ANATOMICAL STUDY OF THE CANINE LIMBS IN RELATION TO EXTERNAL SKELETAL FIXATION

INTRODUCTION AND DELIMITATION OF SAFE, HAZARDOUS AND UNSAFE CORRIDORS

by

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DEDICATION

Este trabajo se lo dedico a mis padres, por su constante apoyo moral y financiero a lo largo de mi carrera.

This work is dedicated to my parents, for their constant moral and financial support through my career.

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DECLARATION

I, Juan Manuel Marti Herrero, do hereby declare that the work in this dissertation is original, was carried out by myself or with due acknowledgement and has not been presented for the award of a degree at any other university.

signed:

dated: 1st July 1993

AIMS

The aims of this work are as follows:

1- To introduce the concept of safe, hazardous and unsafe corridors, areas and lines for external skeletal fixator pin insertion in veterinary orthopaedic surgery.

2- Through an anatomical study, including topographical dissections and the study of cross sectional anatomy, to locate the above mentioned areas and to delimitate and measure their extent on the canine limbs.

3- By using the anatomical findings of this study, to discuss the feasibility of the use, following sound application principles, of different external skeletal fixator configurations in the canine extremities.

SUMMARY

An anatomical study of the canine limbs was carried out in order to identify, locate and measure the extent of the safe, hazardous and unsafe corridors for pin insertion for the use of external skeletal fixation. Topographical dissections and cross-sections of fresh anatomical specimens of canine limbs were used to localise important neurovascular structures and musculotendinous units and to measure the extent of the corridors.

Safe corridors for external skeletal fixator pin insertion are clearly present in the eccentric bones of the canine lower limbs. Although no clear safe passages were identified in concentric bones of the upper limb, hazardous areas and lines are described as the safest for application of external fixation frames. The feasibility of the application of different fixator configurations through safe areas in the canine appendicular long bones is discussed. Some guidelines are given in order to allow the orthopaedic surgeon to follow sound anatomical principles of fixator application and to reduce the incidence of some avoidable complications.

INTRODUCTION

External skeletal fixation is a method of fracture immobilisation in which metallic wires, pins or screws are inserted percutaneously into the bone and connected outside the leg to an external frame (Egger 1991). One of the main advantages of this method of fixation is its great versatility. By using different combinations of pins and bars to build up increasingly complex configurations, the modern orthopaedic surgeon is able to address successfully almost any fracture situation. Although, as any other method, it has its advantages and disadvantages, external skeletal fixation can be applied to any size of patient to treat almost any type of fracture found in small animal orthopaedic practice.

External skeletal fixators have been used traditionally in small animal orthopaedics to treat open and infected fractures associated with soft tissue injuries (Nunamaker 1985a), mandibular fractures (Davidson and others 1992), comminuted fractures and to perform corrective osteotomies (Johnson 1992). The use of external skeletal fixation is not devoid of complications. Nonunion of fractures, osteomyelitis, failure of fixation and pin-bone interface or soft tissue problems are the most commonly cited (Green 1983). In the 1950's, lack of adequate training and knowledge of proper application technique and indications led to an unacceptable complication rate which made orthopaedic surgeons abandon their original enthusiasm for the technique (Petit 1992). Later conceptual improvements in crucial areas such as pin design, pin insertion technique, biomechanics of fracture fixation and fixator frames and handling of soft tissues, maximized the effectiveness of this system of fracture management and made its recent resurgence possible.

External fixation is nowadays a widely accepted form of fracture management, particularly in situations where significant soft tissue injury, bone loss or bone infection complicates the clinical picture. Its use in small animal orthopaedic surgery is increasing steadily thanks to the versatility of the technique, low cost of the necessary equipment compared to other fixation methods and increasing awareness of its indications and limitations. The external fixator has become an essential addition to the veterinary surgeon's armamentarium of techniques (Carmichael 1991). Moreover, there exists a trend in modern orthopaedic surgery to move away from the absolute rigid fixation which was strongly advocated by the ASIF philosophy of internal fixation. The search for primary bone healing under absolute rigidity has now been questioned and a "biological" approach to fracture healing by callus, mostly using external skeletal fixation, is advocated.

Complications associated with the use of external fixators are, nevertheless, limiting its usefulness (Halsey and others 1992). Premature pin loosening, leading to the loss of rigid fixation before complete bone healing has occurred, is still the leading complication (Aron and others 1986, Halsey and others 1992). Some of the important complications arising from the use of external skeletal fixation are due to lack of attention in the handling of the soft tissue envelope around the bone (Behrens 1989). These complications are well recognised in human orthopaedic surgery (Green 1983). Careless insertion of pins and wires, particularly when using complex fixator configurations, can cause injuries to vessels, nerves, and musculotendinous units. Damage to important vascular structures may lead to severe bleeding and compartment syndromes; injuries to peripheral nerves can cause paresthesia and loss of sensation. Impalement of musculotendinous units will produce joint stiffness, muscle pain, decreased use of the limb and increased patient morbidity. Soft tissue irritation around the pin is also believed to predispose to pin-tract sepsis and premature pin loosening, jeopardising the fixation. Most of these complications are avoidable if the orthopaedic surgeon adheres to sound pin insertion techniques and a clear understanding of the limb anatomy (Green 1981, Behrens and others 1986).

In human orthopaedic surgery, an increasing amount of attention has been paid in recent years to the anatomical considerations of pin insertion for safe and effective use of external skeletal fixator frames. The introduction of the concept and delimitation of safe, hazardous and unsafe corridors for pin insertion in the human leg by Behrens (1989) shows the concern of human orthopaedic surgeons for the proper application of external fixators, following sound biomechanical and anatomical considerations.

It is possible to reduce or indeed avoid the incidence of these complications if pins are inserted in safe corridors, where the bone is in a subcutaneous position. Interference with the soft tissue envelope should be kept to a minimum. Although this effectively limits the surgeon to the use of unilateral frames, these can be used perfectly satisfactorily for the repair of the majority of fractures in small animal orthopaedics. Bilateral frames, despite their popularity, are not free of complications and are not considered safe by many surgeons (Behrens 1986). Several experimental and clinical studies have been carried out showing the biomechanical characteristics of different fixator configurations and clearly show that the alleged increased stiffness of bilateral frames does not warrant their systematic use. It is widely accepted now that unilateral configurations with stiffness characteristics similar to those of the most rigid bilateral can be easily built (Behrens and others 1989). Consequently, the rigidity of routine, simple unilateral frames can be increased to meet the mechanical demands of almost any fracture situation encountered in small animal orthopaedic surgery. An increased, solid understanding of the new methods of external fixation, limitations of the technique, mechanical properties of frames and needs of particular fractures and patients, allows orthopaedic surgeons to move away safely from sophisticated designs and use improved, strong, simple configurations, avoiding potential complications. In human orthopaedic surgery, the success of the clinical application of external fixators is largely independent of the device employed (Schmidt and others 1983, DeBastiani and others 1984). Some results encourage the use of simple, well-made, unsophisticated designs (Behrens 1986) rather than sophisticated, expensive and overdesigned external fixation systems (Habboushe 1992).

Fixator frames are usually aligned in longitudinal planes and, due to the clear biomechanical implications of the use of maximal pin spread in the bone, it is useful to structure the regional limb anatomy in longitudinal corridors (Behrens 1989). To the best of the author's knowledge, no anatomical studies have been published concerning the location and measurement of safe corridors for pin insertion in the canine limbs. The purpose of this study is to introduce the concept and delimitate the extent of safe, hazardous and unsafe corridors in the canine extremities by carrying out topographical dissections and measurements of angles on cross section anatomical specimens. Special attention is devoted to the lower limb but some considerations of the use of external skeletal fixation in the canine upperlimb are addressed.

LITERATURE REVIEW

1. HISTORICAL PERSPECTIVE

Almost 2400 years ago, Hippocrates described the first method of external skeletal fixation used to stabilise a fractured tibia while at the same time permitting the inspection and treatment of the associated wound or soft tissue injury (Adams 1939).

Clayton Parkhill is, however, recognized as the inventor of the first half-pin splint, the Parkhill clamp, used in human orthopaedics. This device, designed in 1897, consisted of four pins inserted perpendicular to the bone through a series of steel and silver plates connected together with clamps. It was claimed to provide a one hundred % cure and its main advantages were easy and accurate adjustments, prevention of longitudinal and lateral movements between fragments and absence of material left in tissues. In 1902, Lambotte improved this design and recognized the advantages of easy access to open wounds and early mobilisation of the limb. By the 1920's, a number of adaptations and improvements in the use of pins and screws into bone fragments for better control of reduction and fixation had been achieved.

It was not until 1934 that external skeletal fixation was used in veterinary orthopaedics, when Otto Stader described a full pin transfixation splint in which the Kirschner wires were anchored in padded plywood splints. In 1937, he introduced the Stader splint, the first half-splint to provide reduction as well as fixation. This device consisted of two moulded plastic bars with holes which served as guides to control the angle of pin insertion. The pins were locked in position by means of Allen screws and the two pin-bar units were connected to a threaded extension bar, which provided extension or compression along the main axis of the bone. After manual reduction of the fracture, final adjustments could be made in two different planes. The Stader splint became extremely popular and widely used by human surgeons during World War II because its compactness, relative light weight and easy application in the less than ideal war conditions

The A.M.A.H. (Angel Memorial Animal Hospital) splint, later known as the Schroeder splint, was designed by R. Leighton and the veterinary student E. Schroeder, in 1938. It was a half-pin splint in which Allen screws connected the pins to stainless steel blocks and secured the extension rods to provide either extension or compression by means of a screw mechanism with a removable handle. Later improvements on the design included allowance for adjustment of angles and spacing of pins, extra holes in the pin blocks to accommodate long handles to reduce fractures under fluoroscopy and removal of the entire extension screw mechanism to reduce weight. The Schroeder splint was never patented for commercial production.

In the 1940's, E. A. Ehmer, working for the Kirschner Manufacturing Company of Vashon, Washington, introduced a modification of the Anderson splint used for humans, which became the ancestor of the most popular external skeletal fixator used nowadays in veterinary orthopaedic surgery. The Kirschner-Ehmer fixation splint consisted of half-pins connected through single clamps to short connecting bars and double clamps were used to attach a longer connecting bar to the short ones. Its main advantage was flexibility in the selection of pin angles which allowed correction of rotational and angular deformities once each half-pin unit had been inserted. Further improvements in its design and use included the elimination of the double clamps, identified as weak points in the frame and the introduction of complex fixation configurations.

The acceptance and popularity of external skeletal fixation has gone through different phases along its history. Fixators became very popular during World War II, because of the need for prompt ambulation and transportation of the patients. Surgeons in the U. S. Navy favoured the Stader splint due to the poor conditions of asepsis for internal fixation at sea. Furthermore, thanks to its lightweight, if the patient had to abandon ship, it did not became an anchor as a plaster cast would.

After the war, the technique went out of favour because of poor results and serious complications, arising from improper use of the devices and lack of adequate training and experience in their use. Otto Stader, in 1949, recommended a thorough revision of the regional anatomy in cadavers and bone specimens before embarking on the application of his splint on clinical cases, stating the importance of proper technique if good results were to be achieved. Following the same argument, in 1950, the American Academy of Orthopaedic Surgeons advised the average surgeon not to employ the method unless he had seen or assisted in at least 200 cases.

Later improvements in the understanding of the indications and limitations of the technique, asepsis and wound management, pin insertion techniques and biomechanical characteristics of the fixators led to consistent good results that justified the role of external skeletal fixation in modern orthopaedic surgery.

2. THE USE OF EXTERNAL SKELETAL FIXATION IN VETERINARY ORTHOPAEDICS.

External skeletal fixation can be used in the treatment of a great variety of orthopaedic conditions in small animals. Although this technique is particularly useful in comminuted or infected fractures associated with derangement of the surrounding soft tissue envelope, more simple fractures can also be repaired with external fixators.

External skeletal fixation is commonly used in the treatment of:

2.1. Long bone fractures.
2.2. Highly comminuted fractures.
2.3. Open or infected fractures.
2.4. Mandibular fractures.
2.5. Delayed unions and nonunions.
2.6. As auxiliary fixation to other fixation devices.

2.7. Corrective osteotomies.

2.8. Immobilisation of fractures or joint injuries with extensive soft tissue trauma.

2.9. Avian fractures.

2.1. Long bone fractures

Simple and more complicated fractures of long bones can be treated effectively with external skeletal fixation, particularly in the lower limb, where complex frames can be built without excessive interference with soft tissues and the body wall. Patients treated with external fixation will become ambulatory much faster than with external coaptation. External fixation devices immobilise fracture fragments yet allow freedom of movement, which encourages circulation, minimises muscle atrophy and aids in preventing joint stiffness (Aron and others 1984). Properly timed, staged disassembly of the fixator frame enhances the rate of fracture healing and decreases stress protection associated with prolongued plate fixation (Uhthoff and others 1971). Reduced cost of implants and necessary specialised equipment, ease of use and versatility represent some of the clear advantages over other methods of fracture fixation, particularly bone plating (Egger 1989).

2.2. Highly comminuted fractures

Fixators are particularly useful in the treatment of severely comminuted fractures where anatomical reconstruction is not possible. Most comminuted fractures are the consequence of rapid absorption of very high amounts of kinetic energy which is released to the soft tissues when the fracture occurs (Carter and others 1982). Open reduction will often lead to further compromise to the vascularity of the area and can jeopardise revascularisation of the bony fragments, leading to sequestra formation. Closed reduction is, therefore, indicated whenever reasonably accurate reduction is possible. The soft tissues surrounding the fracture hold the fragments in position and provide blood supply for rapid healing (Roush 1992).

In non-reconstructable comminuted fractures none of the ground reaction force is transmitted through the bone column (Palmer and others 1992). Consequently, strong fixator configurations must be used when treating comminuted fractures with loss of bony stability, to allow use of the limb during the healing period (Carmichael 1991).

2.3. Open or infected fractures

These were the original and remain one of the most common indications for the use of external skeletal fixation. Bone can heal in the presence of infection, if fixed rigidly (Rittman and others 1974), hence the importance of rigid skeletal fixation in infected fractures. In these circumstances, this technique presents several distinct advantages over other methods of fixation (Carmichael 1991). First, spreading of contamination or infection is avoided by placing the external fixator pins well away from the infected area. Secondly, fracture and soft tissue immobilisation are achieved without traumatising the area, which allows primary management and care of the open wound and delayed autogenous cancellous bone procedures (Egger 1989). Depending on the specific situation, fixators applied to treat open fractures can be mantained in place until the infection is successfully controlled and a switch to definitive internal fixation is needed or can be left in situ until complete bony healing takes place.

2.4. Mandibular fractures

Mandibular fractures are quite common in dogs involved in road traffic accidents (Kolata and others 1975) and represent 2.5 % of all fractures seen in the dog (Weigel 1985). Due to the high frequency of open, comminuted fractures and the peculiar shape of the canine mandible, the external fixator is particularly useful for the treatment of fractures of the mandibular ramus (Carmichael 1991). In a recent study, bone plating of mandibular fractures was not recommended because of unavoidable damage to the dental roots due to their position along the mandibular body (Verstraete and others 1992).

In the repair of mandibular fractures, perfect dental occlusion is mandatory for good clinical results and is more important than perfect reduction of bone fragments. Malocclusion may result in temporomandibular joint arthritis (Chambers 1981).

Percutaneous pins or screws can be connected to stainless steel bar and clamps or to a dental acrylic (polymethylmethacrylate) connecting bar as a cheap, versatile alternative to treat unilateral or bilateral mandibular fractures (Davidson and others 1992). The use of a biphasic splint has been described for the repair of mandibular fractures (Greenwood and others 1980). In the first phase, special bone screws are placed percutaneously in the mandible and secured with external clamps and bars. In the second stage, an acrylic bar is placed across the ends of the screws and the metal bars are removed. No major complications have been reported with the use of this splint (Weigel and others 1981). External fixators in the mandible are well tolerated by the animals and client education prevents potential disruption of the protruding splint (Chambers 1981).

2.5. Delayed unions and nonunions

The use of a unilateral biplanar configuration of external skeletal fixator has been described for the treatment of delayed unions and nonunions of distal radius and ulna fractures in toy breeds (Egger and others 1990, Lincoln 1992). Fixators are particularly applicable to atrophic nonunions where bone atrophy around the site reduces the holding power of the bone. Transfixation pins can be implanted away from the fracture where the bone quality is better (Eger 1990). Using this configuration, the surgeon can apply a compressive force across the fracture site, improving the fixation and reducing the mechanical stresses on the pins (Aron and others 1984).

2.6. As auxiliary fixation

External skeletal fixation can be used as a primary means of fracture stabilisation or as an adjunct to other fixation devices. A fixator frame can provide temporary additional stability when bone plating, because of fracture location or comminution, does not achieve satisfactory fracture repair and fixation failure is expected (Matthiesen 1992). Fixators can also be used as an additional auxiliary method of fixation in combination with an intramedullary device and cerclage wires (Carmichael 1991). When external skeletal fixation is used in combination with an intramedullary pin, each complement the mechanical stability of the other (Aron and others 1991). Because of its proximity to the neutral axis of the bone, the intramedullary pin resists bending equally well in all directions (Smith 1985), but stabilises poorly against forces of shear, torsion and compression. Conversely, a simple fixator has difficulty stabilising bending, but is best able to resist the forces of shear torsion and compression (Egger 1983, Smith 1985). This technique is not limited to the distal limb, since a simple two-pin unilateral uniplanar configuration can be applied in the upper limb without significant interference with muscle masses in situations where rotational instability might be present after repair using an intramedullary device (Carmichael 1991).

An intramedullary pin external skeletal fixator tie-in configuration has been described for the repair of severe femoral and humeral fractures in the dog and cat (Aron and others 1991). This method gave the pin fixation system more strength compared to the traditional arrangement without the need to add significantly more weight, bulk or cost.

2.7. Corrective osteotomies

The surgical management of growth plate deformities in small animal orthopaedics can be greatly facilitated by the use of external fixators. Depending on the specific circumstances of the patient, these deformities can be treated in three ways (Carmichael 1991):

2.7.1. Corrective osteotomy of angular deformities

2.7.2. Lengthening osteotomy

2.7.3. Manipulation of the existing growth plate

2.7.1. Corrective osteotomy of angular deformities

Angular deformities occur most commonly in the canine antebrachium as a result of premature closure of the distal radial and ulnar growth plates (Fox 1984). Correction or improvement of multiplanar bone deformity and elbow joint malarticulation to the specific needs of the patient can be achieved by different osteotomies and the use of the fixator applied to the radius. Definitive correction by means of an oblique radial osteotomy stabilised with a four to six-pin, medially inserted unilateral uniplanar frame is the preferred technique (Brinker and others 1990a). One of its main advantages over bone plating is that it allows the surgeon more flexibility in the correction of the deformity and the amount of limb loss is also diminished.

2.7.2. Lengthening osteotomy

In situations where significant loss of limb length ensues, surgical lengthening of the involved bones is necessary to correct the asymmetry. Dynamic correction of limb malalignment, prevention of elbow joint incongruity and gradual limb lengthening can be carried out using a Charnley apparatus (Knecht and others 1983) or with equipment readily available and commonly used by most practicioners (Robertson 1983). The use of fixators to correct pes varus deformity as a result of premature closure of the distal tibial growth plate has been described in the Dachshund (Johnson and others 1989). The use of ring configurations, such as the Ilizarov fixator, allows gradual, controlled tridimensional correction of limb deformities and has revolutionised the surgical management of these conditions in man (Ilizarov 1990), although this demanding technique is associated with a high complication rate (Paley 1990).

The method of application and several isolated reports of the use of the Illizarov fixator in the dog have been published (Latte 1991, Thommasini and others 1991), but its complexity, high cost and lack of understanding and proper training in its use explain the current relatively low acceptance of this technique by veterinary orthopaedic surgeons.

2.7.3. Manipulation of the existing growth plate

Dynamic stretching of the open growth plate to accelerate or stimulate bone growth (epiphyseal distraction) has been used in humans (Aldegheri and others 1989) and in experimental rabbits (DeBastiani and others 1986). To prevent or correct angular deformities, the fixator is applied to the side of the limb showing least growth and continuous traction is exerted across the plate (Carmichael 1991). This technique is not of current use in veterinary orthopaedics.

2.8. Transarticular immobilisation

Joints can be immobilised at a required angle by means of an external fixator. This might be necessary to protect the surgical repair of certain fractures, such as peri or intra articular fractures, repaired by adaptation osteosynthesis. This provides accurate reduction but only weak fixation which would fail under normal weightbearing forces (Bjorling and others 1982). Transarticular application of external skeletal fixation has been described to perform joint arthrodesis (Brinker and others 1990c), to immobilise the canine tarsocrural joint after collateral prosthetic ligament replacement (Aron 1987), to protect Achilles tendon repairs (Morshead and others 1984) and to immobilise the traumatically dislocated canine stifle joint after stabilisation with extra-articular sutures (Aron 1988).

Joints must be immobilised in a functional position or normal standing angle (Bjorling and others 1982), in order to allow comfortable, immediate weightbearing to the patient. Some of the disadvantages of transarticular fixators using straight connecting bars, such as their excessive size and weight and the presence of double clamps, can be overcome by the use of angled connecting bars. Their application to immobilise the stifle, elbow and hock joints has been described (Toombs and others 1989). Recently, the use of a fixator boot for transarticular fixation of carpus or tarsus has been reported (Gallagher and others 1990). It consists on the application of a short plaster of Paris boot to the foot distal to the site of the injury or surgery and fixing the boot to external fixation pins in either the radius or the tibia, therefore avoiding pin placement in the matacarpal or metatarsal area.

2.9. Avian fractures

External skeletal fixation is commonly used for the treatment of long bone fractures in captive or wild birds. The peculiar bony structure of birds, with very thin and fragile cortices which do not hold implants well makes some forms of internal fixation unsuitable, particularly bone plating (Withrow 1982). The vast majority of limb fractures in birds are open or gunshot injuries in wild birds, with the associated soft tissue complications and potential for infection (Redig 1986).

Fracture immobilisation by external fixators offers a viable alternative to internal fixation, avoiding problems associated with implant removal, periarticular and articular damage (MacCoy 1983). Although the use of this technique follows the same indications and restrictions as in other animals, special considerations must be taken into account when applying fixators in birds. Weight and size of the device, seldom a consideration in other patients, can unbalance the bird making movement difficult and increasing the chance of further injury (MacCoy 1992). Small trocar-tipped Kirschner wires are used commonly in birds if threaded pins are not available in the appropriate sizes. Standard stainless steel, cast materials or polymethylmethacrylate can be used for connecting bars.

3. NOMENCLATURE AND CLASSIFICATION OF EXTERNAL FIXATORS

Considerable confusion has existed in the past concerning the definition, nomenclature and classifications of the external skeletal fixator components and configurations used both in human and veterinary orthopaedic surgery. The lack of consistent vocabulary and term definition has made communication difficult. A survey of small animal surgeons on fixators terminology revealed that some configurations were known by many different popular names and, often, the same name was used for different configurations (Roe and others 1985).

A classification was not essential in the beginning, as very few devices were available and a limited number of configurations could be built. The tendency was to name the fixator after its developer (Roe 1992). Hence, the Stader reduction splint, the Hoffmann apparatus and the Kirschner-Ehmer splint.

The standard Kirschner-Ehmer splint was the first external skeletal fixator device accepted widely for veterinary use. Originally, it was a double clamp configuration (Brinker and others 1990d), but it was soon adapted to a single clamp configuration and became known as the modified Kirschner-Ehmer splint (Brinker and others 1975). Different applications of this device gave rise to the first classification: the half or the full (through-and-through) Kirschner-Ehmer splint, depending on whether or not the pins transfix the limb and are connected to external bars at one or both sides of the leg.

In 1978, Hierholzer and others proposed a new classification in which fixators were classed according to pin type. Hence, half pins were used in type I fixators, full (through-and-through) pins were employed to build up type II fixators and a combination of half and full pins was used in type III configurations. Due to the mechanical differences between single and double clamps, this classification was extended by Egger stating the type of clamps used in the configurations. Aron (1984) proposed a change to a more descriptive terminology, using the terms unilateral, bilateral and biplanar as alternatives to Type I, Type II and Type III. A recent terminology was proposed by Toombs (1990), in which Type I fixators were divided into Type Ia for unilateral frames and Type Ib for bilateral frames.

The nomenclature used throughout this text is based on classification by Behrens (1989). This is a descriptive terminology to characterize all kinds of fixator devices. These are classified into simple, clamp and ring fixators depending on their degree of pin adjustability. Configurations are classified depending on the extent of the limb that they occupy. So, unilateral frames encompass an extremity sector of 90 degrees or less of the complete circumference of the limb, and bilateral frames occupy a sector larger than 90 degrees. Each of these groups is further subdivided into uniplanar and biplanar frames, according to how many planes the device is built into. This gives rise to the four basic configurations used most commonly in veterinary orthopaedic surgery (**Fig. 1**):

Unlateral uniplanar, formerly named Type I, half frame, etc.

Unilateral biplanar, formerly named quadrangular, delta frame.

Bilateral uniplanar, formerly named Type II, quadrilateral, etc.

Bilateral biplanar, formerly named Type III, tent frames, chalet frames, etc.

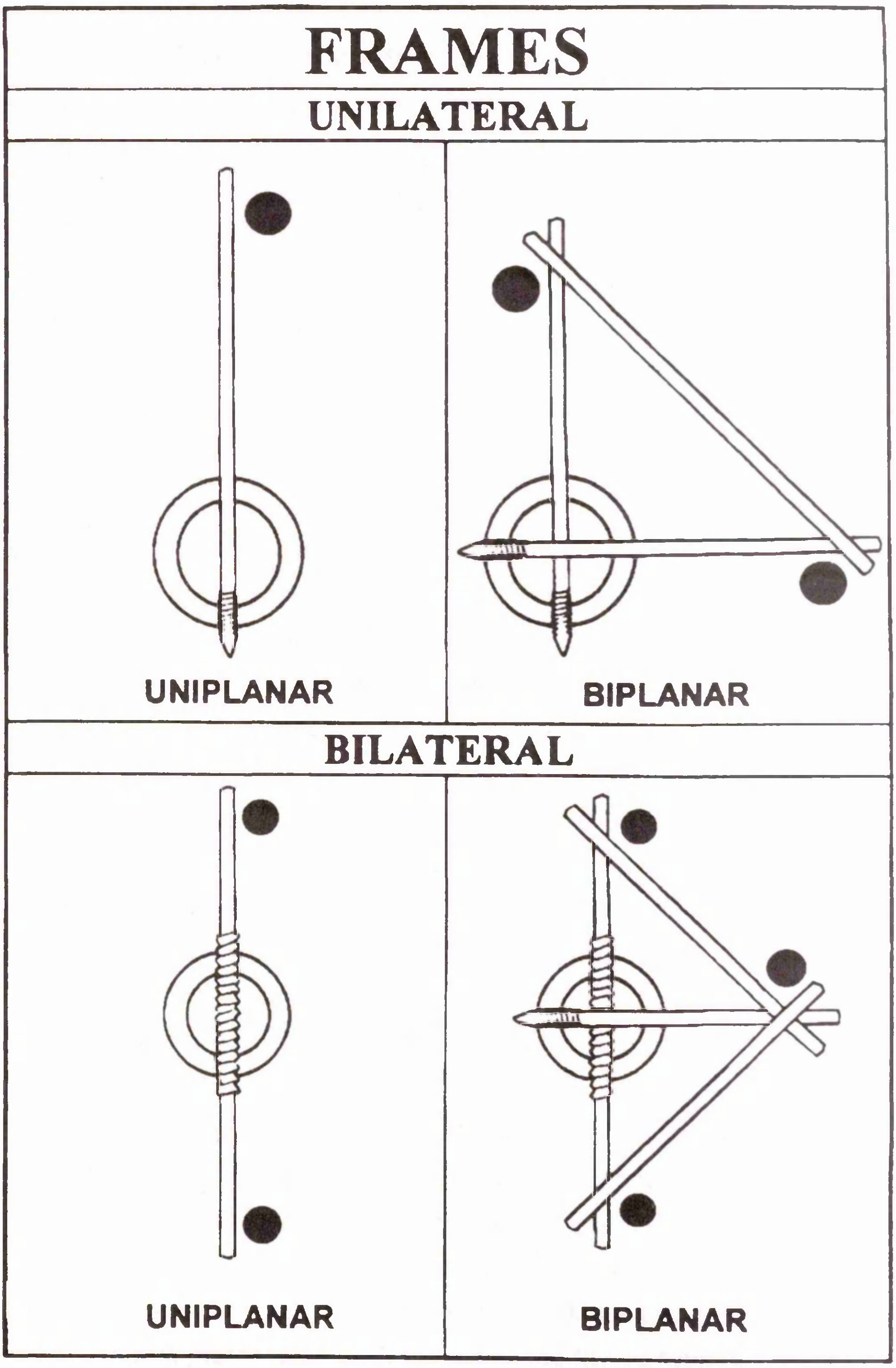


Fig. 1: The four basic configurations of external fixator frames.

4. BASIC PRINCIPLES AND METHODS OF APPLICATION

4.1. BIOMECHANICS: FRAME CONFIGURATION

To achieve the goal of fracture healing and consolidation, the fixator frame must meet the biomechanical demands of the specific fracture and patient, over the required period of time. Frame configuration and properties are, therefore, essential considerations to take into account when dealing with fractures in a clinical situation. One of the main advantages of the use of external skeletal fixation is its versatility to vary the characteristics of the frame, changing the number, thickness and orientation of its components to suit the needs of a specific situation.

Traditionally, unilateral uniplanar configurations have been used for more simple fractures. More complicated structures, like bilateral or biplanar fixators, were reserved for situations where extra stability was required. Considerable research has been undertaken on the biomechanical properties of the external fixator frames used in human orthopaedic surgery. Biomechanical studies of the frames most commonly used in veterinary surgery are also available (Brinker and others 1985).

Due to the increased incidence of postoperative complications associated with the use of bilateral frames, particularly related to the soft tissue envelope, there was a return to unilateral designs in the early 1980's in human orthopaedic surgery. It is widely accepted now that unilateral frames with similar biomechanical characteristics to those of the most rigid fixators can be built easily (Behrens 1989).

Several factors can be varied to increase or decrease the stiffness of a unilateral fixator frame. Frame application on a biomechanically advantageous position, use of more pins per main fragment, increasing the thickness of the pins, the use of a second connecting bar, increasing the spread of the pins in the bone, etc, are very effective measures to significantly increase the strength of a unilateral fixator configuration.

4.2. PIN DESIGN AND INSERTION TECHNIQUE

The pin-bone interface is the weakest link in any external fixation configuration (Aron and others 1986) and the point of maximal stress concentration of the bone-fixator system during normal and maximal loading (Chao and others 1982). It is subjected to substantial dynamic axial and bending forces with postoperative mobilisation, particularly on the cis cortex when unilateral fixators are used (Palmer and others 1990). The very high dynamic stresses placed upon both the metal and the surrounding bone causes bone resorption and replacement with fibrous, synovium-like and cartilaginous tissue around the pin with subsequent loosening and loss of fixation (Schatzer and others 1975). Pin loosening is one of the commonest complications of external skeletal fixation (Aron and others 1986) and it has been reported to occur earlier in transarticular fixators than when they are confined to a single long bone (Toombs and others 1989).

It is accepted that pins will loosen with time. The holding power of the pins depends largely on the design of the pins, the method used for their insertion and the nature and quality of the involved bone. This pin-to-bone purchase is not an essential factor in situations of rapid bone healing or when good bone stability relieves the load-bearing stress from the metal frame. When the fixation is the only load-bearing member of the bone-frame system, however, increased stress concentration at the pin-bone interface over a prolonged period of time can lead to premature pin loosening (Weber 1985). Loose pins do not contribute to the overall stability of the fixation, stimulate pain receptors in the periosteum and surrounding soft tissues leading to poor use of the limb, and predispose to pin tract infection (Aron 1989).

In order to increase the holding power of pins and, therefore, minimise the incidence of pin loosening, threaded pins are almost exclusively used in human orthopaedics and their use in veterinary orthopaedics is increasing (Aron 1989). Several threaded pins are available for veterinary use. These can be totally or partially threaded, with the thread at the end, in the centre or along its length, to accommodate to the needs of the frame. Threaded pins have an increased resistance to axial extraction in both the acute and chronic situation compared to smooth pins, due to their "screwed-in" fixation (Bennett and others 1987). Their main disadvantage is their tendency to structural failure in the threaded portion or at the threaded and non-threaded junction, which represents the weakest point along the pin (Egger and others 1986a). To avoid this complication, the core diameter is the same in both the threaded and non-threaded portions in some of the pins used in human orthopaedic surgery, like the Schanz pin. In partially threaded pins, more commonly used in the veterinary field, the thread only engages the far cortex, so the junction is protected from the excessive stress in the medullary cavity of the bone (Behrens 1989). The use of pins with a smaller core diameter and larger thread to bone contact provide greater holding power and higher pullout strength in human cancellous metaphyseal bone and their use has been advocated recently (Halsey and others 1992).

The Ellis pin is the most commonly used partially threaded pin in small animal orthopaedic surgery. Pin breakage, loosening and slippage are recognized complications (Palmer and others 1990). The use of a combination of smooth pins and threaded pins in clinical situations has been advocated (Aron and others 1986). The rationale behind this strategy is that the presence of smooth pins would increase the rigidity of the frame and the threaded pins would provide stability at the pin-bone interface, reducing the incidence of premature loosening.

In an another attempt to reduce the incidence of premature pin loosening, porous titanium-surfaced smooth stainless-steel trocar pointed Steinmann pins were used as fixator pins in a chronic fracture model in dogs. Although these pins required a greater force for extraction than smooth fixator pins at eight weeks after surgery, it was unclear whether this was due to bony ingrowth into the porous surface or to the increased friction between the roughened titanium and the bone (DeCamp and others 1988).

The method of pin insertion influences greatly the incidence of pin loosening, since the way the bone reacts to the trauma of insertion will determine the quality of the pin-bone interface. High-speed drilling produces an excessive increase in temperature, which leads to thermal necrosis of bone (Matthews and others 1984). Manual insertion with a hand chuck is very difficult and, inevitably, causes mechanical damage to the bone due to excessive wobbling of the pin (Egger and others 1986a). Slow-speed drilling in canine cortical bone has been proposed as an acceptable insertion technique since it does not lead to excessive heat build-up and thermal necrosis (Egger and others 1986a). A combination of predrilling with a smaller drill bit and manual insertion with a hand chuck is said to be the best way to avoid thermal damage (Matthews and others 1984) and has become the standard technique of pin insertion in human orthopaedic surgery.

The design of the pin tip is also a very important factor associated with the effects of pin insertion. The importance of the use of a pin with a tip that allows elimination of hot chips and fragments when drilling was emphasized by Matthews and others (1972). When a smooth pin is inserted, bone debris is compresed between the pin and the wall of the hole, producing a significant increase in friction.

4.3. AFTERCARE

The approach to postoperative pin care is still a controversial matter among orthopaedic surgeons using external skeletal fixation. A variety of pin care protocols are used by different orthopaedists and no one in particular has shown to decrease the incidence of complications.

Avoidance of pin tract infection is of major importance because it leads to pin loosening, soft tissue irritation, patient discomfort and decreased use of the limb. Pin-tract sepsis has been associated with increased soft tissue movement around the pin. The amount of soft tissue motion can be reduced by choosing areas for pin insertion with small amounts of subcutaneous tissue and by applying a bulky bandage between the skin and the pin groups, which also controls postoperative limb swelling (Aron 1992).

There is agreement that skin tension around the pin is a source of patient morbidity resulting from tissue necrosis, inflammation and secondary infection. Therefore, the use of large rather than small skin incisions and the relief of skin tension around the pin are indicated (Aron 1992, Green 1983).

The serosanguinous fluid which drains from a non-infected pin site during the first days after the surgery forms a crust around the pin, sealing the skin incision. Some surgeons advocate the meticulous removal of this crust, to allow continous drainage of the discharge. Daily swabbing and cleansing with different antiseptics (i.e. hydrogen peroxide) around the pin area and application of antiseptic or antibiotic ointments has been recommended (Behrens 1989; Green 1983; Aron 1989). Some surgeons leave the pin hole to granulate and form a crust, which is left intact throughout the complete postoperative period (Bradley 1980, Carmichael 1991).

MATERIALS AND METHODS

Topographical dissections of the brachium (arm), antebrachium (forearm), manus (forepaw), femoral region (thigh), crus (leg) and pes (hindpaw) and cross-sections of antebrachium and crus of fresh canine cadavers (euthanased or died for unrelated reasons) were carried out to identify the location and extent of safe corridors for pin insertion with a view to the safe and effective use of external skeletal fixation.

The specimens used for this study were obtained from skeletally mature animals of medium size breeds (weigth range 30-40 Kg). Ten canine forelimbs and ten hindlimbs were used for this study. After removal of the skin and subcutaneous fat for better identification of the specific cross section points, all specimens were deep-frozen for 24 hours. In each specimen, cross sections of the forearm and leg were prepared, perpendicular to the longitudinal axis of the main bone of the limb segment, using an electric saw at specific points. The number of sections corresponded with the minimum ideal number of pins that would be used in a uniplanar unilateral frame used to stabilise a diaphyseal fracture. The location of the most proximal and distal sections was determined by the ideal position of the corresponding pins from a biomechanical viewpoint. After submerging the sections in water at room temperature until thawed, important neurovascular structures which would limit pin insertion were located and identified on each cross-section. Safe corridors for pin insertion in a particular bone were measured at each level with a plastic goniometer **(Fig. 2)** from the visually estimated center of its cross section.

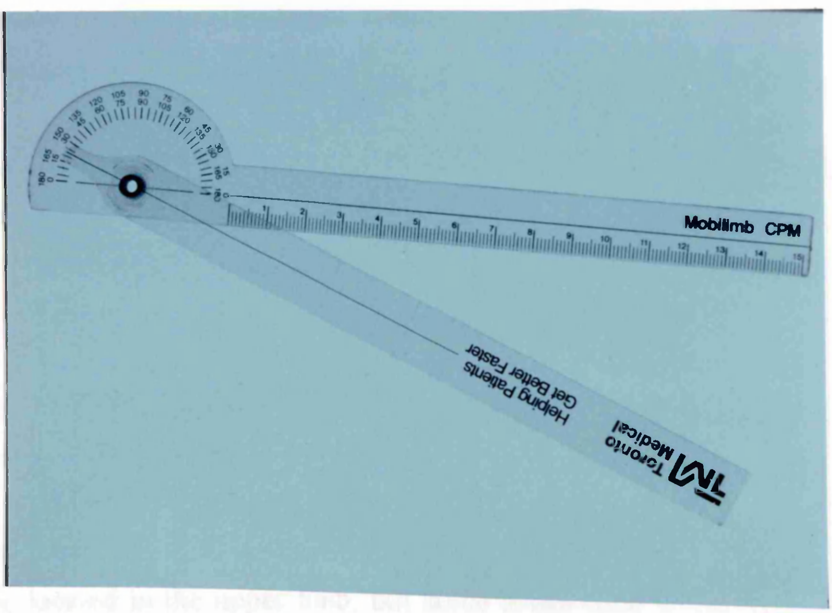


Fig. 2: Angle measurements were carried out with a plastic goniometer.

Only traditional topographical dissections of fresh specimens were carried out in the upper limb (brachium and femoral region) and in the manus and pes. Some lower limb specimens were also dissected as a useful complement to the anatomical findings in the cross-sections and to provide a general view of the regional anatomy.

To maximise the consistency in the points at which the limbs were sectioned, these were easily identified directly or by palpation of the bone involved. In the antebrachium, the section points along the radius were **(Fig. 3)**:

1- Immediately distal to the radial neck, approximately at the level of the radial tuberosity.
2 to 5- Due to the absence of palpable anatomical points of reference along the radial body, the remaining radius was sectioned to achieve five portions of radial diaphysis of equal length.
6- Distal radial metaphysis, at a level slightly proximal to its more prominent bony feature.

In the crus, the levels chosen to study the cross sectional anatomy were **(Fig.4)**:

1- Immediately distal to the insertion of the patellar ligament in the tibial tuberosity.
2- Distal end of cranial border of the tibia (margo cranialis, formerly called tibial crest).
3- Junction between margo cranialis and tibial shaft.
4 & 5- Two sections through the remaining tibial shaft.
6- Junction between the medial malleolus and tibial shaft.

DEFINITIONS

Safe corridors are defined as longitudinal regions through which pins can be inserted safely, for they contain neither musculotendinous nor important neurovascular structures. These are easily identified in eccentric bones, as regions where the bone can be palpated subcutaneously. Hazardous corridors contain musculotendinous units but no important neurovascular structures. These are, however, the safest areas for pin insertion present in concentric bones. Unsafe corridors contain both musculotendinous units and important neurovascular structures (Behrens 1989).

Concentric bones were defined as those completely or almost completely surrounded by muscle masses and not offering clear safe passages for pin insertion. They are usually located in the upper limb, but some lower limb bones with less orthopaedic interest also lie in this category.

Eccentric bones were defined as those which have at least two-thirds of one of its aspects in a subcutaneous location. These bones lie eccentrically in the cross section of their limb segment.

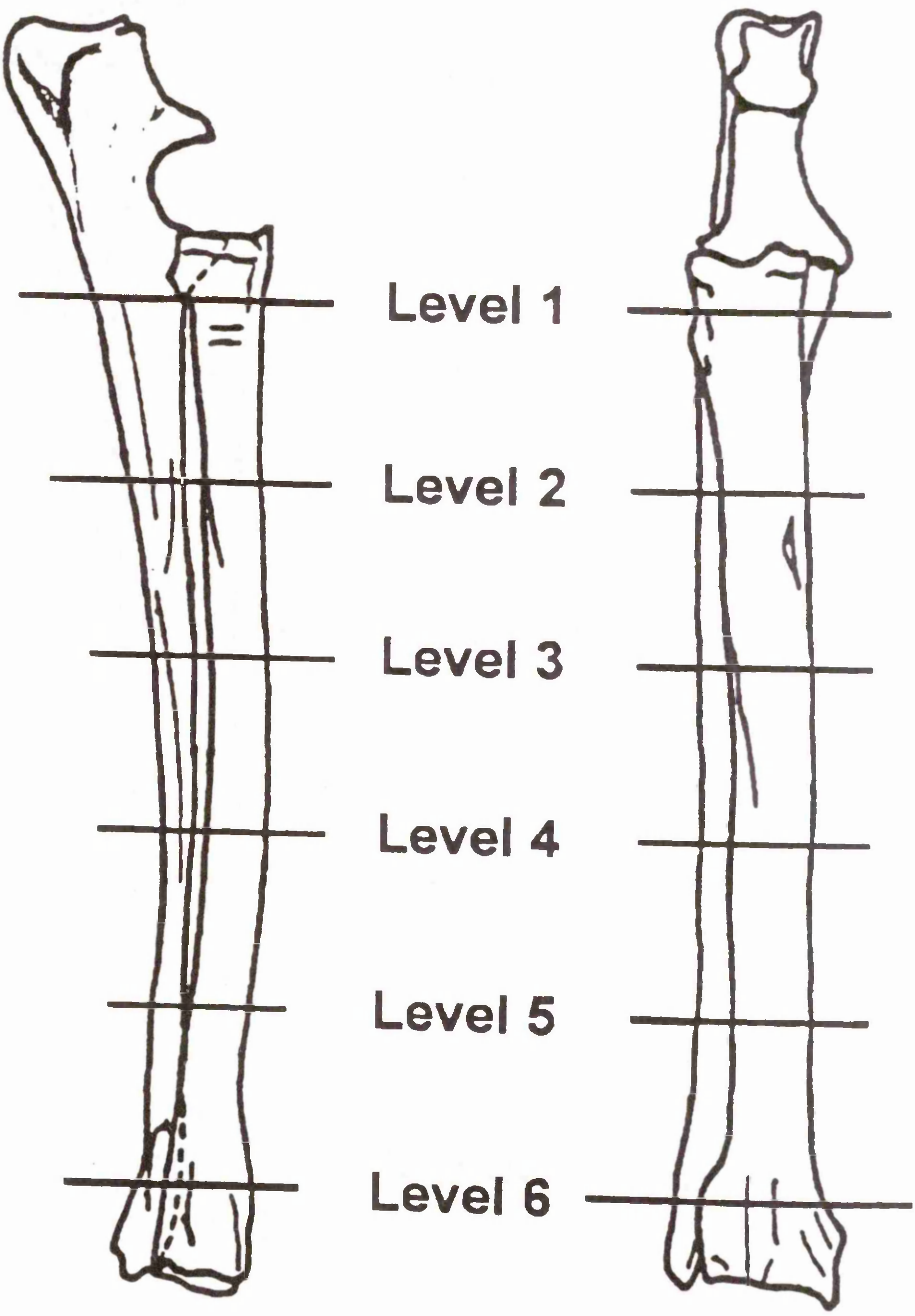


Fig. 3: Levels of cross section in the antebrachium.

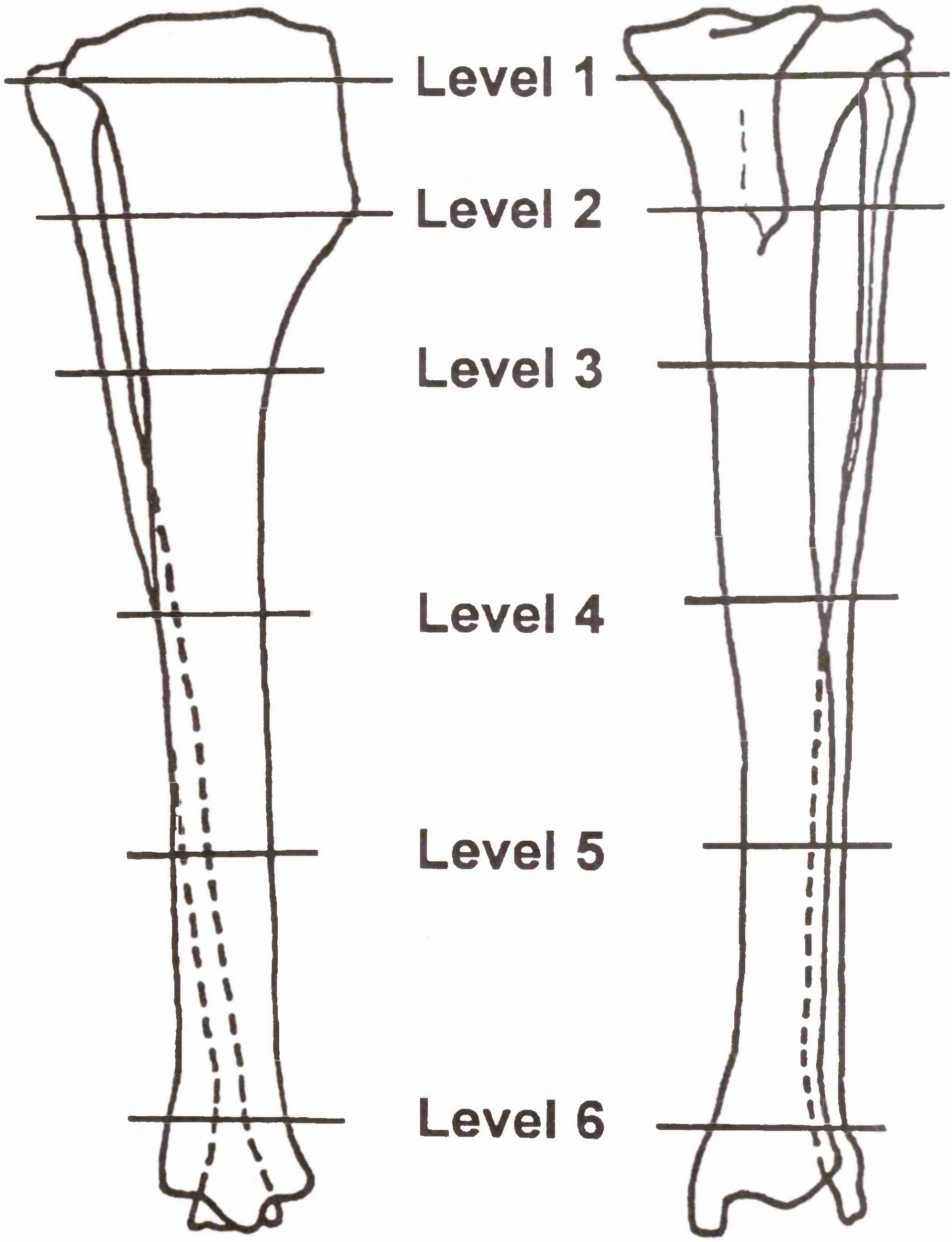


Fig. 4: Levels of cross section in the crus.

RESULTS

CANINE BRACHIUM

The canine humerus is considered a concentric bone. Therefore, no clear safe corridors for pin insertion could be identified in the topographical dissections. However, safe areas and lines which could be used for safe pin placement when applying a fixator frame were identified and located **(Fig. 5)**.

There exists a region in the craniolateral aspect of the proximal humerus, involving the distal part of the greater tubercle and an area distal to it, which is palpable subcutaneously and not covered by muscle masses. This area, approximately comma-shaped with its apex pointing distocaudally, is delimited dorsally by the insertion of the supraspinatus muscle on the free edge of the greater tubercle; caudally by the acromial head of the deltoideus muscle and medially by the insertion of the superficial pectoral muscles on the crest of the greater tubercle and the belly of the brachiocephalicus muscle running craniodorsally. The small omobrachialis vein, formerly called proximal communicating branch of the cephalic vein, usually crosses this area at the level of its proximal third, running in a craniocaudal direction to drain directly into the external jugular vein. This area was considered as safe for pin insertion.

More distally along the humeral diaphysis, the area tapers down into a line delimitated medially by the insertion of the superficial pectoral muscles on the crest of the greater tubercle and laterally by the insertion of the deltoideus muscle in the deltoid tuberosity and origin of lateral head of the triceps on the humeral crest. This safe line disappears at the point where the brachialis muscle crosses the lateral aspect of the humerus, coursing distally on the musculospiral groove. The comma-shaped safe area and the contiguous safe line represent almost half of the total humeral length.

From the apex of the proximal safe area to the lateral epicondylar crest, the lateral aspect of the humerus is occupied by the brachialis muscle. The radial nerve lies on this muscle, following it around the humerus, and it bifurcates into deep and superficial branches. The superficial branch runs distally over the extensor carpi radialis muscle and, after dividing into a larger lateral and a smaller medial branch, it joins the cephalic vein. The deep, motor branch of the antebrachial part of the radial nerve travels caudodistally and passes under the extensor carpiradialis muscle near its origin on the lateral epicondylar crest.

The next distal palpable point is represented by the lateral epicondylar crest on the lateral aspect of the distal fourth of the humerus. The brachioradialis muscle, when present, arises from its proximal part and the extensor carpi radialis muscle arises from the remaining part. The supratrochlear foramen is level with the distal third of the crest. The most proximal part of the crest is covered by the distal edge of the lateral head of the triceps and, as it extends distally, it becomes subcutaneous as a thick, rounded crest ending in the lateral epicondyle. This is the enlarged distolateral end of the humerus, palpable bony protuberance which can be used as a useful anatomical landmark. Another

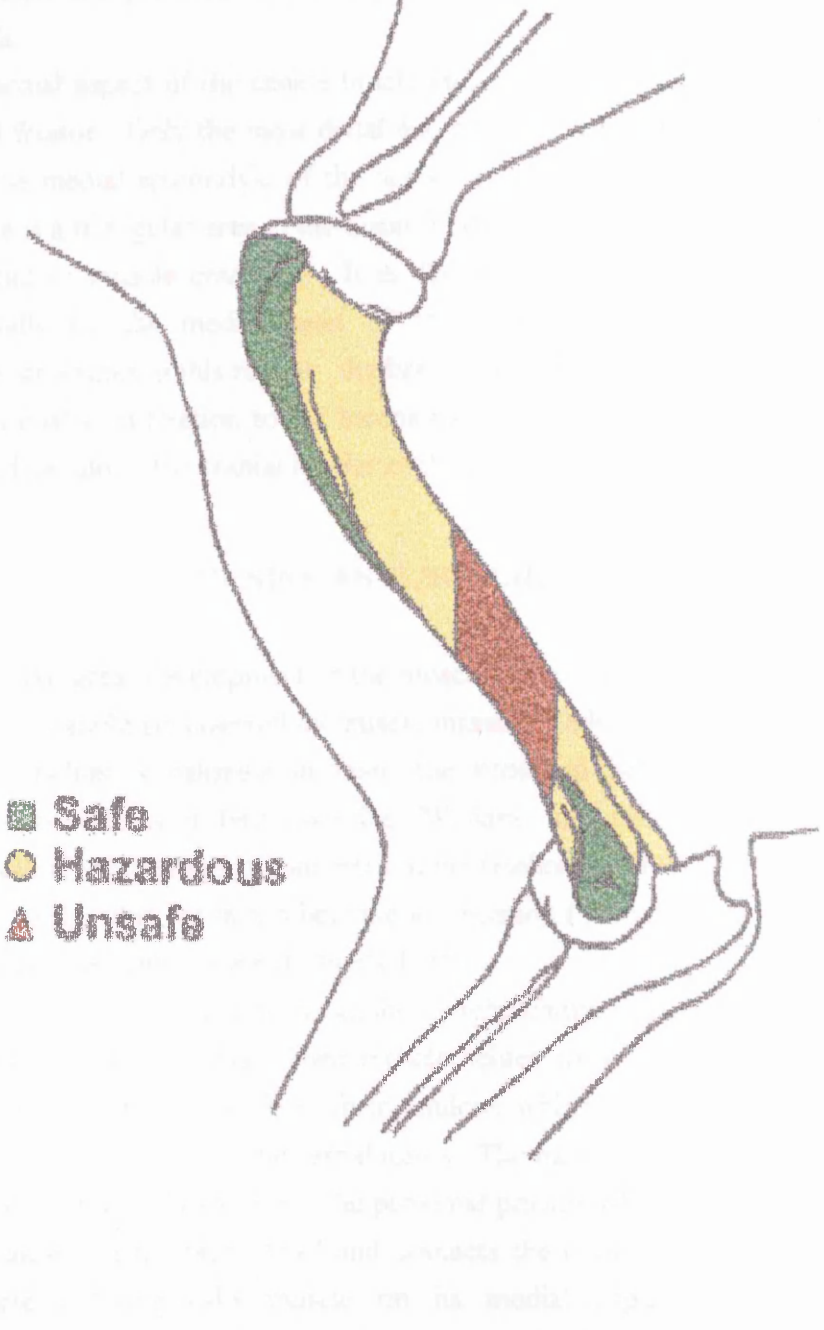


Fig. 5: Safe, hazardous and unsafe corridors on the canine brachium.

comma-shape safe area for pin insertion is, therefore, identifiable in the lateral aspect of the distal humerus. Its apex is situated at the midpoint of the lateral epicondylar crest and it widens in a distocaudal direction to include the lateral epicondyle. This is a much smaller area than the proximal and it represents approximately a ninth of the total humeral length.

The medial aspect of the canine brachium is obviously unsuitable for application of an external fixator. Only the most distal end of the humerus is readily palpable from the outside, the medial epicondyle of the humerus representing its most palpable bony feature. There is a triangular area in the distal fourth of the medial aspect of the humerus which is devoid of muscle coverage. It is delimitated cranially by the biceps brachii muscle, caudally by the medial head of the triceps. There are also important neurovascular structures in this region: the brachial artery and vein and the median nerve are situated cranially, in relation to the biceps muscle; the ulnar nerve lies caudal to the medial epicondyle, along the cranial border of the medial head of the triceps.

CANINE ANTEBRACHIUM

Due to the great development of the musculature of the antebrachium in man, the radius is almost completely covered by muscle masses. Only the distal half of the medial aspect of the radius is palpable in man, the proximal half being covered by the brachioradialis and pronator teres muscles (Williams and others 1980). The human radius is, therefore, considered a concentric bone (Behrens 1989). The entire posterior border of the human ulna lies in a subcutaneous location (Williams and others 1980) and it is regarded as an eccentric bone (Behrens 1989).

The craniolateral aspect of the canine antebrachium is occupied by the extensor muscles of the carpus and digits. Their muscle bellies are located in the proximal third and they taper progressively to form their tendons which run roughly parallel to each other in a distal direction across the carpal joints. The most cranial of the extensor group is the extensor carpi radialis muscle. The proximal portion of its muscle belly covers the craniolateral aspect of the radial head and contacts the common insertion of the biceps brachii muscle and brachialis muscle on its medial aspect. Consequently, the craniolateral surface of the antebrachium overlying the lateral border of the radius is considered a hazardous corridor due to the presence of the extensor musculature . The deep branch of the radial nerve determines the presence of an unsafe area on the proximal fifth of the lateral aspect of the antebrachium **(Fig. 6)**.

The only safe corridor present in the canine antebrachium is located on the medial aspect of the radius **(Fig. 7, 8)**. The proximal fifth of the medial aspect of the antebrachium represents a clear unsafe corridor for external skeletal fixator pin insertion in the radius. Pins inserted in this area could damage the brachial artery and vein and the median nerve as they cross the radial neck under the pronator teres muscle. The

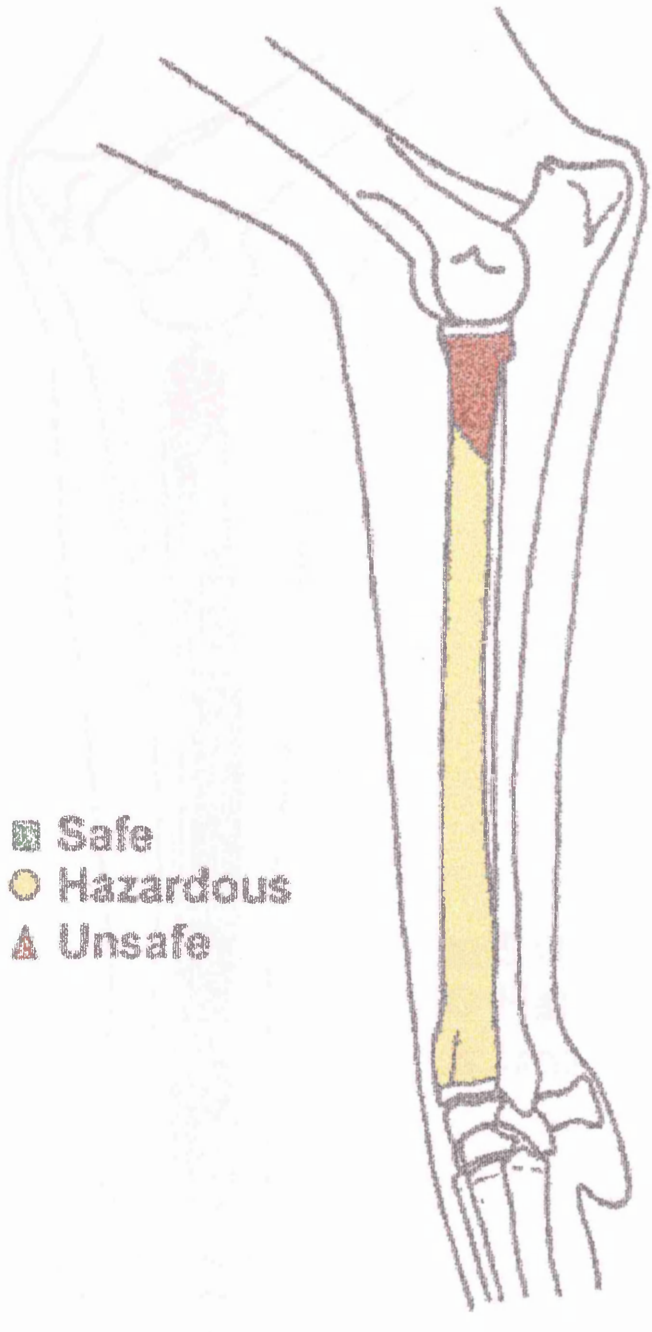


Fig. 6: Safe, hazardous and unsafe corridors on the lateral aspect of the canine antebrachium.

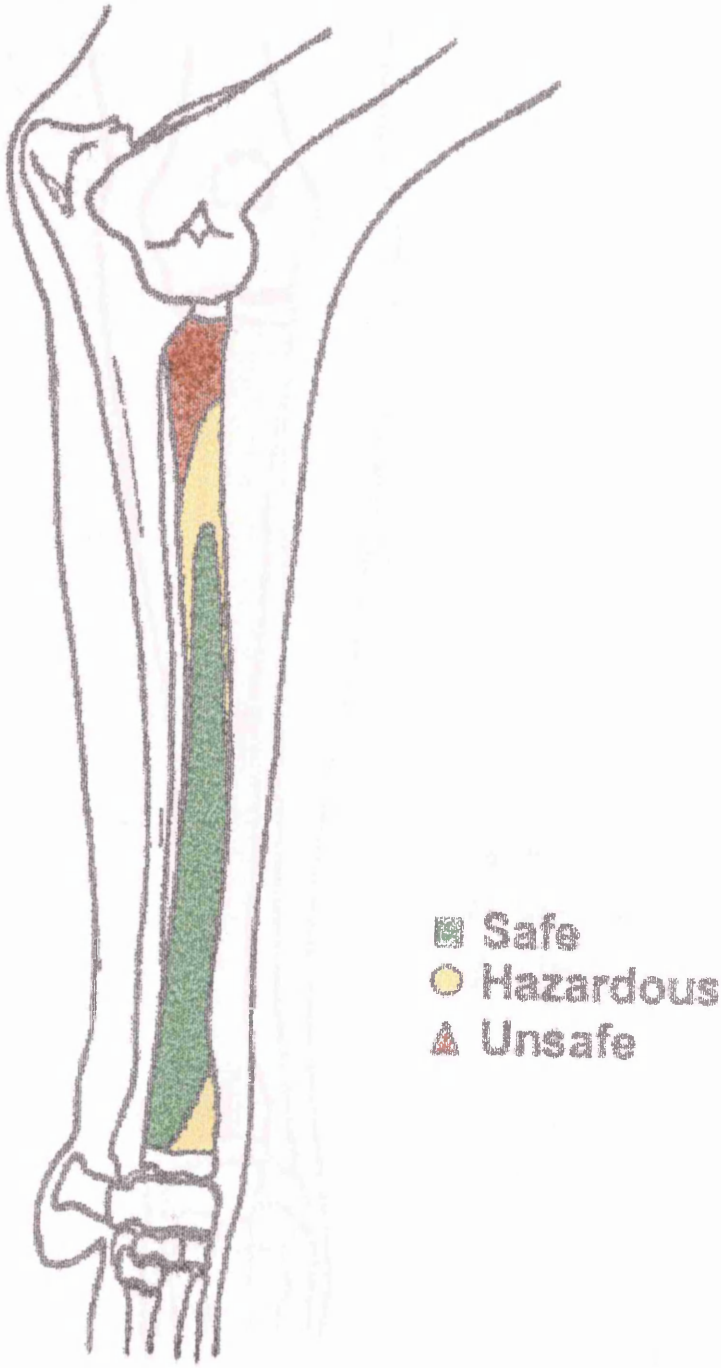


Fig. 7: Safe, hazardous and unsafe corridors on the medial aspect of the canine antebrachium.

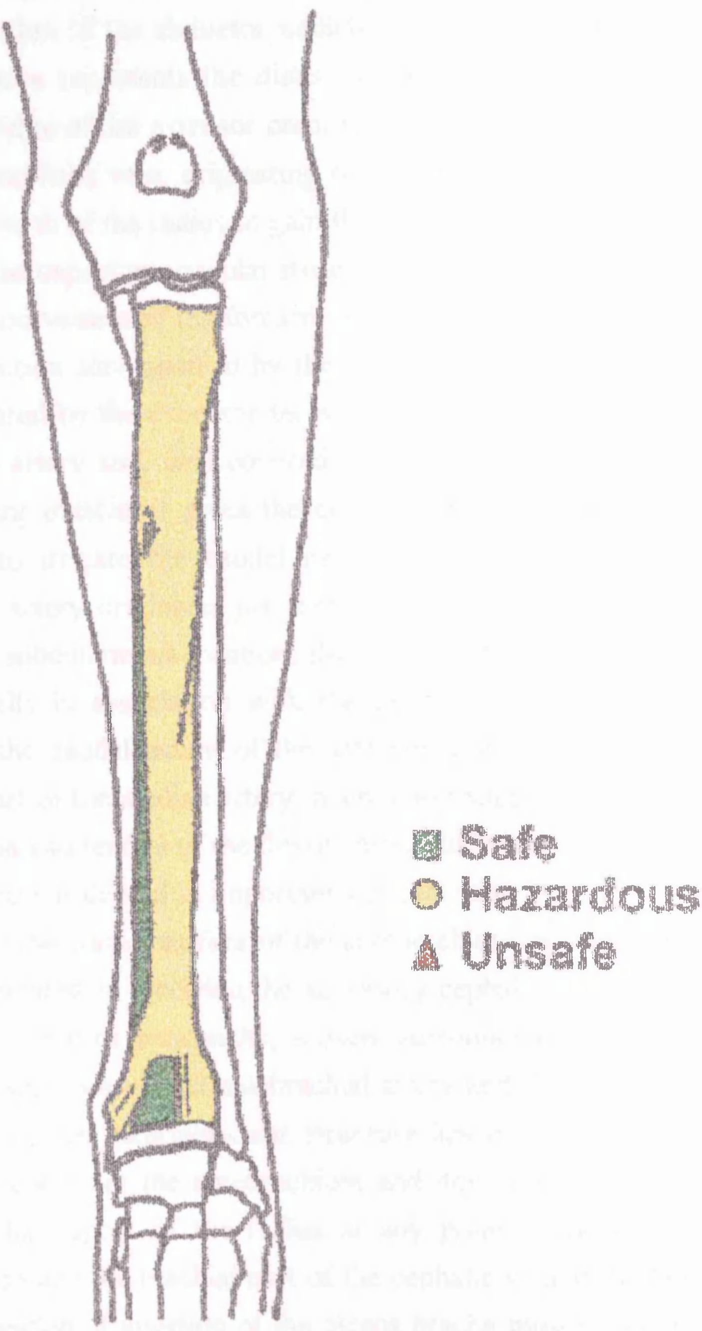


Fig. 8: Safe, hazardous and unsafe corridors on the cranial aspect of the canine antebrachium.

proximal third of the medial border of the radius is occupied by the pronator teres muscle, but the remainder of its medial border, from the insertion of the pronator teres muscle to the styloid process in the distal radius, is palpable subcutaneously. At this point, the oblique tendon of the abductor pollicis longus can be identified gliding on its groove. This safe area represents the distal two-thirds of the radial length and it is delimitated by the tendon of the extensor carpi radialis cranially and the radial artery and vein caudally. The cephalic vein, originating on the palmar aspect of the paw, crosses obliquely the distal fourth of the radius to gain the cranial surface of the antebrachium. It was not regarded as an important vascular structure.

The main blood vessels of the forearm, the brachial artery and vein run obliquely in a caudodistal direction accompanied by the median nerve, over the medial aspect of the radial neck, covered by the pronator teres muscle. At this point the brachial artery becomes the median artery and, well covered under the flexor carpiradialis muscle and the deep digital flexor muscle, it gives the common interosseous artery and the deep antebrachial artery to irrigate the caudal muscles of the antebrachium. One of its branches, the radial artery originates just proximal to the middle of the forearm and closely follows, in a subcutaneous location, the caudomedial border of the radius. This vessel, running distally in association with the radial head of the deep digital flexor muscle, delimitates the caudal extent of the safe corridor on the medial aspect of the radius. The distal part of the median artery, main blood supply to the forepaw lies under the antebrachial fascia and tendon of the flexor carpiradialis muscle. The lateral aspect of the canine antebrachium is devoid of important vascular structures.

Upon gaining the cranial surface of the antebrachium, the antebrachial part of the cephalic vein is augmented by receiving the accessory cephalic vein, originating from the dorsum of the paw. It runs proximally, loosely surrounded by the superficial fascia, accompanied by the small superficial antebrachial artery and the superficial branch of the radial nerve. This complex neurovascular structure lies over the extensor carpiradialis muscle along all its course in the antebrachium and does not cross or invade the safe corridor of the medial aspect of the radius at any point. The median cubital vein, connecting the median and the brachial part of the cephalic vein at the flexor angle of the elbow, crosses the tendon of insertion of the biceps brachii muscle obliquely and lies too proximally to be a concern to the surgeon operating in the forearm.

At LEVEL 1 **(Fig. 9)**, the canine radius is completely surrounded by musculature and, therefore, no safe areas can be found. The hazardous corridor **(Fig. 10)**, of 130 degrees, is located cranially and bounded by the deep branch of the radial nerve laterally and the brachial vessels medially. The unsafe sector occupies the rest of the limb circumference and includes the brachial vessels, median nerve and ulnar nerve as the most important neurovascular structures. LEVEL 2 **(Fig. 11)** coincided with the beginning of the distal third of the pronator teres muscle and the radius does not show any safe corridors on this section. The hazardous sector **(Fig. 12)**, of 250 degrees, is

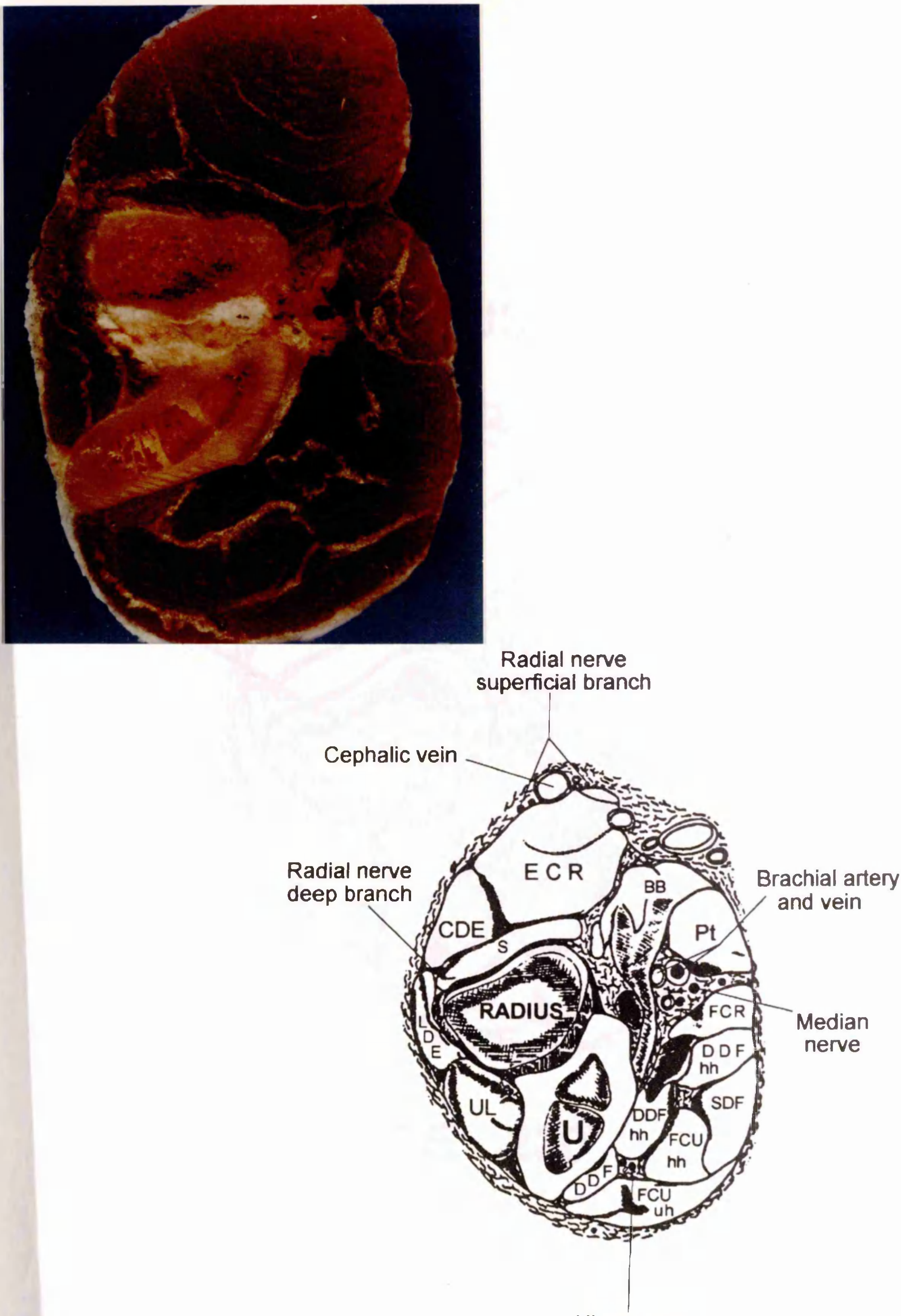


Fig. 9: Cross section of left canine antebrachium at level 1, proximal view. Schematic drawing of the relevant cross sectional anatomy. **BB**: biceps brachialis; **CDE**: common digital extensor; **DDF**: deep digital flexor, **hh** humeral head; **ECR**: extensor carpi radialis; **FCR**: flexor carpi radialis; **FCU**: flexor carpi ulnaris, **hh**: humeral head, **uh** ulnar head; **LDE**; lateral digital extensor; **Pt**: pronator teres; **S**: supinator; **SDF**; superficial digital flexor; **UL**; ulnaris lateralis

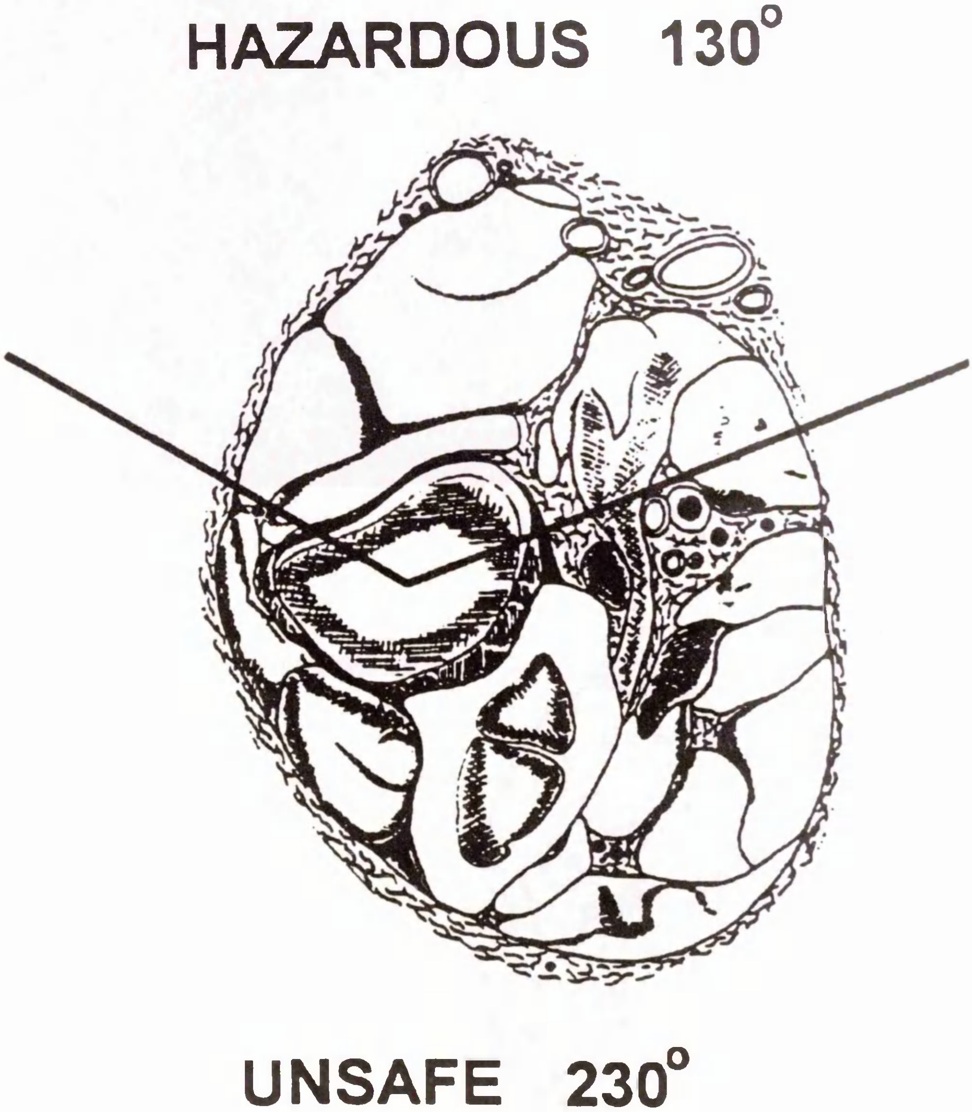


Fig. 10: Safe, hazardous and unsafe sectors in the canine antebrachium, level 1.

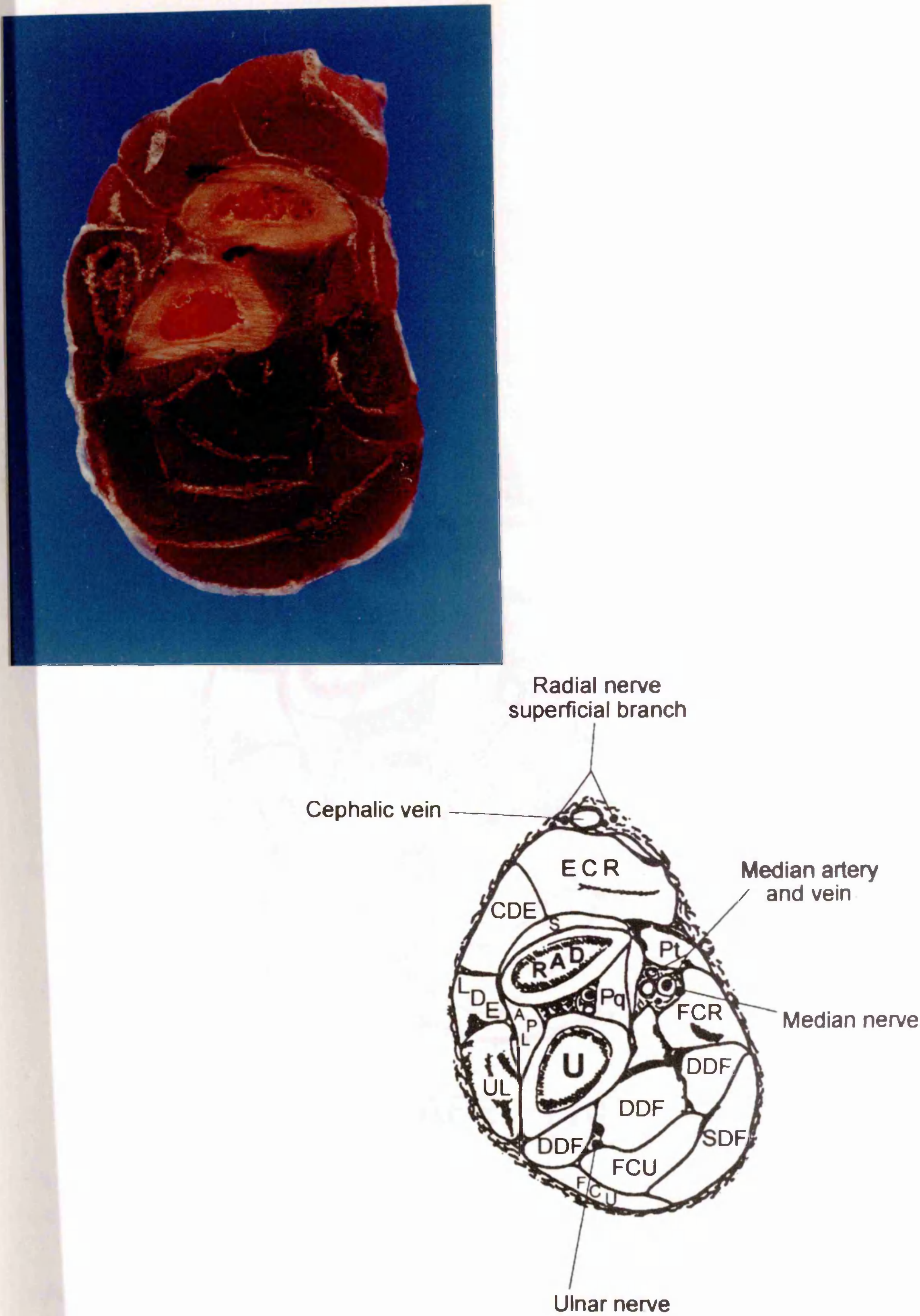


Fig. 11: Cross section of left canine antebrachium at level 2, proximal view. Schematic drawing of the relevant cross sectional anatomy. **RAD:** RADIUS; **U:** ULNA; **APL:** abductor pollicis longus; **CDE**: common digital extensor; **DDF**: deep digital flexor; **ECR**: extensor carpi radialis; **FCR**: flexor carpi radialis; **FCU**: flexor carpi ulnaris; **LDE**; lateral digital extensor; **Pq**: pronator quadratus; **Pt**: pronator teres; S: supinator; **SDF**; superficial digital flexor; **UL**; ulnaris lateralis

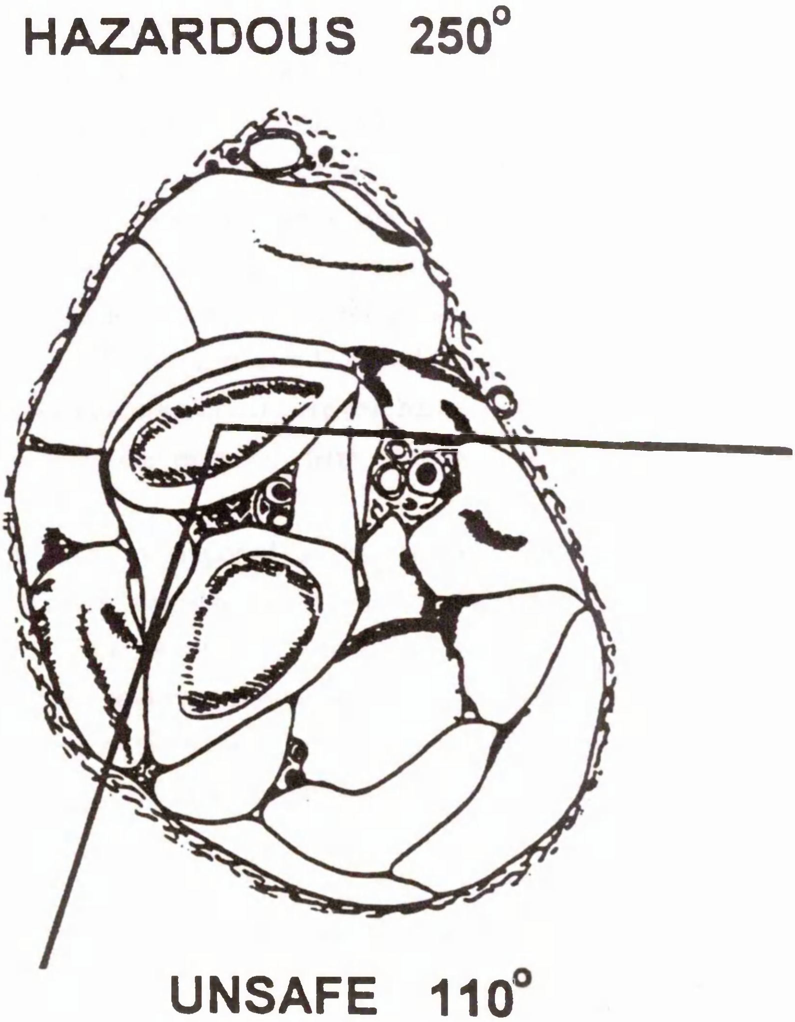


Fig. 12: Safe, hazardous and unsafe sectors in the canine antebrachium, level 2.

considerably increased over the lateral aspect of the forearm since this section is distal to the deep branch of the radial nerve. A clear safe area starts to appear on the medial radial border at LEVEL 3 **(Fig. 13)**, distal to the insertion of pronator teres muscle, bounded by the extensor carpi radialis muscle craniolaterally and the radial head of the deep digital flexor caudomedially. At this point, it comprises a sector of 35 degrees and is complemented by a hazardous corridor of 195 degrees **(Fig. 14)**. The radial artery and vein start to move cranially towards the medial border of the radius and mark the beginning of the unsafe corridor. At LEVEL 4 **(Fig. 15, 16)**, the extent of the safe sector is increased to 60 degrees as the extensor carpi radialis muscle tapers into its tendon. The complementing hazardous corridor occupies 170 degrees of the limb circumference. On this section, the radial artery and vein lie next to the caudomedial border of the radial diaphysis so the medial safe corridor is directly replaced by the unsafe corridor. The safe area is further increased to 75 degrees at LEVEL 5 **(Fig.17, 18)** and the hazardous sector is reduced to 155 degrees. At LEVEL 6 **(Fig. 19, 20)**, the safe corridor is reduced to 25 degrees by the presence of the abductor pollicis longus tendon, crossing obliquely the medial radial border in its distal extremity. Another 45 degrees safe sector can be considered between hazardous areas on the cranial aspect of the radius, bounded by the extensor carpi radialis tendon and the common digital extensor tendon.

The canine ulna, as opposed to its human counterpart, was regarded as a concentric bone. Its only palpable points are the olecranon, the proximal fourth of its caudal border and its distal extremity, the lateral styloid process. The body of the ulna is surrounded by the flexor and extensor musculature of carpus and digits. The ulna is not a major weight-bearing bone in the dog and, consequently, the attention of veterinary orthopaedic surgeons is focused in the radius when treating combined fractures of radius and ulna.

CANINE MANUS

The osseous component of the canine manus is formed by the bones of the carpus, metacarpal bones, phalanges and associated sesamoid bones. Only the metacarpal area will be studied.

The metacarpal bones, five in number in the dog, are irregular rods of relatively uniform diameter composed of a thick-walled, cilindrical midsection known as the body and two enlarged extremities to form the base, proximally and the head, distally. The base of the metacarpal bones articulates with the distal row of carpal bones in the carpometacarpal joint and the head provides the metacarpal articulating surface for the metacarpophalangeal joint. The first metacarpal bone in the dog is considerably shorter than the others. Metacarpals II and V are four-sided in cross section and are shorter than III an IV, which present a more triangular shape proximally. They articulate

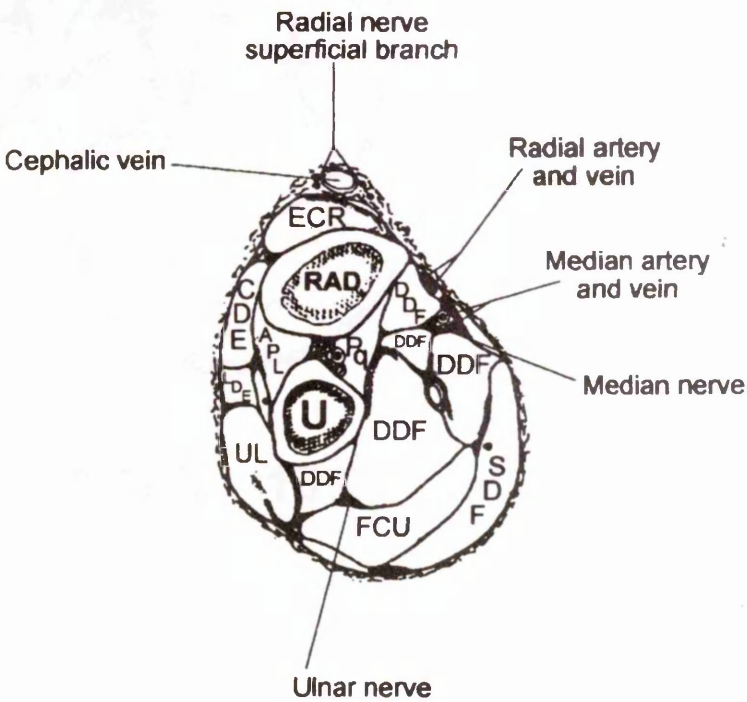


Fig. 13: Cross section of left canine antebrachium at level 3, proximal view. Schematic drawing of the relevant cross sectional anatomy. **RAD:** RADIUS; **U:** ULNA; **APL:** abductor pollicis longus; **CDE**: common digital extensor; **DDF**: deep digital flexor; **ECR**: extensor carpi radialis; **FCU**: flexor carpi ulnaris; **LDE**; lateral digital extensor; **Pq**: pronator quadratus; **S**: supinator; **SDF**; superficial digital flexor; **UL**; ulnaris lateralis

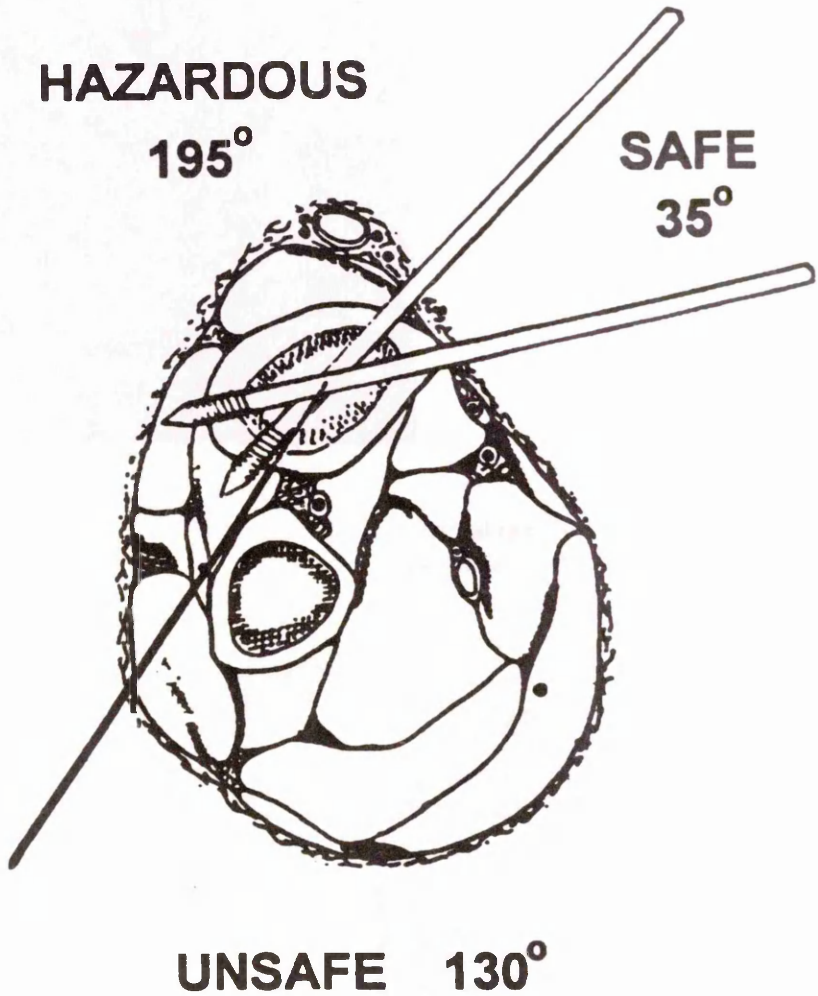
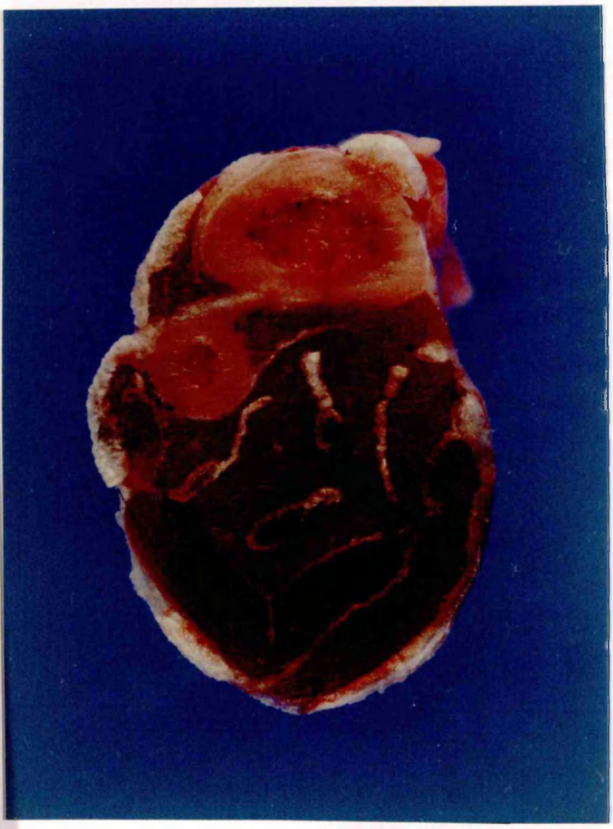


Fig. 14: Safe, hazardous and unsafe sectors in the canine antebrachium, level 3.



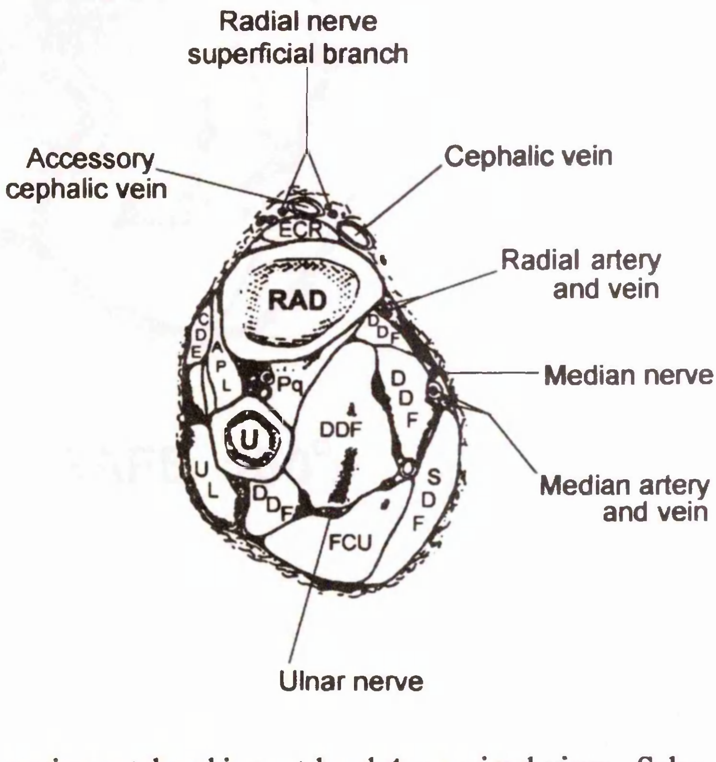


Fig. 15: Cross section of left canine antebrachium at level 4, proximal view. Schematic drawing of the relevant cross sectional anatomy. **RAD:** RADIUS; **U:** ULNA; **APL:** abductor pollicis longus; **CDE**: common digital extensor; **DDF**: deep digital flexor; **ECR**: extensor carpi radialis; **FCU**: flexor carpi ulnaris; **Pq**: pronator quadratus; **SDF**; superficial digital flexor; **UL**; ulnaris lateralis

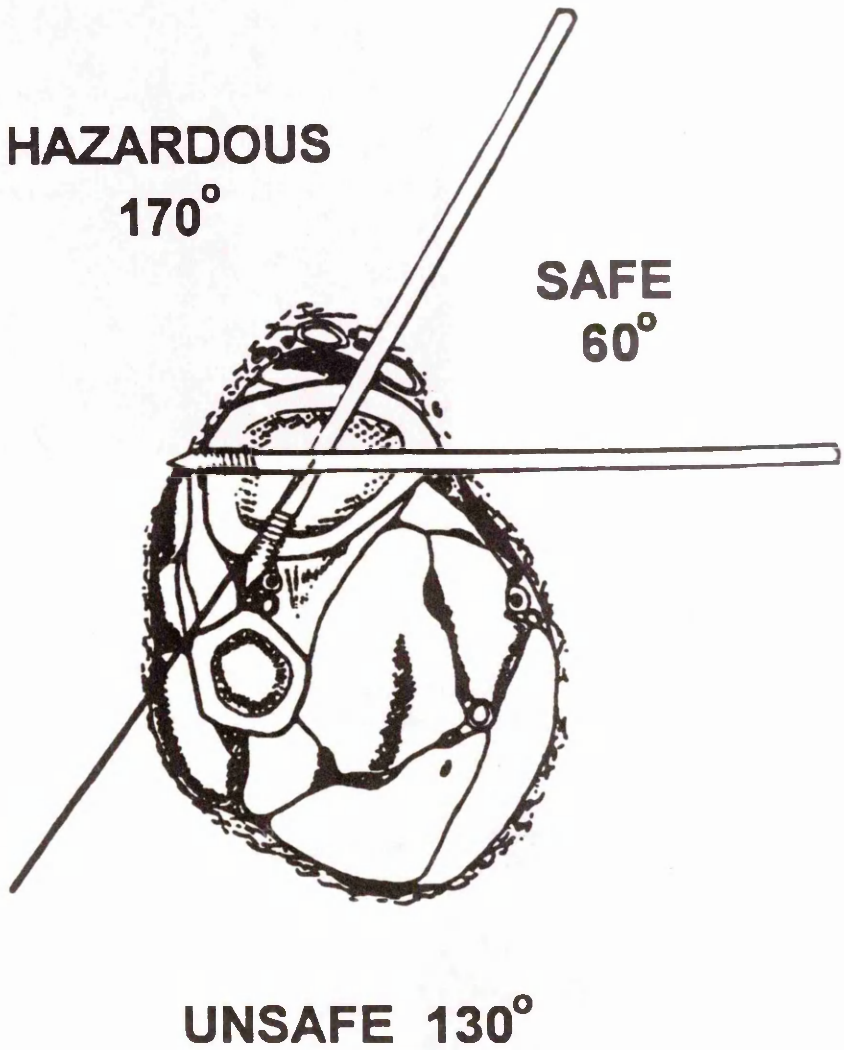


Fig. 16: Safe, hazardous and unsafe sectors in the canine antebrachium, level 4.

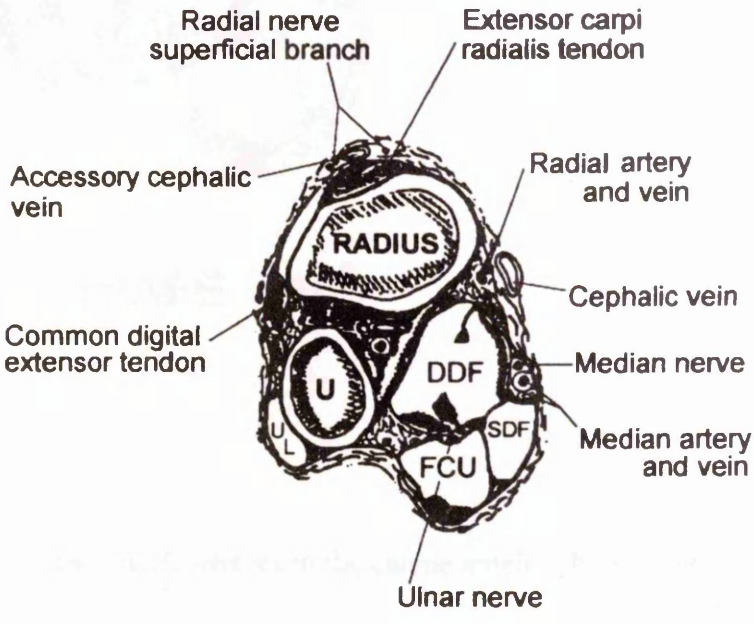


Fig. 17: Cross section of left canine antebrachium at level 5, proximal view. Schematic drawing of the relevant cross sectional anatomy. **U:** ULNA; **DDF**: deep digital flexor; **FCU**: flexor carpi ulnaris; **SDF**; superficial digital flexor; **UL**; ulnaris lateralis

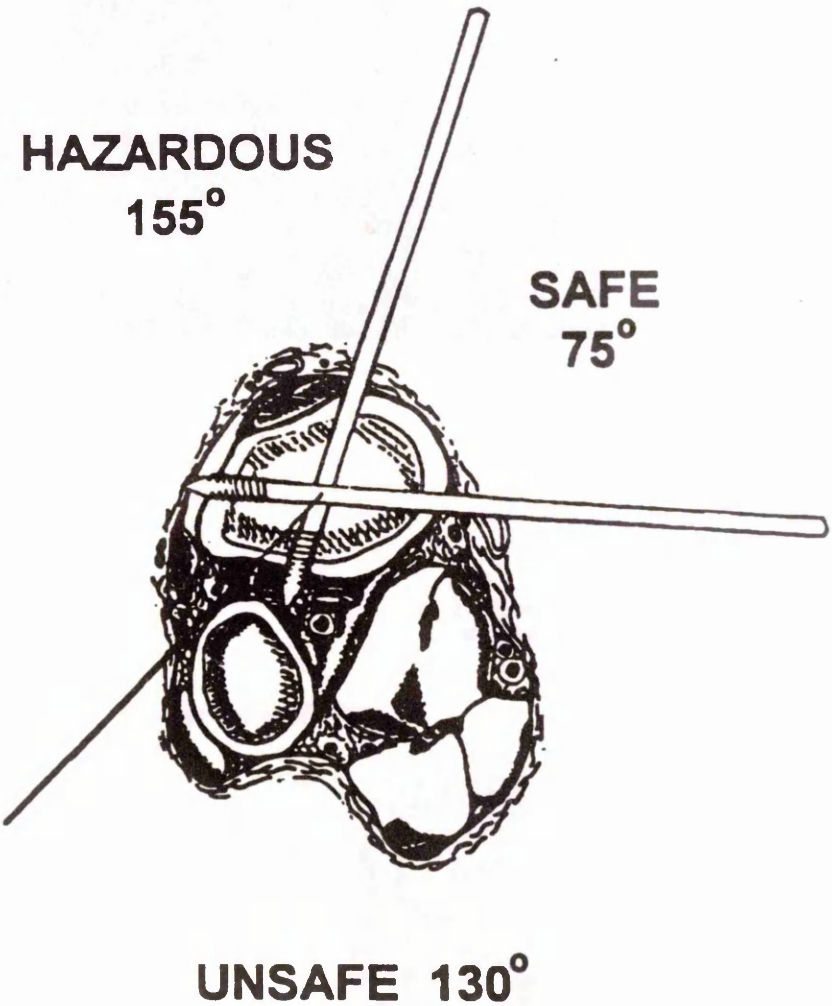
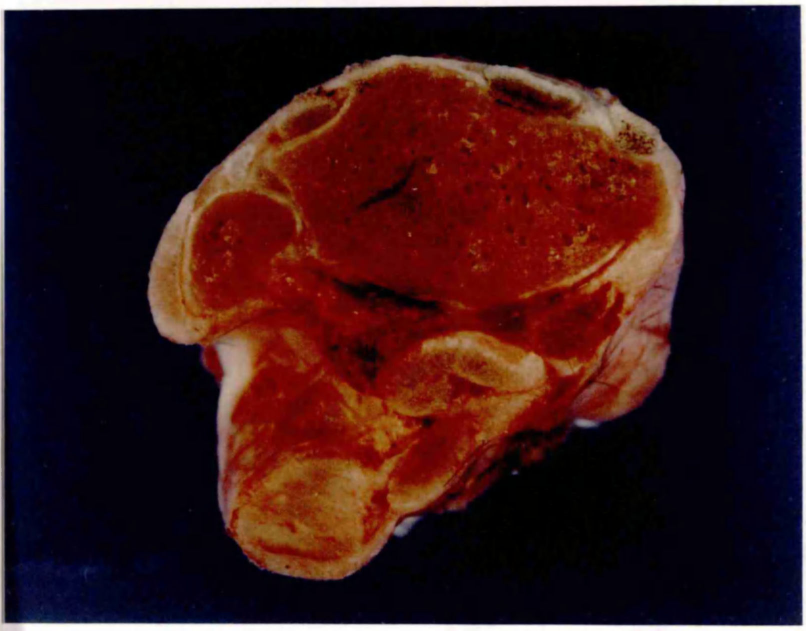


Fig. 18: Safe, hazardous and unsafe sectors in the canine antebrachium, level 5.



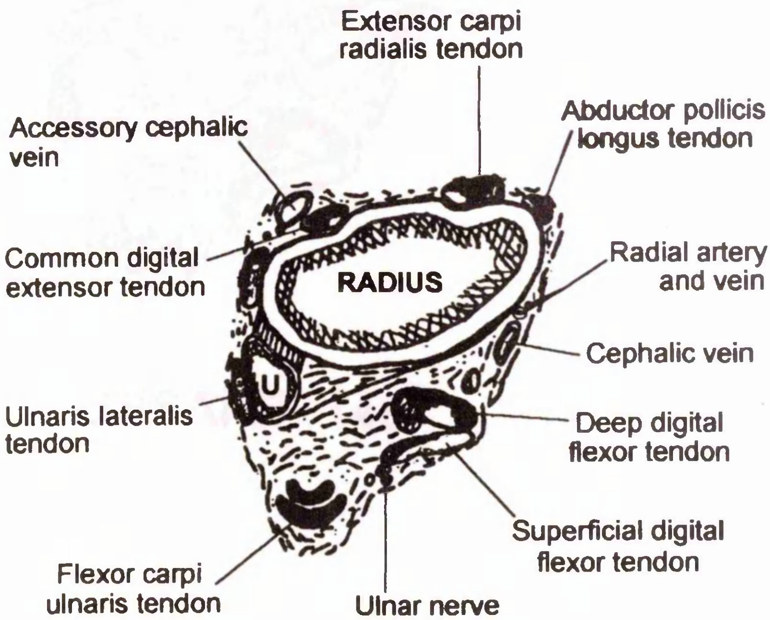


Fig. 19: Cross section of left canine antebrachium at level 6, proximal view. Schematic drawing of the relevant cross sectional anatomy. U: ULNA.

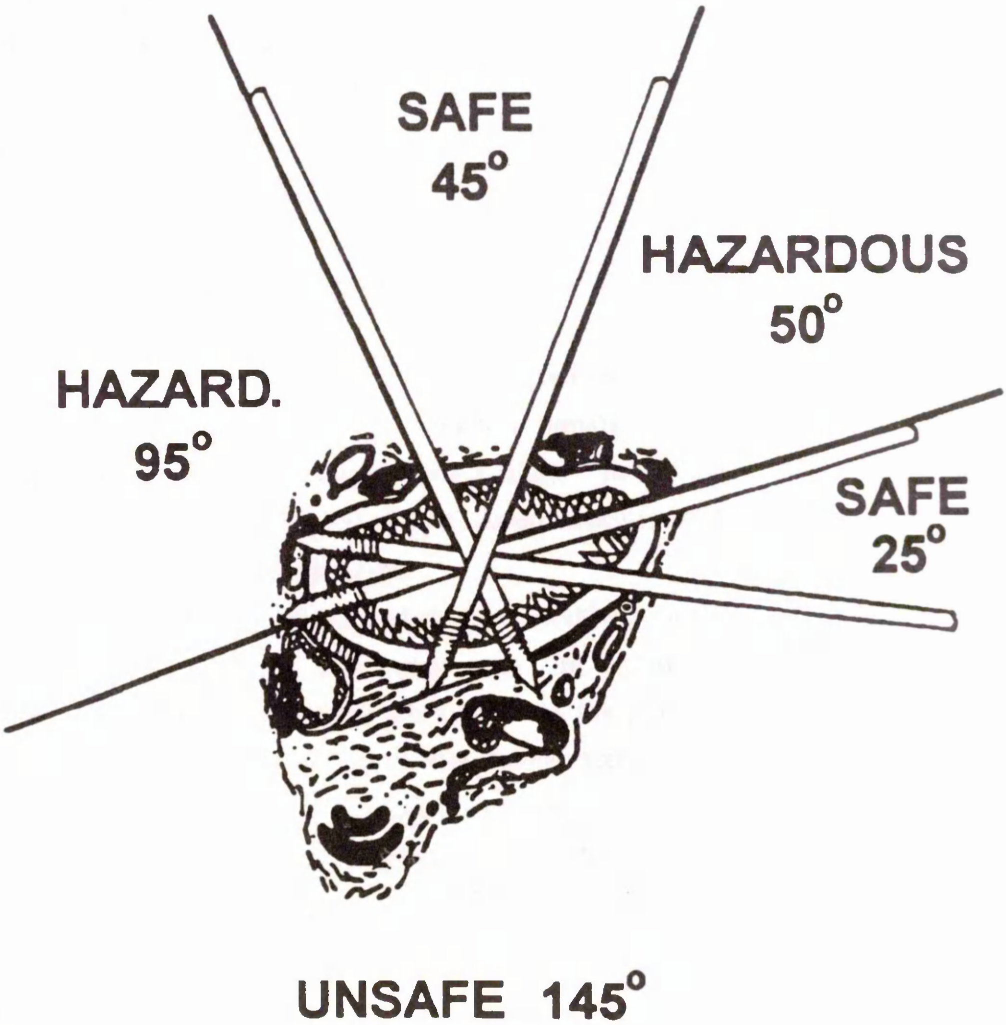


Fig. 20: Safe, hazardous and unsafe sectors in the canine antebrachium, level 6.

intimately in the proximal end of the metacarpus, forming the intermetacarpal joints. Distal to this, transverse ligamentous bands, the interosseous metacarpal ligaments, join the metacarpal bones together for variable distances. In this area, the metacarpal bones loose their axial alignment and are arranged in a curve of dorsal convexity, where the central metacarpals lie in a more dorsal position in relation to the others.

The dorsal aspect of the metacarpal bones provides insertion to and is partially covered by the tendons of the extensor muscles of the antebrachium and digits. The base of the I metacarpal bone serves as insertion point for the abductor pollicis longus muscle. The extensor carpi radialis muscle inserts with two tendons on the proximal end of metacarpals II and III, while the lateral aspect of the base of the V metacarpal provides insertion to the ulnaris lateralis muscle. The tendons of the extensor pollicis longus et indicis proprius, common digital extensor muscle and lateral digital extensor muscle occupy the dorsal aspect of the metacarpal area as they glide down to their insertions in the distal phalanx. Considerable variation exists in the distribution of these tendons in the dog.

The palmar aspect of the manus is covered by the fleshy interossei muscles and special muscles of digits I and V, which originate from the proximal end of the metacarpal bones and palmar carpal fibrocartilage. Immediately palmar to them lie the tendons of the superficial digital flexor, interflexorius, lumbricales, flexor digitorum brevis and deep digital flexor muscles.

Branches of the superficial radial nerve, cranial superficial antebrachial artery and accessory cephalic vein are distributed over the dorsum of the forepaw. All the important neurovascular structures are located on the palmar aspect of the manus. The palmar branch of the ulnar nerve, on the medial aspect of the accessory carpal bone, crosses the space between the two accesoriometacarpal ligaments and arches medially to penetrate the interosseous muscle group. The median nerve, bifurcating into the medial and lateral branches, is accompanied by the median artery and vein across the carpus.

CANINE FEMORAL REGION

The canine femur is completely surrounded by musculature and, therefore, is considered as a concentric bone. No safe corridors are present and only hazardous corridors and points could be identified.

The major trochanter of the femur is an important landmark for pin insertion. It is not directly subcutaneous since it is covered by the thin, flat tendon of insertion of the superficial gluteal muscle and partially by the cranial border of the biceps femoris muscle. Despite these anatomical features, pins inserted into or immediately distal to it should cause minimal interference with soft tissues and this point is regarded as hazardous. Distal angulation is necessary so that the pin penetrates the thick medial femoral cortex at the level of the lesser trochanter and achieves good purchase. Pins inserted in the correct position should avoid the trochanteric fossa, to maximise bone purchase. Depending in the size of the bone and pin, it is occasionally possible to insert two pins in this location.

The entire length of the femur is covered laterally by the biceps femoris muscle or its aponeurotic insertion, the fascia lata. In a deeper plane, the vastus lateralis component of the quadriceps femoris muscle covers the lateral aspect of the femur almost completely, although it only takes origin in the femur on its proximal fifth and can be mobilised cranially to expose the femoral diaphysis for pin insertion.

In the distal femur, the lateral aspect of the lateral femoral condyle is only covered by the fascia lata as the biceps femoris muscle thins and the vastus lateralis muscle tapers cranially towards the patella. This area, which has an intra-articular component, is readily palpable subcutaneously and it is often used for external skeletal fixator pin placement. Proximal angulation of this pin is necessary to avoid penetrating the proximal part of the intercondyloid fossa and damage to the origin of the cruciate ligaments. Due to the intra or peri-articular location of this implant, interference with normal movement of synovial soft tissues is unavoidable and abnormal adhesions and periarticular fibrosis ensues, often limiting normal range of movement.

Pin placement on the medial aspect of the femur is strictly limited to the distal end of the bone due to the presence of important musculotendinous units, vital vascular structures and interference with the body wall. Only a small triangular area on the medial aspect of the medial femoral condyle is palpable under the skin. This area is bounded caudally by the caudal head of the sartorius muscle, which overlies the medial fabella, and by the cranial head and vastus medialis muscle dorsally and cranially. It is only covered by the medial femoral fascia. A small branch of the descending genicular artery and vein, accompanied by an articular branch of the saphenous nerve can be found crossing this region towards the stifle joint. The origin of the medial collateral ligament of the stifle joint in the medial femoral epicondyle is also identifiable. The synovial membrane of the stifle joint extends caudally to insert on the medial femoral condyle approximately at midpoint of the extent of this bony surface. Therefore, placement of a transfixation pin in the canine femur is only possible at this point. The abovementioned neurovascular structures were not considered important.

CANINE CRUS

In humans, the entire medial aspect and most of the cranial aspect of the tibia are completely subcutaneous (Williams and others 1980) and, although they are not completely devoid of anatomical features, they represent safe corridors for external skeletal fixator pin insertion.

In the dog, the flat tendon of the caudal head of the sartorius muscle is very short and the distal end of the muscle overlies the caudomedial corner of the proximal tibia. The aponeurotic insertion of the gracilis muscle and semitendinous muscle on the medial aspect of the proximal tibia are much longer and not mobile over the bone. By definition, the presence of the sartorius muscle determines the location of a hazardous area on the caudomedial corner of the proximal tibia **(Fig. 21)**. In man, the tendons of insertion of these muscles on the medial tibial condyle are flat and aponeurotic and no muscle tissue is present over the bony surface of the tibia (McMinn and others 1988). Hence, this area is regarded as safe for pin insertion. Distally, the tendon of the tibialis caudalis muscle passes caudal to the medial malleolus and determines the caudal extent of the safe corridor on the medial aspect of the distal tibia, both in man and in the dog.

The neurovascular bundle present on the medial aspect of the canine tibia (cranial branch of saphenous artery, cranial branch of saphenous vein and saphenous nerve), which crosses the tibial diaphysis obliquely on its middle third, was not considered important. It can be avoided by direct visualisation through the skin or if minimal blunt dissection is used to reach the bone before pin insertion.

The lateral aspect of the canine crus does not offer any point for safe pin insertion, since it is completely covered by the flexor muscles of the hock joint and extensor muscles of the digits **(Fig. 22)**. In humans, a safe corridor exists in the lateral aspect of the proximal tibia, which makes this area suitable for transfixation, allowing the use of bilateral configurations. Several anatomical features differentiate the proximal canine tibia from the human tibia:

-The proximal end of the canine tibia, above the level of the proximal tibiofibular joint is much smaller than in humans.

-The cranial tibial muscle originates much more proximally in the convex lateral aspect of the proximal tibia than in man.

-The lateral tibial condyle is divided by the extensor groove, occupied by the tendon of the long digital extensor muscle, which originates in the extensor fossa of the lateral femoral epicondyle. In man, this muscle takes its origin on the medial aspect of

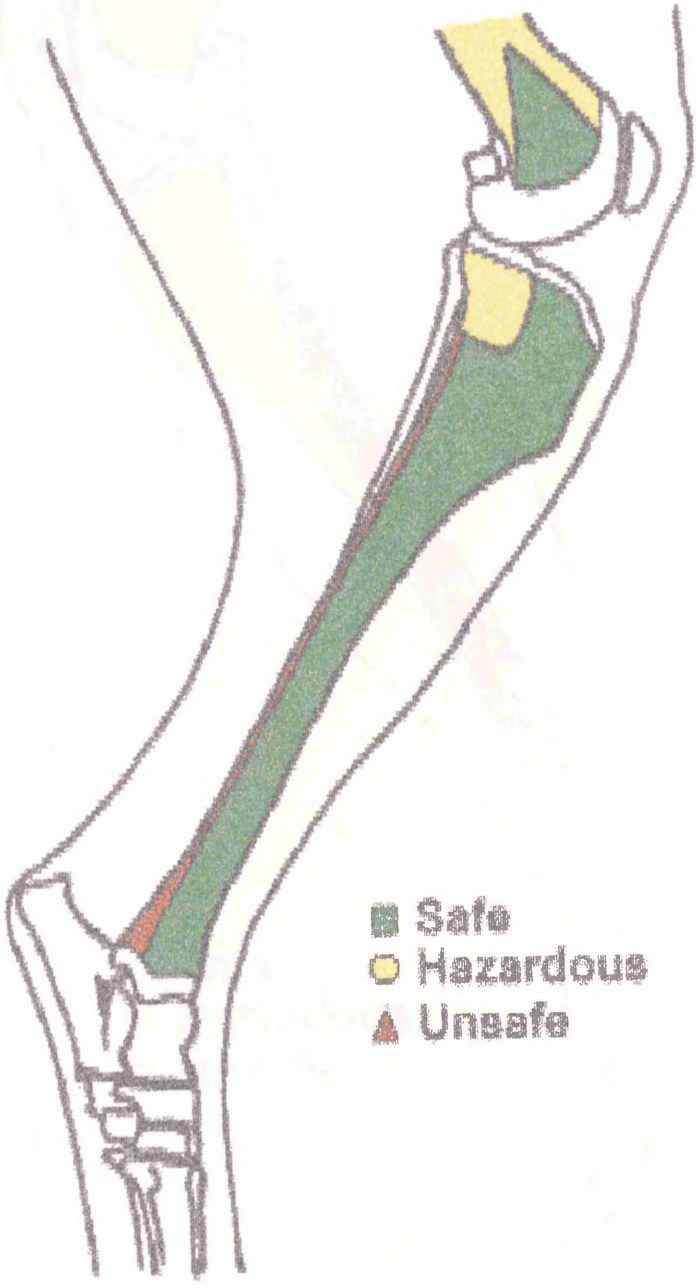


Fig. 21: Safe, hazardous and unsafe corridors on the medial aspect of the canine crus.

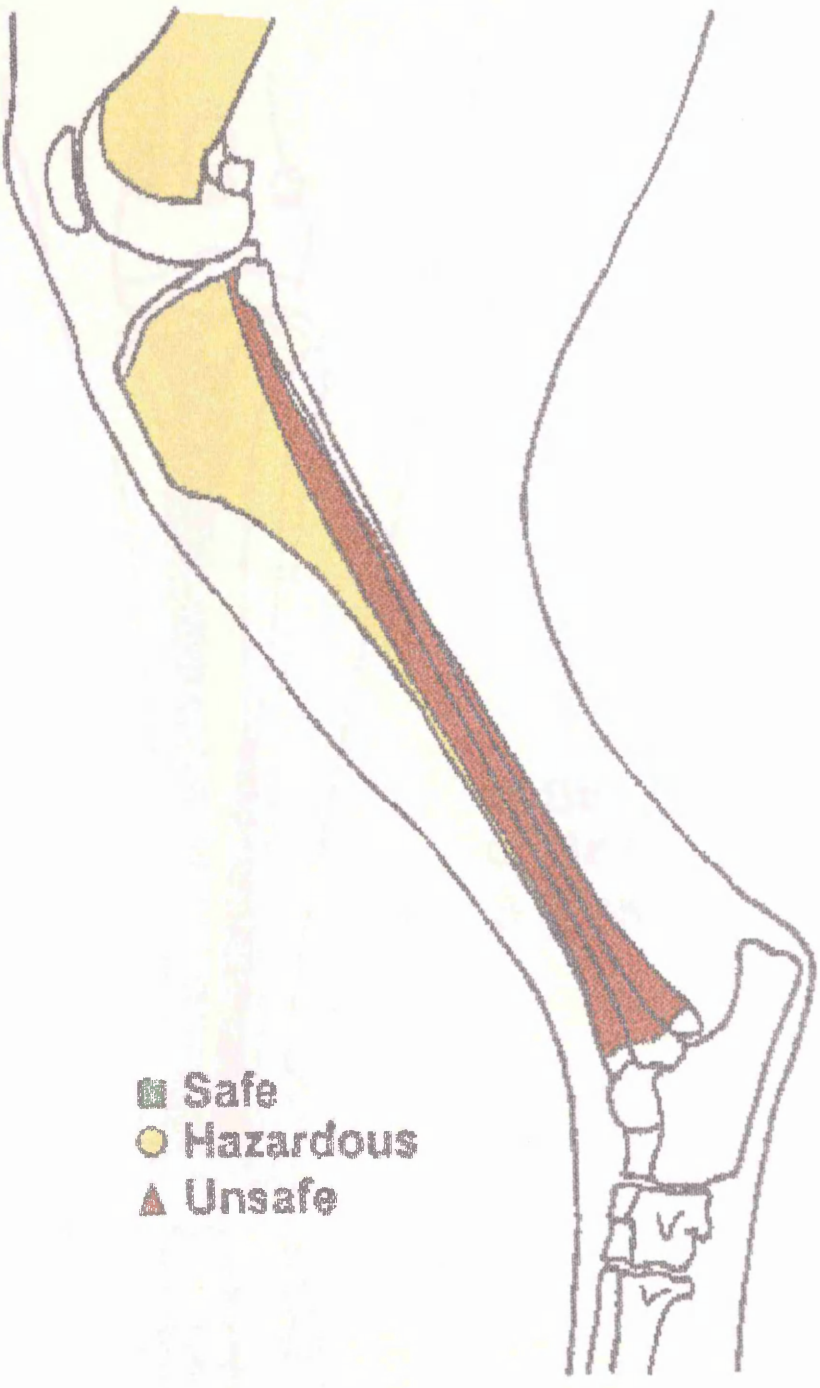


Fig. 22: Safe, hazardous and unsafe corridors on the lateral aspect of the canine crus.

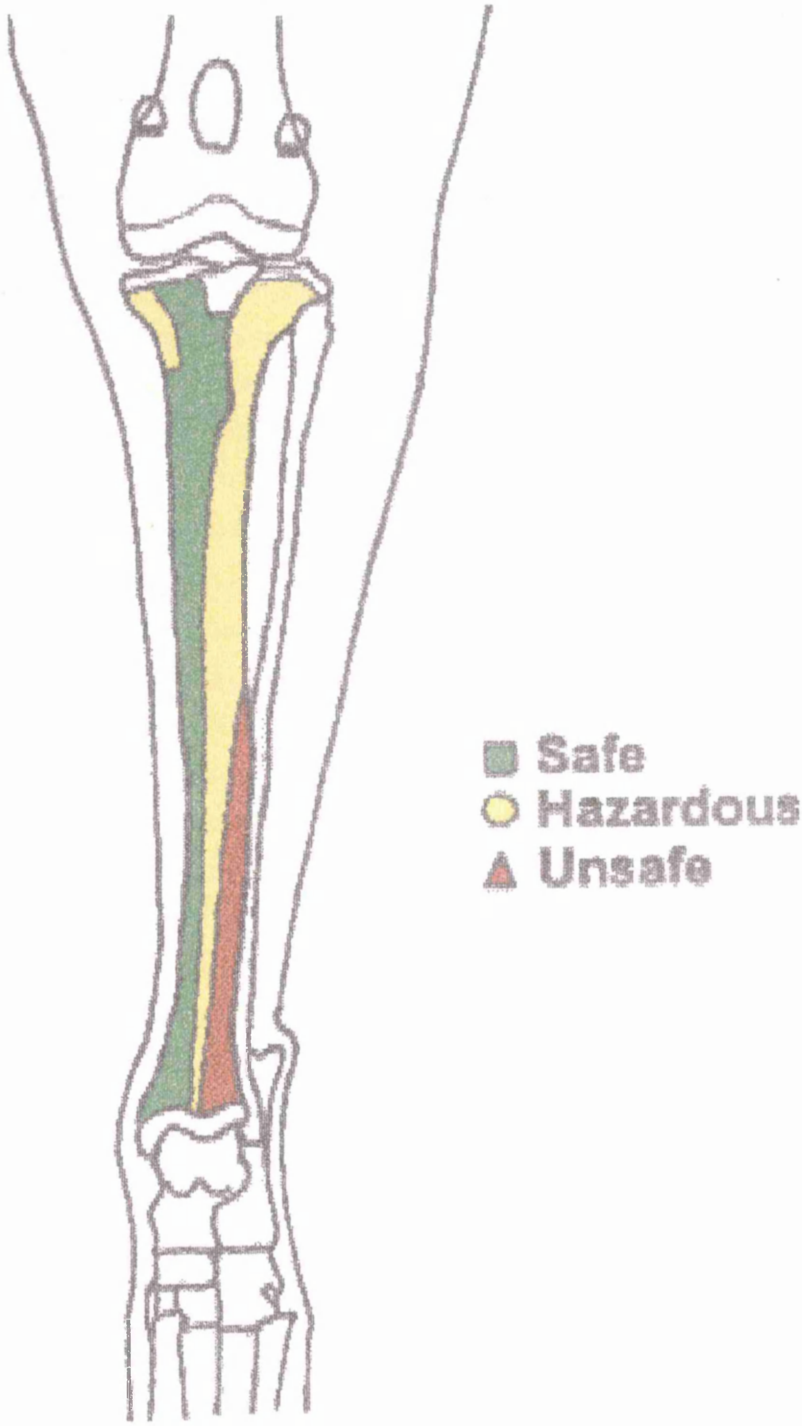


Fig. 23: Safe, hazardous and unsafe corridors on the cranial aspect of the canine crus.

the fibula, interosseus membrane and a small area above the cranial tibial muscle (Williams and others 1980).

The cranial aspect of the canine tibia is almost completely subcutaneous **(Fig. 23)**. Its most proximal portion is occupied by the insertion of the patellar ligament in the tibial tubercle and cannot be considered as a safe point. The cranial border of the cranial tibial muscle, more developed than in man, crosses the tibial sagittal midline towards the medial aspect immediately distal to the margo cranialis and its tendon lies on the midline in the distal tibia, medial to the tendon of the long digital extensor muscle. Both tendons are held in place by the extensor retinaculum.

Angle measurements in cross sections of the canine crus show that, at LEVEL 1 **(Fig. 24, 25, 26)**, pin placement is safe within an arc of 75 degrees, from the cranial limit of the insertion of the caudal head of the sartorius muscle, across the sagittal midline, to the cranial border if the cranial tibial muscle. Hazardous sectors are found on the caudomedial corner of the tibia where the caudal head of the sartorius overlies the bone and on the lateral aspect of the tibia. The unsafe corridor, which occupies the rest of the circumference, includes important neurovascular structures such as the common peroneal nerve, tibial nerve and popliteal vessels.

At LEVEL 2 **(Fig. 27, 28)**, the safe corridor is larger since the entire medial tibial surface is now subcutaneous and comprises a sector of 130 degrees. The cranial tibial vessels, main branches of the popliteal vessels, are located next to the caudolateral border of the tibia and determine the end of the hazardous corridor and the beginning of the unsafe corridor.

The tibial safe corridor shows its lowest extent in the diaphysis at LEVEL 3 **(Fig. 29, 30)**, 105 degrees, as the midpoint of the cranial tibial muscle belly invades the sagittal tibial midline towards the medial side. It is complemented with a hazardous corridor of 110 degrees. The extent of the hazardous corridor starts to diminish at this point due to the presence of the cranial tibial artery and vein on the lateral aspect of the section, gradually approximating the sagittal midline of the tibia. At LEVEL 4 **(Fig. 31, 32)**, the tendon of the tibialis caudalis muscle starts to determine the caudal limit of the medial safe area. The safe angle is slightly increased to 110 degrees as the cranial tibial muscle tapers down distally. The hazardous corridor is further reduced to 80 degrees. The safe angle is mantained at LEVEL 5 **(Fig. 33, 34)** and reduced to 105 degrees at LEVEL 6 **(Fig. 35, 36)**, and the hazardous corridor is gradually reduced to 30 degrees and 25 degrees, respectively.

The hazardous corridor in the canine crus is, consequently, located on its craniolateral aspect and has a triangular shape. On each cross-section, it extends from the medial limit of the tibialis cranialis muscle across the craniolateral aspect of the tibia, the cranial tibial vessels being its caudal limit. These vascular structures take an oblique course from the proximal posterolateral tibial border to a more dorsal location in the distal tibia, so gradually reducing the extent of this hazardous corridor. The hazardous

Fig. 24: Cross section of right canine crus at level 1, proximal view.

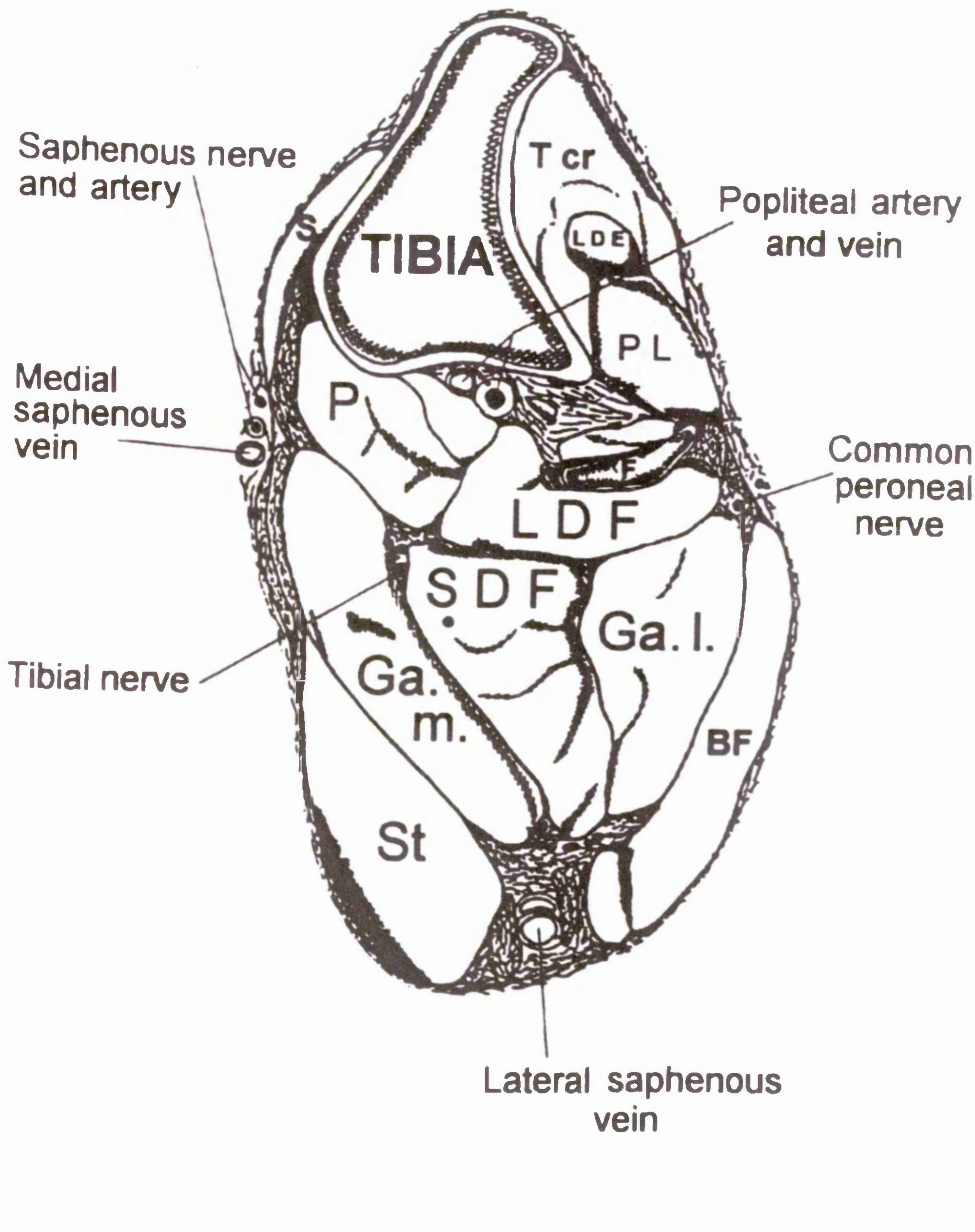


Fig. 25: Schematic drawing of the relevant cross sectional anatomy, level 1. **F**; FIBULA; **BF**: biceps femoris; **Ga. l.**: gastrocnemius lateral head; **Ga. m.**: gastrocnemius medial head; **LDE**: long digital extensor; **LDF**: lateral digital flexor (deep digital flexor); **P**: popliteus; **Pl**: peroneus longus; **S**: sartorius, caudal head; **SDF**: superficial digital flexor; **St**: semitendinosus; **Tcr**: tibialis cranialis

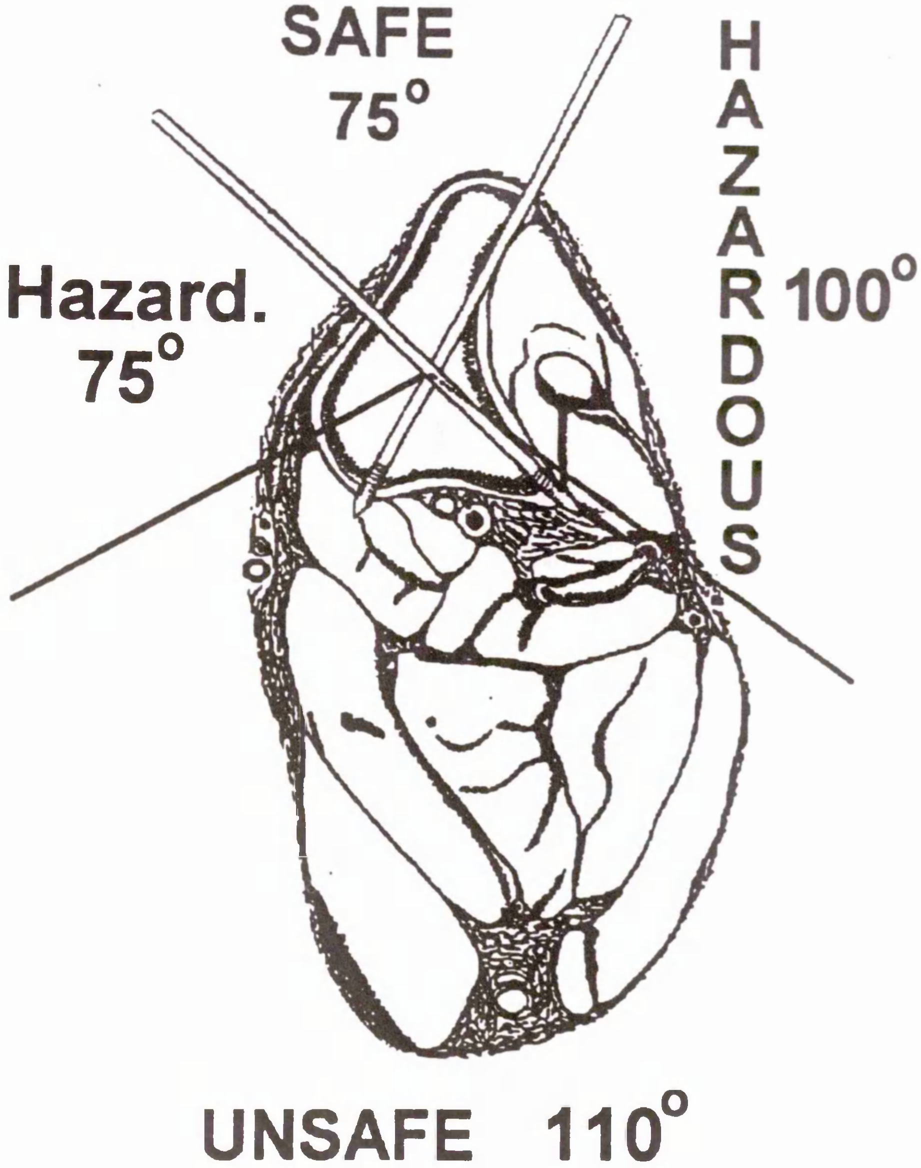


Fig. 26: Safe, hazardous and unsafe sectors in the canine crus, level 1.

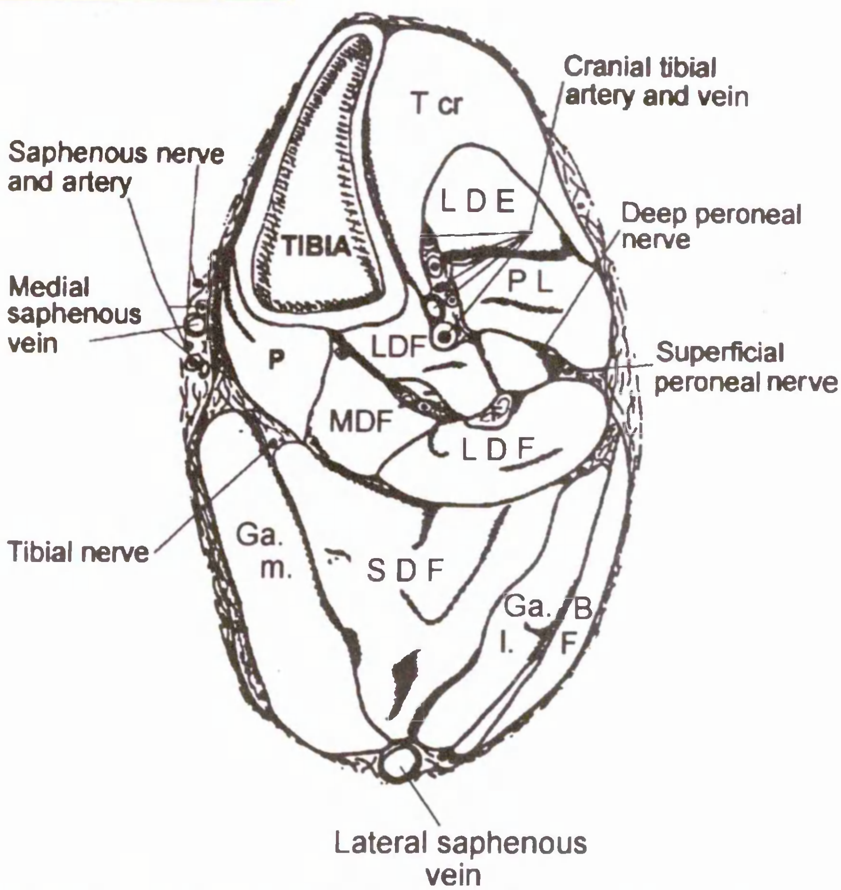


Fig. 27: Cross section of right canine crus at level 2, proximal view. Schematic drawing of the relevant cross sectional anatomy. **F**; FIBULA; **BF**: biceps femoris; **Ga. l.**: gastrocnemius lateral head; **Ga. m.**: gastrocnemius medial head; **LDE**: long digital extensor; **LDF**: lateral digital flexor (deep digital flexor); **MDF**: medial digital flexor (deep digital flexor); **P**: popliteus; **Pl**: peroneus longus; **SDF**: superficial digital flexor; **St**: semitendinosus; **Tcr**: tibialis cranialis

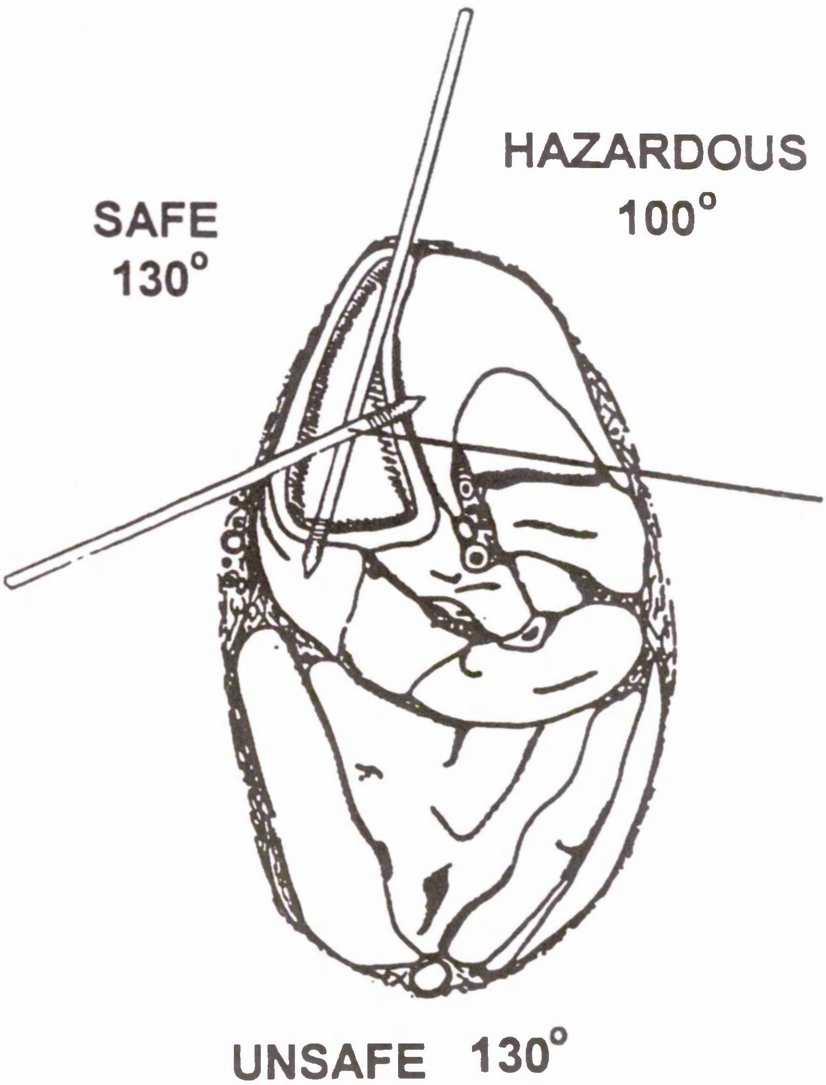


Fig. 28: Safe, hazardous and unsafe sectors in the canine crus, level 2.

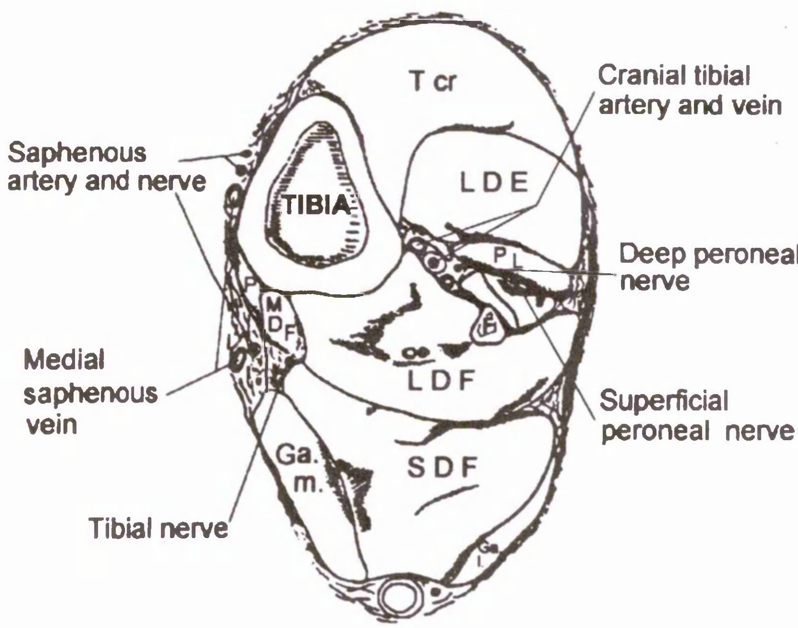


Fig. 29: Cross section of right canine crus at level 3, proximal view. Schematic drawing of the relevant cross sectional anatomy. **F**; FIBULA; **Ga. l.**: gastrocnemius lateral head; **Ga. m.**: gastrocnemius medial head; **LDE**: long digital extensor; **LDF**: lateral digital flexor (deep digital flexor); **MDF**: medial digital flexor (deep digital flexor); **P**: popliteus; **Pl**: peroneus longus; **SDF**: superficial digital flexor; **Tcr**: tibialis cranialis.

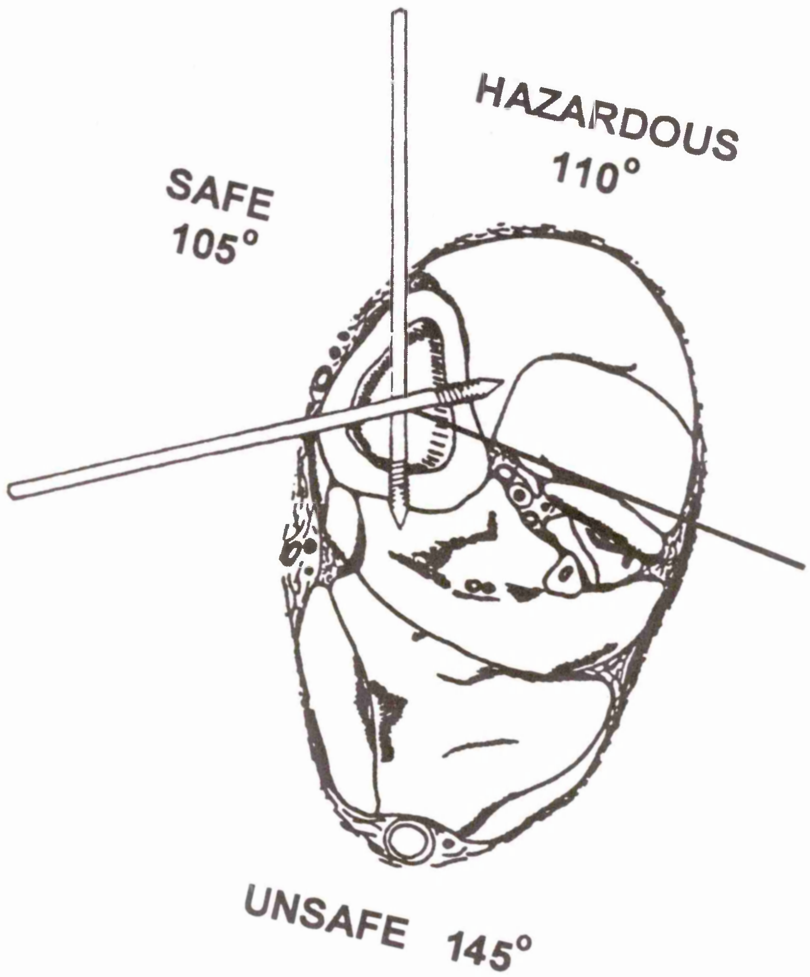


Fig. 30: Safe, hazardous and unsafe sectors in the canine crus, level 3.

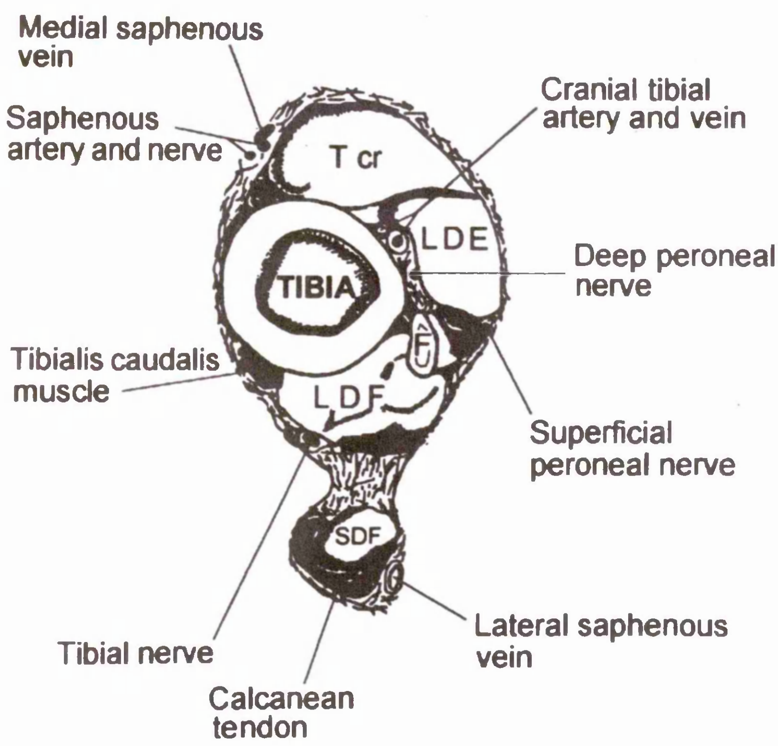


Fig. 31: Cross section of right canine crus at level 4, proximal view. Schematic drawing of the relevant cross sectional anatomy. **F**; FIBULA; **LDE**: long digital extensor; **LDF**: lateral digital flexor (deep digital flexor); **SDF**: superficial digital flexor; **Tcr**: tibialis cranialis.

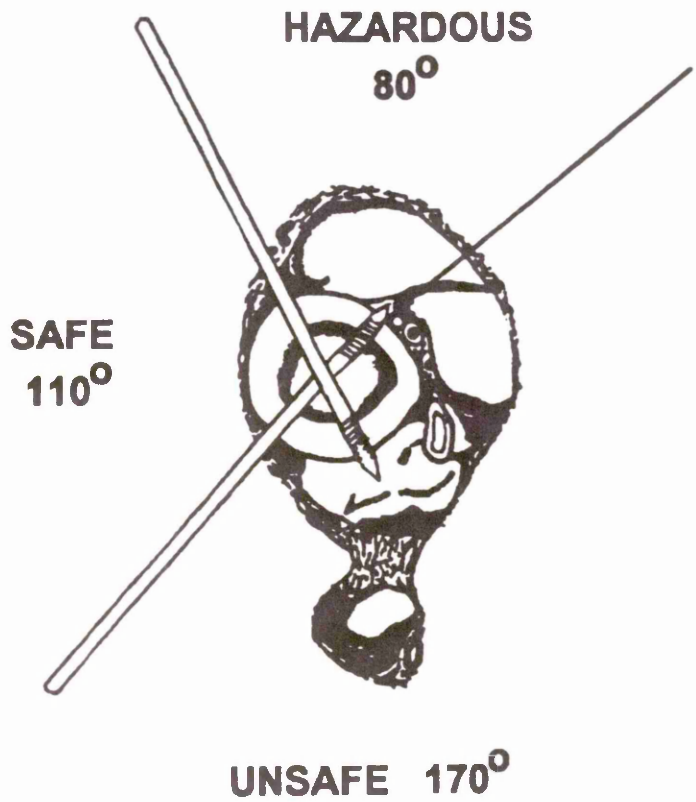


Fig. 32: Safe, hazardous and unsafe sectors in the canine crus, level 4.

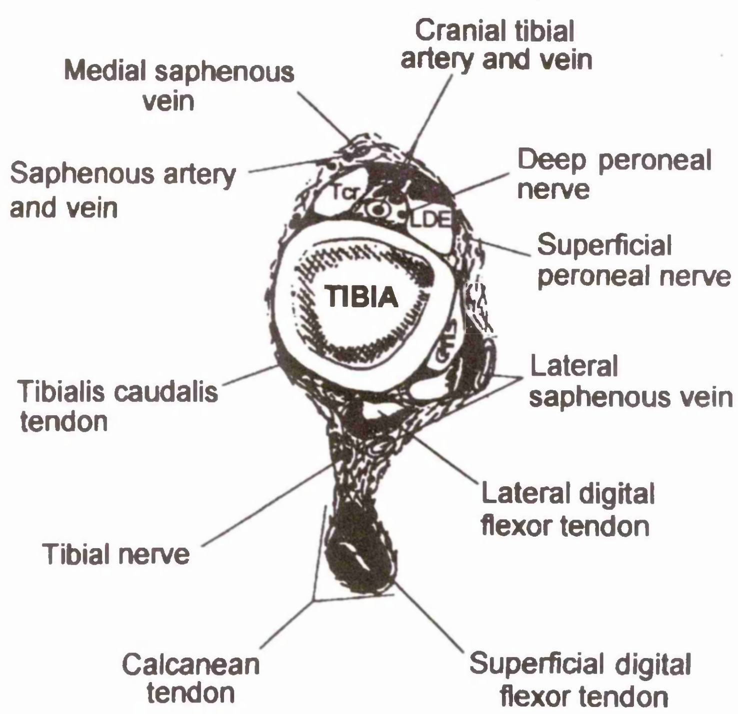


Fig. 33: Cross section of right canine crus at level 5, proximal view. Schematic drawing of the relevant cross sectional anatomy. **F**; FIBULA; **LDE**: long digital extensor; **Tcr**: tibialis cranialis.

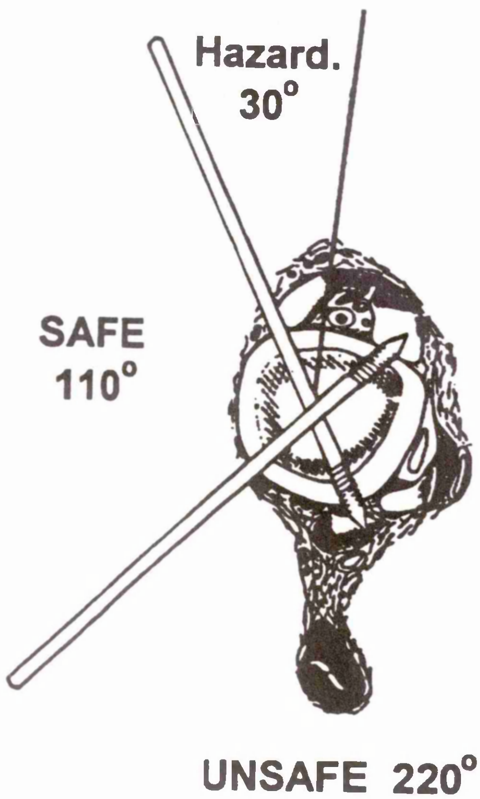
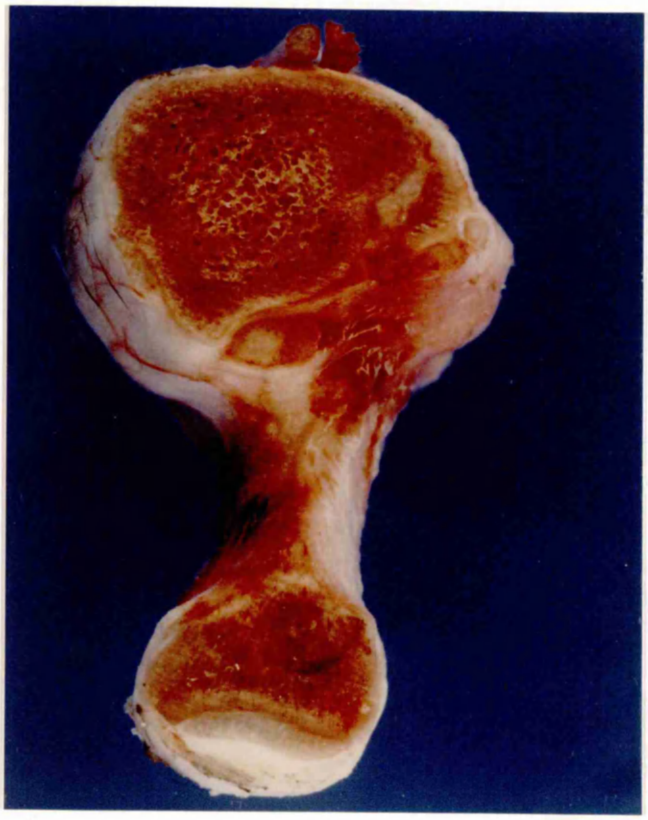


Fig. 34: Safe, hazardous and unsafe sectors in the canine crus, level 5.



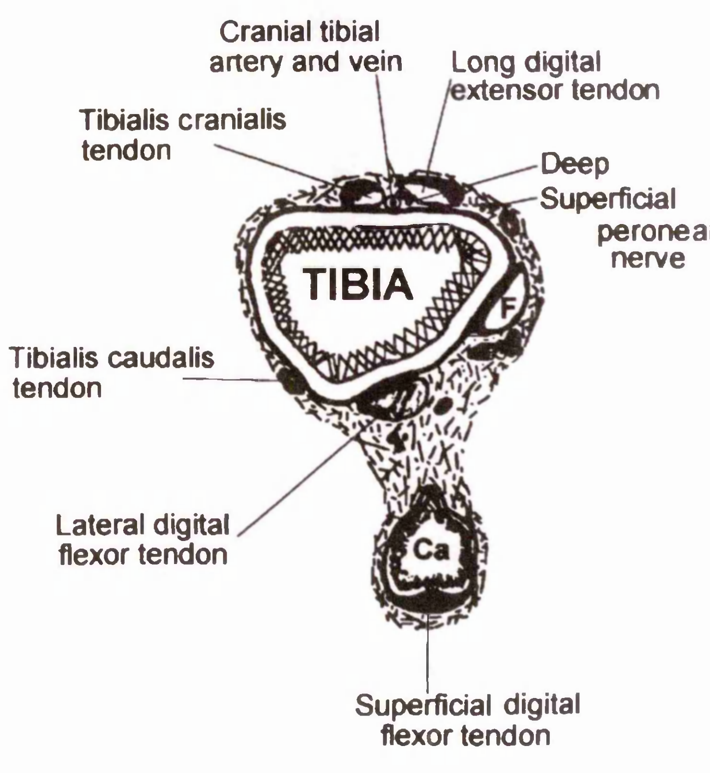


Fig. 35: Cross section of right canine crus at level 6, proximal view. Schematic drawing of the relevant cross sectional anatomy. **Ca**: CALCANEUS; **F**: FIBULA.

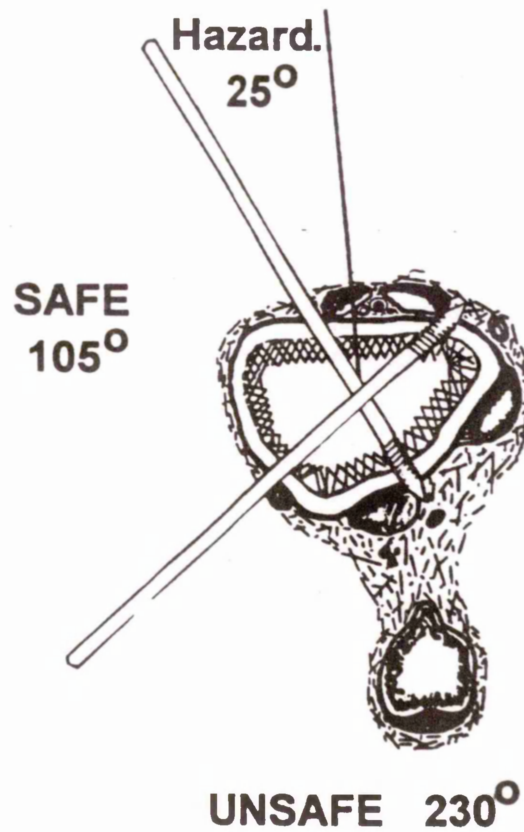


Fig. 36: Safe, hazardous and unsafe sectors in the canine crus, level 6.

angle is progressively reduced to a minimum of 25 degrees as the measurements are made in more distal sections. The rest of the circumference of the crus represents an unsafe corridor for pin insertion due to the presence of the cranial tibial vessels, peroneal and tibial nerve and important musculotendinous units. Studying the cross section specimens, it becomes clear that transfixation of the canine tibia through safe areas is not possible at any point, as opposed to the human tibia where transfixation is feasible in the proximal tibia, as mentioned before.

The fibula is considered as a concentric bone, but due to its small size and its lack of weightbearing function, it has no veterinary orthopaedic interest whatsoever.

CANINE PES

The canine pes, or hindpaw, comprises the tarsus, metatarsus, phalanges and associated sesamoid bones. Only the metatarsal region will be considered in this study.

Although the structure of the bony support in this area resembles the one in the metacarpal region, several significant differences are noticeable. Metatarsal I is much reduced in size and sometimes fused to the first tarsal bone. The general shape of the metatarsals resembles the corresponding metacarpal bones, but they are longer. They are compressed transversely so that, in the cross section of their bases, the dorsoplantar diameter is much greater than the transverse diameter. The intermetatarsal joints have, therefore, a greater surface than in the manusand the intermetatarsal spaces are smaller. Their bases articulate with the distal row of tarsal bones in the tarsometatarsal joint and their distal extremity, the head, joins the base of the proximal phalanx and the paired sesamoid bones in the metatarsophalangeal joint.

The tendon of the tibialis cranialis muscle attaches on the medial side of the base of metatarsal II. The lateral aspect of the base of the V metatarsal provides insertion to the peroneus brevis muscle and the insignificant, partially tendinous abductor digiti quinti muscle. The dorsal aspect of the metatarsal area is partially covered by the tendons of long digital extensor, short digital extensor and lateral digital extensor muscles. The plantar aspect, as in the metacarpal area, is intimately covered by the interossei muscles and special muscles of digits II and V.

The dorsal pedal artery, continuation of the cranial tibial artery and main blood supply to the hindpaw, can be identified on the dorsal aspect of the hock, medial to the tendon of the long digital extensor muscle. One of its branches, the arcuate artery runs transversely to the lateral side at the proximal end of the metatarsus, covered by the extensor tendons. The dorsal pedal artery becomes the perforating metatarsal artery when it passes from the dorsal to the plantar surface of the pes, by passing between the proximal ends of the second and third metatarsal bones. The rest of the arterial distribution in the canine pes is similar to that of the manus.

The dorsal aspect of the metatarsal area is covered by the dorsal metatarsal arteries (ramifications of cranial branch of saphenous artery), dorsal metatarsal nerves and dorsal common digital nerves, from the deep and superficial peroneal nerves, respectively. The tibial nerve provides the innervation to the plantar aspect.

DISCUSSION

Complications arising from the mishandling of the soft tissue envelope have been recognised increasingly in recent years. These will often determine the success or failure of the fixation and further surgery is sometimes needed for their correction. Several extensive atlases showing the relevant anatomy of the human extremities and its application to safe external skeletal fixator pin insertion have been published (Green 1981), with particular attention to the clinical application of circular configurations in which tranfixation pins and wires are used. The importance of a thorough knowledge of the regional limb anatomy is emphasized throughout the human literature and adherence to the rules of sound anatomical pin insertion is strongly advocated.

The study of the cross sectional limb anatomy and the introduction, definition, location and measurement of safe, hazardous and unsafe corridors for the different limb segments show the interest of human orthopaedic surgeons in avoiding these complications. Due to the slower rate of bone healing compared to the canine, human fixators need to be kept in place for much longer periods. Therefore, soft tissue complications must be kept to a minimum to increase the useful life of the frame and to avoid the need to switch to internal fixation. In concentric limb segments, devoid of safe corridors, hazardous corridors are the safest regions for pin insertions (Behrens 1989). In unsafe corridors, open insertion of the pin is essential to avoid pin-induced nerve and vessel damage.

Damage to neurovascular structures has been reported in numerous occasions although they tend to be pushed aside rather than being transfixed by percutaneous pins (Green 1983). Some researchers found that "it was almost impossible to pierce a major vessel with pins" (Dwyer 1973). Vessel wall erosion can occur as a late complication of a pin lying against an artery, leading to profuse haemorrhage several weeks after the surgery (Green 1981, Seligson and others 1979) or even after pin removal (Green 1983). Paresthesia, progressive numbness and partial loss of sensation are the common signs of pin related nerve damage (Green 1981).

Profuse or uncontrollable bleeding immediately after pin insertion necessitating pin removal and temporary cancellation of surgery has been reported associated with pins placed in the proximal aspect of the canine tibia (Johnson and others 1989) and radius (Harari 1992). Persistent bleeding from erosions of the brachial artery adjacent to proximal medial pins in the radius in two dogs have been described (Freeman and others, cited by Egger 1991) and from the cranial tibial artery associated with pins aplied to the proximal aspect of the lateral tibia (Egger 1991). Blood transfusion, pin removal and ligation of the artery were necessary. A potential complication of the severance of the brachial artery, a compartmental syndrome, has been described in a dog (Olivieri and others 1978).

Impalement of neuromuscular units leads to muscle adhesions and joint stiffness, muscle pain, predisposition to pin tract sepsis, poor extremity use and increased patient discomfort (Green 1983, Aron 1989, Behrens 1989). Limb use after external fixation of a long bone fracture depends on the amount of muscle transfixation by fixation pins necessary at that location (Egger 1989). Quadriceps contracture has been reported as a complication of a cranially applied fixator in a canine femur (Egger and others 1985). Ankle and foot stiffness have been reported as the most frequent complaint following repair of tibial fractures in humans using bilateral frames (Emerson and others 1983).

To the author's knowledge, no specific information concerning nerve damage associated with pin insertion in veterinary patients has been published. Paresthesia and loss of sensation would be extremely difficult to recognise in animals (Egger 1991). Also, joint stiffness or muscle discomfort might not be immediately apparent in animals and, therefore, might not have been recognised in the past or might have been accepted as minor, unavoidable complications.

It has been hypothesized that the clinical success of safe and effective use of external skeletal fixation depends upon three principles: the avoidance of damage to vital anatomical structures, the provision of access to injured area for other procedures and the need to meet the mechanical demands of the specific patient and injury (Behrens 1986). Although insertion of all pins within a safe corridor clearly limits the orthopaedic surgeon to the use of unilateral frames, it does prevent neurovascular lesions, damage to muscles and musculotendinous units and problems of soft tissue irritation around the pin. An external fixator frame should not damage any vital anatomical structures and this can be achieved by proper knowledge of the regional anatomy and by limiting pin insertion to areas with minimal soft tissue coverage. In two series of human tibial fractures repaired with external fixators, pin-tract problems were virtually eliminated with proper care of the soft tissues (Behrens 1986, DeBastiani 1984). In safe corridors, pin-tract infections and pin loosening are reduced by 50% (Burny 1984).

The use of bilateral frames to repair human tibial fractures has been associated with a high incidence of complications. Malunion ocurred in up to 39% of cases (Kimmel 1982); refracture in up to 21% of cases (Tolo 1983) and pin tract infection was observed in 30% (Edwards and others 1979) to 50% (Kimmel 1982, Tolo 1983). Damage to anterior tibial vessels or peroneal and saphenous nerves have also been reported (Green 1981, Kimmel 1982). Permanent ankle and foot stiffness was found to be the most frequent complaint after repair of tibial fractures immobilised with bilateral frames (Emerson and others 1983). It is likely that these and less serious complications, such as joint stiffness and impaired muscle function due to muscle and tendon impalement associated with pin transfixation occur with much higher frequency in veterinary orthopaedics than we believe. The idea that thin transfixation wires used with ring fixators are inocuous and excluded from the laws of limb anatomy is both unfounded and dangerous (Behrens 1989).

CANINE BRACHIUM

External skeletal fixation can be used occasionally as a primary or solitary method of fixation of humeral fractures, particularly in comminuted, open fractures with severe soft tissue disruption in which the use of large implants might be contraindicated (Matthiesen 1992). Most commonly, fixators are placed in the humerus as auxiliary fixation, in combination with intramedullary pin systems or to augment an insufficient plating where an adequate minimal number of screws could not be inserted. Treatment of humeral fractures with external fixation alone or in combination with an intramedullary pin system is technically easier and considerably less expensive than plating. On the other hand, some humeral fractures, particularly those affecting the elbow joint, are best treated with bone plate fixation (Brinker and others 1990b).

As in the canine femur, the use of external skeletal fixator in the canine upper forelimb is limited by the regional anatomy, since the proximity of the body wall does not allow the application of complex, more stable arrangements. For relatively simple fractures, a four to six pin unilateral arrangement applied craniolaterally is commonly used. In severely comminuted fractures, with loss of bone structure and lack of cortical continuity, a solid understanding of new methods is necessary to thoughtfully augment a routine unilateral assembly (Aron 1989). In severe fractures of the femur and humerus, a switch to internal fixation after 6 to 12 weeks of rigid immobilisation with a fixator has been advocated to avoid potential complications (Aron and others 1986). However, understanding and using new techniques of external skeletal fixation will reduce the need to switch fixation before fracture healing (Aron 1989).

In order to reduce the incidence of premature pin loosening and, therefore, to increase the life of the fixator, the surgeon must strive to achieve maximal pin-bone contact and bone purchase. Proper angulation of the pins is essential to guide them through the largest possible bone diameter. Pins in the proximal humeral safe area are, therefore, ideally inserted with a slight craniolateral to caudomedial angulation. This proximal humeral safe area and line, representing almost half of the total length of the humerus along its craniolateral aspect, allows the surgeon to insert three pins proximally in fractures affecting the mid-diaphysis.

The segment of the lateral aspect of the humerus occupied by the brachialis muscle, from the apex of the proximal safe area to the apex of the distal safe area, represents a clear unsafe corridor due to the presence of the radial nerve. The loss of skin sensation on the craniolateral aspect of the antebrachium and dorsum of the foot which would, theoretically, be associated with damage to its superficial branch might not be significant. However, the consequences of damaging its deep, motor branch are obvious and important. Damage to the cephalic vein, also present in this segment, would be of much less importance.

Precision in the angle of pin insertion must be particularly great in the distal humerus, in order to avoid damage to the articulating surfaces of the elbow joint. The most distal pin is usually inserted lateromedially across the condyle, from a point immediately distal to the lateral humeral epicondyle. Depending on the size of dog and pin, is is occasionally possible to insert two pins in this distal humeral safe area, the second most distal pin being inserted obliquely, with a slight mediodistal angulation. Great care has to be exercised when inserting pins in the supracondylar area, on the lateral epicondylar crest, since placement of a pin through the distal half of the olecranon fossa would interfere with the anconeal process during full extension of the elbow joint. A pin inserted at the apex of the comma-shape distal humeral safe area will have to be directed proximocranially in order to avoid this complication and to achieve maximal bone purchase. The use of pins on the proximal end of the crest will partially interfere with the lateral head of the triceps and might be dangerously close to the motor branch of the radial nerve.

Due to anatomical limitations, assemblies applied to the humerus are mostly unilateral. However, the use of more complex configurations has been described to repair severely comminuted or unstable humeral fractures. It is possible to augment a craniolateral uniplanar frame by connecting a proximal pin inserted in a lateromedial direction to the most distal transcondylar pin. Both external bars can then be linked to build a triangular arrangement or connected to an intramedullary pin as a "tie-in" configuration (Aron and others 1991). As in the femur, the most distal, transcondylar pin can be used to build up a modification of the unilateral external skeletal fixator if driven through to the medial aspect of the distal humerus. This more complex configuration has been used clinically for difficult, comminuted fractures of the supracondylar femoral and humeral area (Klause and others 1990).

Due to the absence of clear, longitudinal safe corridors in this concentric bone and the complexity of the regional anatomy in the canine brachium, it is not possible to mantain a direct axial alignment in the pins inserted in the safe areas and lines previously described. This precludes the use of a straight external connecting bar and perfect assembly of all the pins to a metallic connecting bar would require careful countouring to an awkard S-shape. Another alternative, the use of a column of methylmethacrylate as a substitute for pin clamps and connecting rods has been described (Aron 1976). This technique overcomes some of the disadvantages of the pin-clamp systems, such as cost of the clamps, lack of versatility of pin and clamp size, limitation in the direction and angle of the pins, weight of the assembly and superimposition of a metal connecting bar with the fracture site when radiographic evaluation of the fracture is necessary (Okrasinsky and others 1991). The diameter and cross sectional shape of the acrylic column will affect its strength and these can be modified to suit the mechanical needs of the specific fracture and patient. Although no extensive studies have been carried out concerning the strength of various diameter acrylic columns and how the cross section geometry affects their biomechanical properties, it has been shown that a 3/4-inch diameter tube fixation model is stronger than the medium size Kirschner aparatus (Willer and others 1991). It is well accepted now that unilateral acrylic fixators can perform as well as unilateral Kirschner fixator (Okrasinsky and others 1991). There is no information available concerning the mechanical performance of bent acrylic columns.

CANINE ANTEBRACHIUM

Examining the cross-sections of the antebrachium, it is easily noticeable that the largest diameter of the radial diaphysis lies in a 45 degrees oblique craniomedial to caudolateral plane and not in a clear transverse, mediolateral plane. Therefore, fixator pins must be applied along that plane if maximum bone purchase and pin to bone contact is to be achieved. Pins inserted in a mediolateral plane would not penetrate the radius through its widest diameter.

External fixator frames have traditionally been applied to the medial aspect of the canine radius, but lateral orientation for proximal fractures and cranial orientation for small bones has been advocated (Egger 1990). Application of the external fixator frame on the cranial surface of the radius is ideal from the mechanical viewpoint. Although the distribution of strains in the diaphysis of the radius during gait is complex, tensile longitudinal stresses were found at their maximum on its cranial, convex surface (Carter and others 1980). This is identified as the tension side of the bone and metal implants applied closer to this surface will be in a mechanically advantageous position (Nunamaker 1985c). However, due to the small craniocaudal diameter of the radius, pin purchase in the bone would be limited.

Pin spread over the entire length of the radius when applying unilateral uniplanar fixators to its medial aspect is not possible without inserting pins in a hazardous or unsafe corridor. Due to the presence of an important neurovascular bundle crossing over the medial aspect of the radial neck, pin application on the proximal third of the radius can give rise to complications and open pin placement is strongly recommended if pins are to be inserted in this area. The oblique tendon of the abductor pollicis longus in the styloid process of the radius, determines the presence of a hazardous point at the medial aspect of the distal radial extremity.

The use of unilateral biplanar frames for fractures of radius and ulna has been reported (Egger and others 1985). According to the findings of this anatomical study, safe application of a fixator frame on the cranial aspect of the radius is not feasible. The muscle belly of the extensor carpi radialis muscle covers this surface almost entirely in the proximal half of the radius. The cranial surface of the distal radius is occupied by the tendon of the abovementioned muscle, the abductor pollicis longus muscle crossing obliquely over it and the tendon of the common digital extensor muscle. Interference with these tendons might cause discomfort, joint stiffness and decrease use of the limb.

Hence, the use of unilateral biplanar configurations is limited in the canine radius to a very restricted arc of the circumference of the antebrachium, if the safe areas are to be respected. Safe application of two frames to almost 90 degrees to one another, as in the tibia, is not possible in the canine radius.

Bilateral frames have also been used in this area, particularly in clinical situations where there is considerable loss of soft tissue and bone. Their ability to tolerate higher axial compressive loads will prevent fracture collapse (Egger 1983). Full pins will interfere with hazardous corridors on the lateral aspect of the antebrachium. As in the canine tibia, transfixation of the canine radius cannot be carried out through safe corridors at any point.

CANINE MANUS

Mediolateral placement of external skeletal fixator pins through the metacarpal bones is routinely carried out for transarticular stabilisation of the carpal joints in small animals. These pins are connected to the rest of the fixator pins in the radius by means of a straight or angled connecting bar.

Insertion of the pins in a dorsopalmar direction is never attempted since they would only penetrate one metacarpal bone and very limited bone purchase would be achieved. The regional anatomy is very favourable to the surgeon since all the important structures are located in the dorsal and palmar aspects and a clear safe corridor is present for mediolateral or lateromedial insertion of the pins. Due to the particular arched arrangement of the metacarpal bones, penetration of all their cortices is only feasible at their bases and less ideal fixation is achieved with pins inserted more distally. The only limiting factor for the insertion of percutaneous pins in the manus is the diameter of the metacarpal bones. A certain size of pin might be acceptable for insertion in the radius but prove too large for the metacarpal bones and could lead to their iatrogenic fracture, particularly in small dogs and cats. A suitable size of pin, however, might be too small for the size of clamp.

The use of acrylic connecting bars overcomes these difficulties by offering more versatility in the size, angle and direction of the pins (Okrasinsky and others 1991). Alternatively, the use of a fixator boot for transarticular fixation has been advocated to avoid drilling into the metacarpal bones of small dogs and cats (Gallagher and others 1990).

CANINE FEMORAL REGION

Although external skeletal fixation can be used in the canine upper hindlimb when no other option is available, i.e. severely comminuted distal femoral fractures, open or infected fractures, this technique is rarely used as a means of primary repair of femoral fractures. The presence of large muscle masses and the proximity of the body wall limit pin application and preclude the use of more complex, rigid configurations, often necessary to provide enough stability to counteract the considerable stresses to which the bone is subjected during the healing process. The surgeon is limited to unilateral configurations with pins applied in hazardous, distal insertion sites (Whitehair and others 1992). Safe corridors do not exist in concentric bones like the canine femur. Hazardous corridors or points are, hence, the safest areas for pin insertion. Some interference with the surrounding soft tissues is expected and the likelihood of soft tissue problems increases, shortening the life of the fixator and increasing patient morbidity (Behrens 1989).

External fixators are, however, most commonly used in the femur as auxiliary fixation to intramedullary pin systems, particularly when rotational instability is a concern during the early stages of the healing process (Carmichael 1991). The combined use of these two techniques has a symbiotic nature, since the intramedullary pin helps the fixator to resist bending and the fixator helps the pin against shear, torsion and compression (Aron and others 1991).

No region of the femur accepts percutaneous pin fixation innocuously. Transfixion of muscle groups has predictable consequences with partial loss of function (Alonso and others 1989). Pin application is, in any case, limited to hazardous corridors along the lateral aspect of the femur and a small area on the medial aspect of the distal femur. Cranial insertion of pins is not feasible because of the presence of the quadriceps muscle mass. Pins crossing this muscle interfere markedly with knee function and are used mainly in knee arthrodesis (Alonso and others 1989). Quadriceps contracture as a result of its impalement has been reported as a very likely complication in cranially applied frames (Egger and others 1985). Lateral pin placement implies certain interference with partially overlapping muscle masses and penetration of the fascia lata. It is mechanically advantageous from the mechanical viewpoint since the implants are on the tension side of the bone (Nunamaker 1985c).

The sciatic nerve, the main peripheral nerve of the hindlimb, runs caudal to the femur and should be far enough from the bone to avoid damage during surgery. The important vascular structures in the hindlimb, the femoral and saphenous artery and vein are located on the medial aspect of the femoral regionand should not be a concern to the surgeon when unilateral uniplanar fixators are applied, if pins are inserted correctly. Placement of the most proximal and distal pins can be carried out through a stab incision in relatively subcutaneous, hazardous areas of the bone, like the greater trochanter and the femoral condyles. The rest of the pins in the femoral diaphysis, require open pin placement with blunt dissection until the bone is reached and protection of soft tissues when drilling.

Although the regional anatomy limits the orthopaedic surgeon to the use of relatively simple fixator configurations, more complex devices can be built to repair specially unstable fractures. A modification of the unilateral external skeletal fixator has been described for the repair of supracondylar femoral fractures (Klause and others 1990). This configuration includes a transfixing pin in the distal femur connected to the most proximal lateral pin with a curved connecting bar and can be augmented further with additional pins medially and/or laterally and an additional curved connecting bar bent over the stifle joint. The presence of this distal transfixing pin in an intra or peri-articular location will inevitably cause some irritation to the synovial soft tissues, abnormal adhesions and fibrosis, leading to some interference to normal joint movement and decreased range of motion. Although more clinical and experimental data is necessary, this modification appears to have advantages over other configurations in its use in comminuted supracondylar femoral fractures.

The tie-in configuration mentioned previously is also applicable to severely comminuted supracondylar femoral fractures (Aron and others 1991).

CANINE CRUS

The canine tibia seems to have unique characteristics which contribute to the successful application of external fixation. Tibial fractures are often open, comminuted and their fixation has an increased chance of postoperative osteomyelitis (Alexander 1982). The relative lack of soft tissue coverage, particularly on its medial aspect, provides poor protection from external trauma (Smith 1978) and increases the complication rate of cast application (Gofton 1985) but provides easy surgical access for external fixation (Nunamaker 1985b).

External fixators are generally placed on the medial aspect of the tibia, but cranial placement has been advocated based on the extrapolation from human data showing that there is significantly more weightbearing force in the craniocaudal plane than in the mediolateral plane in the tibia (Behrens 1983). Placement on the lateral aspect of the tibia has been reported (Egger and others 1986b). Although unilateral uniplanar configurations are generally used in the tibia, reports of the application of bilateral unilateral (Bradley 1980), unilateral biplanar (Egger 1985) and bilateral biplanar fixators (Foland 1991) are found in the veterinary literature.

Traditionally, unilateral frames have been used for more simple fractures because of the fear that they would not be rigid enough to hold unstable fractures. It is widely accepted now that the rigidity of a unilateral configuration can be considerably increased to suit the biomechanical demands of any fracture. Placement of the fixator on the tension side of the bone, increasing the pin spread in each main bony fragment, number of pins, diameter of the pins, number of connecting bars and decreasing the distance between the connecting bar and the bone are effective ways of increasing the structural stiffness of the frame (Behrens 1989). Several experimental and clinical studies have shown that unilateral configurations can be as stiff as bilateral ones and are, therefore, suitable for fracture fixation in small animal orthopaedics (Brinker and others 1985, Egger and others 1985, Egger and others 1986b).

This anatomical study shows that almost the entire medial aspect and part of the cranial aspect of the canine tibia represent a safe corridor for external skeletal fixator pin insertion. This allows the surgeon to achieve maximal pin spread in the application of medially placed fixators, which is mechanically advantageous (Behrens and others 1983). The cranial branch of the saphenous artery, medial saphenous vein and nerve were not considered important neurovascular structures and did not influence the characterisation of the medial aspect of the tibia.

The proximal segment of the canine tibia has a triangular cross section and, therefore, pin insertion in the proximal tibia should be carried out as caudally as possible in order to drive the pin through the widest bony diameter and achieve the best purchase. This is particularly important because the cortical thickness in the proximal tibia is much decreased (Foland and others 1991) and there is an increased incidence of premature pin loosening in the proximal segment of long bones (Gumbs and others 1988, DeCamp and others 1988, Foland and others 1991). There is also some clinical evidence of increased incidence of proximal screw loosening when bone plates and screws are used (A. Miller, personal communication). Although the ideal location of this proximal pin is on a hazardous area, the interference with the soft tissues should be minimal due to the negligible movement of the musculotendinous unit and the benefits clearly outweight the disadvantages. Transfixation in the proximal tibia is not recommended because of the increased chance of damaging the cranial tibial vessels, peroneal nerve and extensor muscles on the lateral aspect of the tibia, particularly the long digital extensor tendon. This is feasible in man for the reasons described previously.

The cranial aspect of the canine tibia does not offer a clear safe corridor to the surgeon. However, placement of unilateral biplanar configurations is possible in the canine tibia, with total adherence to the basic principles of sound anatomical and biomechanical application. Due to the presence of the patellar ligament proximally and the extensor tendons and cranial tibial vessels in the sagittal midline of the distal tibia, maximal pin spread is not possible. In cranially placed frames, the most distal pin could interfere with flexion of the tarsocrural joint, due to its distal angulation. This also prevents the surgeon from placing the cranial frame at 90 degrees to the medial frame and a more craniomedial position is indicated.

On each cross-section, the arc between the cranial medial extent of the tibialis cranialis muscle and the cranial tibial vessels was considered as a hazardous corridor. On a general view of the canine crus, this area occupies a triangle on the lateral aspect of the tibia. The position of the unsafe corridor along the canine tibia is determined by the location of the important neurovascular structures on the lateral and caudal aspects of the crus. It occupies, at any point, most of the circunference of the cross-section.

Since safe areas in the canine tibia do not occupy more than 180 degrees of its circumference at any level, transfixation is not possible at any point without entering a hazardous or unsafe corridor. If this is considered necessary, open pin insertion with direct visualisation of the area is strongly recommended.

CANINE PES

External skeletal pin insertion into the metatarsal area is commonly carried out for transarticular immobilisation of the tarsal joints in the dog and cat, usually to protect a collateral prosthetic ligament replacement of the tarsocrural joint (Aron 1987) or an Achilles tendon repair (Morshead and others 1984).

The basic anatomy of the canine pes is very similar to that of the manus and, therefore, the same considerations of the use of external skeletal fixation discussed previously are applicable here.

CONCLUSIONS

1. The canine radius and tibia are considered eccentric bones. The canine humerus and femur are regarded as concentric bones.

2. Safe corridors have been identified on the entire medial aspect of the canine tibia and distal two-thirds of the medial aspect of the radius. Safe areas and lines are located on the craniolateral aspect of the canine humerus. Only hazardous corridors and points can be identified as the safest areas in the canine femur.

3. In the canine, the application of unilateral biplanar configurations through safe areas of bone is only feasible in some segments of the lower limb, like the crus. It is not possible to apply a cranially inserted frame in the canine radius without entering a hazardous corridor and interfering with flexion of the elbow joint.

4. Unilateral fixator configuration are preferable due to the low complication rate associated with their use. When using more complex arrangements, the orthopaedic surgeon must find the balance between the benefits and the potential complications of each particular technique.

5. The craniolateral aspect of the canine humerus and the lateral aspect of the femur satisfy both the anatomical and the biomechanical criteria for sound application of external fixators. In the antebrachium, the cranial aspect of the radius, the most biomechanically advantageous, cannot be used safely when applying a fixator frame. In the crus, the medial aspect of the tibia is a safe corridor but no conclusions can be drawn from a biomechanical viewpoint since there is a lack of information concerning the true location of the tension side of the canine tibia

6. A thorough knowledge of the regional anatomy of the canine limbs is necessary to make safe and effective use of the external skeletal fixation technique. The veterinary orthopaedic surgeon must be aware of the possible complications that can arise from the misuse of this technique.

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