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The vascular supply of the chondro-epiphyses of the elbow joint in young swine*

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INTRODUCTION

Hyaline cartilage has been said to be avascular (Ham & Cormack, 1979; Dellmann & Brown, 1981; Jee, 1983), but there is evidence that, for cartilage of immature animals, this statement is untrue (Haines, 1933; Hurrell, 1934; Haraldsson, 1962; Levene, 1964; Trueta, 1968; Lutfi, 1970*a*, *b*; Wilsman & Van Sickle, 1970; Stockwell, 1971 *a*, *b*; Wilsman & Van Sickle, 1972; Haines, 1974; Sinha & Varma, 1982; Cole & Wezeman, 1985). Cartilage canals (C-C) traverse the hyaline cartilage of the chondro-epiphyses in the young of many species of mammals (Haines, 1933; Hurrell, 1934; Trueta, 1953; Levene, 1964; Stockwell, 1971 *b*; Wilsman & Van Sickle, 1972; Sinha & Varma, 1982; Cole & Wezeman, 1985; Rodriguez, Delgado & Paniagua, 1985) and contain vascularised pluripotential tissue (Lutfi, 1970*a*, *b*; Stockwell, 1971 *b*).

The vascularity of cartilage is more than simply an interesting curiosity. Vessels in C-C probably are a major source of nutrients and oxygen as well as avenues for the removal of metabolites and carbon dioxide for the developing chondro-epiphysis, the epiphyseal growth cartilage of the articular–epiphyseal cartilage complex (AECC) (Haines, 1933; Hurrell, 1934; Haraldsson, 1962; Wilsman, 1970; Haines, 1974) and the growth plate (Hill *et al.* 1987). Additionally, vessels occupying C-C are implicated in the aetiopathogenesis of osteochondrosis in swine, a condition affecting the AECC of the distal part of the humerus with a frequency second only to that occurring in the AECC of the distal part of the femur (Reiland, 1978).

In spite of the apparent importance of C-C, their distribution and that of the vessels in the distal part of the humerus of the pig have hardly been described (Kincaid & Lidvall, 1982, 1983; Hill *et al.* 1985*a*). Consequently, the objective of this study was to examine the vasculature of the elbow joint in young swine.

MATERIALS AND METHODS

Crossbred pigs (n = 39) from 3 farms were divided into 8 groups; 5 pigs each at 1 day, 1 week, 2·5 weeks, 5 weeks, 7·5 weeks, 10 weeks and 12·5 weeks of age and 4 pigs at 15 weeks of age.

Although the same general procedure was followed in the preparation of specimens, modifications were made in the perfusion technique. Each pig was heparinised and

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anaesthetised using a mixture of heparin sodium (220 units/kg) and sodium pentobarbitone (26·4 mg/kg) after venipuncture of an ear vein, external jugular vein, or the cranial vena cava. Pigs at 12·5 and 15 weeks of age received intramuscular ketamine hydrochloride (Ketaset, Bristol Laboratories Division of Bristol-Meyers Co. Syracuse, N.Y.) (17·6 mg/kg) as a sedative to facilitate restraint. The left common carotid artery was isolated, cannulated, and then the pig was exsanguinated. In the first set of pigs (3 at 1 week of age, 5 each at 2·5 and 10 weeks of age), the brachial artery was exposed and catheterised through an axillary incision. The cephalic and brachial veins were severed for drainage of residual blood and perfusion fluids. In the second set of pigs (5 each at 1 day, 5 weeks, 7·5 weeks and 12·5 weeks, 2 at 1 week and 4 at 15 weeks), a thoracotomy was performed, and both subclavian arteries were isolated and then cannulated for perfusion. Both brachiocephalic veins and the cranial vena cava were incised for drainage of residual blood and perfusion fluids. The vasculature of each thoracic limb was flushed with physiologic saline using a syringe and gentle digital pressure until the fluid flowing from the incised veins was clear. Two perfusion media were used to demonstrate vasculature, but each was given in a similar manner using randomised alternate limbs for different fluids. One limb was injected with India ink (Higgins waterproof drawing ink) and the other with one of two silicone rubber injection compounds, Microfil MV-122 and MV-117 (Canton Bio-Medical Products, Boulder, CO). Perfusion was considered complete when only perfusion medium flowed from the incised veins. In those specimens that were perfused with the silicone rubber injection compound, the medium was allowed to polymerise at room temperature for 3 hours. The humeri, ulnae and radii of each pig were dissected free of all surrounding tissue and articular cartilages were examined for gross abnormalities (erosions, cracks or flaps). If abnormalities were present, that pig was excluded from the study. Bones perfused with the silicone rubber injection compound were fixed in 70% ethyl alcohol for a minimum of 1 week. Bones perfused with India ink were fixed in neutral-buffered 10% formalin for a minimum of 3 weeks. All bones were dehydrated through graded alcohols and cleared in methyl salicylate by the modified Spalteholz method (Guyer, 1953). The distal end of the humerus and the proximal ends of the ulna and radius were examined and photographed while immersed in methyl salicylate using a Wild M7A dissection microscope and a Nikon 35 mm camera.

After whole bones and the cartilages associated with them had been examined, at least 2 humeri, ulnae and radii which had been perfused with silicone rubber were randomly chosen from each age group of pigs. Using a band saw, each bone was cut in the sagittal plane into slabs approximately 5 mm thick. The slabs of bone and cartilage were examined mesoscopically and photographed. (Mesoscopic anatomy is a level of study requiring only slight magnification such as that provided by a hand lens or dissecting microscope.) The method provides the opportunity for observing spatial relationships of organs and the smaller three dimensional forms not revealed by macroscopic or microscopic examination.

Thoracic limbs from an additional 2 pigs at 2·5 weeks were perfused with yellow silicone rubber injection compound, fixed for 7 days in 70% ethyl alcohol and dissected to confirm the origin of vessels transected during preparation of specimens for clearing by the Spalteholz technique.

RESULTS

Vessels supplying the distal part of the humerus and proximal part of the radius and ulna

Vessels on the caudal and cranial periosteal and perichondrial surfaces supplied branches to the AECC and ultimately the C-C of their respective aspects of the distal part of the humerus. A primary branch of the distal branch of the caudal circumflex humeral artery and a vessel derived from the nutrient artery of the humerus were the source of vessels to the caudal surface of the humerus (Fig. 1*a*, *b*, *c*). On the cranial aspect of the humerus, the transverse cubital artery and a branch of the distal branch of the caudal circumflex humeral artery supplied vessels to the cartilage, joint capsule and tendons of the medial epicondyle (Fig. 2*a*, *b*).

A large vessel, a branch of the collateral ulnar artery and a terminal portion of the distal branch of the caudal circumflex humeral artery anastomosed and provided many branches to the proximal portion of the ulna (Figs. 3, 4*a*, *b*, *c*). The cranial surface of the proximal epiphysis of the radius was also supplied by vessels which were branches of the collateral ulnar artery, as well as branches of the distal branch of the transverse cubital artery and branches of the brachial artery.

Cartilage canals of the distal part of the humerus

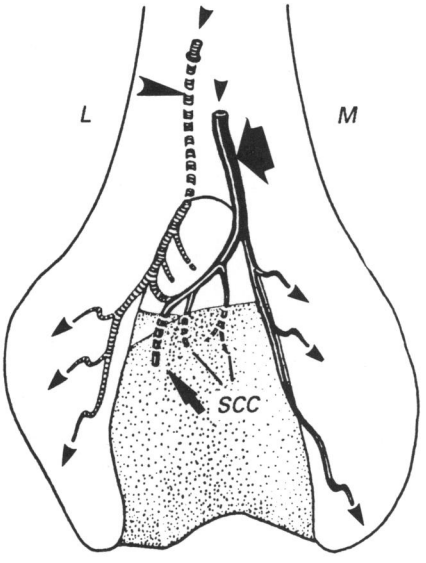
Cartilage canals were seen as tubular spaces containing perfused blood vessels, that meandered through the cartilage of the AECC or formed branching channels in the growth plate. Cartilage canals were orientated in the sagittal and transverse planes. Sagittal C-C were orientated proximal to distal, and transverse C-C were orientated surface to midline. The lengths and patterns of branching of both types of C-C varied and no anastomoses occurred between or within groups of C-C in the AECC. However, within the medullary cavity of the epiphyseal centre of ossification (ECO) of the condyles of the humerus there were anastomoses between vessels that originated from the caudal and cranial aspects (Fig. 5). Perforating cartilage canals were canals that projected from the ECO into the deeper layer of the AECC or the growth plate. All types of C-C branched dichotomously.

Sagittal cartilage canals

Sagittal C-C on the caudal aspect of the humeral condyles were supplied by arteries from branches of the distal branch of the caudal circumflex humeral artery. In younger pigs, the ECO and the AECC were well supplied with sagittal C-C (Fig. 1*a*, *b*, *c*), but the AECC distal to the ECO was sparsely supplied (Fig. 2*a*, *b*). By 15 weeks of age, only sagittal C-C that entered the ECO remained.

On the cranial aspect of the humeral condyles, which was supplied by the transverse cubital artery and distal branch of the caudal circumflex humeral artery, there was pronounced variation in the length of the sagittal C-C with a range between 0·8 and 6·2 mm in one day and one week old pigs. The longest C-C coursed most of the length of the cranial surface of the chondro-epiphysis. More sagittal C-C were in the hyaline cartilage of the cranial aspect of the humeral condyles than in the caudal aspect.

Whereas sagittal C-C were in all areas of the cranial aspect of the chondro-epiphysis of the humeral condyles in one day and one week old pigs (Fig. 6*a*), in 2·5 to 7·5 weeks old pigs (Fig. 6*b*) they were absent from the medial sagittal sulcus. In 10 and 12·5 weeks old pigs (Fig. 6*c*), sagittal C-C were located at the proximal margin of the chondro-epiphysis and many entered the ECO. Fewer canals were in the AECC at the



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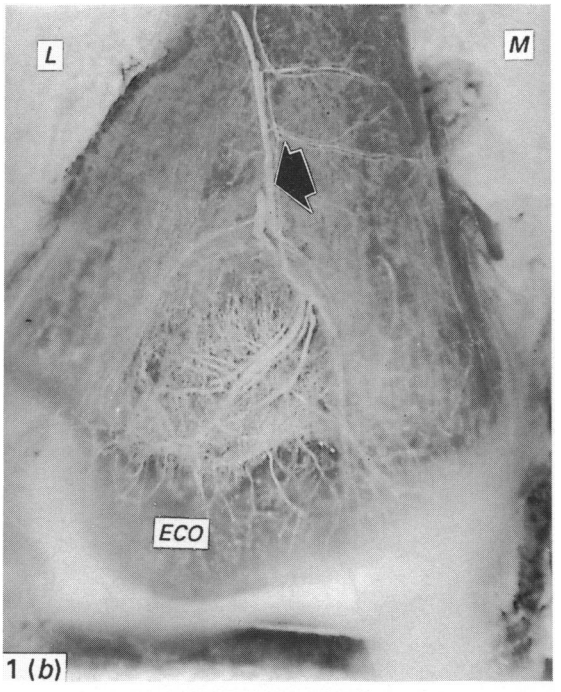
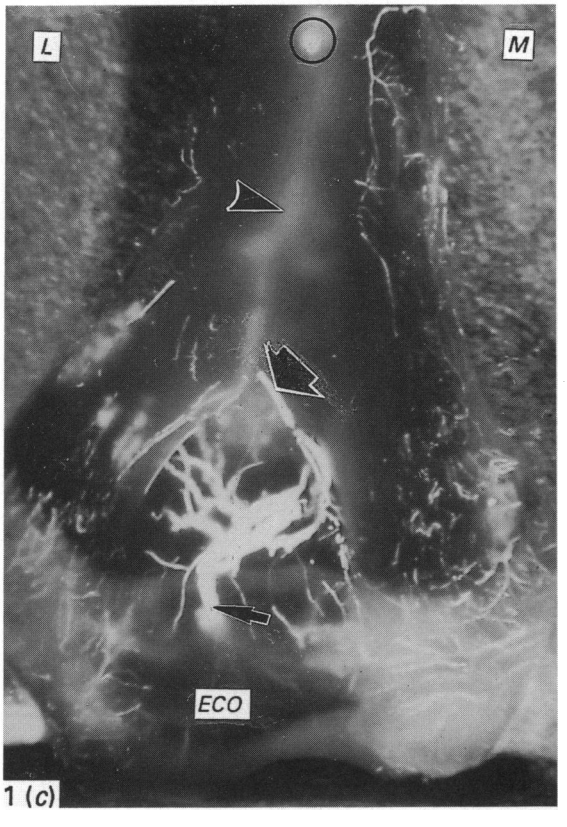


1 (*b*)



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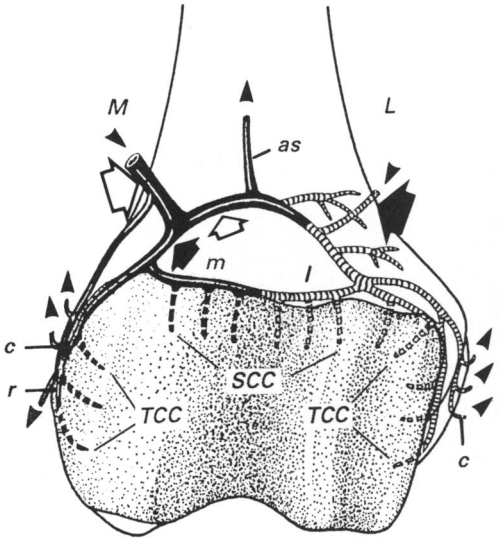
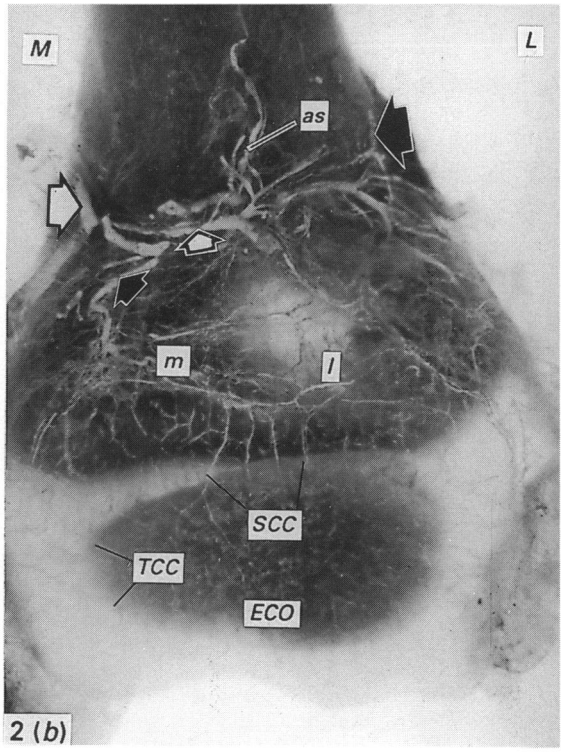


2 (*a*)



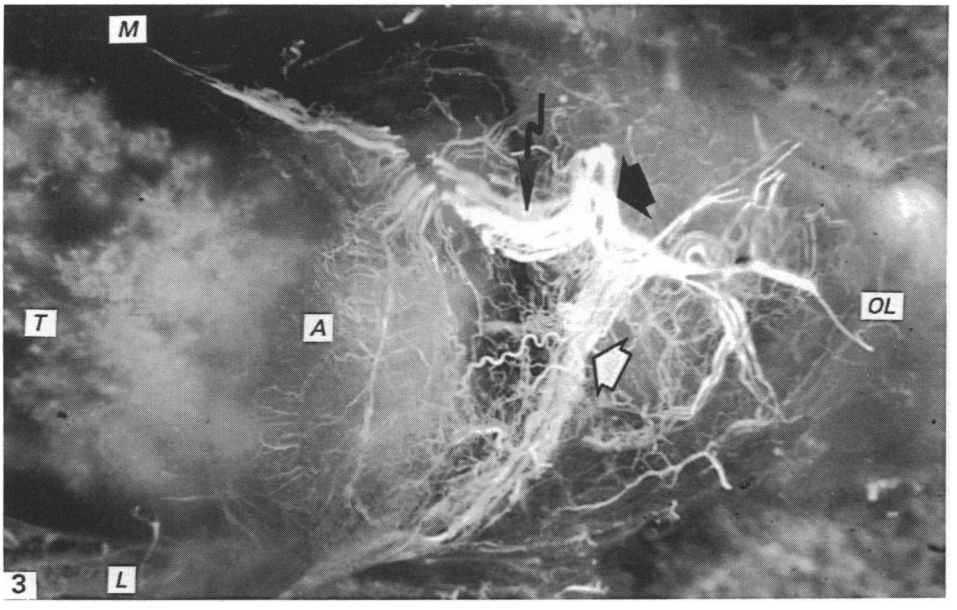
2 (*b*)

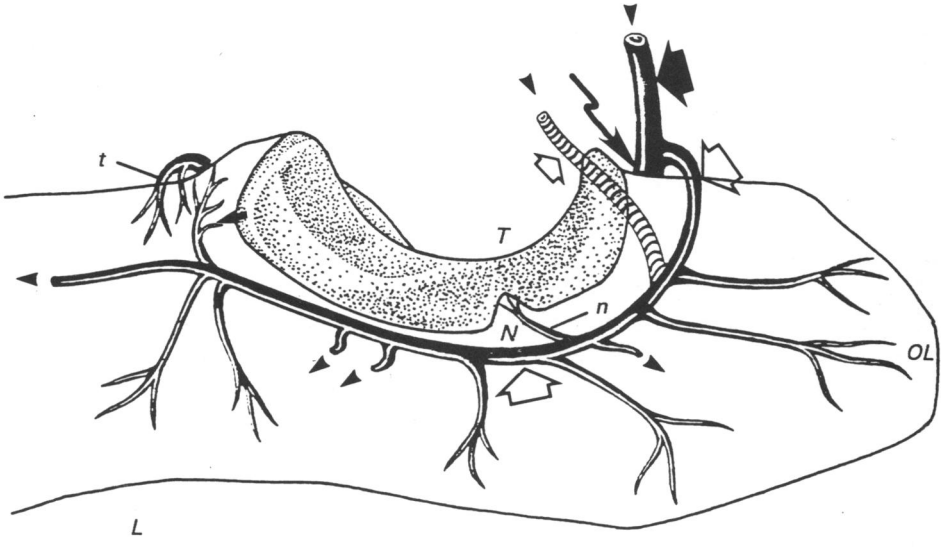
Fig. 2(*a–b*). Cranial aspect of the distal part of the humerus. Large open arrow, transverse cubital artery. Large, closed arrow, distal branch of the caudal circumflex humeral artery. Small, open arrowhead, proximal branch of transverse cubital artery. Small, solid arrowhead, distal branch of transverse cubital artery. *ECO*, epiphyseal centre of ossification. *L*, lateral; *M*, medial; *SCC*, sagittal cartilage canals; *TCC*, transverse cartilage canals; *as*, branch of the transverse cubital artery ascending on the anterior aspect of the humerus; *c*, Branches to the joint capsule and ligaments; *r*, branch supplying the radius; *l*, lateral transverse anastomosing vessel; *m*, medial transverse anastomosing vessel. Small arrowheads indicate direction of blood flow. (*a*) Schematic. (*b*) 1 day old pig. Silicone rubber perfusion.

medial and lateral margins of the condyles. By 15 weeks of age, few (3 to 6) C-C were in the AECC cranial to the ECO or at the margins of the condyles.

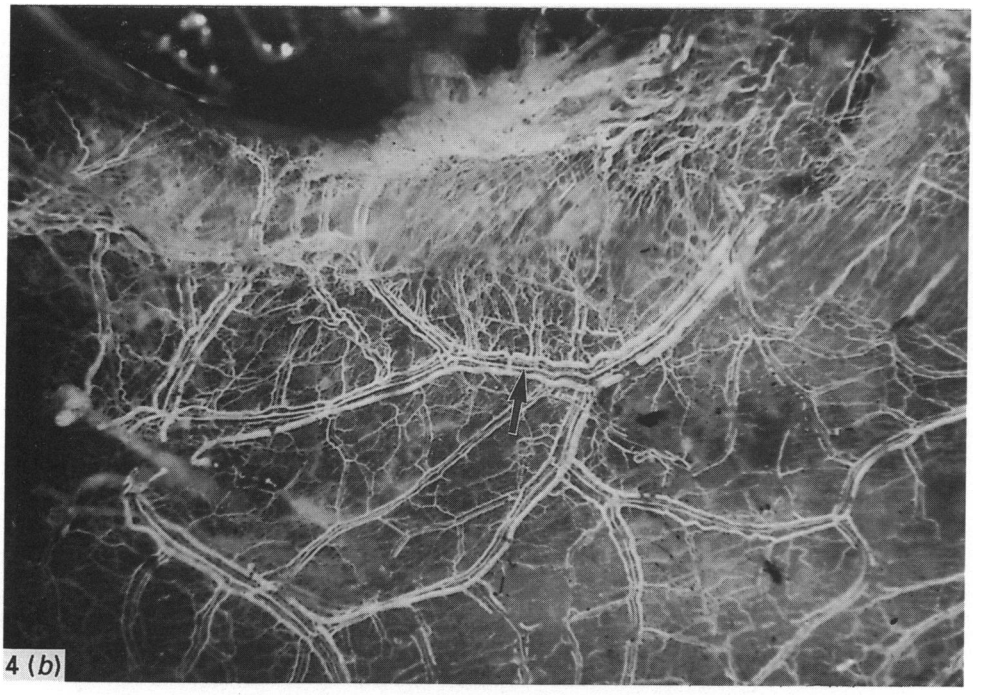
The growth plate of the condyles of the distal part of the humerus also contained sagittal C-C. After originating from the vessels at the cranial osteochondral junction, sagittal C-C entered deeply into the matrix of the epiphyseal growth cartilage of the growth plate, but curved back toward the metaphyseal osteochondral border before reaching the ECO (Fig. 7). These C-C branched dichotomously and their branches also looped proximally.

Fig. 1(*a–c*). Caudal aspect of the distal part of the humerus. Note the distal branch of the caudal circumflex humeral artery (large arrow), the branch of the descending medullary artery (large arrowhead), and a vessel derived from anastomosis of these branches (small, condensed arrow) that supplies the epiphyseal centre of ossification (ECO). Circle, nutrient foramen with vessel; *M*, medial; *L*, lateral. (*a*) Schematic. Vessels supplying the perichondrium, joint capsule and tendons are represented by sigmoid outlines and small directional arrowheads. *SCC*, sagittal cartilage canals. Small arrowheads indicate direction of blood flow. (*b*) 1 day old pig. Silicone rubber perfusion. (*c*) 1 week old pig. Silicone rubber perfusion.





4 (*a*)



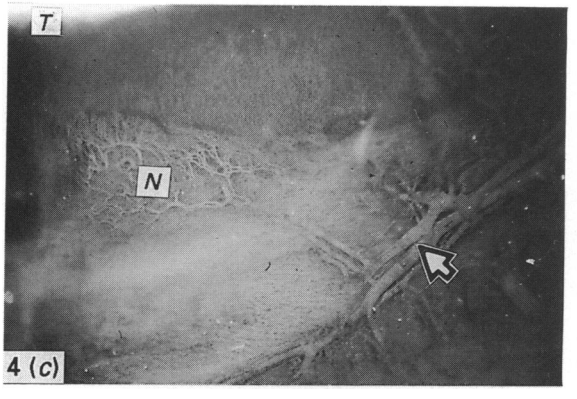


Fig. 3. Cranial surface of the olecranon process (*OL*), anconeal process (*A*), and part of the trochlear notch (*T*) of a 2·5 weeks old pig. Large, closed arrow, a branch of the collateral ulnar artery. Large open arrow, branch to the lateral aspect of the trochlear notch. Sigmoid arrow, branch to the medial aspect of the trochlear notch. *L*, lateral; *M*, medial. Silicone rubber perfusion.

Fig. 4(*a–c*). Proximal part of the ulna and radius. Large, closed arrow, branch of collateral ulna artery. Large, open arrow, branch to lateral aspect of the trochlear notch and radius. Sigmoid arrow, branch to medial aspect of trochlear notch. Small, open arrow, anastomosing branch from the distal caudal circumflex humeral artery. Small, condensed arrow, vessel supplying the head of the radius. *N*, synovial notch; *OL*, olecranon process; *T*, trochlear notch; *n*, vessel supplying the synovial notch; *t*, branches from the transverse cubital artery and the brachial artery. (*a*) Schematic of lateral aspect. Small arrowheads indicate direction of blood flow. (*b*) Medial aspect of a 10 weeks old pig. Small long arrow, artery supplying medial aspect of the ulna. Silicone rubber perfusion. (*c*) Cranio-lateral aspect of a 1 week old pig. Enlargement in the area of the synovial notch. India ink perfusion.

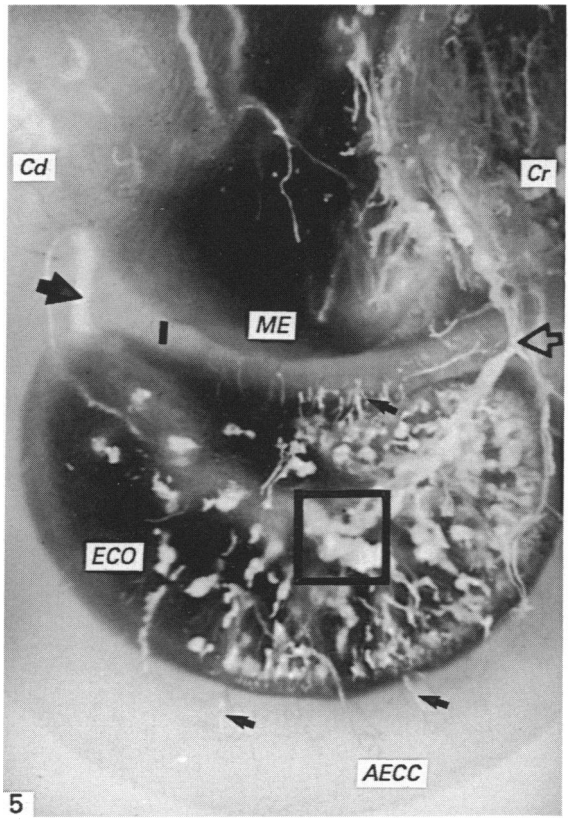


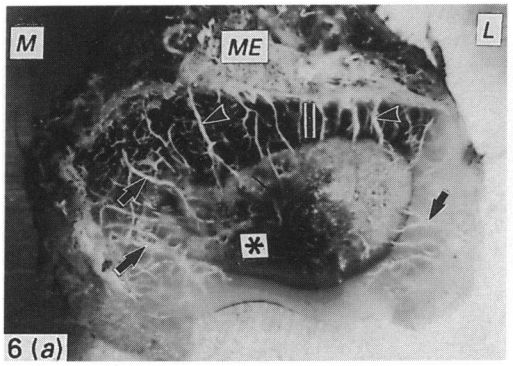
Fig. 5. Sagittal section (5 mm thick) of the distal part of the humerus in the area of the intercondylar crista. Large closed arrow, vessel within sagittal cartilage canal derived from anastomosis of the distal caudal circumflex humeral artery and the descending medullary artery that supplies the epiphyseal centre of ossification (*ECO*) and anastomoses with a vessel (open arrow) derived from the cranial surface in the area delineated by the square. Small arrows, perforating cartilage canals. Bar, growth plate. *AECC*, articular epiphyseal cartilage complex; *ME*, metaphysis; *Cd*, caudal; *Cr*, cranial. Silicone rubber perfusion.

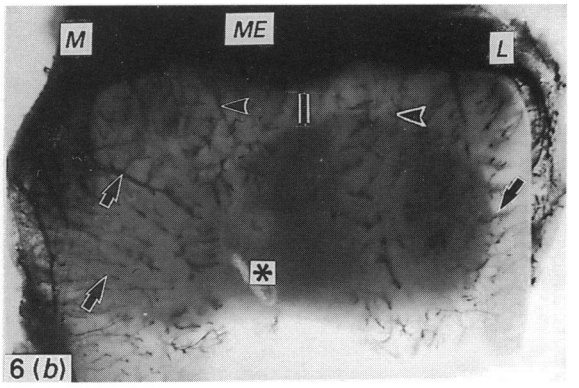
Transverse cartilage canals

Transverse cartilage canals (Fig. 2), ranging between 0·8 and 8·5 mm in length, were in the AECC medial, proximal, distal, caudal and cranial to the ECO in all humeri. There were fewer transverse C-C on the caudal aspect than on the cranial aspect and these were in the chondro-epiphysis of the epicondyles. Only after removal of the perichondrium were many of the transverse C-C in the hyaline cartilage of the medial and lateral epicondyles visible. The canals were numerous and branched repeatedly.

On the cranial aspect, the transverse C-C originating from the medial margin of the condyle were twice as long as those originating from the lateral margin. In one day (Fig. 2*b*) and one week old (Fig. 6*a*) pigs, transverse C-C extended to the edge of the ECO on the lateral side. On the medial side, they extended over the ECO to approximately the middle of the medial condyle. Few C-C entered the cranial aspect of ECO.

Transverse cartilage canals in 2·5 (Fig. 6*a*) and 5 weeks old pigs extended further across the lateral and medial condyles than did corresponding canals in the younger pigs. Cartilage canals originating from the lateral margin continued into the lateral condyle. On the medial side, however, they extended through the AECC of the medial





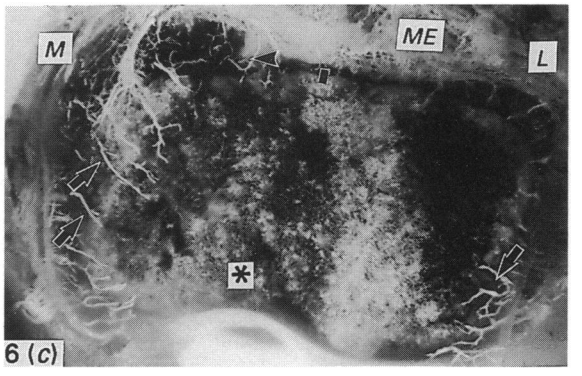


Fig. 6(*a–c*). Cranial aspect of the distal part of the humerus. Arrows, transverse cartilage canals. Arrowheads, sagittal cartilage canals. Bar, growth plate. *L*, lateral; *M*, medial; *ME*, metaphysis; *, medial sagittal sulcus. (*a*) 1 week old pig. Silicon rubber perfusion. (*b*) 2·5 weeks old pig. India ink perfusion. (*c*) 10 weeks old pig. Silicone rubber perfusion.

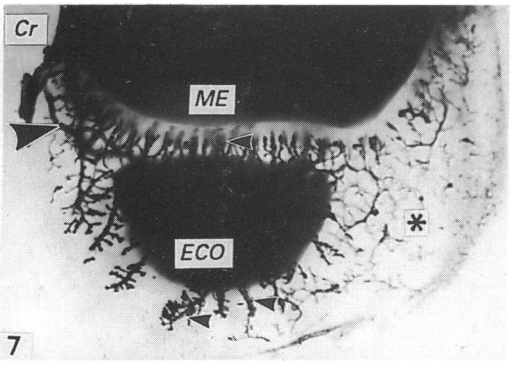
condyle almost to the medial sagittal sulcus. In these groups of pigs, most C-C entered and terminated in the ECO. However, a few transverse C-C entered and left the ossification centre in an undulating manner.

In 7·5, 10 (Fig. 6*c*) and 12·5 weeks old pigs, the transverse C-C were located nearer the periphery of the ECO and by 15 weeks they did not extend more than 5 mm across the condyles. However, as observed in the younger pigs, the C-C were longer in the medial condyle than in the lateral condyle and many entered the ECO.

As the centres of ossification enlarged in pigs between 5 and 15 weeks of age, some canals bridged the epiphyseal cartilage between the ossification centres of the medial epicondyle and the medial humeral condyle. Transverse cartilage canals were around the centre of ossification of the lateral epicondyle, but bridging between the centres of ossification did not occur. With age, the number of C-C decreased.

Perforating cartilage canals

Perforating cartilage canals extended from the proximal surface of the ECO of the condyles in a proximal direction into the growth plate or into the AECC. However, the C-C did not completely traverse the growth plate except at the periphery of the plate at the cranial or caudal surfaces. Whereas perforating C-C were numerous on the caudal aspect of the humerus in the younger pigs, by 15 weeks of age they were rare.



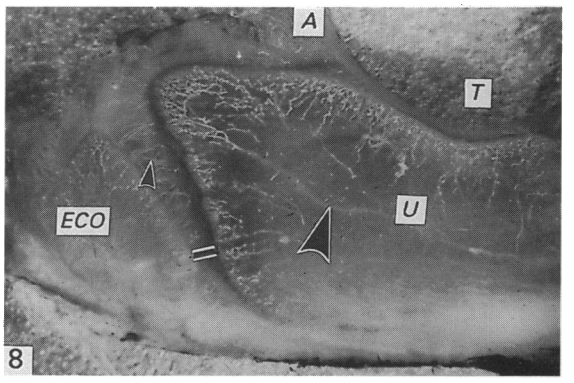


Fig. 7. Sagittal section (5 mm thick) of the distal part of the humerus through the medial condyle of a 1 week old pig. Small arrowheads, perforating cartilage canals. Large arrowhead, sagittal cartilage canal. *Cr*, cranial; *ECO*, epiphyseal centre of ossification; *ME*, metaphysis; *, medial epicondyle. India ink perfusion.

Fig. 8. Sagittal section (5 mm thick) through the proximal part of the ulna of a 5 weeks old pig. Large arrowhead, medullary artery. Small arrowhead, perforating cartilage canal. *A*, anconeal process; *ECO*, epiphyseal centre of ossification of the olecranon process; *T*, trochlear notch; *U*, ulna; Bar, growth plate. Silicone rubber perfusion.

In one day and one week old pigs, numerous perforating C-C projected from the ECO in all areas of the cranial surface of the condyle of the humerus (Fig. 5). The perforating C-C in the medial sagittal sulcus had almost disappeared in pigs at 7·5 weeks of age. By 15 weeks postnatally, there were perforating C-C in neither sagittal sulcus.

Cartilage canals of the proximal part of the ulna and radius

In the ulna, C-C were in the anconeal process, the olecranon process, along the medial edge of the trochlear notch and in the distal part of the coronoid process adjacent to the radius. The anconeal process was composed of hyaline cartilage that contained numerous C-C originating from perichondrial vessels on the proximal surface as well as medial and lateral margins of the articular surface. Although the C-C did not reach the articular surface, they projected in a proximal to distal direction toward it. The origins of the canals were parallel and the canals branched many times. In pigs between one day and 2·5 weeks of age there were many C-C, but, as the pigs increased in age, the numbers decreased. The front of endochondral ossification from the body of the ulna extended into the cartilaginous anconeal process and some of the C-C were incorporated into the bony structure by 12·5 weeks of age.

In 7 of 10 one day old and 2 of 10 one week old pigs the proximal half of the olecranon process was cartilaginous and contained numerous C-C. The C-C originated from the perichondrium and periosteum of the olecranon. No obvious pattern of distribution of the vessels could be determined. The C-C entered the cartilage and branched so that the whole area was vascularised. In 3 of 10 one day old pigs, 8 of 10 one week old pigs, and 10 of 10 2·5 weeks old pigs, the olecranon contained an ECO. The ECO of the olecranon incorporated some of the C-C and as the pigs increased in age the number of C-C decreased. In 5 week old pigs, C-C were in the distal part of the ECO, but a few were in the cartilage proximal to the apex of the ossification centre. The C-C were curved, extending in a distal direction (Fig. 8). Perforating cartilage canals continued distally into the growth plate from the distal portion of the centre. In the cleared whole bones or slabs of bones, C-C did not cross the growth plate.

Cartilage canals also were along the medial edge of the trochlear notch of the ulna. On the distal aspect of the coronoid process, C-C were in the epiphyseal cartilage cranial to the bone. These C-C originated from the edge of the trochlear notch where the joint capsule and synovial membrane were attached, and although initially they were few (between 3 and 6), the numbers decreased with age. Cartilage canals that predominated in the medial coronoid process originated from the cranial or medial surface of the ulna and were located in the epiphyseal cartilage superficial to the diaphyseal bone. Perforating cartilage canals were rare.

Cartilage canals of the proximal epiphysis of the radius contained vessels that originated from arteries which were around its circumference at the level of the growth plate. The canals entered the hyaline cartilage and extended proximally before curving distally toward the ECO. In one day and one week old pigs the cartilage canals were in the hyaline cartilage at the medial and lateral margins. By 15 weeks, the only C-C remaining were those that entered the ECO. Perforating cartilage canals did not protrude from the ECO into the AECC in any of the radii.

DISCUSSION

Injection technique

Despite changes in sites of perfusion and perfusion media, the quality of the perfusions did not improve and variability between pigs and between sites remained. However, perfusion by India ink generally resulted in more complete filling of arteries and veins. It was considered important to ensure that the tip of the catheter was proximal to the origin of the caudal circumflex humeral artery because a distal branch (collateral radial artery) originates from the caudal circumflex humeral artery and supplies the lateral and caudolateral aspects of the elbow joint, as well as the nutrient artery to the humerus (Getty, 1975).

The vascular supply to the elbow joint

The caudal aspect of the distal part of the humerus was supplied by more than one vessel. A branch of the descending medullary artery left the bone in the proximal portion of the olecranon fossa and anastomosed with vessels on the surface. The artery resulting from the fusion of the two vessels then re-entered the ECO of the distal part of the humerus. No report of vessels leaving the bone, traversing a portion of the surface and then re-entering the bone was found in the literature reviewed. The vessel that re-entered the bone was the largest vessel supplying the ECO of the condyles of the humerus.

The vascular supply to the cranial aspect of the distal part of the humerus consisted of a vascular ring supplied by both a major (transverse cubital artery) and a minor (branch of the distal caudal circumflex humeral artery) artery. The dual supply of both aspects of the humerus could be important if the supply of blood through any one of the vessels was compromised.

Cartilage canals

Despite the reports describing C-C (Haines, 1933; Hurrell, 1934; Haraldsson, 1962; Levene, 1964; Trueta, 1968; Lutfi, 1970*a*, *b*; Wilsman & Van Sickle, 1970, 1972; Stockwell, 1971*a*, *b*; Haines, 1974; Sinha & Varma, 1982; Cole & Wezeman, 1985; Rodriguez *et al.* 1985) authors of textbooks continue to ignore the existence of C-C and to describe hyaline cartilage as avascular (Ham & Cormack, 1979; Dellmann & Brown, 1981; Jee, 1983). In the present project, vascularised C-C were clearly

demonstrated in the chondro-epiphysis of all three bones comprising the elbow joint of the pig.

In a comparative study of the proximal part of the tibia of various species, Levene (1964) considered that the distribution of C-C was site- and species-specific. In distal parts of humeri and proximal parts of radii from the present study, the pattern of C-C was consistent in a general configuration. However, considerable individual variation occurred.

The absence of anastomoses between C-C within the AECC was consistent with previous reports (Haines, 1933; Hurrell, 1934; Lutfi, 1970*a*; Brookes, 1971; Firth & Poulos, 1982). Within the medullary cavity of the ECO of the condyles, anastomoses linked vessels originating from the caudal and cranial aspects of the distal part of the humerus, indicating that blood flow to the area could be maintained if one vessel were damaged. It was not possible to determine whether the vessels which supplied the perforating C-C did or did not anastomose within the ECO.

Perforating cartilage canals, as described by Lutfi (1970*a*), are C-C that project into the growth plate. In the present study, in the distal portion of the humerus, perforating C-C originated from the ECO of the condyles and extended into the growth plate and the AECC. In the lateral condyle, a large number of the perforating C-C originated from branches of the sagittal C-C that had been enveloped by the ECO. However, in the medial condyle, the perforating C-C originated from transverse C-C. The AECC of the lateral condyle appeared to be nourished by blood vessels supplied by sagittal C-C, whereas the medial condyle was supplied by vessels in transverse C-C. In the AECC of the humerus, especially in the medial sagittal sulcus, as the thickness of the AECC decreased the number of perforating C-C decreased until there were none. Generally, the thinnest segment of AECC was in the medial sagittal sulcus (Kincaid & Lidvall, 1983).

The perforating C-C in the growth plate of the olecranon process and C-C in the anconeal process formed a distinctive pattern, but elsewhere in the ulna there was no specific arrangement of C-C. In pigs at one day and one week of age, the chondro-epiphysis of the olecranon process was occupied by many C-C which had no obvious pattern, but, by the time the ECO was well established, a pattern became apparent. The arrangement of C-C in the anconeal process was similar to that reported by Van Sickle (1966) in a large breed of dogs. Although C-C were found in all areas of the anconeal process in the pig, they were not present in the cartilage between the cartilaginous *anlage* of the anconeal process and the diaphysis of the ulna as occurs in dogs. It appears from the present study and the work of Van Sickle (1966) that although the patterns of distribution of C-C in the anconeal processes of pigs and dogs are similar and although the patterns observed in the growth plates of the distal condyles of the humerus and the olecranon are similar in pigs, there is considerable individual variation. Therefore, the distribution of C-C may not be as site- and species-specific as Levene (1964) reported.

Perforating cartilage canals were not found in the proximal part of any of the radii examined. However, they were seen along the medial edge of the trochlear notch and medial coronoid process of the ulna. The AECC of the proximal part of the radius and the trochlear notch of the ulna were thin in comparison to areas of the distal part of the humerus which had perforating C-C. Although the existence of perforating C-C may depend on a minimum thickness of the AECC, this could not be confirmed because the thickness of the AECC was not measured. An alternative hypothesis is that the absence of C-C was the result of the effect of compressive forces placed on specific portions of cartilage and bone. Therefore, additional research is warranted to

determine why perforating C-C are present in the AECC and growth plate of some bones and not in others.

Cartilage canals did not cross the growth plate of any of the bones examined. It has been suggested that blood vessels in perforating C-C of the growth plate carry nutrients to the zone of proliferating chondrocytes of the physis (Trueta, 1968; Kincaid & Lidvall, 1982). However, disagreement exists regarding the presence of communicating C-C which pass from the ECO to the metaphysis (Trueta, 1968). The results of the present study disagree with the conclusions of Bullough & Heard (1967), Kincaid & Lidvall (1982) and Hill *et al.* (1985*a*). Bullough & Heard (1967) considered that vessels that crossed the growth plate in young pigs were abnormal and were associated with the pathogenesis of lesions in the physis, whereas Kincaid & Lidvall (1982), Hill, Ruth, Hilley & Hansgen, (1984) and Hill *et al.* (1985*b*) found that the vessels crossed the depth of the normal growth plates and were considered normal morphologic features of the growth plate in young domestic pigs.

Different techniques were used in the studies reviewed. Slabs of cartilage and bone that were radiographed were relatively thick (Hill *et al.* 1985*a*). It was possible that overlapping images of vessels at different levels in the slabs created an impression that vessels in C-C crossed from the epiphysis to the metaphysis (Bullough & Heard, 1967; Hill *et al.* 1985*a*). However, vessels crossing growth plates in histologic sections (Kincaid & Lidvall, 1982; Hill *et al.* 1985*a*) conflicted with findings in the present study and it could be argued that, in the present study, perfusion media or perfusion techniques were such that vessels in C-C in growth plates were incompletely filled. Therefore, the question as to whether or not patent vessels cross the growth plates of young pigs is still open to debate.

In pigs in which the ECO of the medial epicondyle was well-developed, branches of some C-C were observed entering both the ECO of the medial epicondyle and the medial condyle. This was not the case on the lateral side. The anastomosis of the vessels may have been associated with the orientation of the respective ECOs of the distal part of the humerus. The ECO of the medial epicondyle was located caudal and partially overlapped the medial condyle, whereas the ECO of the lateral epicondyle was located caudal and lateral to the lateral condyle. Whatever the reason for the bridging vessels, their existence allowed for an additional route for blood to be supplied to either ECO.

SUMMARY

The vasculature of the elbow joint was examined in 39 pigs between one day and 15 weeks of age. Each pig was anaesthetised, exsanguinated and the thoracic limbs were perfused with India ink or a silicone rubber injection compound. The humerus, ulna and radius were dissected free, examined, fixed in formalin or ethyl alcohol, cleared by the modified Spalteholz technique and examined mesoscopically. Features of interest were photographed and then a limb from two pigs in each age group was cut into slabs and examined mesoscopically. The vascular supply of the distal part of the humerus was complex. It was supplied by vessels on both the cranial and caudal aspects and locally each aspect had a dual blood supply. Vessels anastomosed and on the cranial aspect formed a vascular ring. The proximal part of the ulna was supplied by vessels that were on its medial and lateral surfaces. The vessel on the lateral surface continued distally and supplied the lateral aspect of the proximal part of the radius. The proximal part of the radius was also supplied by arteries that were on the cranial and medial surfaces. Blood vessels provided branches to numerous cartilage canals of the

articular–epiphyseal cartilage complexes, epiphyseal centres of ossification, and growth plates. The patterns of blood vessels in cartilage canals which were in sagittal or transverse planes were best exemplified by those in the distal part of the humerus. Perforating cartilage canals emerged from the epiphyseal centres of ossification. The pattern of cartilage canals was consistent in a general configuration, but individual variation did occur. Although cartilage canals were abundant in the youngest pigs, with increasing age the distribution of cartilage canals changed and the numbers of cartilage canals decreased.

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