4

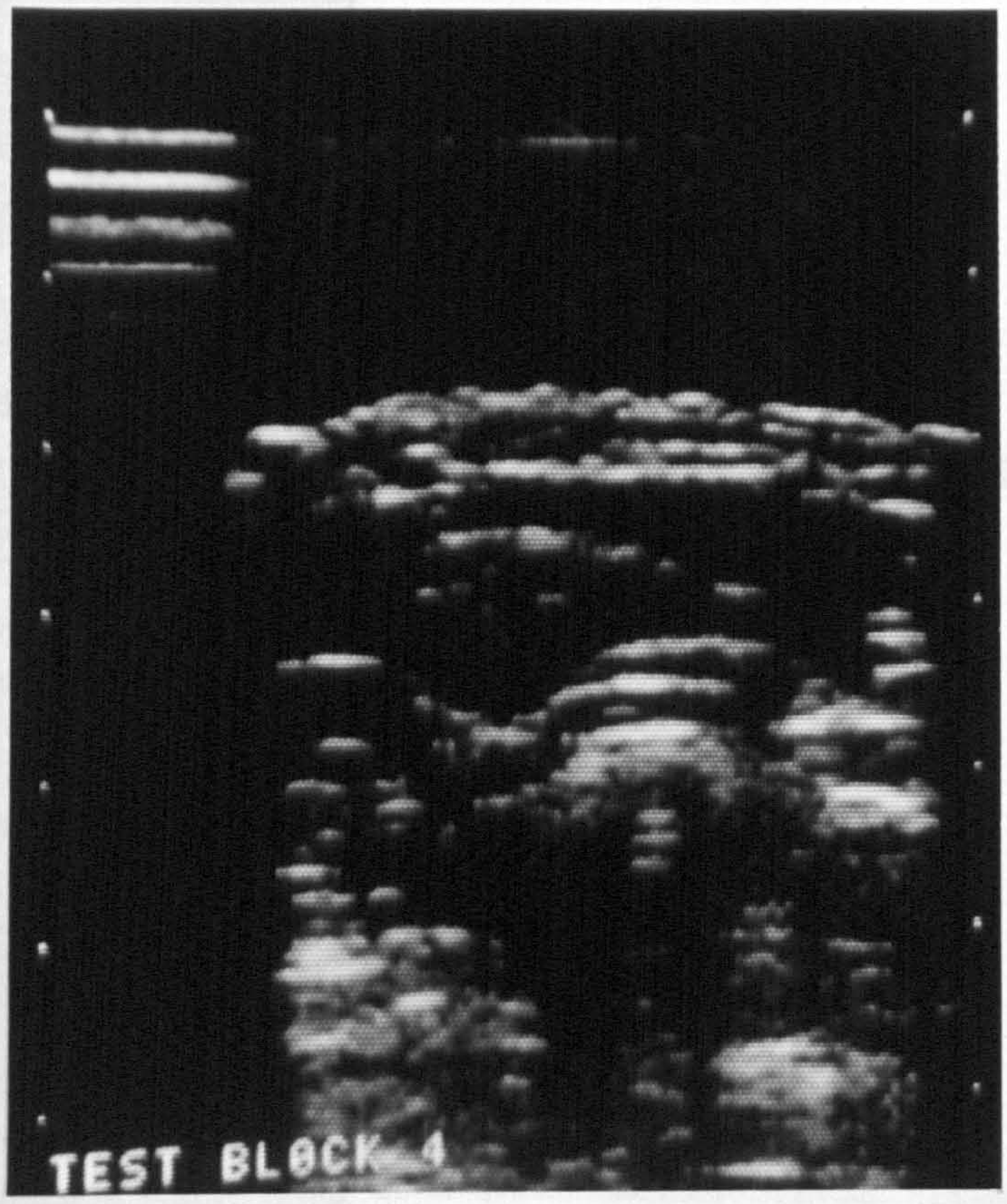


Fig.8.6b Radial head scanned through proprietary gel stand-off medium, Kitecho (R)

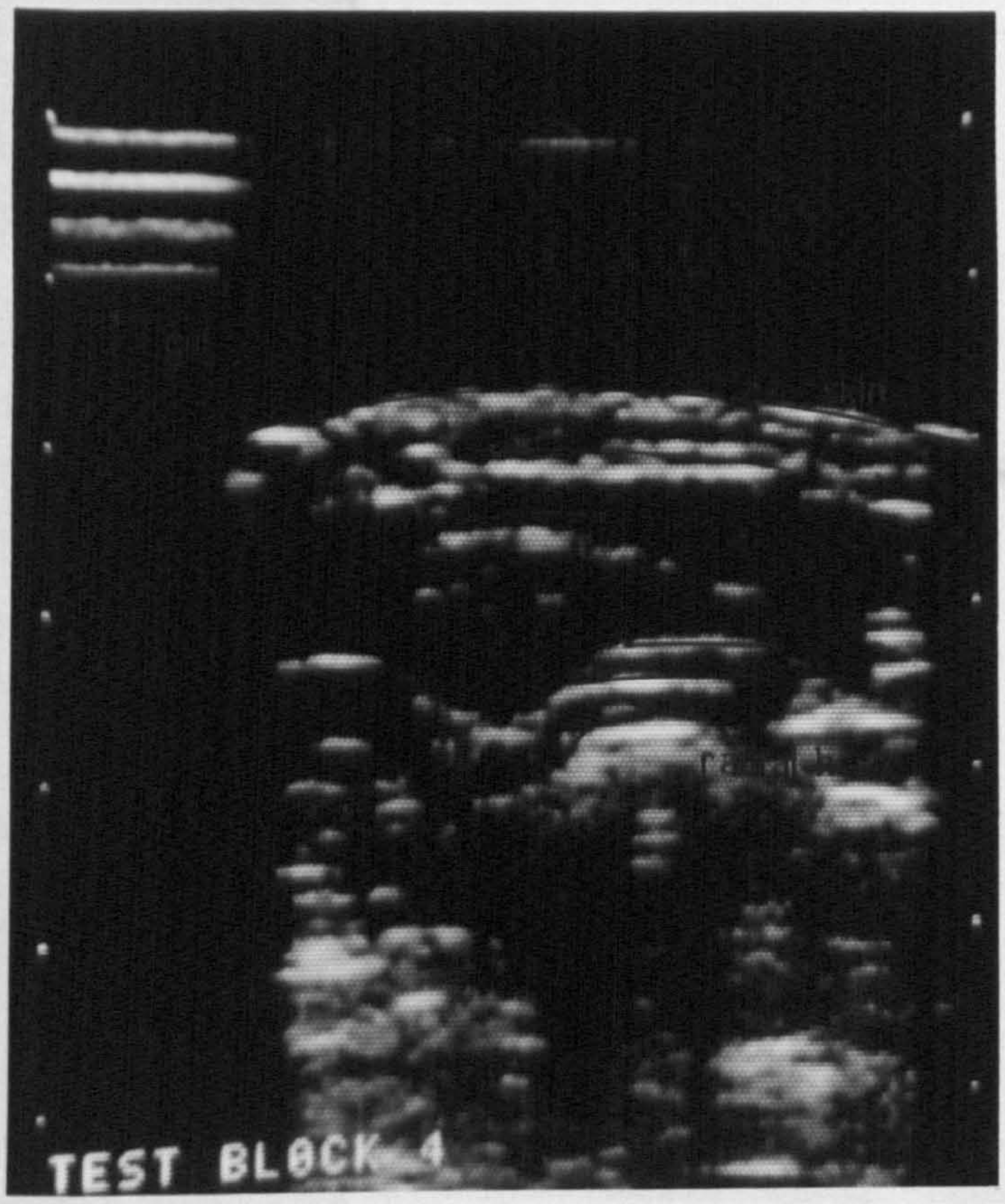


Fig.8.6b Radial head scanned through proprietary gel stand-off medium, Kitecho (R)

Conclusions

For all three gels, the velocity of sound was found to be less than that given for the Kitecko ® jelly and likewise body tissue. The attenuation was also found to be less. Despite this, none of the gels were found to assist imaging or the final image quality. The use of gels as standoff media was discontinued and all scanning procedures used only the ultrasound gel and in some instances for peripheral joints, a waterbag. The water bag was a water filled latex surgical glove. Care was taken to remove any talc within the glove, which would give rise to echoes within the water. Some reverberation was found to occur when using the waterbag. Over bony areas eg. the foot, echoes within the waterbag made images difficult to obtain.

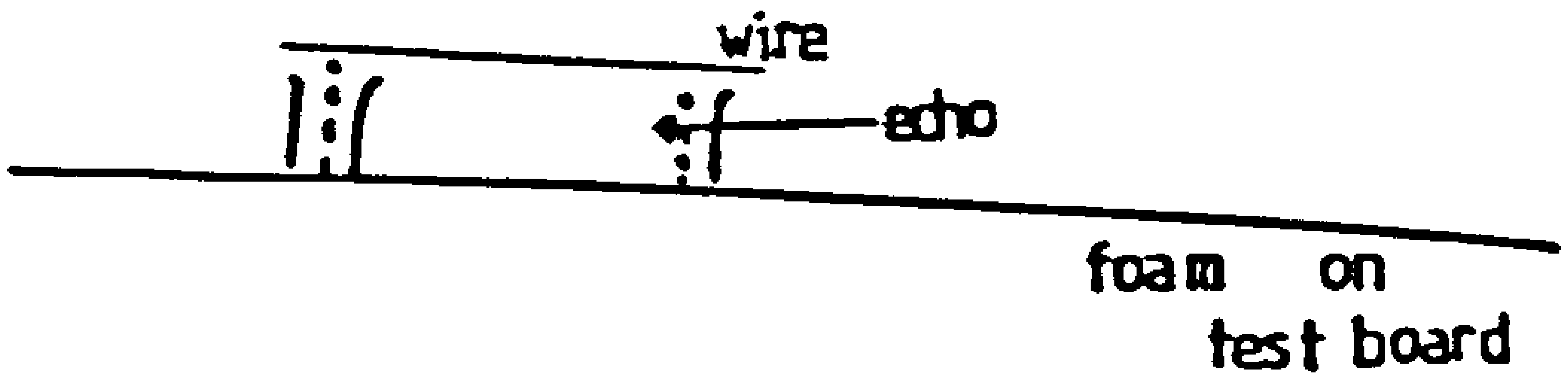
8.4 COMPARISON OF DISTANCES MEASURED BY VARIOUS TECHNIQUES

8.4.1 Test Board.

To ascertain the ability of the scanner to discriminate between two objects a distance apart, a simple test object or "board" was constructed.

The test board (Fig. 8.7) was built on the principles of the more sophisticated test systems with objects a defined distance placed in the path of the ultrasound beam. the lateral resolution of the scanner was to be tested in this manner. A perspex board was covered with a sheet of dense foam. Fine metal pins were placed through the foam and board. Two lengths of fine wire (0.7mm diameter) were soldered onto the pins to create two parallel lines.

The board was placed in a waterbath with water at room temperature. The transducer head (5MHz probe) was held in a clamp so that the face of this probe was just below the water but vertically above the wires. Using this test board, several tests were made, using fine wire (Fig. 8.7), thread and catgut in an attempt to find out if different types of structures imaged differently and if there were problems with the resolution of the equipment if the probe head was angulated.


wire
echo
foam on
test board

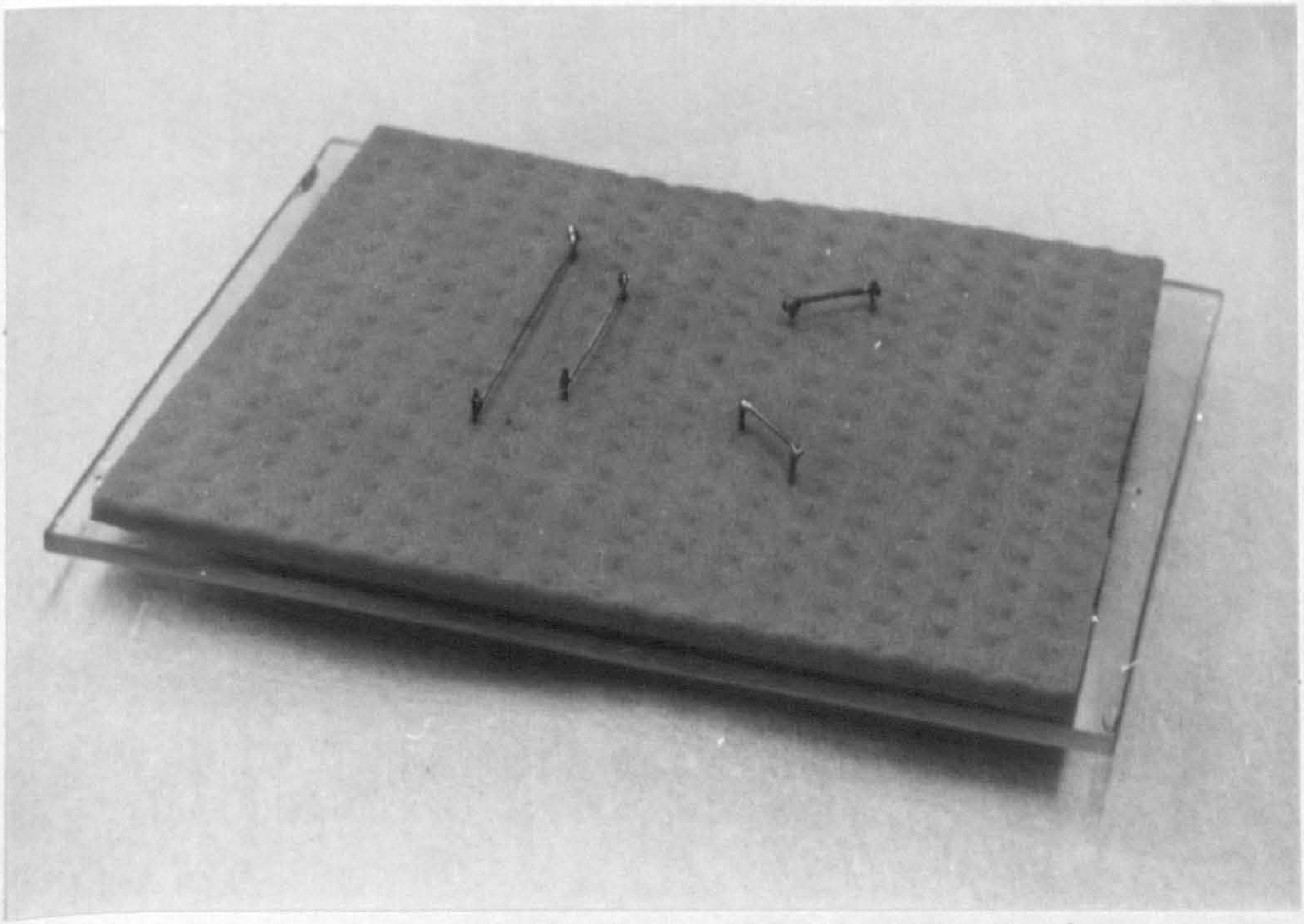


Fig.8.7 Test board with wire (0.7mm diameter)

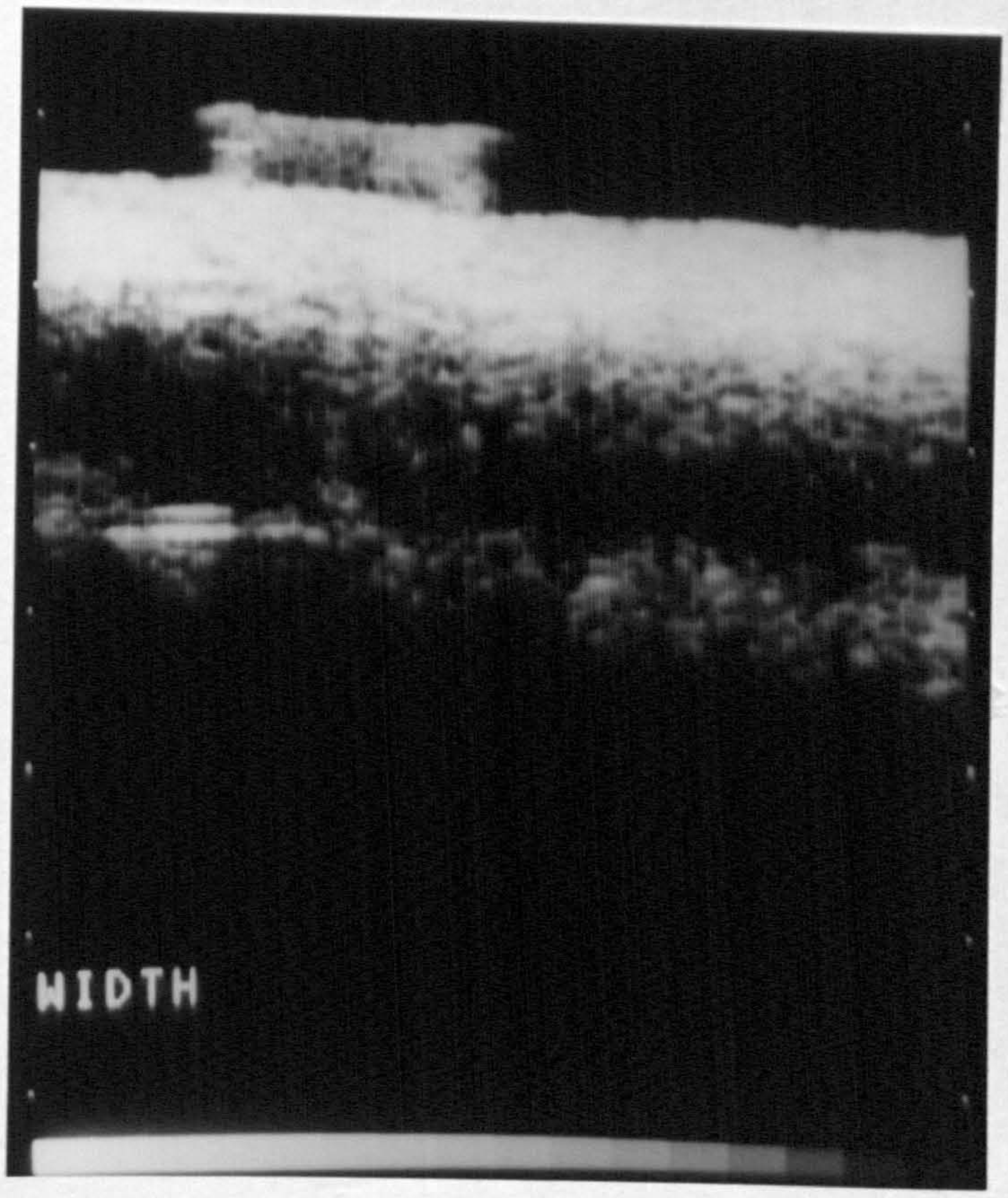


Fig.8.8 U.S. image of wires

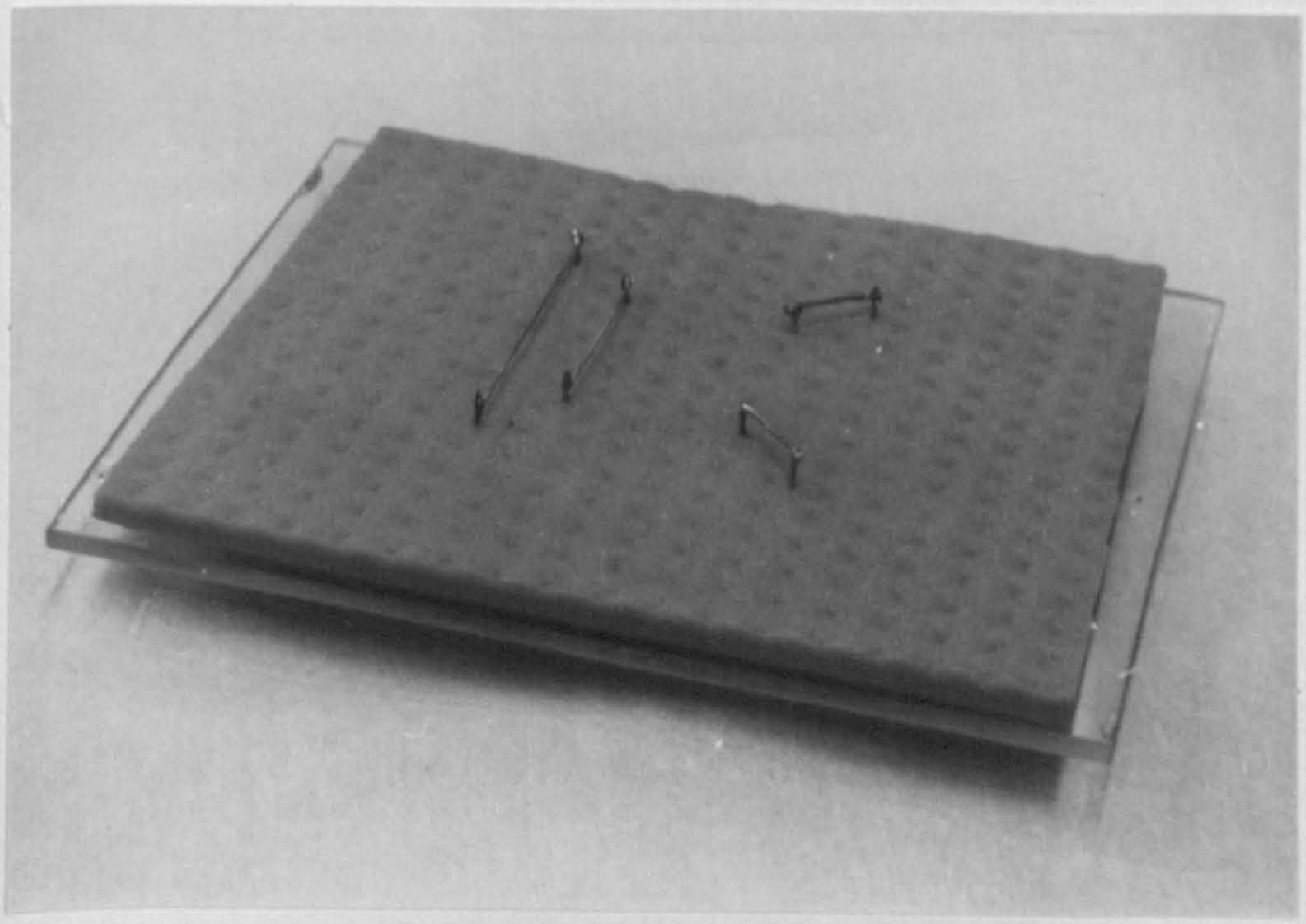


Fig.8.7 Test board with wire (0.7mm diameter)

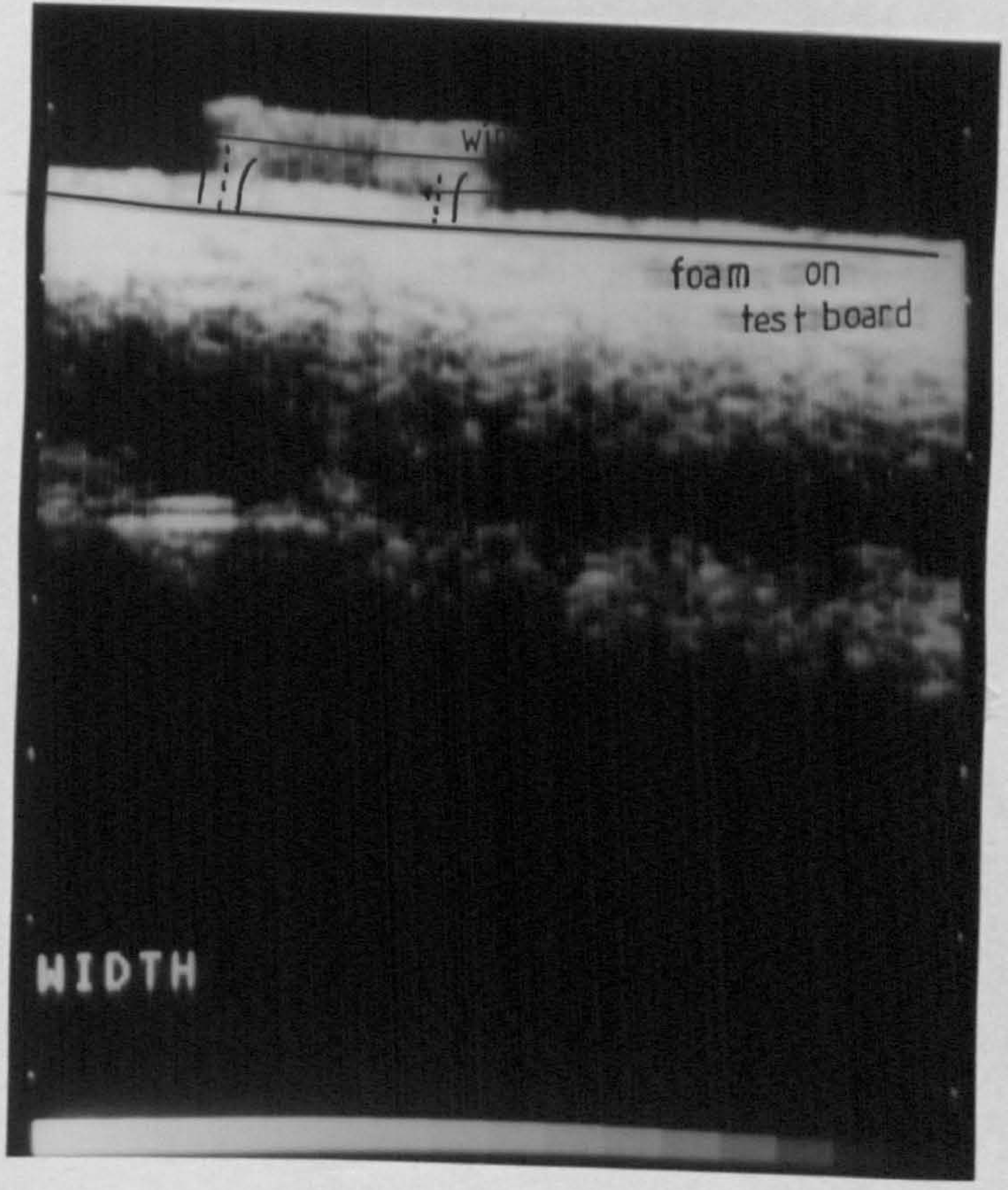


Fig.8.8 U.S. image of wires

8.4.2 Test Board and Fine Wire, •0.7mm diameter, with probe in 3 positions 0°, 15°, 30°.

In order to test the lateral resolution of the equipment the test board previously described was used. Two lengths of fine wire (0.7 mm diameter) were soldered to the upright pins so that they were parallel and 10mm apart. The probe was to be placed vertically over the wires and then angled at 15° and 30° . Angulation of the probe was considered by Porter et al (1978) to be of importance for the scanning of the spinal canal. However the cervical spine is different in size shape and content and the importance of probe angulation on the skin has not been established.

Method

The distance between the wires was measured by vernier caliper. The test board was placed in the waterbath with water at room temperature. The transducer head was clamped just submerged and vertically over the parallel wires. The images collected were held (freeze frame) and recorded on video tape.

The transducer head was then moved 15°, then 30 ° to the vertical and further images were collected and recorded as before. The images were then digitised using the Kontron Videoplan System and data obtained.

Results.

Two groups of data (n=50, each group), were taken for the vertical position and one set each for the 15° (n=50) and the 30° (n=50) positions of the probe. Two sets of data for the vertical position was an arbitary decision but allowed the pooling of results or scores in the comparison with the angled positions.

Using the X, SD and the n=50 for both of the vertical groups, a "t" test of two independent samples, assuming no equality of variance in scores, was used to test for difference between the two groups. A significance level of p= 0.05 was set.

Data point values were taken from the digitiser. Results for the four groups were plotted directly as histograms with a loss of raw data so further statical analysis was impossible.The main statistical results are given.

	POSITION OF PROBE.			
	Vertical		15°	30°
	1	2		
X,mm	9.80	9.22	8.77	8.41
SD	0.30	0.25	0.33	0.37
CV%	3.06	2.71	3.76	4.39

Table,8.3.

Changes in measurements with probe in 3 positions (vertical, 15°, 30°). The mean (X), standard deviation (SD) and coefficient of variance (CV) for the four groups (n=50 to each group).

Conclusions

Data collected allowed a comparison of the means, standard deviation and coefficient of variance(%) between the four groups in three different scanning postions.

The two sets of results for the vertical position gave a mean score value of 9.51mm . When compared to the mean scores of distance at 15° and 30° there was 1mm difference. The measured distance would appear to decrease as the angle of the probe to the skin increases. A difference of 1.59mm between the mean reading at 30° and the true distance of 10mm, gave almost a 19% difference which is considerable. However the CV% at the most is still less than 5%.

Results comparing the two vertical groups's scores would indicate that at a significance level of p= 0.05, there is a difference between the two groups. This might imply that the siginificant degree of variability in readings from two occassions with the probe vertical, would make a comparison with results when the probe was angled, difficult to interpret. The question of variability would suggest that this aspect of scanning would benefit from further attention at a later date.

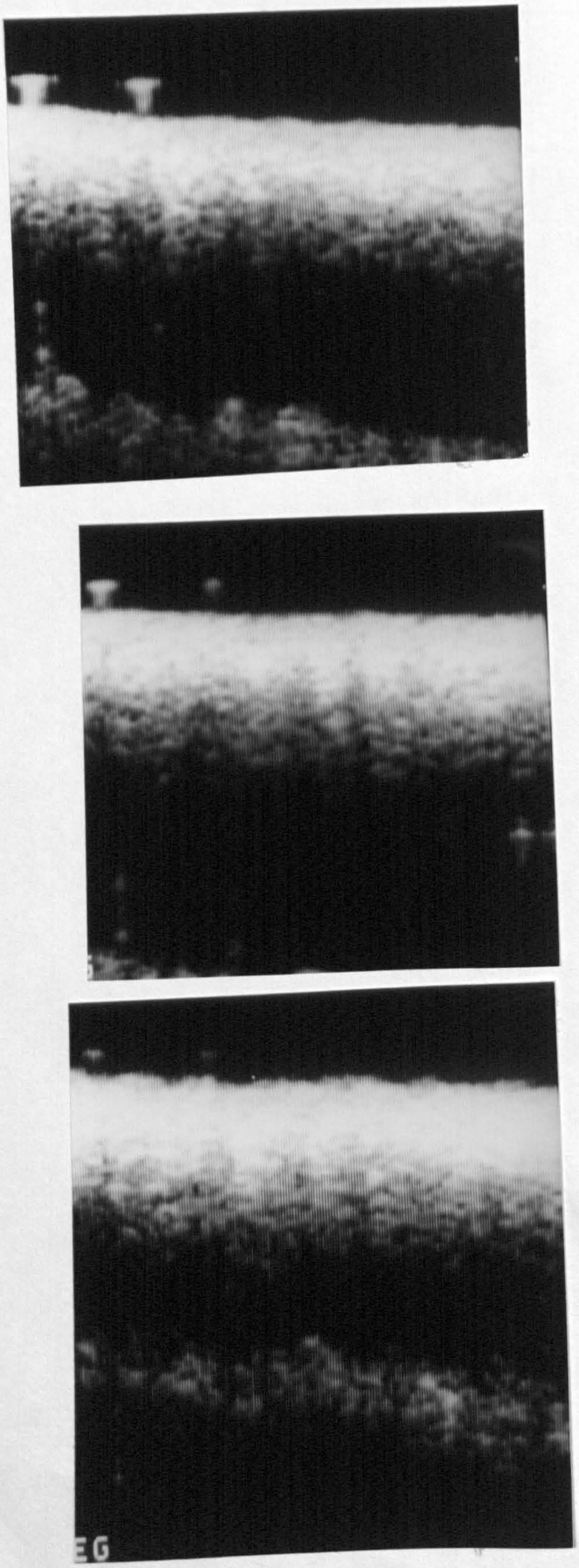
From a practical viewpoint, it was found that at about 30°and above, it was possible to lose the image altogether from the probe's field of view.

Results do not strongly indicate that probe angulation, unless

Threads at 0°

Threads at 15°

Threads at 45°



<u>Fig.8.9</u> Thread (profile) viewed from 3 angles; Normal, 15° and 45°

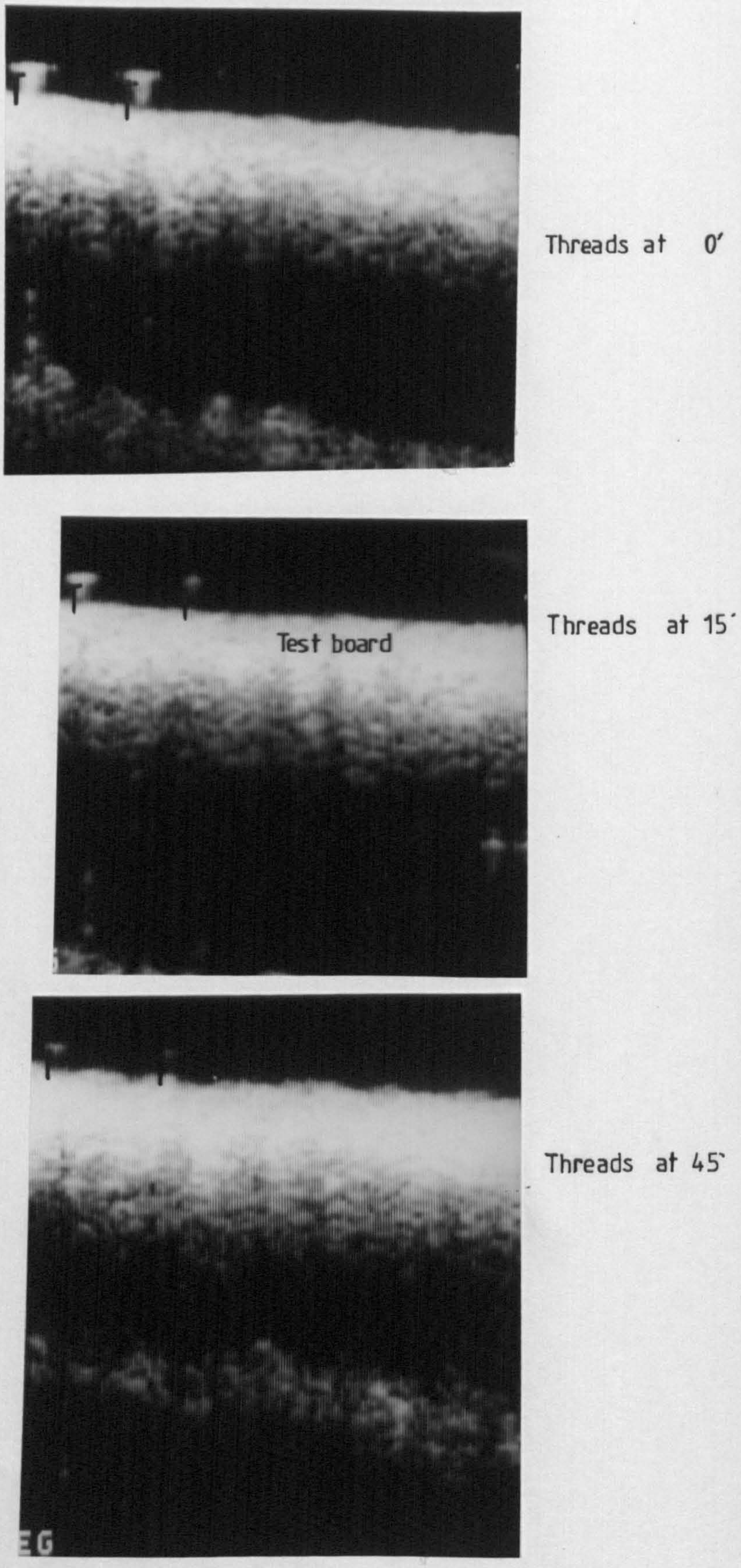


Fig.8.9 Thread (profile) viewed from 3 angles; Normal, 15° and 45°

more than 30°, is a vital part of the scanning proceedure. The position of the vertebra within the neck and the shape of the vertebra would in any case mean, that the ultrasound beam would probably not strike the bony surface at the same angle as on the skin.

8.4.3 Test Board, Fine Thread, 0.13mm diameter and the probe at 0°,15°, 45°using 2 measuring systems.

The ability of the scanner to laterally resolve small diameter objects was tested. The caliper function of the scanner was to be compared to the measuring facility of the digitising system for measuring the distance between the threads. The effect of angulation of the probe on the ability to measure distance was also considered.

A null hypothesis was stated that there would be no significant difference between the two methods of measuring the distance between the threads, using the ultrasound scanner and the digitiser.

Method

The test board was set up as before, but fine monofilament (0.13mm diameter) threads were attached to the pins to make parallel lines 8mm apart. The board was placed in a waterbath with still water at room temperature. The probe face was just submerged and the probe was placed vertically above the threads, then later the probe was angled to 15° and 45° to the vertical. All images of the threads were recorded (Fig. 8.9) on video tape using the freeze frame facility of the scanner to minimise any movement artifact. The caliper function allows the positioning of two caliper "pips" and the measurement of the distance between the pips is shown on the screen. The scanner measures only in units of 1mm. Recorded video tape was used in the digitising system to allow two points to be identified and the distance measured

Results

A summary of the statistical results for the digitiser and the scanner in the three positions are given in Table 8.4. The real distance was 8.000 mm and the results using the digitiser are closer to this figure. Considering the two methods of imaging the threads and the three positions of the probe the analysis of the results required using ANOVA at p= 0.05 .

The value of the F obtained was -13.617 which greatly exceeded the F critical value (between, 3.39 and 3.32). The null hypothesis which supported the viewthat there would be no difference between the measuring systems was rejected.

A two way analysis of variance was again applied to detect a difference between the measuremens taken with the probe in different positions. Again for each position the F value exceeded the F critical value. The position of the probe should be considered in scanning techniques.

A sample of data is given as APPENDIX II.

	PROBE POSITION					
	vertical		15°		45°	
	digitiser	US	digitiser	US	digitiser	US
X,mm	7.984	8.600	8.169	8.600	8.080	8.600
SD	0.189	0.516	0.225	0.516	0.294	0.516
CV%	2.367	6.000	2.754	6.000	3.637	6.000

Table 8.4.

Distance between two threads as measured by the digitiser and the scanner with the probe in 3 positions, comparing the main statistical results.

Conclusions

This test did demonstrate that the US equipment could image small diameter (0.13mm) objects in a waterbath. The images were very clear as there was no acoustic shadow thrown by the thread. In this instance it was still possible to image the objects with the transducer at 45°

The null hypothesis, that there would be no significant difference between the two methods of measuring was rejected, as a significant difference (p= 0.05) was found for all groups. Once again the problems of obtaining an image and measuring distance with an angulated probe was identified. However the results were in a test environment of a waterbath, and it could be difficult to extrapolate to the in vivo situation, where tissue boundaries would refract the beam and movement of the neck would cause all the structures to reposition themselves.

8.4.4 Test Board, Surgical Catgut (0.31 & 0.38 mm diameter)measured using 2 systems.

Test phantoms for ultrasound equipment usually have a series of shapes or wires embedded in a medium which has similar sound attenuation and velocity properties to body tissue. By testing surgical catgut (Ethicon ®) a protein material, any differences in the image quality compared to the wires previously imaged could be assessed visually allbeit subjectively.

Measurements were to be made with the ultrasound scanner caliper function and the digitiser from the video tape recording. A null hypothesis was again set that there would be no significant difference between the two methods of measuring the distance between the parallel lines of catgut. Two thicknesses of thread were used

Method

The test board, waterbath and probe were set up as for the previous tests. Using the two thickness of catgut (0.31mm & 0.38mm), two sets of parallel lines were made using the pins on the board. The transducer was placed in position vertically over the catgut. Images of the catgut were achieved and the distance between them were measured using the caliper function of the scanner. All images were recorded on video tape. Scanning, measuring and recording of images was completed as quickly as possible as it is appreciated that catgut absorbs fluid and expands.

<u>Results</u>

Results from the scanner's caliper function were compared to those of the digitiser. With p= 0.05, a 't' test on scores for the 0.31mm catgut, showed that in the vertical position there was no difference between the two sets of scores. For the 0.38mm catgut, under the same constraints, there was a difference between scores which was felt to be significant(p= 0,05), the 't' value was -5.833 compared to a 't' critical value of 1.734.

The lack of a value for the SD made it imposible to undertake a Matched pairs "t" test.

	CATGUT.			
	0.31mm diam.		0.38mm diam.	
	Digitiser	US	Digitiser	US
Imm	11.01	11.00	10.755	11.00
SD	0.175	0.0	0.134	0.0
CV%	1.59	0.0	1.253	0.0

Table 8.5.

Distance between parallel lines of catgut, measured by digitiser and scanner, with main statistical results.

<u>Conclusions</u>

Subjective analysis of the results would indicate that for the 0.31mm Cat gut, a difference in the mean scores of 0.01mm might indicate a satisfactory ability of the two systems to record the same distances. This was not so apparent for the 0.38mm thread. It was noted that the thicker ,of the two threads had a rough surface and this might make the boundary definition of the thread difficult to detect with accuracy.

A difference in the results between measurements made by the digitiser and those made by the scanner may be due partly to the relative size of the thread and perhaps to its slightly textured surface. The caliper function of the scanner operates only in 1mm units whilst the digitiser gives results (mm) to 3 decimal places. The null hypothesis was accepted for the 0.31 catgut but was rejected for the 0.38 catgut. For the thicker catgut, both the SD (0.134) and the CV (1.253), indicate the difference is small, but that would have to be noted.

8.5 EXPERIMENTAL WORK USING THE MODEL SPINE

8.5.1 Distance between 2 Pins with the Probe Head at Different Distances from the Pins

Using the phantom spine and markers for measuring distances, offers the chance to test the scanner in an in vitro situation. Measurements were taken using only the digitising system.

Method

Two metal pins of 1.6mm diameter were attached 10mm apart on the silicone tubing of the spinal canal, both measurements were checked using a vernier caliper. The spine was placed in the waterbath which was then filled. The transducer was placed on the contact gel on the membrane surface of the container. A series of 17 images of the pins were recorded on three occassions, these being with the probe head pushed as far as possible into the soft wall of the container then with the minimum of pressure required to achieve an image and then again at normal pressure. The distances were subjective distances within the capability of the silicon chamber to deform This was to see if there would be a difference in measurement with the probe at differing distances from the object, incase the pressure of the probe was important to take as a variable in recording distances. All results were recorded on video tape for measuring the distance between the pins

Results

The hypothesis had been set that there would be no significant difference in measurements achieved with the probe head at any of the three positions (near, distant or normal) for the in vitro spine in a waterbath. Data was collected to allow an ANOVA to be used to test for the differences between the 3 positions. A significance level of p= 0.05 was chosen.

	Position of Probe Head		
	Near	Distant	Normal
X mm	9.513	9.190	10.186
SD	0.315	0.168	0.176
CV%	3.316	1.836	1.735

Table, 8.6.

Distance measured between two pins attached to the model spine, with the probe head at different relative distances from the pins.

Conclusions

Comparison was made between normal and close-to and normal and distant positions of the probe head.and tested for using ANOVA and significance at the p= 0.05 level, the null hypothesis was rejected for both distances. The F value was considerably greater than the F critical value (F value 47.79 to F critical 3.39/3,32).

The Means for the near and far positions were 0.487 and 0.810mm from the 10.00mm the true distance. At almost a 1mm difference it confirmed the rejection of the null hypothesis.

The use of a standoff mediun which was rejected on other grounds, might bring attention to the possible alteration of distance measurements if the height of the medium was considerable.

The results however do raise the point that pattern of the values obtained may reflect a degree of focusing of the equipment, and this area might require further work.

8.5.2 Interspinous Distance (1). Vernier vs Scanner Measurements.

The use of the model or phantom spine allowed the operator practice in obtaining images and identifying spinal structures. The spine was also used to identify changes in relative position between vertebrae with movements. Measurements could be made by vernier, US scanner or by digitiser for comparison.

Method

A small rubber wedge was placed between two spinous processes to hold them apart (Fig. 8.10a). This distance was measured by vernier caliper(n=10). The spine was then placed in the waterbath and scanned. The images of the spine were collected on video tape. The distance between the spinous processes,(the same distance that had been measured with the vernier calipers) was measured by the caliper function of the scanner (n=20).

Results

A statistical test was used using a 't' test of independent unequal sample groups, the vernier caliper measurements (n=10) and the scanner measurements (n=20). Comparing the two methods of measuring the interspinous distance, it was found that at a p= 0.05, there was a small but significant difference between the scores which should be considered. The mean of the distance was 14.36 for the vernier scale and 13.85 for the digitiser, with the SD of 0.134 and 0.366 respectively.

Conclusions

The 't' test on independent unequal samples demonstrated that there was a difference between the two methods of measuring. The 't' value was 4.25 compared to the critical 't' value of 1.701. The use of unequal samples however might well in itself contribute even

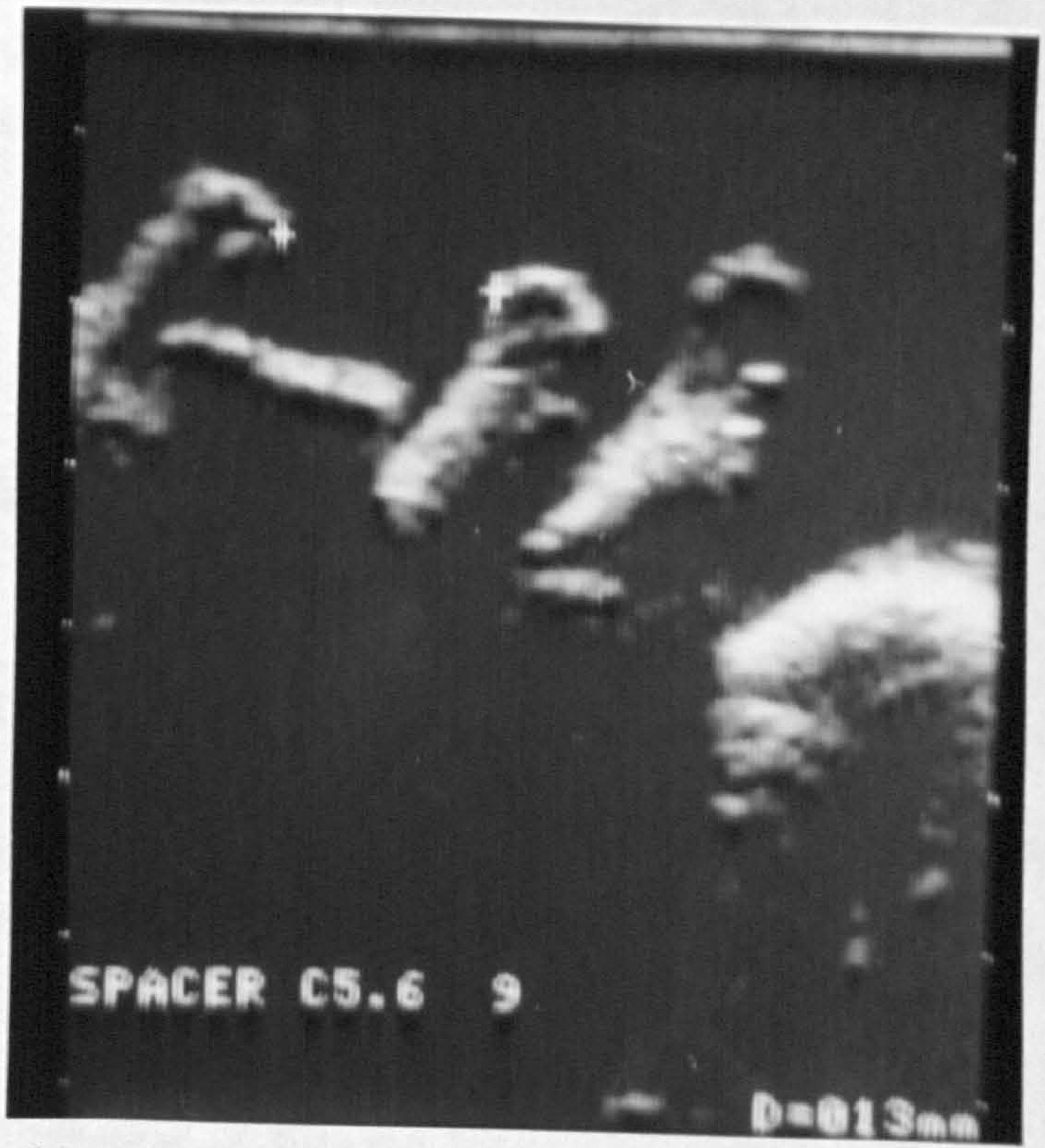


Fig.8.10a

Fig.8.10b Spine in vitro with (a) spacer and (b) without, Distance between spine tips measured

slightly to the rejection of the null hypothesis. That both the SDs were below 0.4, may imply for practical purposes that any differences in measurements would be small.

8.5.3 Interspinous Distance (2)

Method

The above test was repeated without the interspinous block (Fig. 8.10b). Interspinous measurements were made with the scanner caliper function and the vernier calipers attempting to measure the identical position on the spine. The null hypothesis again was that there was no significant difference between the two methods of measuring. A 't' test was carried out on the results to detect if there was a difference between the two methods of measuring.

Results

The "t" test was again on two independent samples of unequal size (vernier n=10, scanner n=20). The null hypothesis was rejected as a significant difference was found between the two methods of measuring. The mean interspinous distance was 6.3mm with the vernier scale and 5.7mm with the digitiser. The difference of 0.6mm is the capability of the US scanner to discriminate, as the caliper function is only to 1mm. The SD were both small, 0.182 and 0.470 respectively.

Conclusions

Although the null hypothesis was rejected, there was only 0.6mm between the two means of the interspinous distance. The difference may also reflect the initial problem identifying the same place on the spine from which to take the measurement. Once again the ultrasound scanner had the large SD and CV% which may be due to the fact it can only measure in 1mm increments.

The problems of detecting small distances on the scanner less than 1mm are noted.

8.5.4 Interspinous Distance (3)

Method

The above test was repeated except that this time the interspinous distance was measured by the caliper function of the scanner and the digitiser from the recorded video tape using points as close to those identified by the scanner. A null hypothesis was set that there would be no significant difference between the two methods of measuring interspinous space. Twenty measurements were made in each group.

Results

Results from two groups of 20 scores when subjected to a 't'test at p=0.05 , showed that a significant difference between scores existed.

Statistical results comparing scores from the scanner to those from the digitiser, gave the means as 13.85mm and 13.52mm respectively and the SDs were 0.366 and 0.594, and the CV% were 2.645% and 4.395%. The difference is present but from a practical view point the SD's and the CV% low.

Conclusions

The caliper function of the scanner measured distance in units of 1 mm as compared to the digitiser which measured to an accuracy of 0.1mm. The caliper function was carried out on a freeze frame realtime image, whereas the digitised results were performed using a cursor from a paused video frame image on a monitor. The errors which must be present are reflected in the results of the two different measuring methods. Another problem was that of identifying boundaries from which to take marker points and it was felt that this problem would contribute greatly to the differences in the scores form the recordings.. Experience in structure identification was required and this was later recognised as a problem of the early stages of the work.

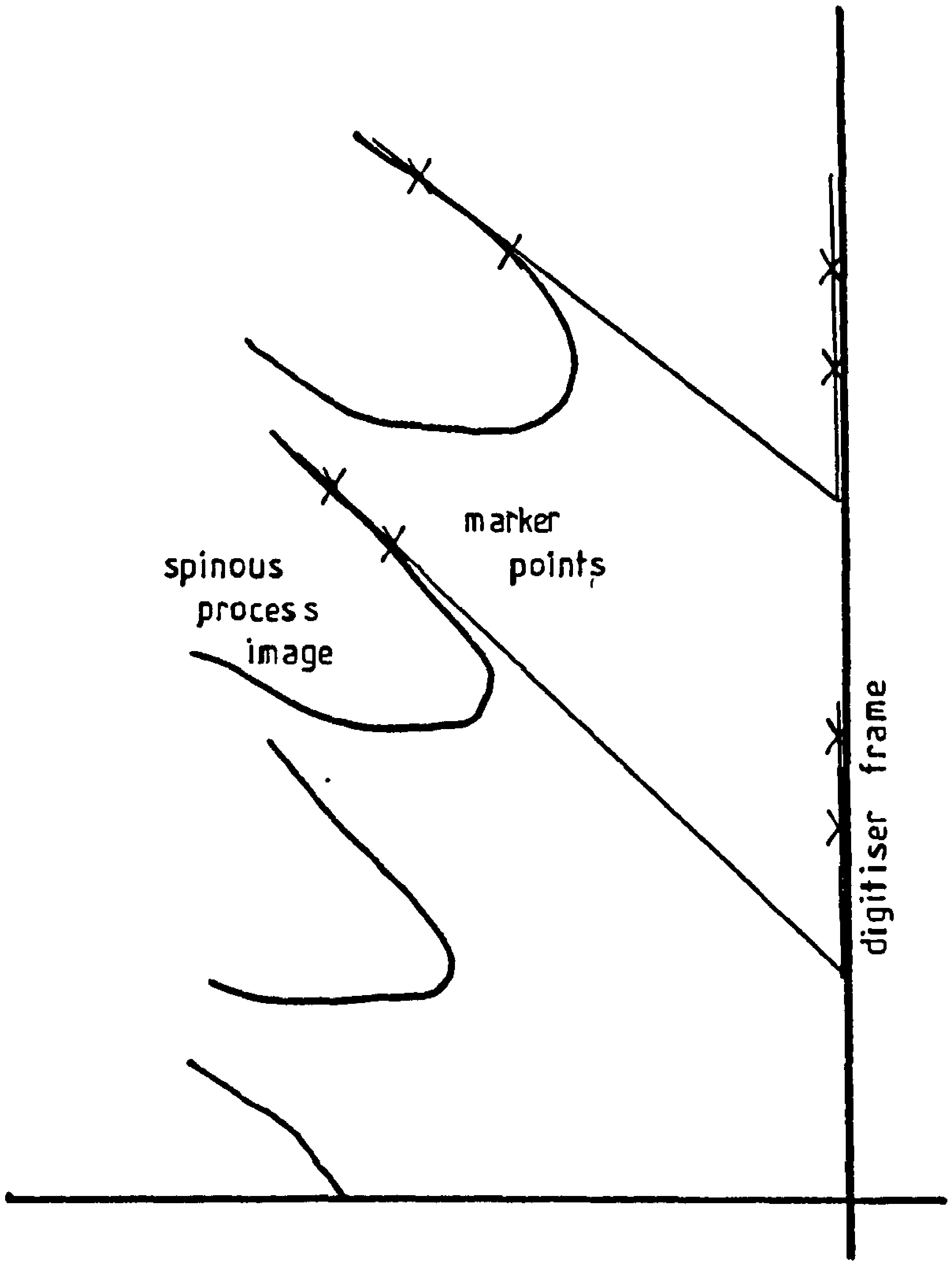


Fig.8.11 Relative change to Vertebra position as determined by comparing angles from at flexion and at extension - using digitised videotape recording

8.6 IN VIVO SPINES - NORMAL

8.6.1 Segmental Flexion and Extension as Measured by the Angle of the Spinous Process to the Vertical

The imaging of the in vivo spine proved more difficult than had previously been imagined. The different tissues in the cervical spine all with their own ultrasound characteristics made scanning and the interpretation of images difficult.

METHOD

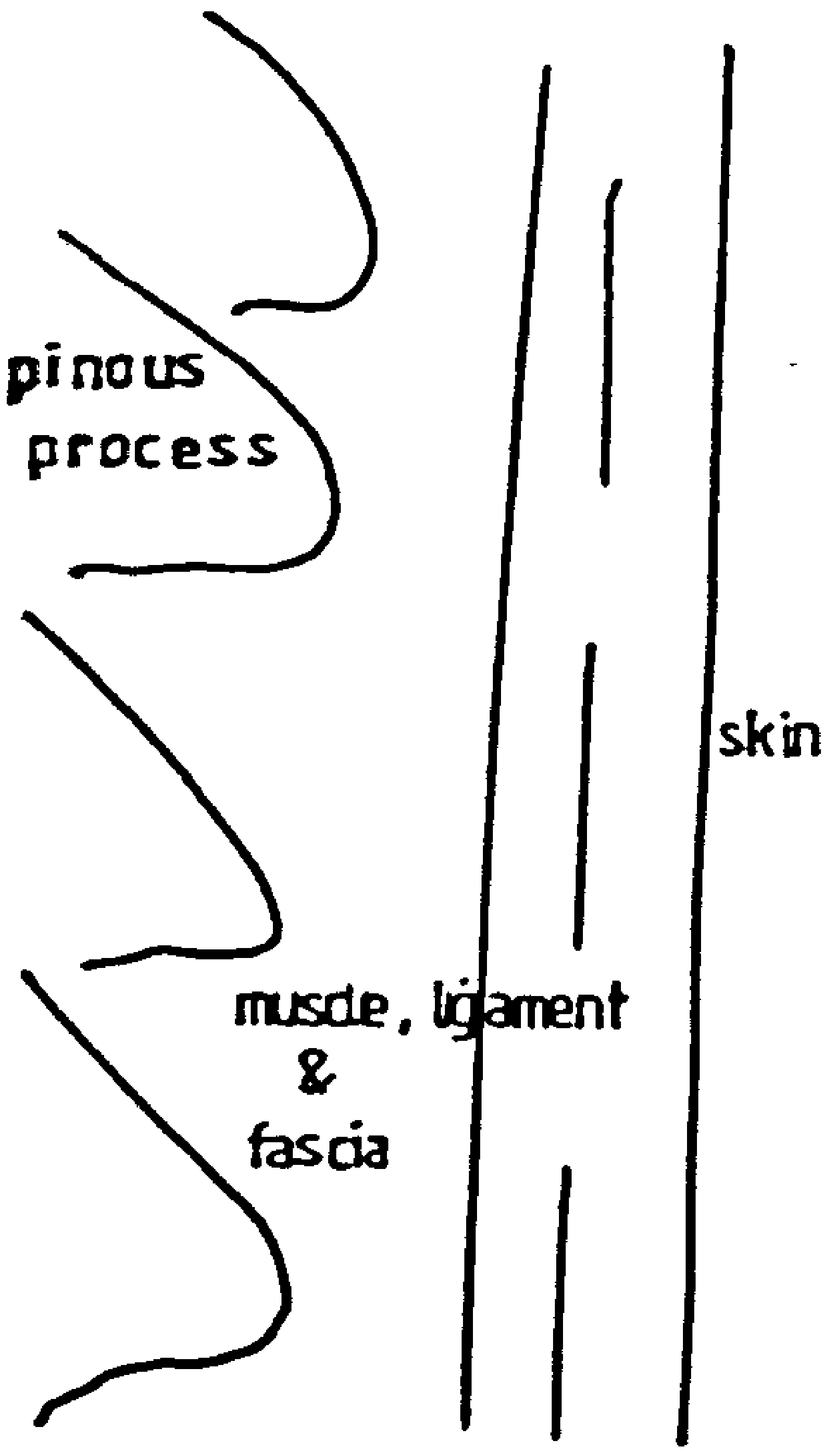
Twenty subjects (ages 23-37 years, mean = 29.2yrs), who had no history of neck problems or other musculo-skeletal disorders had the scanning procedure explained to them and their consent was obtained.

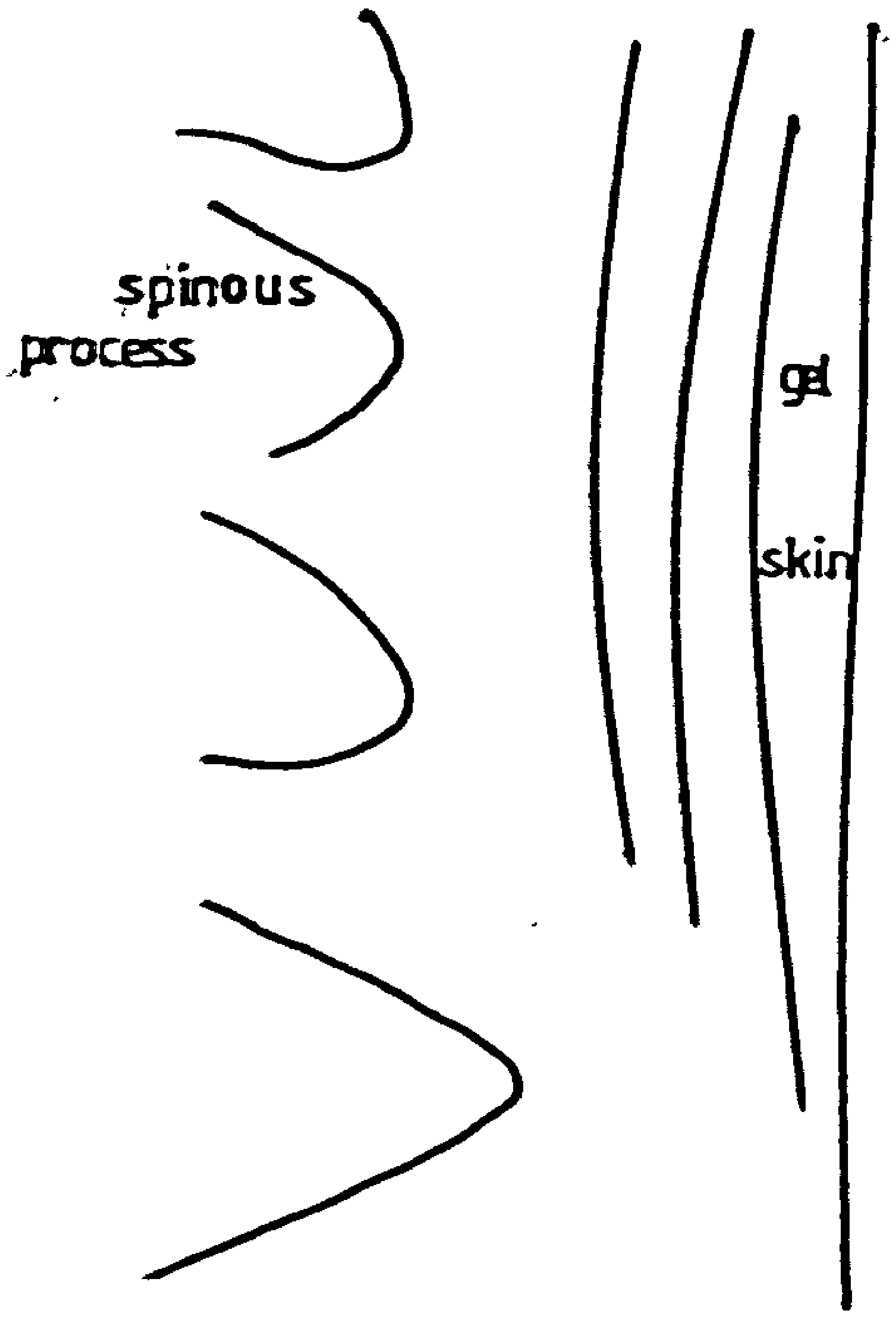
The midline of the cervical spine had iv vitro produced clear images of the vertebrae. It was hoped that the same image could be used in vivo. To that end scanning of the spine in the vertical midline was performed.

The probe was applied to the midline of the spine with the contact gel, and an image of the spinous processes was obtained. The subject was asked to slowly flex and extend the cervical spine while images were recorded.

The measuring of flexion and extension of the neck using the digitising system was to be found by using a line drawn along the line of the image of the spinous process and the angle it would subtend to the fixed frame of the digitiser (Fig.8.11, 8.12a & b). The digitising system allowed a set of four points to define an angle between the two lines created. The angles between two spinous processes were recorded. Points were selected each time in the same order. The points on the spine were placed along the main outline of the spinous process so avoiding the difficulty of the different shapes of the spinous processes.

The null hypothesis was that there was no significant difference between angles of the spinous processes, measured in flexion and extension.


spinous process
muscle, ligament & fascia
skin


spinous process
gel
skin

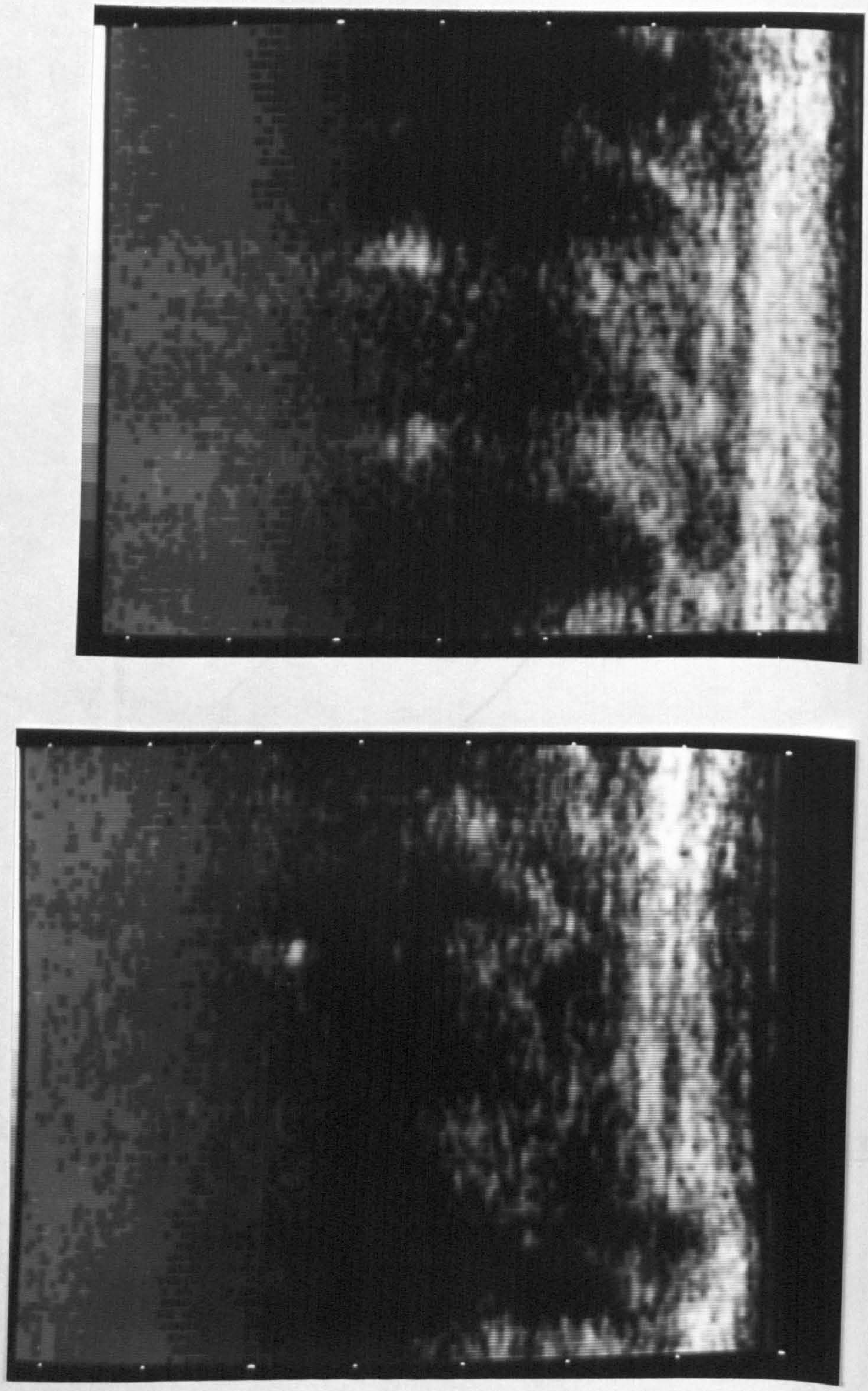


Fig.8.12 Profiles of Cervical Spinae in
Midline a) Flexed Position
b) Extended Position

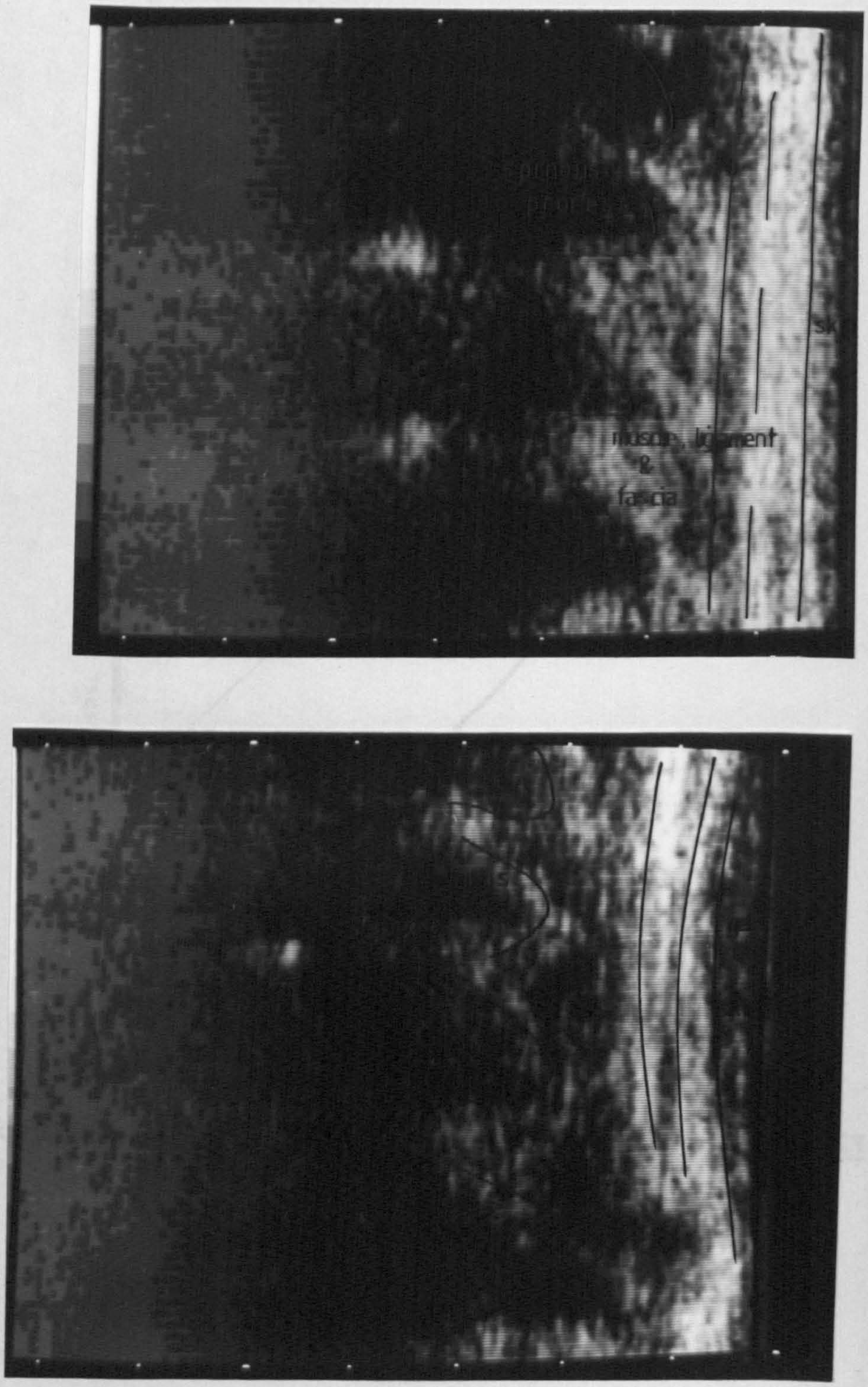


Fig.8.12 Profiles of Cervical Spinae in Midline a) Flexed Position b) Extended Position

8.6 IN VIVO SPINES - NORMAL

8.6.1 Segmental Flexion and Extension as Measured by the Angle of the Spinous Process to the Vertical

The imaging of the in vivo spine proved more difficult than had previously been imagined. The different tissues in the cervical spine all with their own ultrasound characteristics made scanning and the interpretation of images difficult.

METHOD

Twenty subjects (ages 23-37 years, mean = 29.2yrs), who had no history of neck problems or other musculo-skeletal disorders had the scanning procedure explained to them and their consent was obtained.

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The probe was applied to the midline of the spine with the contact gel, and an image of the spinous processes was obtained. The subject was asked to slowly flex and extend the cervical spine while images were recorded.

The measuring of flexion and extension of the neck using the digitising system was to be found by using a line drawn along the line of the image of the spinous process and the angle it would subtend to the fixed frame of the digitiser (Fig.8.11, 8.12a & b). The digitising system allowed a set of four points to define an angle between the two lines created. The angles between two spinous processes were recorded. Points were selected each time in the same order. The points on the spine were placed along the main outline of the spinous process so avoiding the difficulty of the different shapes of the spinous processes.

The null hypothesis was that there was no significant difference between angles of the spinous processes, measured in flexion and extension.

Results

The digitiser was used for all measurements in this section. Angles were obtainable when the spine was in both the flexed and extended positions. Four groups of readings (subjects) (1 - 4), were obtained using ten flexion, and extension scores.

Analysis was by using a Wilcoxon Matched pairs test.comparing angles obtained in the flexed position and the extended position for the 4 groups. The results were not easy to interpret as there were only 4 groups, so Matched pair "t" tests were carried out for each group between flexion and extension. The significance level of p= 0.05 was made.

Flexion / Extension in the four groups								
	1		2		3		4	
	Fx*	Ex	Fx*	Ex*	Fx*	Ex*	Fx*	Ex
X*	72.60	35.29	66.10	55.19	58.38	48.92	72.18	63.30
SD	8.07	5.35	3.42	4.34	5.50	5.70	2.95	7.52
CV%	11.12	15.00	5.18	7.86	9.42	11.66	4.08	11.91

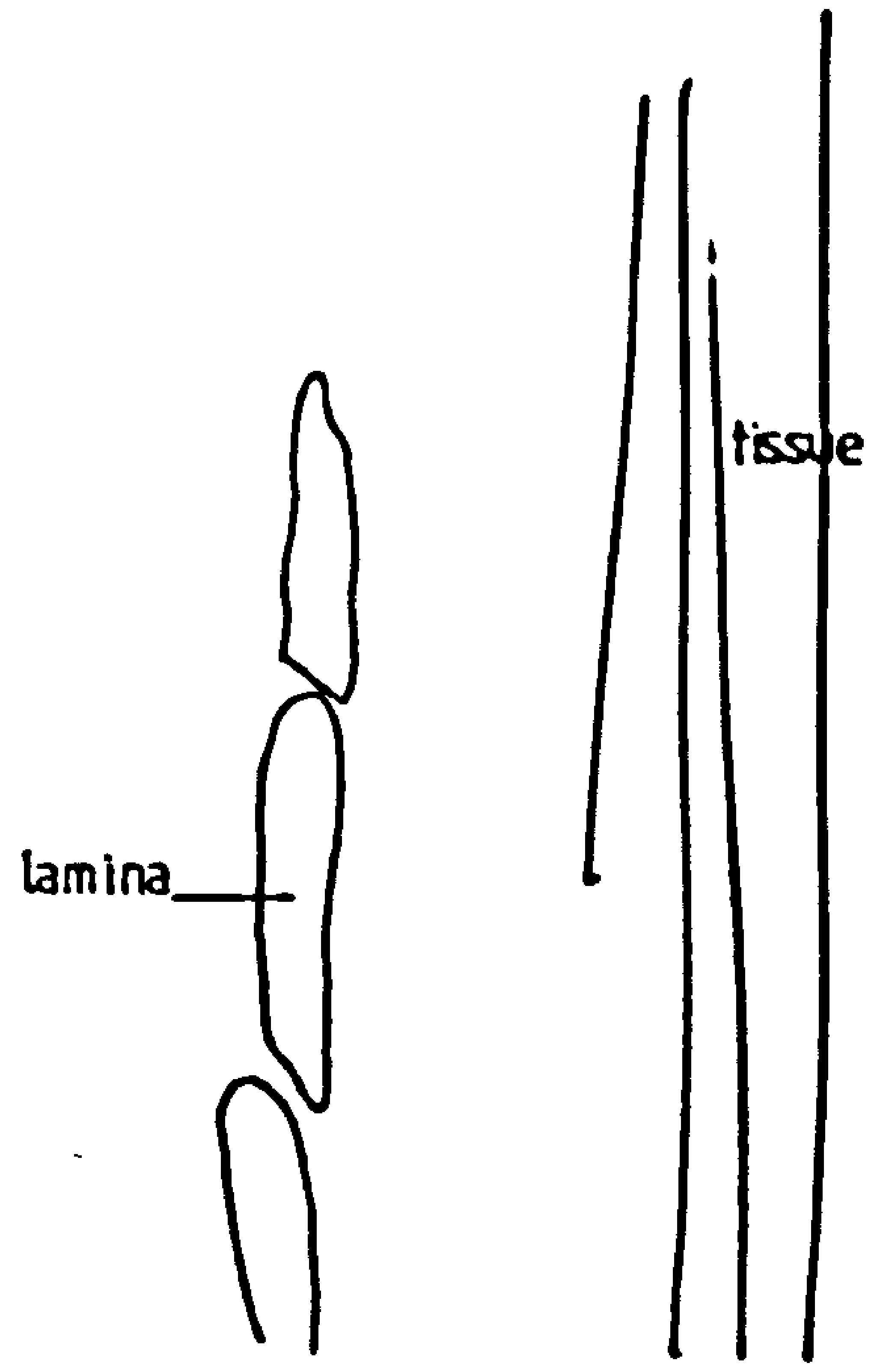
Table 8.7.

Flexion and extension angles subtended by the spinous processes to the fixed frame of the digitiser,summarised by the X, SD & CV% of the four groups

Conclusions

A 't' test was made using data of flexion angles and extension angles of the spinous processes for the four groups of data. From the mean angle for each movement for each group, as given in the table above, it can be seen that there was a difference between the two positions, which was also observable on the video tape. It is possible then, to measure segmental motion using this method. However it was noted that the SD and the CV for almost all the groups is high, greater than 5% which is not really acceptable.

There were practical problems with this method of measuring


tissue
lamina

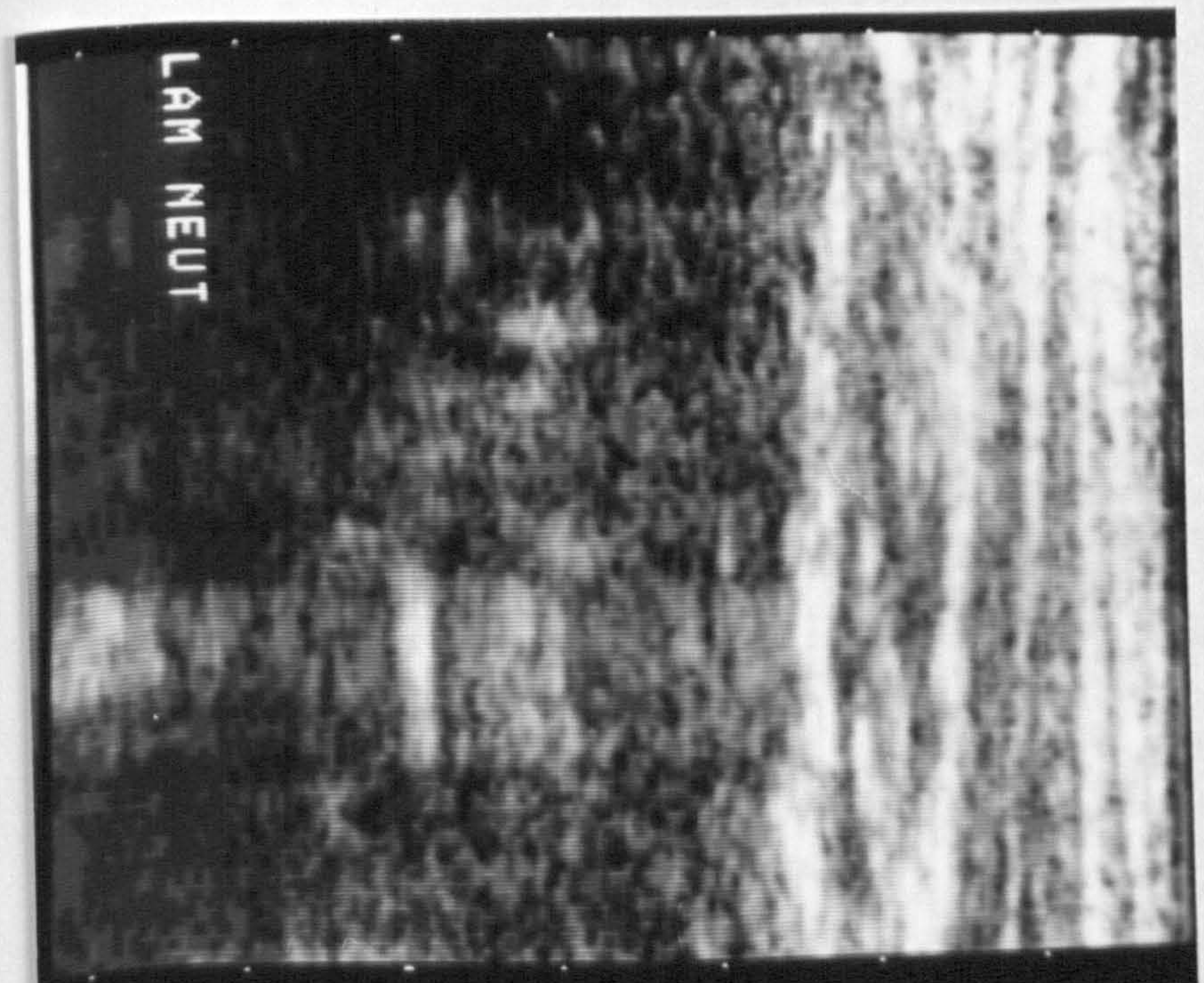


Fig.8.13 In vivo scan of laminae in longitudinal view

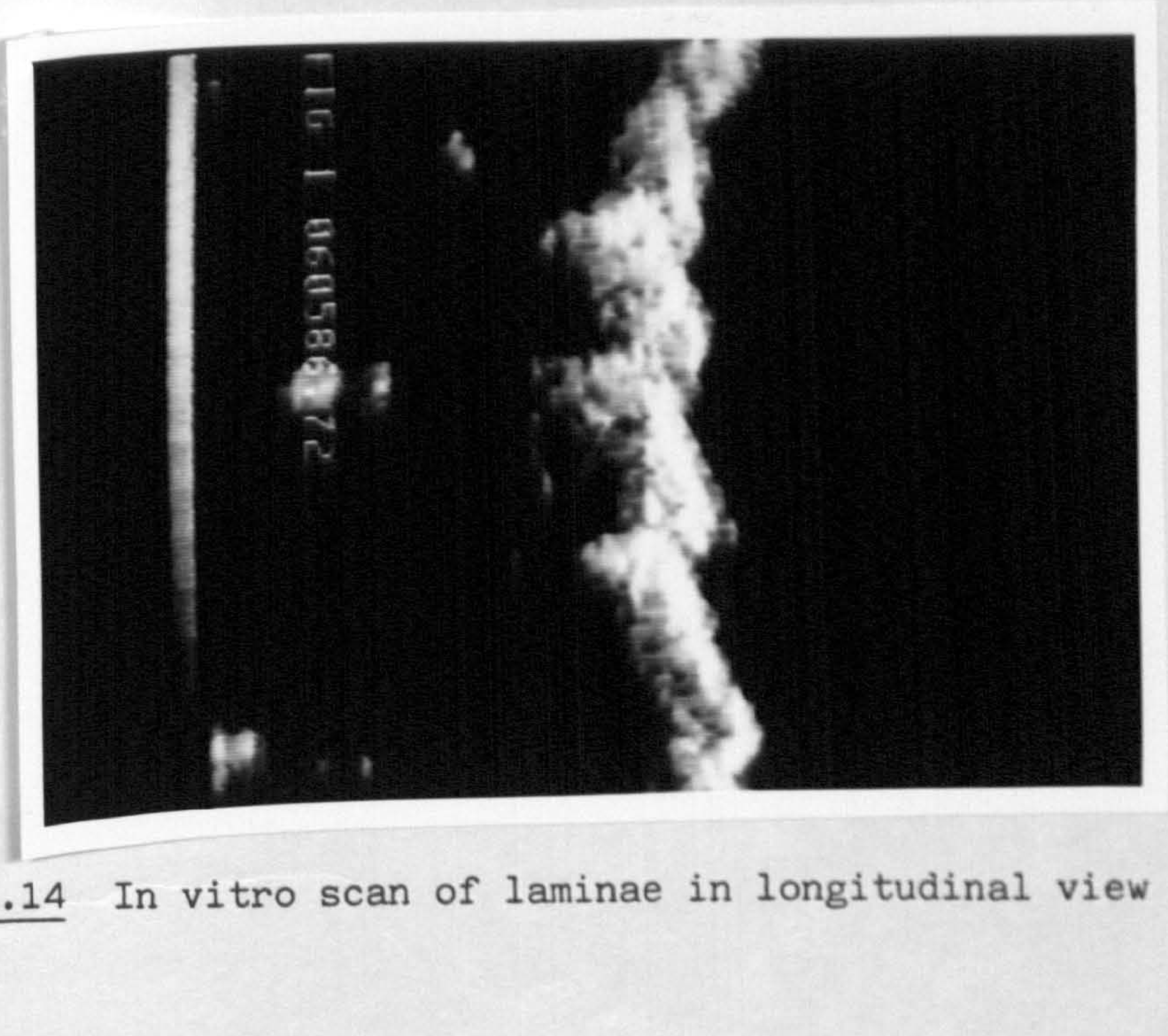


Fig.8.14 In vitro scan of laminae in longitudinal view

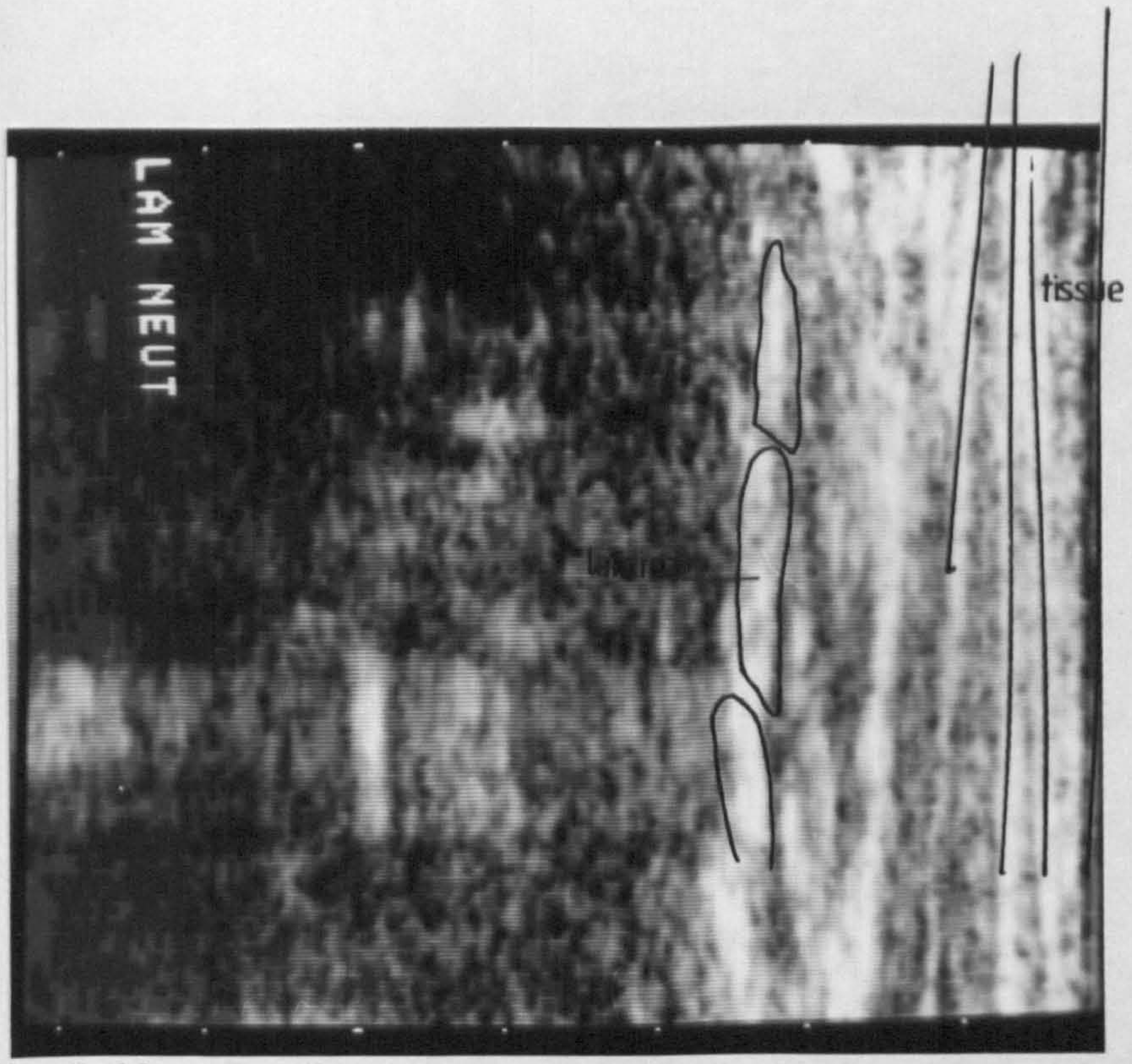


Fig.8.13 In vivo scan of laminae in longitudinal view

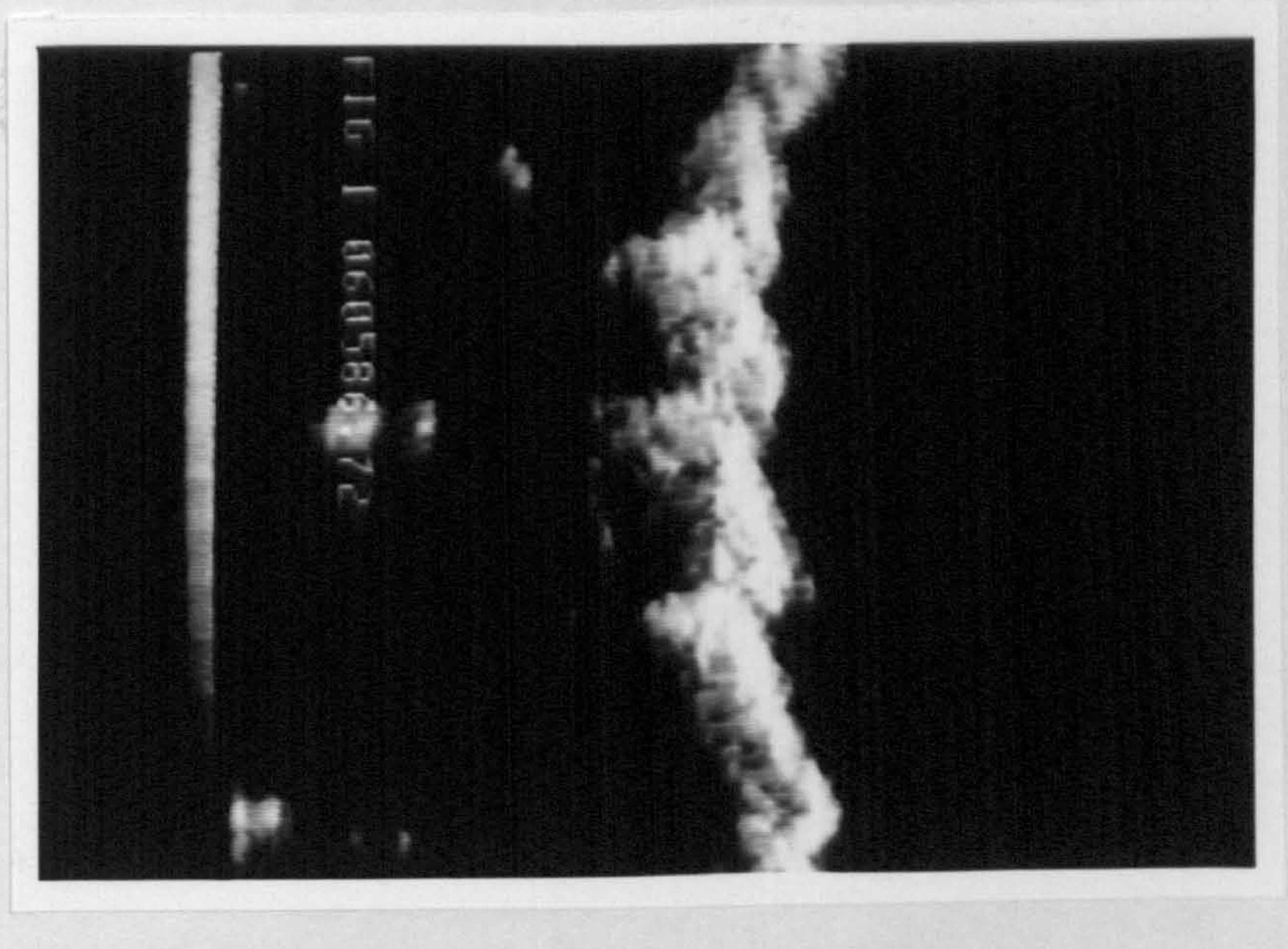


Fig.8.14 In vitro scan of laminae in longitudinal view

segmental motion. There were on occasion problems maintaining the probe against the neck as it moved from flexion to extension, especially if the subject had poor cervical posture, with the head in the forward or "chin-poke" position, then it was difficult to maintain the probe against the skin. Extension could be difficult to image as the lordosis of the cervical spine would be excessive. The body type also influences the quality of the scan as thick musculature or fat would degrade the quality of the image. Lastly, if the quality of the image was poor then it was difficult to accurately place the four marker points for the digitiser. In view of the difficulties found using this scanning plane and the equipment, its use would not be recommended

8.6.2 Segmental Motion of Laminae During Neutral and Lateral Flexion Viewed from the Posterior-Lateral Aspect.

The laminae of the cervical vertebrae showed as clearly defined obliquely placed structures on scanning. The imaging of the laminae was easier to obtain for neutral and lateral flexion than flexion and extension. In extension, the cervical spine "length" was diminished because of the lordosis and contact of the probe on the skin was difficult to maintain

Method

The subjects were from the group used in the previous experiment. The scanning procedure explained and their consent obtained. With the subject seated, and the neck in the neutral position, the probe was applied to the posterior-lateral aspect of the neck and moved until a good image of the laminae was achieved, which was usually at 1.5cm to 2.0 cm from midline and at approximately 15° to the normal. The subject was then asked to slowly laterally flex the spine and return to the neutral position, then to repeat the movement several times, some of which were recorded (Fig. 8.13). The direction of lateral flexion was away from the probe but still remaining in

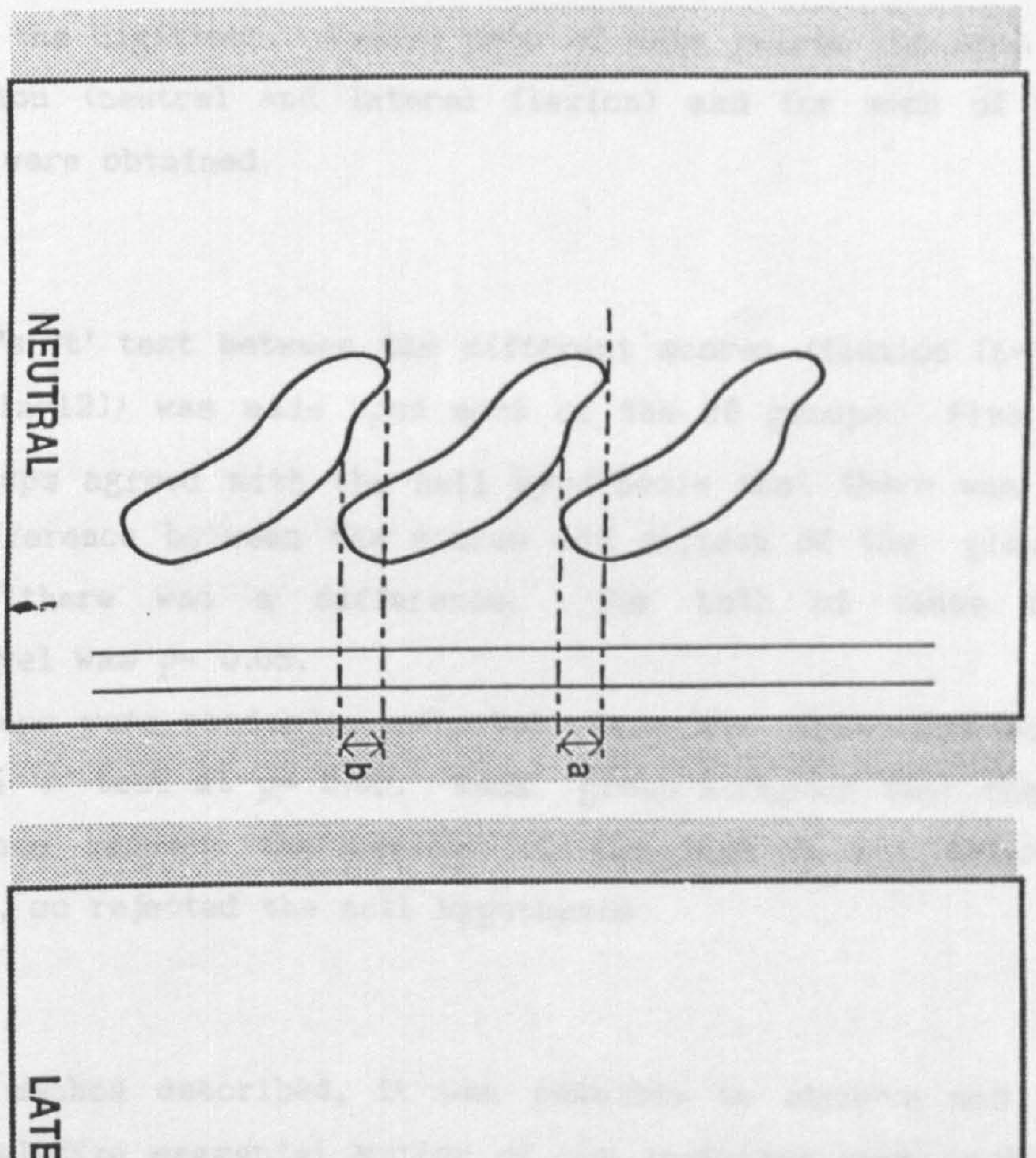


Fig 8:14a

Laminae viewed from post-lateral aspect of neck in two positions.
Laminae overlap distance indicated in the two positions.

contact with the skin, however it was also possible to image the spine in lateral flexion to the same side as the probe. The distances measured by the digitiser were the distances by which each lamina overlapped its neighbour. The difference between the images for the in vitro and iv vivo spines is noticable in Fig. 8.13 and 8.14,14a.

A null hypothesis was made for this trial, that there would be no significant difference between measurements for neutral and lateral flexion as detected by using the laminae overlap distance, measured by digitiser. Images were collected on video tape and measurements made be using the digitiser. Twelve sets of data points for each of the two position (neutral and lateral flexion) and for each of the twenty groups were obtained.

Results

A Student's 't' test between the different scores (flexion [n=12] and extension [n=12]) was made upon each of the 20 groups. Five of the twenty groups agreed with the null hypothesis that there was no significant difference between the scores and fifteen of the groups accepted that there was a difference. For both of these the significance level was p= 0.05.

Four groups were randomly selected from the twenty and were subjected to an 'f' test at p= 0.05. Each group accepted that there was a difference between the results of the neutral and lateral flexion results, so rejected the null hypothesis.

Conclusions

Using the method described, it was possible to observe and to measure the relative segmental motion of the vertebrae from neutral to lateral flexion of the cervical spine. It was felt that this method of scanning the cervical spine deserves further consideration as the laminae are easily visable during movement. The method of scanning and methods of measuring the movement require further work. Application of the probe on the skin must be secure to allow good images.

During scanning it was again noted that the subject's build was important to the possible quality of the ultrasound image. If the neck was muscular or fat, then the images achieved would be of poorer quality and therefore more difficult to interpret. Cadaver dissections of the posterior cervical spine demonstrated the extent of fascial tissue in the neck and the size and integration of the ligamentum nuchae with the posterior muscles. The collagenous nature of fascia and ligamentum nuchae would therefore contribute tothe degredation of the image. The contribution that muscle and fascia make to image degradation is difficult to quantify, but from direct observation of images from lean to muscular and adipose inclined body types, there appears to be a loss of quality with tissues with a high ratio of fibrous or fatty tissue.

For the 20 groups, the means, SD and CV% are given (Table,8.8) as APPENDIX III.

8.6.3. In Vivo, Segmental Motion Pre - Post Manual Treatment

Previous in vivo work found it possible to detect motion using US scanning at the segmental level in the cervical spine. An extension of that work,was to ascertain if changes in relative motion could be detected as a result of applying a manual treatment technique to a specific level of dysfunction,in an otherwise "normal" spine.

Clinical examination of the spine usually includes an estimation of the gross range of motion of the region but not always segmental motion. The ability of practitioners to determine segmental abnormalities of movement and tissue tension have been disputed (Matyas & Bach, 1985). However, the ability of experienced clinicians was demonstrated by Jull and Bogduk (1985).

In this small sample test, the clinician was experienced in manual examination and treatment techniques to the spine (Maitland, 1986). The whole procedure ofexamination, treatment and scanning was explained to the subjects and their consent obtained.

Method

Four female subjects were available for testing, their ages from

22 years to 42 years (mean= 29.5 years). None of the subjects had injuries or other musculo-skeletal problems of the neck requiring surgical or medical intervention. All subjects complained of slight loss of motion at the end of range both for rotation and lateral flexion. No other selection criteria were used at this stage.

The subject's neck was examined by the therapist, who located a segment or level of the spine which in her judgment, was restricted in movement. If there was pain or discomfort during the examination or treatment, the subject was asked to report this. The technique for examination used central and unilateral manual palpation (Maitland, 1986) on the vertebrae.

The US probe was placed on the posterior aspect cervical spine in the mid transverse position at the level found by the clinician and the subject asked to rotate the head to the right, return to neutral, then to laterally flex the neck to the right. This sequence was repeated three times and was recorded on video tape.

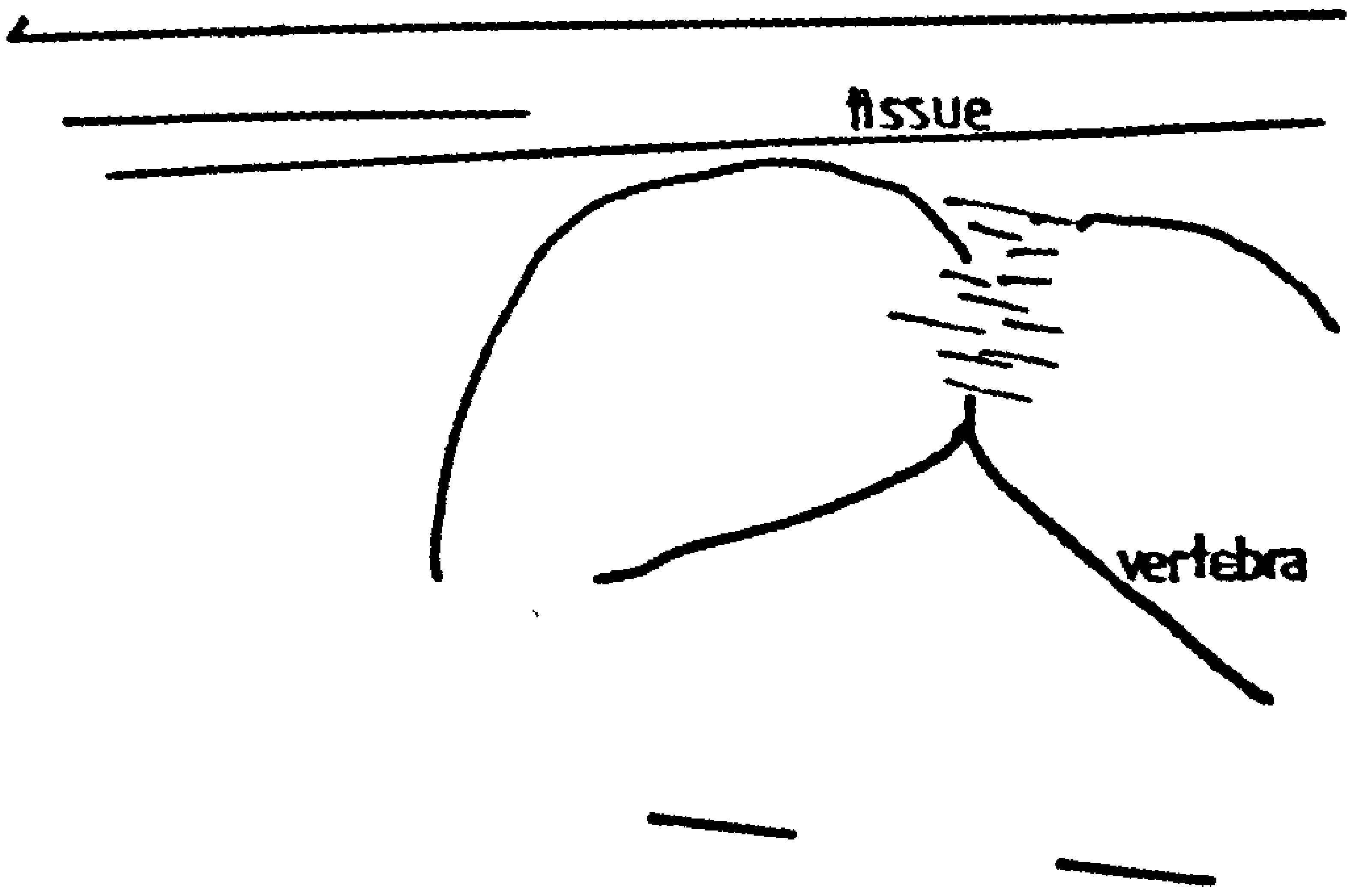
The level of abnormal motion was then treated. An oscillating pressure of the thumbs against the zygapophyseal joints and laminae at the level of the joints of interest was appplied at a strength and duration appropriate for that individual (Maitland, 1986). The duration and grade of technique was at the discretion of the therapist. When an appropriate change in the tissue resistance and joint movement was felt to have taken place at the joint, the scanning procedure was repeated and the same movements recorded.

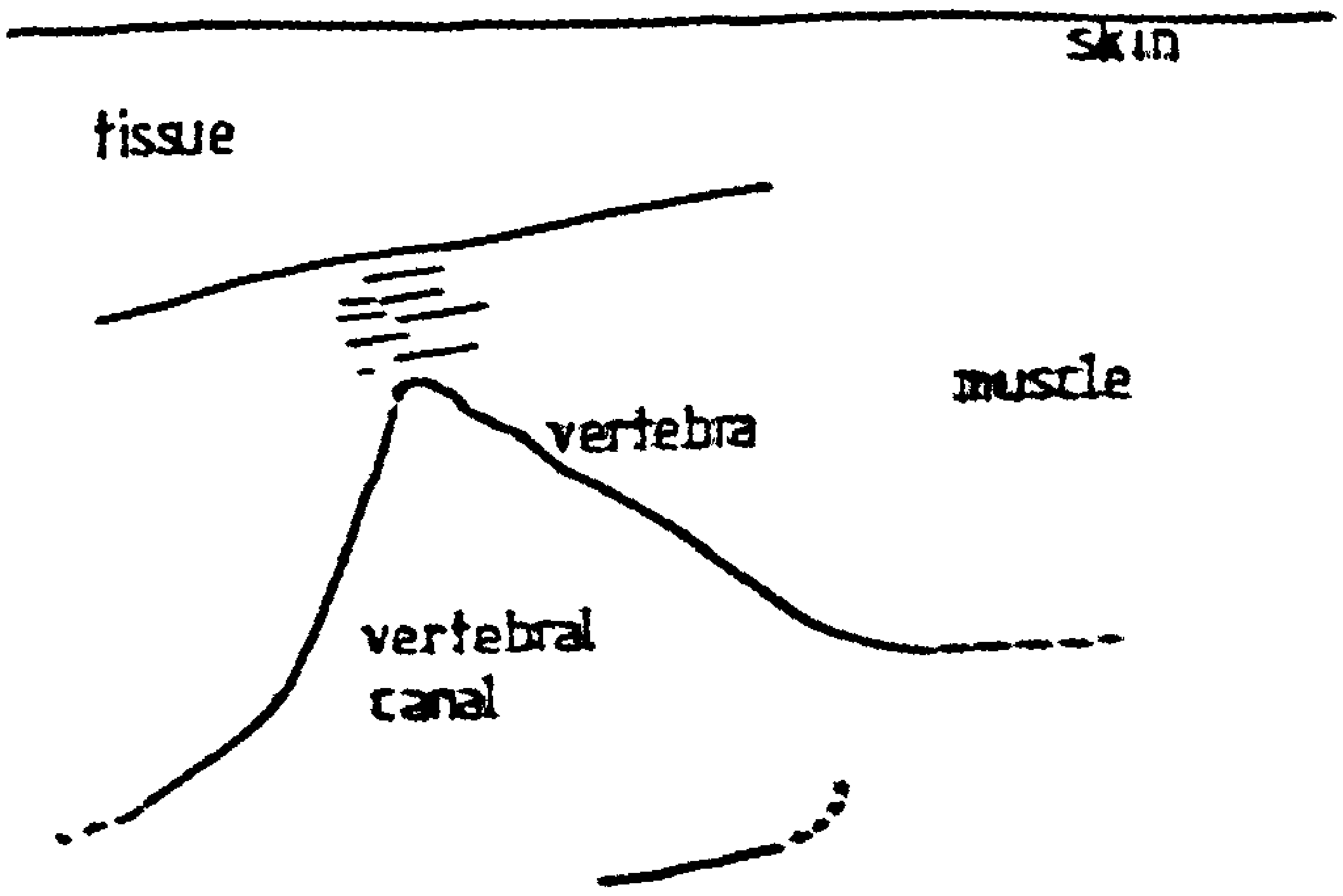
The video tape of the scan was then used in the digitising system to measure the distance between the pedicle root and the digitiser frame to give an indication of relative motion of the vertebrae.

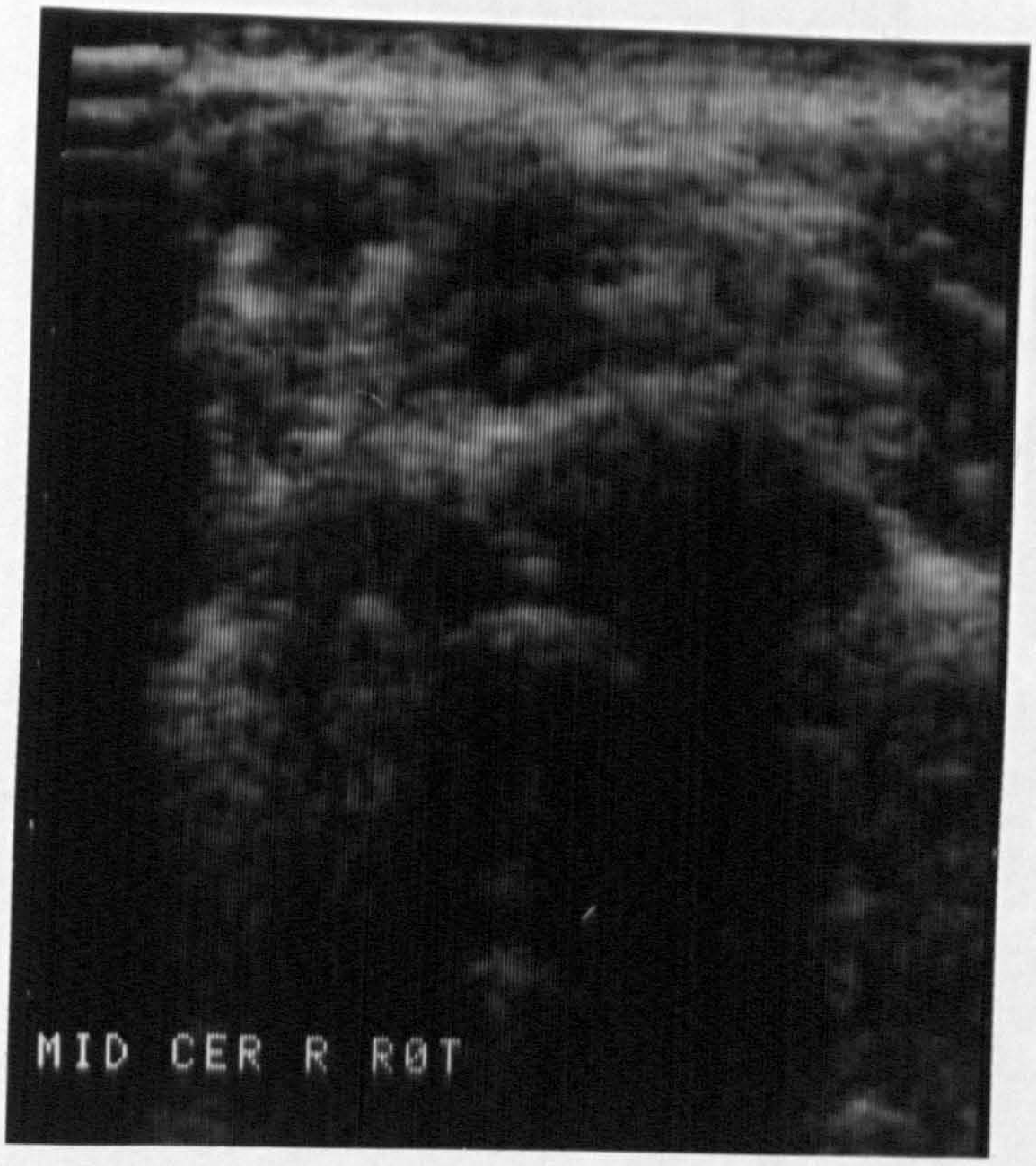
Results

With the probe in the transverse position the cross section of the vertebra was easily seen. The lateral or transverse shift and rotation of the vertebra with cervical right rotation and right lateral flexion was recorded (Fig. 8.15 a,b; Fig. 8.16 a,b;Fig. 18.17;8.18)

The distance between the digitiser frame and the posterior border of the vertebral body at the pedicle for the right and left


tissue
vertebra


skin
tissue
muscle
vertebra
vertebral canal



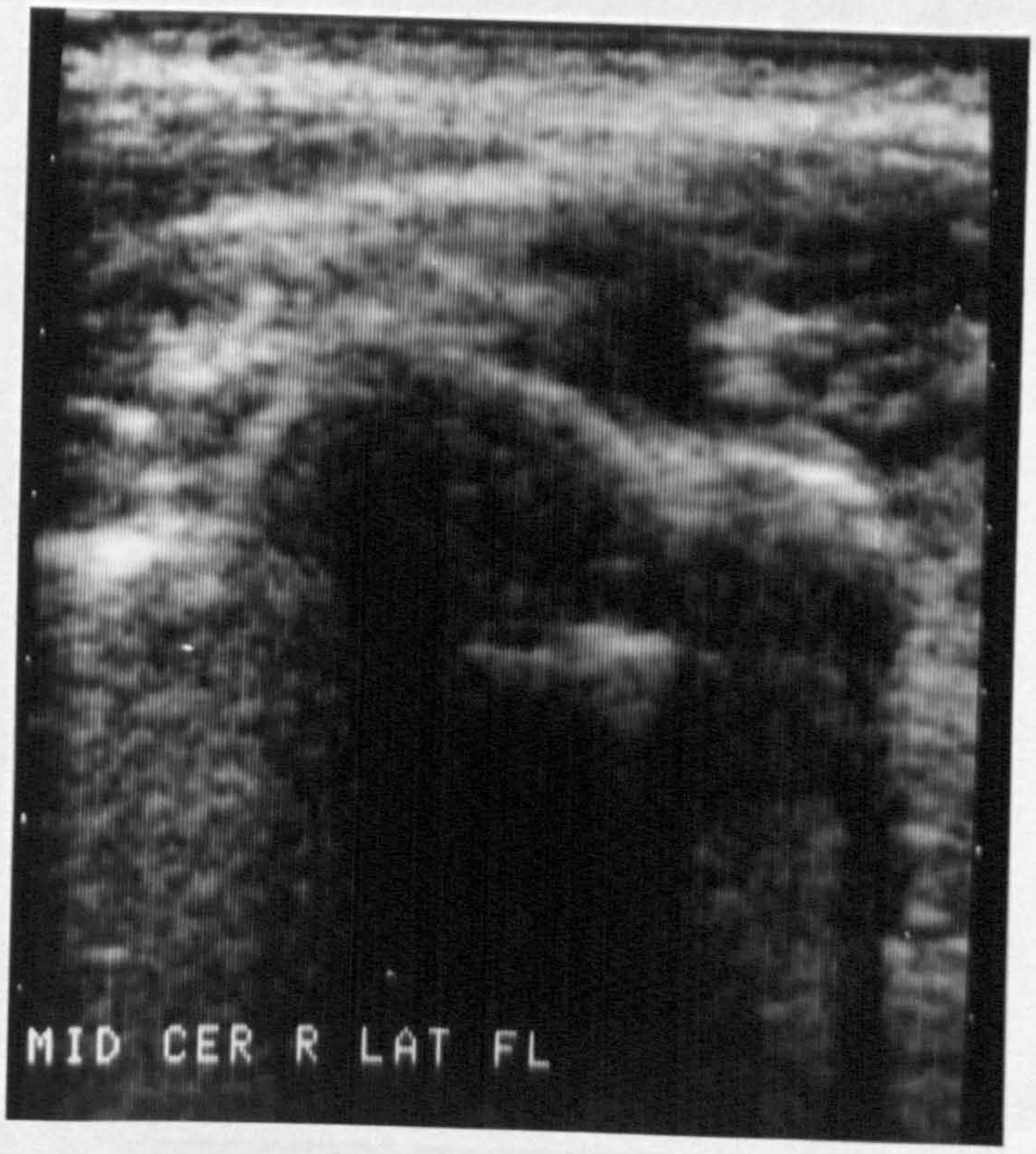


Fig.8.15 Transverse scan of Vertebra in 2 positions
Translation and rotation can be seen

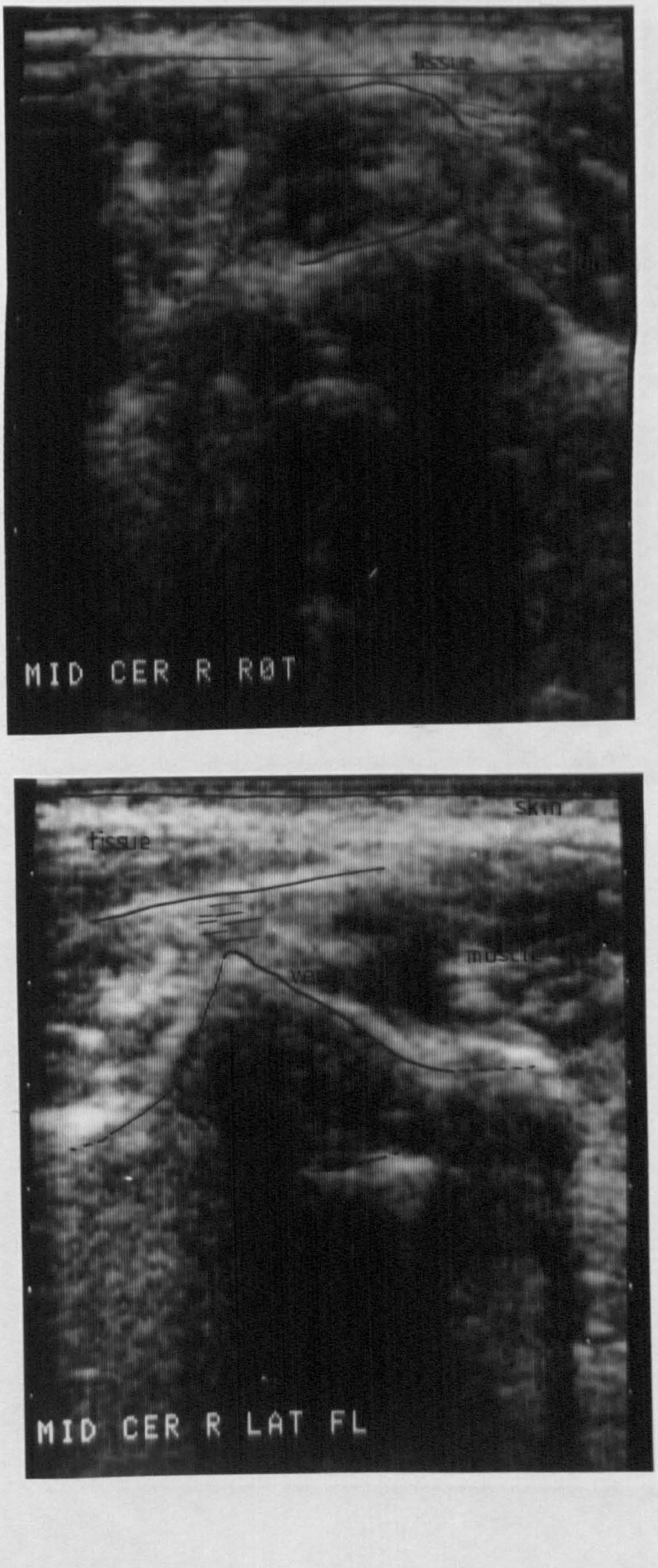
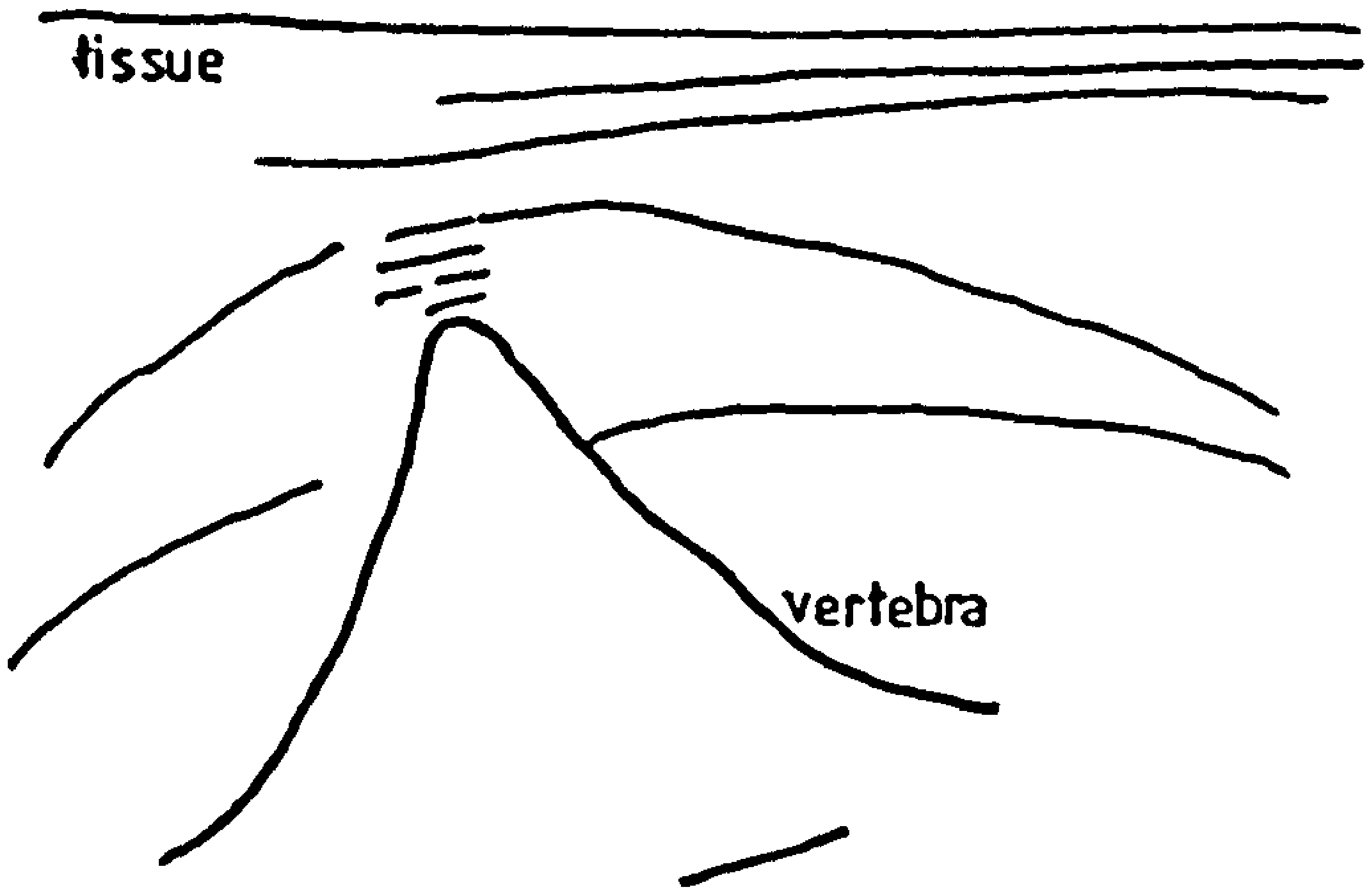
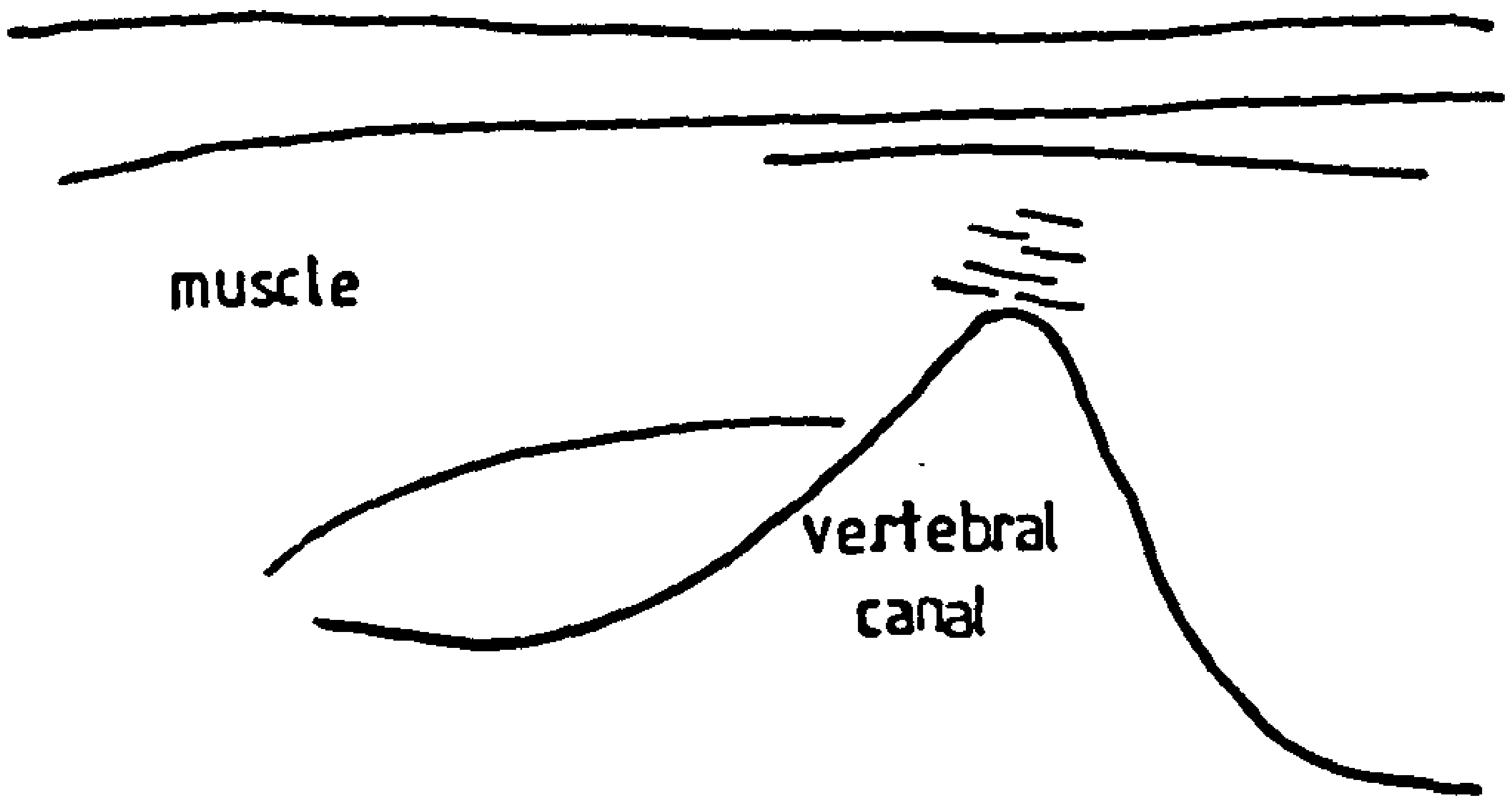


Fig.8.15 Transverse scan of Vertebra in 2 positions
Translation and rotation can be seen


tissue
vertebra


muscle
vertebral
canal

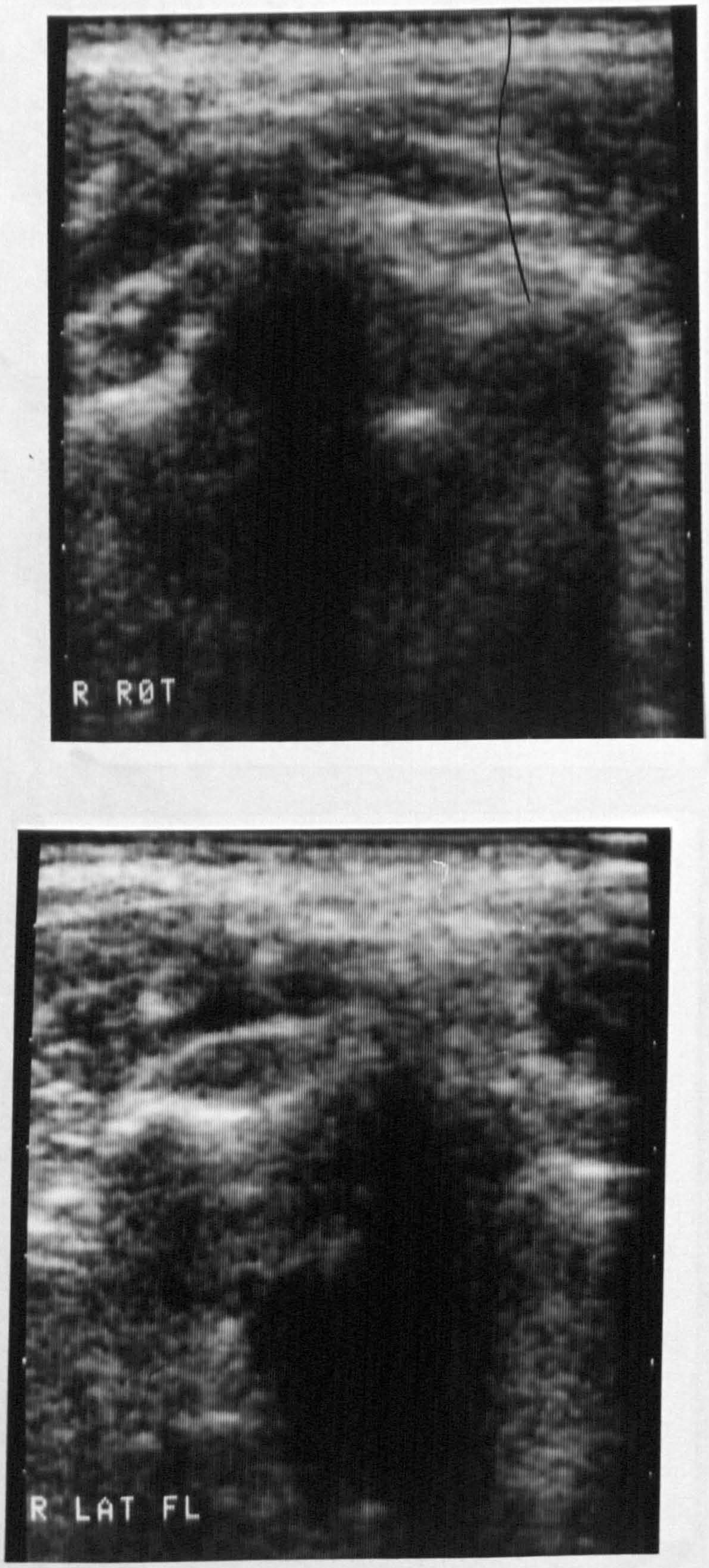


Fig.8.16 Example (2) of Translation and Rotation of the Vertebra with 2 neck movements

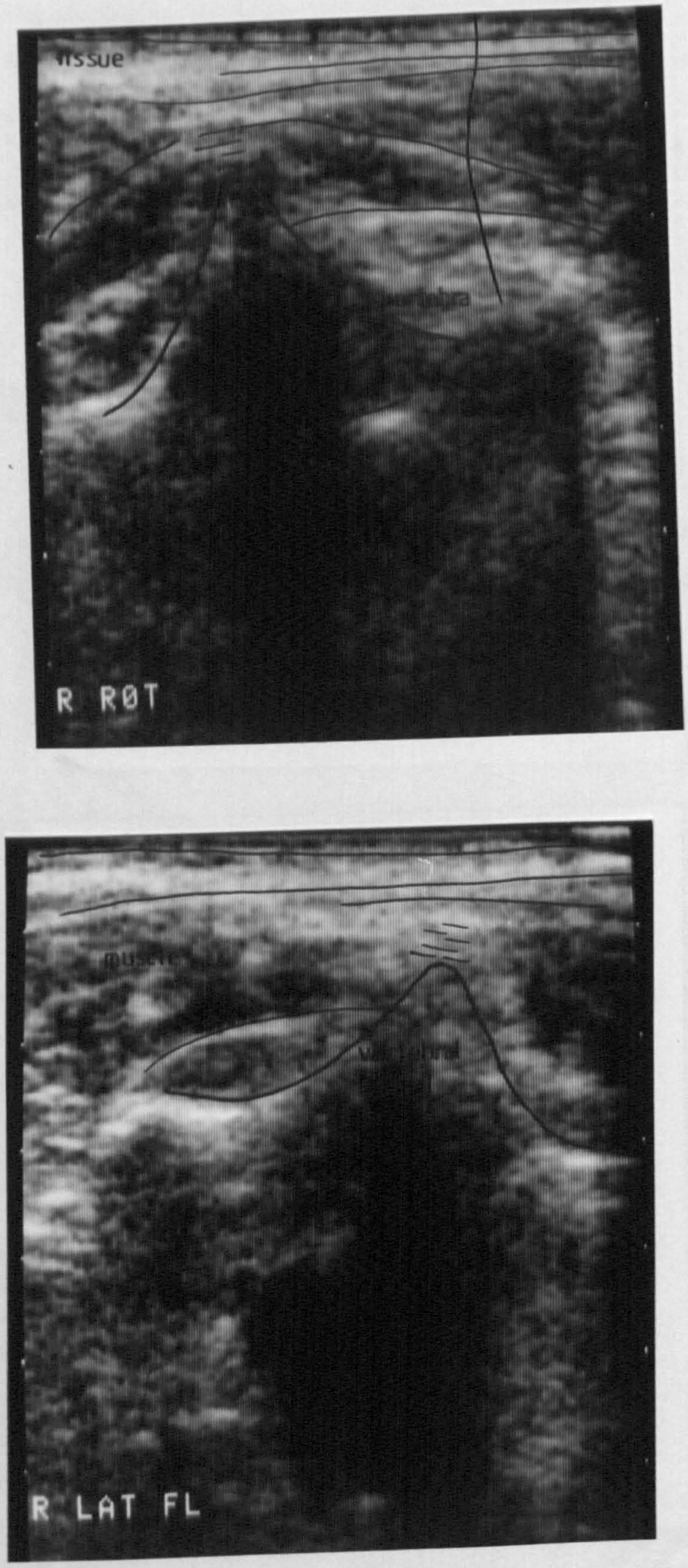


Fig.8.16 Example (2) of Translation and Rotation of the Vertebra with 2 neck movements

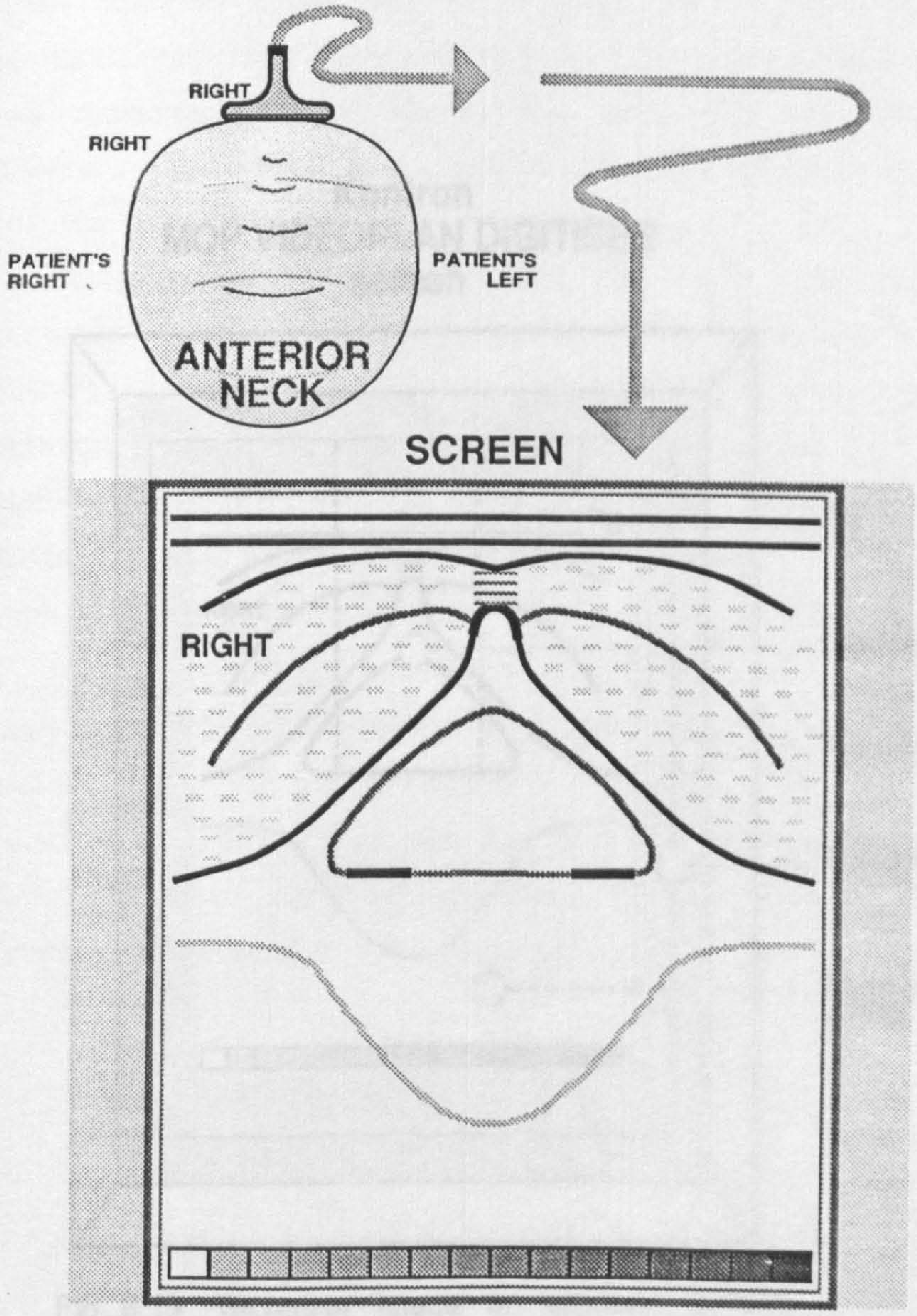
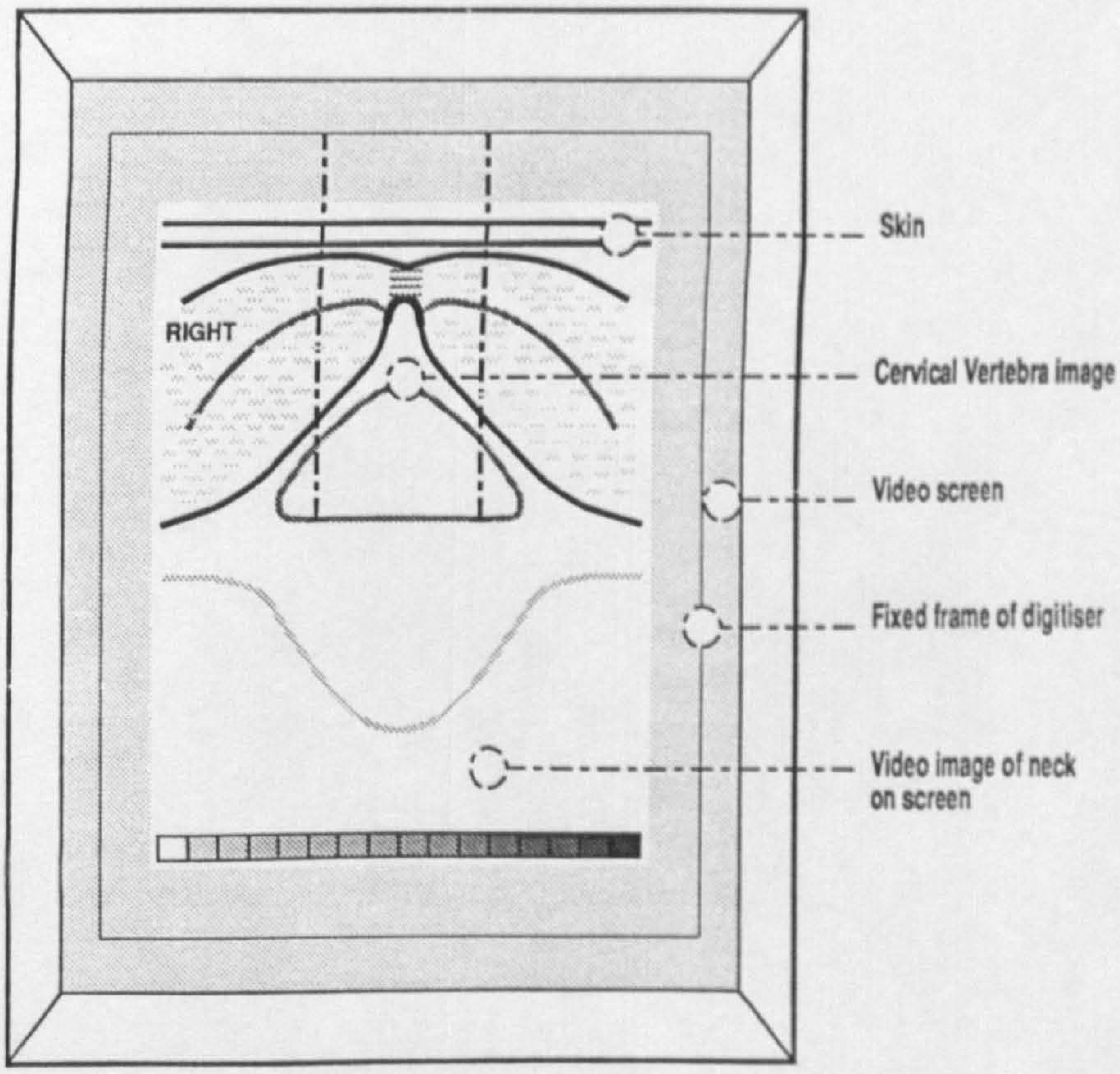


Fig 8·17 Representation of the neck showing probe position and orientation of ultrasound scan image



Kontron
MOP VIDEOPLAN DIGITISER
screen

Fig. 8·18 Vertebral image on digitiser screen sides of the vertebra were recorded three times, for each of the two movements,(right rotation and right lateral flexion). Lateral flexion and rotation are coupled or combined movements in the spine, which, by definition are 3-D movements. A natural consequence of one of these movements is that there will be a small degree of the other movement occuring involuntarily. The measuring of either of these two movements with ultrasound can only be in two dimensions. However, the lateral translation of the vertebra which occurs in the coupled movement can be easily seen.

A value was obtained for the right and left side distance of the vertebra in the neutral position. The same distance was measured when the vertebra was in the two test positions and the difference between these measurements and those from the neutral position were calculated (Fig,8.19). The value of the "difference" either + or - indicated the final rotation of the vertebra for each of the scans, both pre and post treatment (Appendix IV and V).

Pre and post treatment results for the three repetitions were not compared, as each movement and the treatment itself would affect the end result. It was deceided to compare the Mean of the three pre results to the Mean of the three post results, for rotation and then lateral flexion for the four subjects. A summary of the statistical results is given for both movements.

Subject	Difference in (R) & (L) distances			Vertebral Rotation
	X pre mm	X post mm	Difference mm	
1.	-1.875	-3.283	1.408	left
2.	-1.760	-0.030	-1.73	right
3.	2.982	-2.011	4.99	left
4.	-1.500	-1.413	-0.087	right

Table 8.9.

Means of pedicle distances (left and right), both pre and post treatment, producing the final rotation of the vertebra,(n=4) during RIGHT ROTATION.

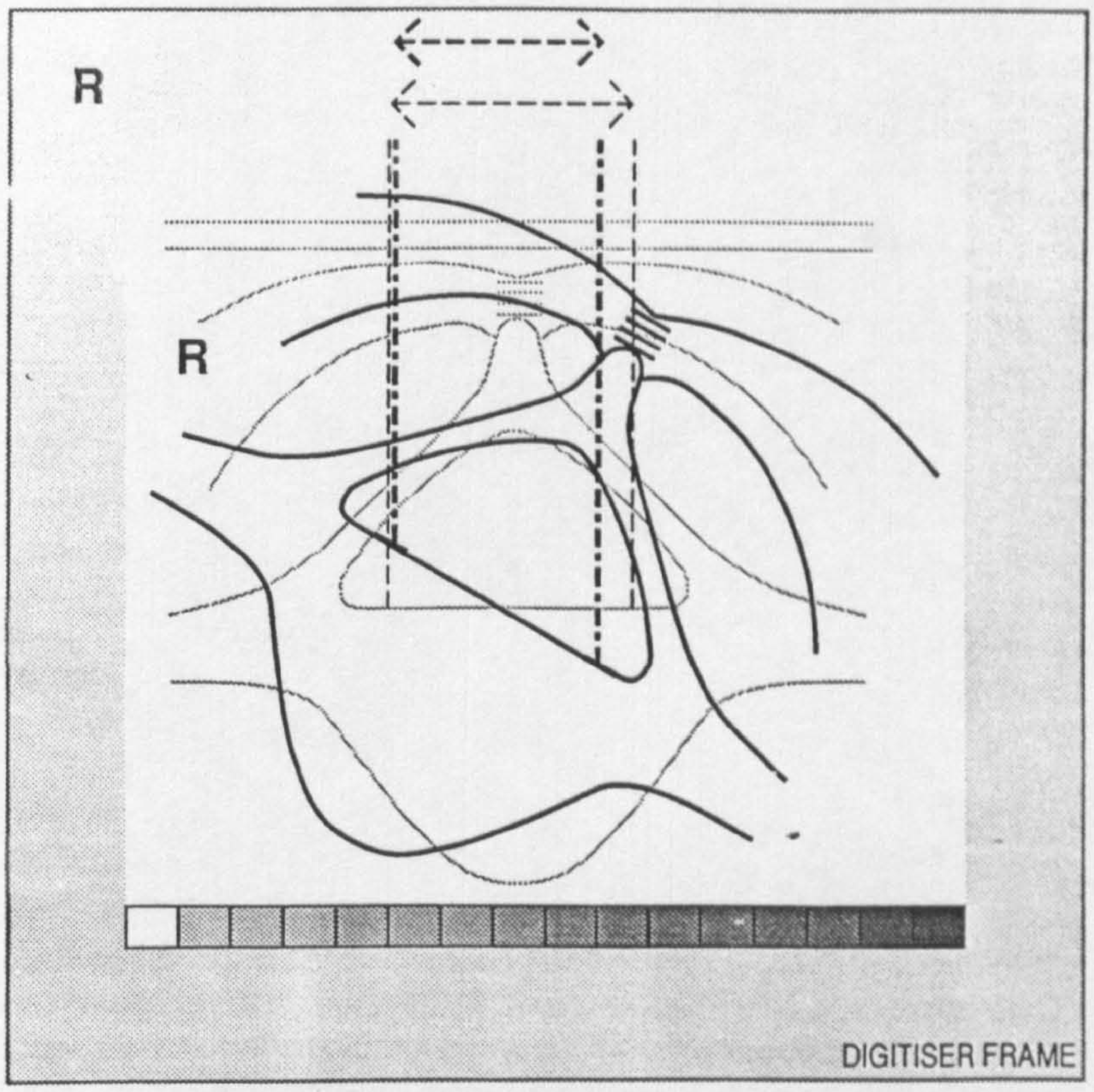


Fig. 8·19

Relative change of position of vertebra with change in position of neck.

Pedicle distance (R) and (L) indicated

Subject	Difference in (R) & (L) distances			Vertebral Rotation
	X pre mm	X post mm	Difference mm	
1.	-3.092	-1.941	-1.151	right
2.	-2.179	-1.337	-0.842	right
3.	0.568	0.236	0.332	left
4.	3.338	2.767	0.571	left

Table 8.10.

Means of the pedicle distances (left and right), both pre and post treatment producing the final rotation of the verteba, (n=4), during RIGHT LATERAL FLEXION.

Conclusions

This test was only one part of the overall scanning of the cervical spine. No attempt was made at this stage to increase the sophistication of the test,to include X-rays, multiple levels, specific age groups, etc. However, the results of the small sample indicated that this would be an area to develop into a pilot project. It was interesting to observe the cervical spine movements in the two related movements of rotation and lateral flexion. Results from this series would not be sufficient to make more than a comment on the direction of the spine in these movements, but it is interesting that they do not consistantly conform to the established idea that rotation and lateral flexion occur to the same side.

The results did not indicate that any difference had been achieved with the manual intervention, for any of the subjects. Functionally , though, all the subjects did feel improvement in their range of motion and less discomfort at the end of range.

An advantage of scanning the spine with realtime US is that the vertebrae can be observed in dynamic motion. The soft tissue and fascia can also be observed.

This section of the project, looking at segmental motion has highlighted and area of clinical interest which would benefit from futher study.

Fig.8.10a Posterior-anterior view. cervical spine

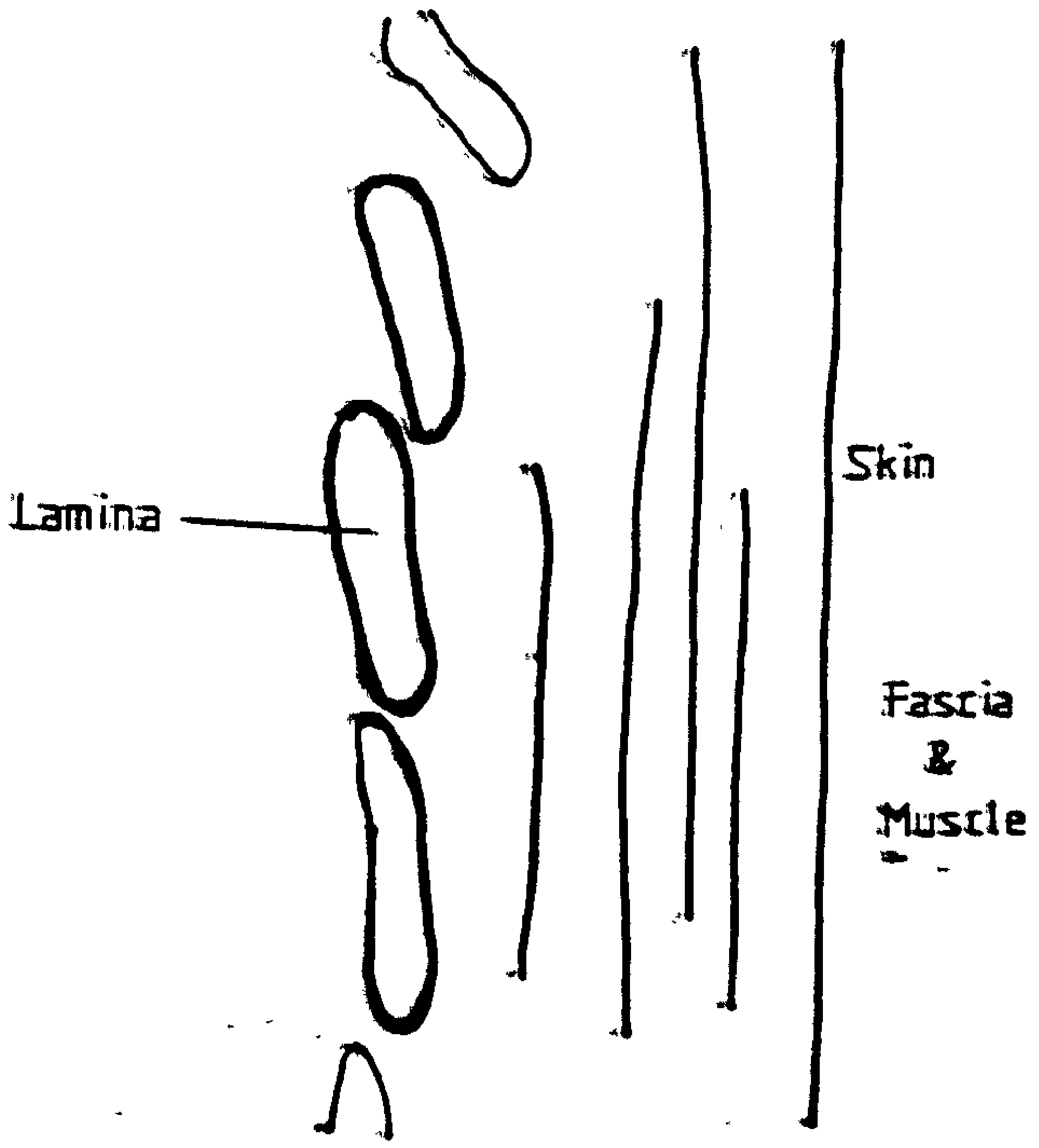


Fig.8.10b Ultrasound scan lamina. posterior-lateral view

Fig. 8.20a.Posterior - anterior view : cervical spine

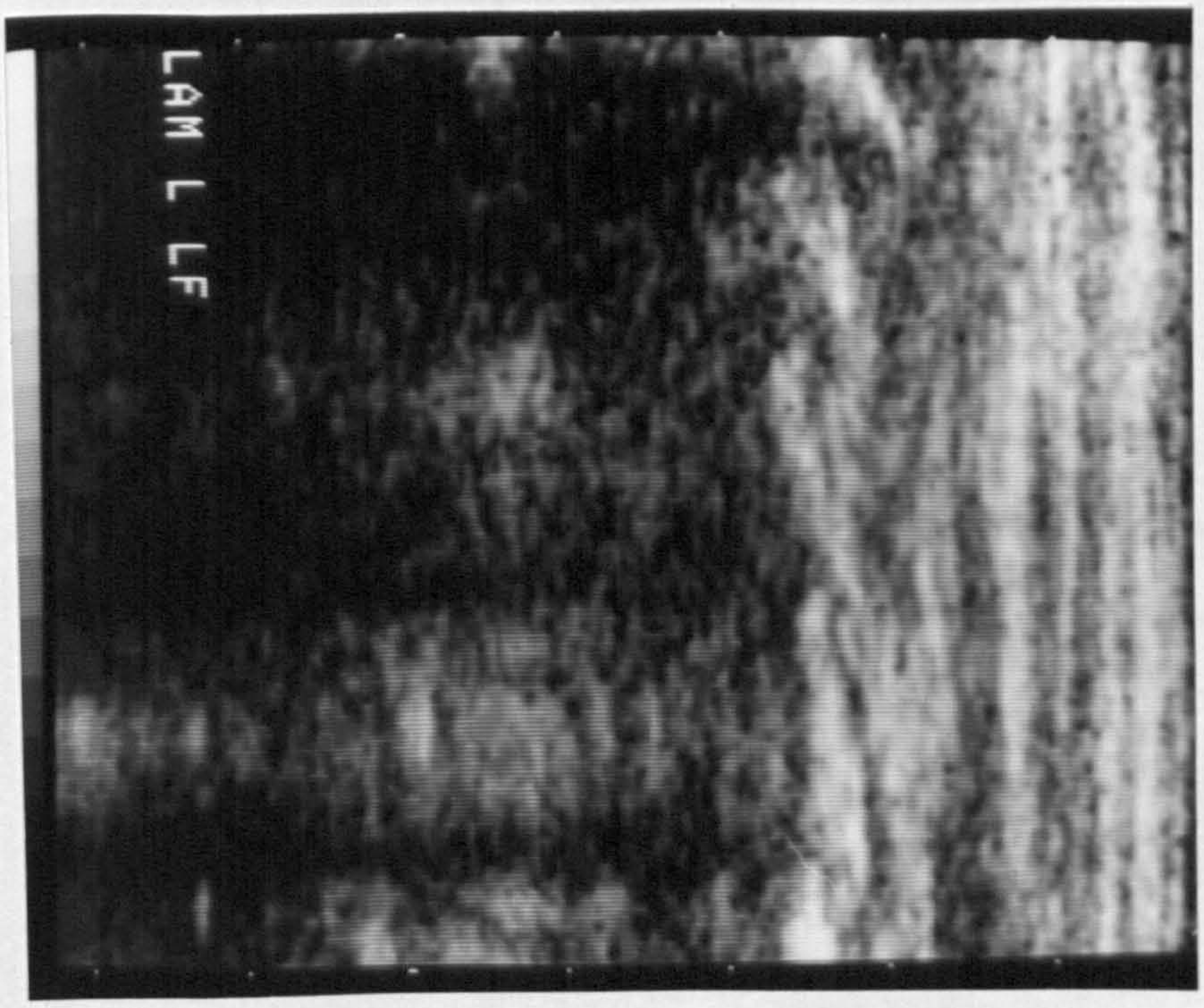


Fig.8.20.b Ultrasound scan lamina : posterior - lateral view

Fig.8.20a Posterior - anterior view . cervical spine

Fig. 8.20a.Posterior - anterior view : cervical spine

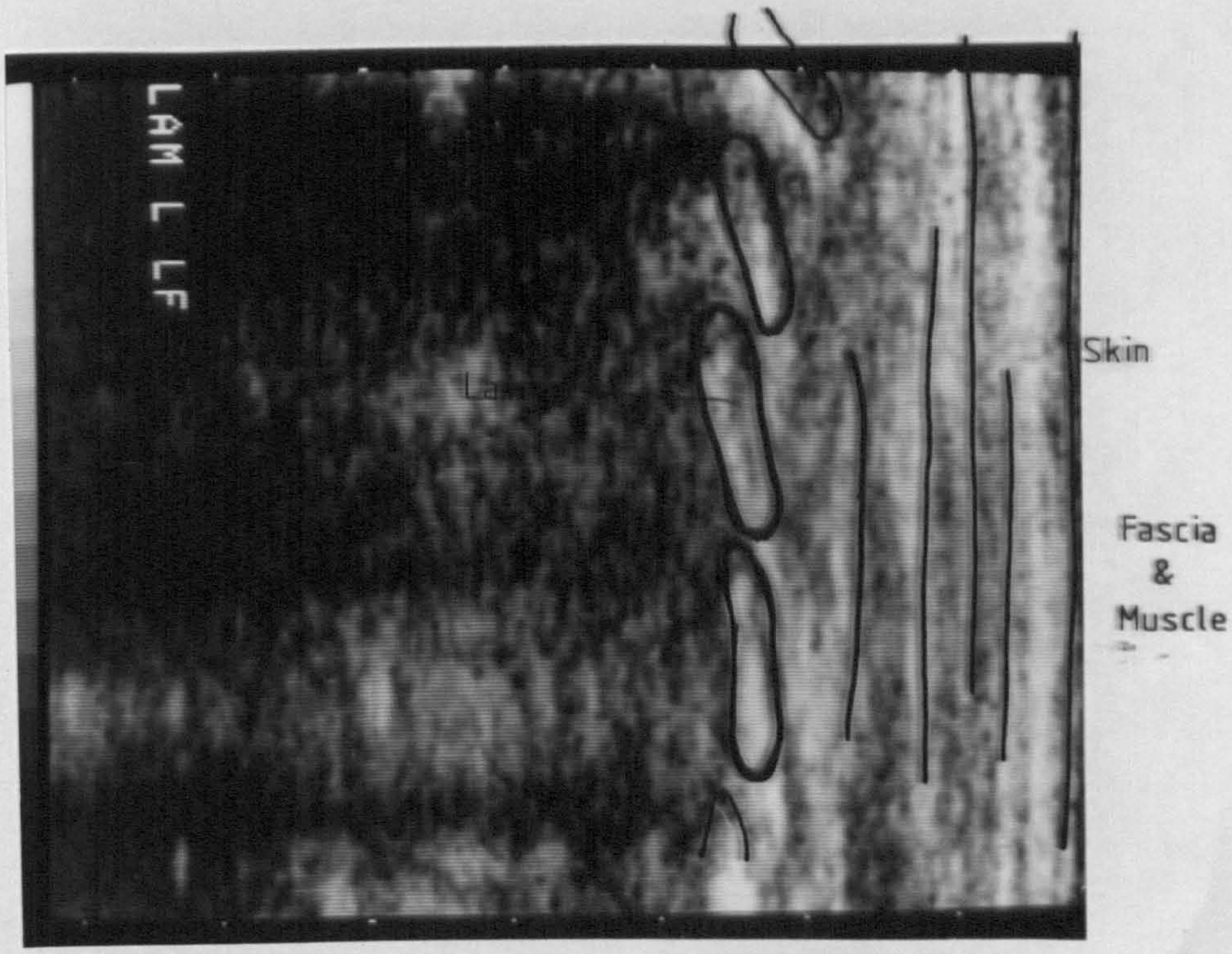


Fig.8.20b Ultrasound scan lamina. posterior- lateral view

Fig.8.20.b Ultrasound scan lamina : posterior - lateral view

8.7 IN VIVO COMPARISON OF X-RAYS AND ULTRASOUND SCANS TO MEASURE LAMINA LENGTH.

As X-rays are the standard method of imaging for musculo-skeletal problems, it was decided to see if measurements taken from a standard X-ray of the neck would be comparable to measurements taken from an ultrasound scan of the same structure in a similar orientation. The longitudinal length of a vertebral lamina was to be identified and measured.

In Chapter eight the same test was applied to peripheral joints. The same procedures were undertaken for testing the cervical spine as were taken for the peripheral joints i.e. the calibration rod was placed in the plane of the joint and the position of the subject was noted. Care was taken when imaging the cervical spine, both with X-rays (Fig. 8.17a) and ultrasound scan (Fig. 8.17b), to view the same structures. The recording of the images and the digitising of X-ray and video were completed as described in Chapter 8. The cervical spine of two subjects were scanned in this way. The hypothesis was also the same, that there would be no significant difference between the measurements taken from the ultrasound scan and those from the X-ray, to a significance level of $p= 0.05$.

Method

The two subjects were positioned in the standard manner for taking an posterior-anterior view of the cervical spine. The probe was coupled with gel and placed on the posterior-lateral aspect of the neck to image the laminae. Video recording of the images were taken. Ten scans were made of each neck. Both the X-ray and the ultrasound scans were then digitised using the superior - inferior length of the laminae as the structure of interest. As described previously, the X-ray, digitising tablet and software all have a magnification factor which had to be taken into account for all results. Two subjects were tested in this manner.

Results

The magnification factor for both X-rays of the neck was found to be identical, = 0.87.

Calculation of the real distance from the X-ray =

real distance = Mag.of Dig.Tab. x Mag. of X-ray x Distance.

= 4.03 x 0.87 x Distance

For the results, of the single scans comparing 10 readings of the X-ray against 10 readings from the scan, there was, at $p=0.05$, a significant difference in the results.

Subject 1			Subject 2		
	X-ray	US		X-ray	US
Xmm	13.748	14.795	Xmm	13.100	11.880
SD	0.225	0.930	SD	0.210	1.267
CV%	1.640	6.290	CV	1.600	10.660

Table 8.11.

Lamina length as measured from X-ray & US scan by digitiser, from 2 subjects; Statistical summary of results.

For both subjects, 3 groups only of 10 measurements were made, again comparing X-ray to ultrasound. For subject 1, the null hypothesis was rejected for all three groups of measurements and for subject 2, it was rejected for two of the three groups. Combining the mean scores for the X-ray and US for the two subjects, and using "t" tests of independent samples the same results were obtained. Both results indicated that from the thinner of the two cervical spines it was easier to obtain reproducible results at a siginficance level of $p= 0.05$.

The two necks were of very different body types, the first being thicker and more muscular and the second being thinner with possibly a greater muscle to fat ratio than the first neck.

This may also have affected\`the quality of the overall 19mage making it difficult to determine boundaries.

Conclusions

It is possible to image the cervical spine with ultrasound and to identify comparable structures on X-ray film. However it was felt that the comparing of measurements between the two, should only be done with the knowledge that there can be a difference (Significant at p= 0.05 level) between them, which could be from the body type.

In the cervical spine a view to image the laminae from a posterior or posterior lateral direction, in fact offers a difficult X-ray to identify exact bony margins of the laminae. It was also noted that the best images on the ultrasound scans of the cervical spine, were obtained from the necks of slim females. A fat or muscular neck tended to reduce the quality of the scanning image, due possibly in part to the excess of fat and fascia in the area.

8.8 SUMMARY

Within this chapter several parameters have been brought forward for observation and testing. Many of these aspects deserve greater attention in their own right especially on the technical side of the scanning proceedures. The Equipment was capable of effective axial and lateral resolution of small objects of differing substances. The ability of the scanner to measure distances could again warrant further work. A restriction of the scanner is its ability to measure only to 1mm increments and when placed against more sensitive measuring systems problems did arise. The differences in body type were also noted to be of importance for the quality of the resultant image.

CHAPTER 9 CONCLUSION & DISCUSSION FOR FURTHER WORK

9.1 INTRODUCTION

The human spine is complex in its structure and function and the cervical region is perhaps the most complicated area of the spine. It is an region of mobility yet requiring stability and protection for some of the most important structures of the body.

New and detailed information on the structure and biomechanics of the regional components is slowly becoming more available, especially with the support of such interest groups as the Cervical Spine Research Society. The problem of obtaining fresh cervical spines for research is probably more difficult than for the lumbar spine, therefore restraining some aspects of research.

This work has revealed that the cervical spine has been a difficult area to simulate with mathematical models (Helleur et al 1982) which would assist in the analysis of the functional inter-relationships of the region. The lumbar spine has been successfully modelled and a quantity of valuable information achieved. This lack of specific information on the neck has resulted in the extrapolation of information from the lumbar spine to the cervical region. It would seem that this practice could probably lead to errors in statements and assumptions as the two regions are profoundly different in structure, function and load bearing. It is vital that research is directed specifically to the cervical area, to increase the available information on that area.

To improve the quality of the information we have on the cervical spine and an appreciation of its segmental motion, a system which would allow safe non invasive internal imaging of the spine is required. Evans (1981) reinforced the importance of positively criticising the application of new techniques to ensure that their application was valid, reliable, safe and necessary to the patient and the outcome of their pathology or problem.

To date, standard X-rays films are the most common method of imaging the spine. To observe motion or abnormal motion in the neck has only been possible by comparing X-ray films of the neck in different positions (Penning, 1978). Three dimensional scanning of the neck has only been documented for the upper cervical spine in cadaver specimens (Worth et al 1978).

Ultrasound scanning has been used for imaging the lumbar spine, particularly the spinal canal and some peripheral joints. There is no mention of its use in the cervical region.

The work in this project has shown that the standard diagnostic ultrasound equipment is capable of scanning the cervical spine, both in a static and dynamic fashion. Images have been obtained which require experience in interpretation. Acceptance of the ultrasound image for complex areas such as the spine may require time. The images are so different to the usual scanning techniques such as X-rays that a different approach to image interpretation is necessary. A wider use of diagnostic ultrasound in the scanning of peripheral joints has also been demonstrated.

Most of the literature on spinal scanning with ultrasound has indicated the use of standard equipment, commonly available in most departments of radiology. However it should be appreciated, that all the scanners were originally intended for scanning soft tissues of the body, obstetric or cardiological conditions. The problems encountered when scanning close to large areas of bone must be considered when trying to achieve good quality ultrasound images from these machines.

With the possible expansion of the use of ultrasound in the area of orthopaedics, it may be possible for manufacturers to alter the equipment specifications sufficiently to improve the images of the skeletal system .

9.2 CONCLUSIONS

The preliminary work of this project was required to ascertain if segmental motion could be observed in the cervical spine. The use of fresh cadavers with pins inserted in the vertebrae, enabled 3-dimensional segmental motion to be recorded with the use of biplanar photogrammetry. The effect that various movements had on segmental motion were also recorded. The recognition that monitoring segmental motion seemed to be possible only by invasive means or with exposure to X-rays, prompted the investigation into the possible use of ultrasound, which had been used for the lumbar spine, to observe the intersegmental motion of the cervical spine

9.2.1 Equipment

The current literature gives little indication as to the optimum equipment for ultrasound scanning with an orthopaedic "bias". Equipment used has included A-scanners, static B-scanners and realtime B-scanners. The frequency and types of the probes used, from 2.5 MHz to 10 MHz, also indicates a lack of agreement within the field.

Both sector scanning probes and linear array probes were tested on in vitro and in vivo spines. The equipment chosen was the Toshiba Sonolayer - L (SAL - 32B) ® with the PLB - 508 ® (5MHz centre frequency) probe ® . It was found that this phased linear array scanning system gave the best images for both situations. This was important, for using one piece of equipment throughout all the tests, a measure of standardisation would be achieved. Several probes with frequencies from 2.5MHz to 10MHz were tested and the 5MHz probe proved to be the most satisfactory for the imaging of the skeletal structures of the cervical spine.

The other advantage of this particular model of scanner was that it was portable which allowed scanning to take place at several centres.

The use of a standoff medium to facilitate focusing of the probe was not required with this frequency of transducer on the cervical spine. Attempts to use a commercial standoff gel to enhance the quality of the ultrasound image were unsuccessful. The gel was too friable and cracks in the medium distorted the signal excessively. Silicone gel produced for this work, was also tested but although the attenuation and velocity were less than that for water, the images were not enhanced. The physical characteristics of these gels were similar to those of the commercial gel, in that even with minimal handling they were friable which distorted the signal and so they were not used.

9.2.2 Testing Equipment

Summarising the work and results of scanning using test objects, several features can be discussed.

The ultrasound equipment selected for this project had no difficulty in imaging very small diameter objects both metallic, polymer monofilament and organic catgut. Well defined images were obtained from all test objects. It was noted that the images of the monofilament thread and the catgut had distinct outlines as minimal acoustic shadows were thrown by the objects in comparison to images of the wires.

Both axial and lateral resolution of the equipment were found to far exceed that of the measuring caliper function of the scanner. So measurements made using the scanner were always subject to the limitations of the measuring calipers. Comparisons of measurements made by ultrasound equipment and the digitiser were attempted. In almost all cases there were differences in measurements which were statistically significant at the $p= 0.05$ level. This most probably reflects the relatively crude distance discrimination level of the ultrasound scanner against the digitiser and the units of measurement of the two pieces of equipment.

The effect of angulation of the probe to the test objects, while measuring distances was considered. Angulation of the probe was felt to be important in the scanning of the lumbar spine and vertebral canal (Porter et al,1978). However the size and shape of the cervical spine and the structures of interest so different, it was necessary to ascertain if the degree of angulation of the transducer head would be of significant importance.

No firm conclusions could be made from the tests, as results comparing one position (0° against 15° angulation) demonstrated a statistically significant result, whilst the other test position (0° against 45° angulation) showed no significant difference. The tests on the reliability of results with the probe at different angles were carried out on a small sample using a test object. Therefore to assume the difference may be present in the in vivo situation may not be valid. The "cylindrical" shape of the neck and the shape of the vertebrae would make it difficult to state, that with the probe on the skin at a specified angle, the ultrasound beam would strike the vertebra at the same angle. Although literature on lumbar spine scanning advocates the angulation of the probe at 15°, the same constraint may not be required for the cervical spine as different structures are to be imaged.

9.2.3 In vitro Cervical Spine Scanning

In vitro scanning was important to allow experience in the use of the scanning equipment and the identification of spinal landmarks. The equipment was well capable of scanning the model spine and excellent images were achieved of the bony skeleton.

The model spine in the cylindrical waterbath permitted scanning to take place at distances similar to those encountered in the in vivo state. Comparing measurements taken of landmarks (pins) a known distance apart, with the probe pressed close to the spine and then just in contact with the waterbath, a statistically significant difference in measurements was found. Measurements were made using the digitiser and the maximum difference between the means of the three situations, "normal", "close" and "distant" was only 0.99mm. This, although significantly different is still less than the capability of the caliper function of the scanner.

The scanner easily imaged the model cervical spine to demonstrate changes in vertebral position with movement, which were measured. The excellent quality of the images allowed the landmarks selected to be on the tips of the spinous processes.

9.2.4 In vivo Cervical Spine Scanning

In vivo scanning presented some difficulties. The images from the in vivo neck were considered to be poor compared to the in vitro spine images. However, for all scanning, in vitro or in vivo, a period of time was required by the operator to become familiar with collecting the images and their interpretation.

With experience, interpretation of the images revealed more information to improve the selection of landmark points required for taking measurements, which in turn improved the reliability of the measuring.

Because the observation of the flexed and extended in vitro spine was successful, the same view was attempted for in vivo scanning. Although this was possible and the change in vertebral position was noticed, the scanning position was not felt to be the most satisfactory. This was primarily because of the difficulty of scanning through the midline structures of the neck. Later, dissections of the cervical spine demonstrated the vast extent of the cervical fascia and the ligamentum nuchae, which as thick fibrous tissue would greatly attenuate the sound signal. A more successful position for imaging the cervical spine was with the probe against the laminae of the vertebrae and the probe in the longitudinal position. Here clear images of the laminae could be identified and their movements from the neutral to the lateral flexed position could be recorded.

Tissues which had high attenuation to ultrasound were bone and muscle and then other tissues with high structural protein contents e.g., fascia. From the dissections it was evident that the neck has a large proportion of muscle relative to its size and also the large ligaments and fascial planes between the muscles would contribute to the degradation of the sound signal. For the posterio-lateral views of the cervical spine, muscle and fascia being in relatively thin but defined layers did not degrade the ultrasound signal as much as in other scanning positions.

In general the optimum scans were obtained with a cervical spine that was not fat or of heavy musculature, both of which features produce poor images.

Cervical vertebral motion was easily seen using the laminae as the object of the scan. By determining the distance which the laminae overlapped and the change in the distance after movement, then an estimation of the segmental motion was possible.

A transverse view of the cervical vertebra was also found useful in observing vertebral motion. Remarkably clear images of the vertebra were achieved. Recording of the images on video tape allowed later analysis of the movements. The transverse scanning position demonstrated in 2-dimensions the rotation of the vertebra and also the lateral translation of the same vertebra with rotation and lateral flexion movements. The lack of consistency in the direction of movements (translation and rotation) is of interest as it appears to be contrary to the usually held view that rotation and side flexion occur to the same side in the cervical spine. General scanning in the transverse plane down the cervical spine, allowed good images of the articular pillar and the posterior vertebral elements.

No attempt had been made in any of the previous tests to scan a cervical spine, real or model, which demonstrated a pathological state. As ultrasound scanning of the neck was novel no information was available on possible presentations of the cervical spine with orthopaedic problems. Therefore, an attempt to scan the neck before and after a manual treatment although interesting, gave little in the way of image information. However the procedure was possible, and perhaps with a different scanning technique, possibly using the transverse scan, it would seem reasonable to attempt the test again. For the small sample tested no attempt was made at this stage to control variables other than those described.

9.2.5 Peripheral Joint Scanning

Ultrasound has been used for the scanning of some peripheral joints, most noticeably the shoulder and the hip joint. Most of the current literature on ultrasound in orthopaedics is related to scanning of these joints or the lumbar spine.

Some peripheral joints can be easily and clearly imaged. Soft tissues about the joint are clearly demonstrated and dynamic scanning is most useful in the functional assessment of joint integrity. The shoulder joint can be usefully scanned by ultrasound. Harland (1987) has demonstrated clear images of the shoulder structures and the effects of movement, which had also been noted during this work.

The elbow joint was easily imaged, but has not been extensively covered as have other peripheral joints. The radio-humeral joint was very clearly seen in all subjects. Dynamic scanning of this joint revealed the extent of rotation of the radial head and the movement of the surrounding soft tissue. With the arm extended, the joint line of the elbow complex was visible in all the subjects scanned.

Much is written in the literature of the benefit of ultrasound for imaging joint effusion in particular for the hip joint. One subject sustained an injury to the knee between scanning sessions. Effusion in the suprapatella pouch was very evident and the effect of effusion on patella position was visible. Effusion could also be detected from the posterior aspect of the knee joint. Monitoring the resolution of the effusion in this subject's knee joint was possible. The patello-femoral joints of all the other subjects were normal.

The sacro-iliac joint was imaged. Its position was identified but because of the dense acoustic shadows thrown by the sacrum and ilium, no clear joint line was seen. An attempt was made to image the tarsal joint of the foot. Again, possibly due to the mass of bone in the region, only poor quality images were obtained. However, the muscles and soft tissues about the first metatarso-phalageal joint were visible and could be demonstrated with movements of the toe.

The use of ultrasound would allow the scanning of many peripheral joints. Both the elbow, the patello-femoral and the gleno-humeral joint were found in this work to be relatively easy to image. The advantage of real-time ultrasound scanning of these joints, especially if soft tissue involvement is suspected, would be the ability to observe the joint and tissues during movement.

It is difficult avoiding direct comparisons with X-ray images of joints and bony structures. Ultrasound scans are so different, a new approach to the interpretation of visual images may be required by the observer. Subjective analysis is often made from X-rays on the width of a joint space. An effort to record the same aspect of a joint by X-ray and ultrasound in order to measure the joint space, or joint structure was undertaken. Results implied that it would be difficult to compare measurements made from one imaging technique to the other. Measurements were made using the digitiser on the recorded video tape and the X-ray film. No comparison was made, at this time, using the caliper function of the scanner.

9.3. FURTHER WORK

Standard diagnostic ultrasound has been demonstrated to be capable of imaging the skeletal system both of peripheral joints and the cervical spine. In vivo scanning of the cervical spine does involve the problems of signal attenuation especially by muscle, ligamentous or fibrous tissues.

Further work is required to refine the optimum positions for successful scanning of cervical spine. The laminae, viewed from the posterior lateral aspect of the neck and the transverse view of the vertebra were found to be the most successful for imaging in the neck.

Laminae were easily visable, but more defined images may be possible with more attention being paid to probe position and the gain settings of the equipment. The movements undertaken when scanning the laminae were lateral flexion away from the neutral and the return movement. An extension of these should be made which would complement the movements recorded in the transverse plane.

Transverse scanning of the vertebra offered a novel view for non invasive scanning of the spine. Results demonstrated rotation and translation of the vertebra in a manner not consistant to that of currently held views of cervical motion. It would therefore be important to return to this aspect of cervical scanning to determine from a larger sample, and improved techniques, if the earlier results were by chance or are infact true movements. Further work is required on the quantification of the degree of rotation and translation observed during movement.

Observation of the cervical vertebrae during movement, without exposure to ionising radiation is therefore possible with ultrasound. The application of this, at this early stage is of interest and should hopefully have clinical application when further development makes scanning easier to perform and interpret.

Although the use of a standoff medium for beam focusing was rejected for this work, it did allow contact to be maintained during some neck movements. If a suitable gel could be found which had appropriate velocity and attenuation properties, then it might facilitate neck scanning.

X-rays form part of the standard diagnostic procedures undertaken for most musculo-skeletal problems. It would seen therefore not unreasonable to look again at measurements from the two imagimg techniques. For ultrasound to be of clinical value in the orthopaedic field, it must be possible to take accurate measurements from scans. This is already accepted in the obstetric field where such important measures as biparietal parameters of the foetus are routinely made. However the same reliability and confidence in using ultrasound scanning has to be acquired for the observation and quantification of musculo-skeletal problems.

The quality of the ultrasound images also has to be improved, before the equipment has the same wide appeal as have X-rays. . It is now possible to obtain much enhanced images of scans, in hard copy or in 35mm slide form. The drawback is that at present, these machines are expensive which inevitably would mean taking the small portable machines back into ultrasound departments and therefore loosing an advantage of having the ultrasound equipment in the clinic setting. However, in the last few years the improvements in all imaging technologies has been significant and developments can only promote the further use of diagnositc ultrasound.

The results of this work do indicate that the cervical spine can be imaged and in some views quite successfully, by ultrasound. It is not felt that the method of scanning would replace currently used methods. It may be that with improved scanning equipment designed specifically for orthopaedic scanning, that the equipment may be used along side existing techniques, as its advantages would enhance the observation of the spine during movement in the examination or treatment setting..

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APPENDIX I

DIGCOL

Programme used for the collection of data points using a Calcomp 9000 Series Digitising table and Digital Equipment Corporation PDP 11/44 computer.

DIGSAL

Programme required to analyse digitised data to account physical and optical sources of error.

PROGRAMME—DIGCOL

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C
C
C PROGRAM DIGCOL.FTN - TO READ IN DATA FROM THE DIGITIZER.
C DATA GOES ONTO DL2: BY DEFAULT, INTO FILE 'NAME.DIG'.
C ABANDON A FRAME BY TYPING 0 OR 0. IN RESPONSE TO INPUT REQUEST.
C TERMINATE THE JOB BY TYPING 1. IN RESPONSE TO INPUT REQUEST.
C
C
        DIMENSION XARR(60),YARR(60)
        LOGICAL*1 IFILE(14),ANS
C
        TYPE *,'DATA GOES INTO 'FILENAME'.DIG ON DRIVE DL2:'
        TYPE *,'TYPE 0 OR 0. TO RESTART CURRENT FRAME'
        TYPE *,'TYPE 1. AT START OF FRAME TO TERMINATE PROGRAM'
        TYPE *,'FORMAT FOR DATA IS F7.3,1X,F7.3'
        WRITE (5,100)
100     FORMAT(//,' FILENAME? (MAX. OF 9 CHARACTERS)')
        READ(5,105)(IFILE(I),I=1,9)
105     FORMAT(9A1)
        IFILE(10)='.'
        IFILE(11)='D'
        IFILE(12)='I'
        IFILE(13)='G'
        IFILE(14)=0
C
C
C OPEN DATA FILE
        OPEN(UNIT=1,TYPE='NEW',NAME=IFILE,CARRIAGECONTROL='LIST'
     2  ,ERR=9000)
C
        TYPE *,' NO. OF POINTS PER FRAME?'
        READ(5,110)NO
110     FORMAT(I2)
C
        TYPE *,' INITIAL FRAME NUMBER'
        READ(5,111)IFRAME
111     FORMAT(I6)
        INITFR=IFRAME              !TO PRINT AT END
        ICOUNT=0                   !SHOWS IT IS FIRST FRAME OF RUN
        IFN=0                      !FRAME COUNTER
C
113     IF(ICOUNT.NE.0) IFRAME=IFRAME+1          !LOOP FOR NEXT FRAME
        IFN=IFN+1
        ICOUNT=1                                 !AFTER FIRST FRAME
115     TYPE *,' FRAME NO.',IFRAME       !OR REPEAT FRAME
C
C LOOP TO READ IN A FRAME OF DATA POINTS
        DO 200 I=1,NO
        READ (5,120)XARR(I),YARR(I)
120     FORMAT(F7.3,1X,F7.3)
        IF(IFIX(XARR(I)).EQ.0) GO TO 115         !REDO FRAME
        IF(IFIX(XARR(I)).EQ.1) GO TO 900         !END OF RUN
200     CONTINUE
C
        TYPE *,' IS FRAME CORRECT? (Y/N)'
        READ (5,205)ANS
205     FORMAT(A1)
        IF (ANS.EQ.'Y') GO TO 300
        GO TO 115                                !REDO FRAME
C
C WRITE TO DISK IF FRAME IS O.K.
300     FRAME=IFRAME
        WRITE(1,304)FRAME
304     FORMAT(F7.3)
305     FORMAT(I3)
        DO 310 I=1,NO
        WRITE(1,315)XARR(I),YARR(I)
315     FORMAT(F7.3,1X,F7.3)
310     CONTINUE
C
        GO TO 113
C
C ERROR MESSAGES
9000    WRITE(5,9005)
9005    FORMAT(' ERROR IN OPENING FILE')
C
900     FRAME=999.0
        WRITE(1,304)FRAME
        CLOSE(UNIT=1)
        IFN=IFN-1
        WRITE(5,901)IFN
901     FORMAT(' NO. OF FRAMES COLLECTED IS:-',I5)
        WRITE(5,903)INITFR,IFRAME-1
903     FORMAT(' FROM FRAME NO.',I6,'      TO',I6)
        STOP
```

DIGSAL

```
C CALCULATIONS
C
      XF=X(3)-X(2)     !S DISTANCE BETWEEN DIG. POINTS 2AND3 ON X AXIS
      YF=Y(3)-Y(2)     !S DISTANCE BETWEEN DIG. POINTS 2AND3 ON Y AXIS
      SF=FD/(XF*2.54)          !SCALING FACTOR: PHYS. DIST./DIGITISED DIST.
      THETA=ATAN2(YF,XF)
C
      WRITE(5,305)INUM,SF,THETA
305   FORMAT(' INUM=',I6,' SF=',F10.4,' THETA=',F10.4)
C
      IF (INUM.GT.7) GO TO 400          !RIGHT CAMERA
C
      DO 350 I=4,15                     !LEFT CAMERA
      IX=IFIX(X(I))
      IF (IX.GT.990) GO TO 380          !MISSING VALUE
C
      XX(I,INUM)=(X(I)*COS(THETA)+Y(I)*SIN(THETA))*2.54
      YY(I,INUM)=(-X(I)*SIN(THETA)+Y(I)*COS(THETA))*2.54-6.448
C
      GO TO 370
C
380   XX(I,INUM)=990.0
      YY(I,INUM)=990.0
C
370   WRITE(5,381)I,INUM,XX(I,INUM),YY(I,INUM)
381   FORMAT(' I=',I6,' INUM=',I6,' XX=',F10.4,' YY=',F10.4)
350   CONTINUE
C
      GOTO 150          !END OF LEFT CAMERA LOOP
C
400   DO 450 I=4,15               !RIGHT CAMERA
      IX=IFIX(X(I))
      IF(IX.GT.990) GOTO 480  !MISSING VALUE
C
      XX(I,INUM)=(-X(I)*COS(THETA)+Y(I)*SIN(THETA))*2.54
      ZZ(I,INUM)=(-X(I)*SIN(THETA)-Y(I)*COS(THETA))*2.54+6.448
C
      GO TO 470
C
480   XX(I,INUM)=990.0
      ZZ(I,INUM)=990.0
C
470   WRITE(5,481)I,INUM,XX(I,INUM),ZZ(I,INUM)
481   FORMAT(' I=',I6,' INUM=',I6,' XX=',F10.4,' ZZ=',F10.4)
450   CONTINUE
C
      GO TO 150          !END OF RIGHT CAMERA LOOP
C
C CORRESPONDING FRAME. ARE MATCHED,AND VALUES ARE CALCULATED
700   DO 710 J=1,7     !J AND J+7 GIVE FRAME NUMBERS
      DO 720 I=4,15    !I GIVES POINT NO. WITHIN FRAME
      IXX1=IFIX(XX(I,J))
      IXX2=IFIX(XX(I,J+7))
      IF(IXX1.EQ.990.OR.IXX2.EQ.990) GO TO 780          !MISSING VALUE
C
      XGR(I)=XX(I,J)*(LFD*LFD-ZZ(I,J+7)*LFD)/(LFD*LFD-ZZ(I,J+7)
     1 *XX(I,J))
      ZGR(I)=ZZ(I,J+7)*(1-(XGR(I)/LFD))
      YGR(I)=YY(I,J)*(LFD-ZGR(I))/LFD
C
      GO TO 720
C
780   XGR(I)=990.0
      YGR(I)=990.0
      ZGR(I)=990.0
C
720   CONTINUE          !END OF LOOP WITHIN FRAME
C
C WRITE CALCULATED VALUES TO OUTPUT FILE
      DO 791 I=4,15
      WRITE(4,790)J,J+7,XGR(I),YGR(I),ZGR(I)
791   PRINT OUT VALUES FOR FINAL CO-ORDS---CONTINUE
790   FORMAT(2I4,3F10.4)
710   CONTINUE          !END OF LOOP FOR ALL FRAMES.
C
C END OF PROGRAM
      CLOSE (UNIT=2)
      CLOSE (UNIT=4)
      STOP
      END
C
C
```

APPENDIX II.

Angulation from the normal 0° of probe					
0°		15°		45°	
Distance measured in mm.					
DIG.	US	DIG.	US	DIG.	US
8.011	8	7.762	9	8.390	9
8.189	8	8.187	8	7.852	8
7.714	9	7.849	9	8.134	9
7.915	9	8.359	9	8.291	8
7.834	8	8.312	9	7.857	8
8.113	9	8.527	8	7.832	8
8.126	8	8.152	8	8.602	9
8.237	9	8.133	9	7.871	9
7.701	9	8.217	8	7.752	9
8.000	9	8.197	9	8.302	9

Table.I

Distance (mm) between 2 fine threads measured by digitiser from the video recording of the ultrasound scan with the probe in 3 positions on the surface of the skin 0°,15°,45° to the normal. (Experimental work 8.4.3.).

APPENDIX III

Laminae overlap distance (mm).					
X		SD		CV%	
Flex	Extn	Flex	Extn	Flex	Extn
2.50	1.68	0.51	0.35	20.47	20.83
2.79	1.89	0.52	0.37	18.73	19.80
2.86	2.19	0.52	0.39	18.14	17.64
3.44	2.33	0.50	0.46	14.58	19.67
2.99	2.06	0.42	0.45	13.93	21.70
2.87	2.04	0.84	0.20	29.38	09.67
2.51	2.39	0.85	0.40	33.81	16.59
3.37	2.16	0.61	0.29	18.16	13.33
3.16	2.46	0.66	0.48	20.87	19.64
2.74	2.27	0.63	0.33	23.26	14.37
3.16	2.24	0.55	0.47	17.46	20.82
3.09	2.33	0.73	0.30	23.66	12.94
2.90	2.60	1.02	0.84	35.00	32.00
3.10	2.62	0.70	0.89	22.63	33.89
2.43	2.07	0.64	0.47	26.54	22.88
2.47	2.23	0.40	0.29	16.00	13.19
3.23	2.17	0.54	0.63	16.74	29.18
3.42	1.93	1.12	0.28	32.43	14.58
2.76	2.26	0.32	0.31	11.66	13.53
2.72	2.02	0.47	0.85	17.42	42.00

Table 8.8.(Experiment 8.6.2).

Measurements of the spine in flexion and extension, measuring the distance of overlap between the laminae. The mean, standard deviation and coefficient of variance is given for each of the 20 groups tested. Distance in mm.

APPENDIX IV.

	Head Rotation to the Right			
Subject	(R) distance	(L) distance	Difference	Vertebral
Pre-Rx	mm	mm		Orientation
1	31.530	33.796		
	34.307	37.436		L
	-2.777	-3.640	0.863	
2	29.625	34.071		
	32.661	33.649		R
	-3.036	0.422	-3.458	
3	29.526	33.769		
	31.370	32.583		R
	-1.844	1.186	-3.03	
Post-Rx				
1	29.106	34.212		
	34.334	33.651		R
	-5.228	0.561	-5.789	
2	26.146	32.934		
	25.835	26.659		R
	0.311	6.275	-5.964	
3	28.283	27.816		
	28.377	29.812		L
	-0.094	-1.996	1.902	

Table II. (Experiment 8.6.3).

Distance measured from the fixed frame of the digitiser to the posterior wall of the vertebral body at the root of the pedicle. Results from 3 subjects, PRE and POST manual therapy intervention to treat a restricted vertebral segment. The final orientation of the vertebra is given for right rotation of the neck.

APPENDIX V.

Head Side-flexed to Right.

Subject Pre-Rx	(R) Distance mm	(L) Distance mm	Difference mm	Vertebral Orientation
1	31.530	33.796		
	29.483	31.538		R
	2.047	2.258	-0.211	
2	29.625	34.071		
	33.482	33.483		R
	-3.857	0.588	-4.445	
3	29.799	33.769		
	33.663	33.011		R
	-3.864	0.758	-4.622	
Post-Rx				
1	29.106	34.212		
	28.825	34.642		L
	0.281	-0.043	0.324	
2	26.146	32.934		
	28.235	28.049		R
	-2.089	4.885	-6.974	
3	28.283	27.816		
	28.683	29.042		L
	-0.400	-1.226	0.826	

Table III. (Experiment 8.6.3).

Distance measured from the fixed frame of the digitiser to the posterior aspect of the vertebral body at the root of the pedicle. Results from 3 subjects, PRE and POST manual intervention to treat a restricted vertebral segment. Final rotation of the vertebra at lateral flexion is given.