The use of bone autografts in canine orthopaedic surgery*

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ABSTRACT

An account is given of the use to which bone autografts may be put in the repair of non-union fractures and in the treatment of severe carpal injuries in dogs. The methods of obtaining grafts of rib, iliac crest and tibial cortex are described, as are also the techniques for their employment at fracture sites and for carpal fusion. Four case protocols are provided for each category of procedure. Important theoretical considerations are discussed regarding the fate of grafted bone, the value of a bone bank and the use of bone homografts and bone heterografts.

INTRODUCTION

The use of bone grafts in the treatment of human orthopaedic conditions began in the nineteenth century. The first record of a homogenous bone transplantation was published by Macewen (1881) who successfully rebuilt two-thirds of the shaft of a child's humerus with fragments that had been removed during osteotomies on a number of patients. Interest in the clinical use of bone grafting gradually increased, no doubt stimulated by confidence gained from the satisfactory results of experimental studies on animals. In a historical review of the literature on bone grafting Chase & Herndon (1955) discovered published accounts of 162 autogenous and twenty-nine homogenous bone transfers in the first decade of this century. By the early 1920s bone grafting had become accepted as routine practice for certain conditions, and the frequency with which the procedure was being undertaken—even in those relatively early days—may be judged from a paper by Albee (1923) based on experience with 3000 such operations.

Since that time a vast amount of literature has been built up on all aspects of bone transplantation, in clinical and experimental studies. The introduction of

inert metallic implants marked an important stage in the development of grafting techniques since it became possible safely to secure massive onlay grafts in position throughout the regenerative process. Very many techniques employing grafts have since been described and grafts are now used in the treatment of many bone problems in the limbs and spine. Interest in recent years has extended to entire bone and joint replacement, with some encouraging results, but such innovations are some way yet from becoming established practice.

By comparison, bone transplantation in clinical situations in animals is in its infancy. This is understandable because bone and joint surgery has evolved through a considerably shorter time scale in veterinary than in human medicine and there has been less time in which to introduce and evaluate some of the more sophisticated techniques. The literature on bone grafting abounds with references to experimental studies using dogs and in this respect, therefore, much of the ground work has already been covered. It has to be realized, however, that the transference of a technique from the experimental to the clinical situation is by no means straightforward even when the same species of animal is involved. Likewise, techniques which are satisfactory in human beings frequently have to be modified for use in animals (or else are doomed to failure).

Small animal orthopaedic surgery has made remarkable progress in the last two decades and the time is opportune to increase the present interest in bone grafting techniques so that they may in time be adequately assessed. In the present paper the author has described experiences with autogenous bone transfer in the treatment of non-union fractures and of severe injuries to the carpus in dogs.

MATERIALS AND METHODS

The purposes for which bone autographs have been employed in this study fall into two main categories, namely;

(a) in the treatment of non-union fractures;
(b) in arthrodesis of the carpus.

The type of graft material used depends largely on the procedure undertaken. It has been obtained from three donor sites, namely rib, iliac crest and tibial cortex.

Rib

Sections of sternal rib in mid-series have been used in order to provide long, and relatively strong sections of bone. They may be taken from either side of the thoracic wall, the choice depending on convenience regarding the limb requiring surgery, and having regard to the problems of maintaining asepsis if the patient has to be repositioned. More than one rib may be needed to supply sufficient bone on some occasions, and in these cases it is advisable to remove alternate ribs, more especially from the left side over the heart.

A lateral approach is made to the chosen rib as in a thoracotomy operation. The
periosteum is split longitudinally and an elevator used to strip it on all sides of the rib. Care is taken to avoid penetrating the pleural cavity because this would needlessly complicate and lengthen the entire procedure. The rib is cut near its vertebral articulation and close to the costo-chondral junction, using sharp bone forceps to avoid splinters. The chest wound is closed in customary fashion before the limb operation is commenced. In the meantime, the graft bone is immersed in sterile saline.

Iliac crest

The bone that may be removed from the iliac crest is flat and thin, and is best suited for the provision of wedges for use in arthrodesis, and for breaking up into chips for introduction into fracture sites, or packing bone cavities. It is not possible in dogs to detach the top of the ilium and scoop out cancellous bone as is practised in human surgery.

A crescent-shaped incision is made over the iliac crest, preferably on the same side of the dog as the leg requiring surgery. The entire wing of the ilium is exposed by detaching muscle from its lateral and medial surfaces with an osteotome. Alternatively, the muscles may be detached using diathermy, and with considerably less haemorrhage. The portion of the ilium that protrudes above the sacro-
iliac joint is removed with bone forceps (Fig. 1). Little force is required to do this even in large dogs because the bone is largely cancellous with only a thin compactum on either side. All remnants of attached muscle are removed from the bone but the periosteum is not disturbed. The wound is packed and left unsutured until the limb operation is finished.

**Tibial cortex**

A long, straight section of compact bone may be removed from the medial cortex of the tibia without significantly weakening the bone. Experience with this technique has been limited but it appears to be practical only in the larger breeds. A medial approach is made to the tibia, the periosteum is split longitudinally and retracted. The rectangular section can be removed with a hammer and chisel but this is a long and tedious method. It is most easily and accurately cut with an electric circular saw with twin blades preset to the required width, and the ends of the strip are detached with a chisel.

This type of material is most suited for use as inlay-grafts in the repair of fractures, or for fusing certain joints. In these cases a similar amount of bone has to be removed from the recipient site and this can sometimes be used to replace the bone at the donor site even though it may be fragmented.

**Bone autografts in the treatment of non-union fractures**

**Indications.** Bone grafts have been found of considerable value in the treatment of most non-union fractures of the radius/ulna, and femur, but they are particularly indicated in the following circumstances.

(a) In small breeds of dogs (Toy and Miniature Poodle, Yorkshire Terrier, Chihuahua) with fractures in the middle or lower thirds of the radius/ulna, which remain un-united despite treatment with closed or open reduction methods. On occasions treatment with some form of external support has failed and it has been followed by internal fixation but still without union. In protracted cases the radiographic findings are characteristic, and include an absence of callus, sclerosis of the bone ends and the development of a pseudo-arthrosis.

(b) In any non-union fracture, regardless of the size of the dog or the bone involved, which is complicated by dissolution of the bone ends, or by osteomyelitis leading to loss of large bone fragments by sequestration.

**Technique.** The precise details of the procedure undertaken depends on the size of the dog, the type and site of the fracture, and the nature of any complications that may be present. Basically, it involves an approach to the fracture by the customary route for the bone in question. The main fracture components are mobilized, the bone ends are cleared of fibrous callus, and an appropriate form of internal fixation is used to maintain close proximation and immobilization of the bones.

For most radial fractures a Sherman bone plate, or a finger plate, secured with screws to the anterior surface of the bone, provides the best means of compression
and fixation. In very small dogs, however, this is not feasible and reliance has to be placed on a fine steel pin introduced into the medullary cavity from the carpal joint.

For femoral non-unions a Sherman bone plate is routinely employed because it is the best means of overcoming the rotation of the lower fragment that is usually the cause of non-union in fractures of this bone.

In the majority of cases the graft bone is used in the form of numerous small chips. These are put into the medullary cavity, packed beneath the plate at the bone ends, and placed on all aspects of the bone up to 1–2 cm from the fracture. The chips in the latter location are not secured but are merely held in place by the pressure of soft tissues following wound closure.

The replacement of large fragments of bone lost at the time of the injury, or due to lysis, or sequestration, requires the introduction of long lengths of bone. In dogs with osteomyelitis, antibiotics should be administered for a week before bone grafting is undertaken. Sections of rib are employed for this purpose. They are usually wide enough in dogs over 15 kg to accept bone screws, and are secured by this means to the main fracture fragments. It is usual also to build the fractured bone up to its normal width with smaller sections of rib placed longitudinally adjacent to the bone, and sometimes even to pack chips into the fracture site. Whether or not some form of internal fixation is necessary depends entirely on the degree of stability achieved. In some instances it has been essential to provide additional rigidity with a pin or plate, while in others a rigid external support proved adequate.

Post-operatively, most radial fractures treated in this way require external support, and in some dogs this has had to be maintained for several weeks, or even months, until union was assured. The dog must be kept restricted in activity until such time as the bone is shown radiographically to be uniting satisfactorily. Callus formation is mostly evident within 4 weeks and, by 6 weeks, the grafted bone has lost its contours and appears to be incorporated with the healing process. Some chips and small bone sections disappear but in only one instance has union failed to occur and made it necessary to repeat the grafting procedure (using bone from the opposite iliac crest). In no instance has infection and sequestrum formation been encountered post-operatively.

The following case records provide examples of the use of autogenous bone chips, and ribs, in the treatment of three non-union fractures of the radius and one of the femur. Re-inspection times are not standard because the needs of the cases differed, and this was also somewhat dependent on the convenience of owners.

Case 401930. Rough Collie, female, 14 months old; body weight 26 kg.

A mid-shaft fracture of the right radius/ulna, sustained in a car accident, was repaired with a steel bone plate. Osteomyelitis supervened and did not respond to antibiotic therapy. Eight weeks after the operation the plate and screws came adrift and had to be removed, although the fracture was still freely mobile. The dog was referred for further treatment in the ninth week.
At this time the leg was carried and there was considerable soft tissue swelling from the elbow to the carpus. The fracture site was relatively painless and the degree of movement between the bone ends was similar to that present in a fresh fracture. On radiographs the bone ends were found to be widely displaced and there was a sequestrum 5 cm long, 8 mm wide, in the middle of the radial shaft (Figs. 2 and 3). The main fracture components were porotic and their entire length enveloped in a wide zone of periosteal new bone which was evidently the consequence of chronic infection.

![Fig. 2. Case 401930. Lateral radiograph of radius-ulna, 3 months after fracture. Note sequestrum.](image)

![Fig. 3. Case 401930. Antero-posterior radiograph of same leg.](image)

Prior to operating on the forearm the seventh and eight ribs were removed, without periosteum. The radius was approached anteriorly and the radial sequestrum was removed. The bone ends were mobilized and brought into alignment but a large gap remained in the radius. A section of rib 10 cm long was secured to both ends of the radius as an onlay graft, using two screws in each half of the bone. Shorter pieces of the other rib were placed alongside the main
graft to bring the width of the donor bone up to that of the radius, and chips were packed into gaps (Fig. 4). The wound was closed in routine fashion and a well padded plaster-of-Paris cast was applied from the elbow to the foot; when dry the cast was split longitudinally into two halves to allow for post-operative swelling and to make re-inspection easier.

2 weeks: Apart from a slight serous discharge from some of the suture holes, wound healing was uneventful. The leg was not used but it was straight and the dog did not resent it being handled. A small amount of hinge-like movement could be obtained at the fracture site. Radiographs showed no change in the position or density of the bone grafts. The cast was re-applied.

![Fig. 4. Case 401930. Immediately after transplantation of rib grafts.](image1)
![Fig. 5. Case 401930. After 3½ months, pin introduced across ulna fracture.](image2)

6 weeks: The leg was now bearing weight but there was still some movement in the fracture. On radiographs a considerable bridge of bone was seen to be developing at mid-radius involving the sections of rib and the latter were less easily identified as such. Support was maintained.
3 months: Leg function was moderately good. Very slight movement was demonstrable in the fracture. The new bone at mid-radius had increased greatly in width and was as dense as cortical bone. The ulna fracture remained un-united with a gap of 3-4 mm and the forearm appeared to be curving. A rigid splint was applied.

3½ months: The ulna fracture was exposed surgically with the intention of correcting the non-union. Fibrous tissue was excised from the bone ends and a ¼ steel pin was driven obliquely across the fracture. The fracture gap was filled with pieces of Kiel bone graft (Fig. 5). A splint was applied.

11 months: In the interim, limb use had gradually improved and the dog now had almost normal function without need for external support. The carpal joint was almost completely ankylosed in extension. The leg was straight with no rotation of the foot but the forearm was slightly bowed antero-posteriorly. The radius and ulna fractures were completely united and there was now a wide, dense bone mass at the fracture level. The screws and pin were embedded in bone and no attempt was made to remove them (Fig. 6).
Case 404284. Miniature Poodle, female, 6 years old; body weight 10 kg.

The dog was hit by a car and sustained a severely comminuted fracture of its right radius/ulna. The leg was extensively bruised, with a few small penetrations of the skin at fracture level. A rigid splint was applied but at re-inspection a month later mobility at the fracture site was unchanged. The splint was re-applied, but inspections every month for 5 months showed no improvement, and the dog was referred for surgical treatment.

At this time little or no periosteal callus formation had developed at any of the several fracture levels, except for small beak-like projections near the ends of some bone fragments. There was a gap of 1 cm between the main radial bone ends and a pseudo-arthrosis had developed at both the upper and lower ends of a long section of ulna shaft (Figs. 7 and 8). The bones of the carpus and metacarpus were porotic.

The radial fracture components were approached anteriorly, mobilized, and brought into alignment. A steel bone plate was secured to the main proximal and distal fragments, and bone chips, from the iliac crest, were packed into and around the bone ends, many of them packed firmly beneath the plate so as to fill any gaps (Fig. 9). The ulna was not treated. A rigid splint was applied.

6 weeks: The wound had healed uneventfully and the leg was firm with little
apparent discomfort. Radiography revealed considerable filling of the radial gap with new bone but some bone chips could still be identified. The two pseudoarthroses in the ulna had greatly changed; the distal fracture had united, and in the proximal one the socket was smaller and less well formed (Fig. 10). A rigid splint was applied.

3½ months: Leg function was moderately good. Radiographically no free fragments were now visible and the new bone mass had the appearance of solid bone shaft. The proximal ulna fracture was almost completely healed. The osteoporosis was unchanged.

6 months: The splint was no longer needed and limb function was good but, there was very little carpal flexion.

10 months: Leg use was normal. Radiographically the radius/ulna had completely re-united, and the mineralization of the bones of the carpus and metacarpus had returned to normal (Fig. 11). Approximately 20° of flexion was now possible at the carpus.

Case 402834. Rough Collie female, 14 months old; body weight 17 kg.

The right femur was fractured in its middle third in a car accident. Treatment with an intramedullary pin but after 4 weeks the leg was still carried and there was
considerable movement at the fracture site. A large pin was introduced in order to improve stability of the fracture fragments. After another 5 weeks healing had still not occurred and the dog was referred for further surgery.

On radiographs the bone ends were found to be in apposition but there were large areas of lysis in each. A wide periosteal reaction enveloped almost the entire length of both components, suggesting chronic infection. The femur was approached laterally and the bone ends cut back to remove the lytic areas. A steel bone plate was applied, and bone chips from the iliac crest were packed into and around the fracture.

16 weeks: Leg use had, in the interim, gradually returned to normal. Radiographs revealed bony union with no evidence of the original periosteal reaction or lysis. The plate was not removed.

Case 403708. Toy Poodle, female, 10 months old; body weight 3 kg.

The dog fell off the seat of a car, fracturing its right radius/ulna close to the carpus. It was not taken to a veterinary surgeon until 2 weeks later because the doctor-owner did not at first believe the leg was fractured. A cast was applied but when this was removed after 5 weeks the foot was grossly angulated laterally and the fracture had not healed. Further casts were applied but healing still did not occur and, 4 months after the injury, the dog was referred for surgery. The leg was carried and there was free hinge-like movement at the fracture site.

The bone ends were brought into apposition, and alignment was maintained with a fine pin introduced along the bone from the carpus. Small chips of bone from the iliac crest were packed around the fracture. A split-cast was applied.

8 weeks: There was now very little movement on the fracture and leg use had improved. On radiographs the fracture line was less evident and the chips had been incorporated into the site.

12 weeks: Leg use was very good and the fracture was clinically united.

20 weeks: Radiographs revealed complete union, with the bone in good shape and normal in diameter; the pin had broken but it was not removed.

Bone autografts in arthrodesis of the carpus

Indications. Carpal fusion has been found to provide the most satisfactory remedy for dogs chronically lame because of the following conditions:

(a) Luxation or subluxation of the radio-carpal joint, with consequent instability or partial locking of the joint.

(b) Injuries, in some dogs, involving damage to individual carpal bones, and in others, complicated by fracture of the distal ulna or proximal metacarpus. The condition is not uncommonly bilateral and may be complicated by varying degrees of carpal hyperextension which, in severe cases, produces a plantigrade posture of the foot.

(c) Arthritis, usually trauma induced, which mostly involves the radio-carpal joint, but occasionally also the other carpal joints.

Technique. The type of procedure required depends largely on the nature of the
condition encountered and to some extent on the size of the dog. Fusion can be accomplished without the use of bone grafts but the outcome is not usually as satisfactory in terms of stability or the rapidity with which limb use returns. Conditions involving the radio-carpal joint far out-number those at other levels in the carpus, and most operations are directed to fusion at the former site. Not uncommonly, some degrees of ankylosis results in the lower joints as a consequence of the interference. For dogs with a plantigrade foot posture, however, all the carpal joints have to be fused in order to correct the hyperextension.

![Fig. 12. Wedge of iliac crest bone inserted between radius and radio-carpal bone.](image)

A tourniquet is routinely applied because the saving of operating time by eliminating haemorrhage is valuable, considering that time is initially spent in obtaining bone for grafting. An anterior approach is made to the carpus and the extensor tendons are isolated. The common digital extensor is retracted laterally. The extensor carpi radialis tendon is severed in order to improve exposure of the joint, and in any case the tendon is rendered functionless by the fusion. The joint capsule is cut horizontally to expose the joint surfaces.

The articular surfaces of the radius and of the radio-carpal bone are removed with an osteotome, together with a narrow band of subchondral bone. Using a sharp osteotome, hand pressure alone suffices in small dogs, but percussion with a hammer is needed in large dogs. A wedge of bone from the iliac crest is cut to
size and shape, and is inserted between the bone ends (Fig. 12). When the joint has been chronically subluxated the effects of tissue contraction have to be overcome before perfect re-alignment of the joint can be achieved. Small chips of bone are also packed in and around the site of fusion, filling in any small gaps.

The maintenance of apposition at the site of fusion can be accomplished in a number of ways. If the site appears stable, the wound is closed in routine manner and an external support applied with the carpus in extension. Frequently, the site is not stable, or the size and temperament of the dog is such that reliance cannot be placed on external support alone. Under these circumstances some form of internal fixation is essential. In small dogs, one or two arthrodesis wires are introduced obliquely across the carpus so as to transfix the radio-carpal bone and the graft, and are embedded in the radius. In medium-sized and large dogs a Sherman bone plate is applied to the anterior surface of the carpus. Wherever possible two screws are placed in the radius and two in the third metacarpal bone. A splint or cast is invariably applied and the dog is rigidly restricted for 6–8 weeks.

The carpus is radiographed at intervals to follow the process of fusion, and the removal of implants cannot be contemplated until union is complete. By this time pins are often loose and are removed, and some plates and screws have to be dealt with similarly. At first, flexion at the intercarpal and carpo-metacarpal levels is minimal but this usually relaxes slightly following a period of normal limb function. Some plates have been left in situ permanently, maintaining total extension of the carpus, but with no untoward sequelae.

Another technique that can be employed to fuse all the carpal joints is to use an inlay-graft of cortical bone across the distal radius and into the proximal metacarpus. Experience with this has been limited to one large dog with a plantigrade posture of both fore feet resulting from severe injury to all the carpal joints.

A long rectangular channel is removed from the anterior cortex of the distal radius, carpal bones, and the head of the third metacarpal bone using an electric saw. The articular surfaces at each joint level are deeply abraded. A cortical bone graft, taken from the tibia, is slotted into the prepared channel and secured with screws to the radius and metacarpus. External support is essential.

The following examples provide clinical data about four dogs in which carpal fusion was performed, three with a wedge graft and one with a cortical graft.

Case 403756. Dachshund, female, 6½ years old; body weight 5 kg.

The dog had been hit by a car 2 months previously, sustaining injury to its right foreleg; there was an oblique fracture 1 cm from the distal end of the ulna, and anterior dislocation of the carpus. The dislocation was corrected and a plaster-of-Paris cast applied. The cast was removed after 14 days because the dog appeared to be in pain and continued to carry the leg. The radius was still displaced anteriorly and there was considerable antero-posterior laxity in the radio-carpal joint (Fig. 13). It was evident that in such a small and awkwardly shaped limb, external fixation could not provide adequate support and consequently the dog was referred for a surgical repair.
Arthrodesis of the radio-carpal joint was performed using bone from the iliac crest. A single fine pin was introduced obliquely across the joint to secure the joint components and the graft together. A plaster-of-Paris cast was applied from the proximal forearm to the digits.

4 weeks: The leg was not being used. The cast was removed and the carpus was found to be firmly fixed in extension with no laxity. On radiographs the graft was clearly identifiable and there was little evidence of bone fusion. The pin was removed because it was loose, but joint stability remained unchanged. A further cast was applied.

8 weeks: Limb use was almost normal and an adhesive bandage provided the only support. The radio-carpal joint was rigid and without pain. Union at the site of arthrodesis was now evident although the graft was not completely incorporated into the fusion.

6 months: Function was normal. Approximately 10° flexion was possible at the lower carpal joints but the radio-carpal joint had completely ankylosed.

2 years: Function had been excellent since the last inspection although there was a tendency for the claws of this foot to wear more than usual. The radio-carpal

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Fig. 13. Case 403756. Lateral radiograph showing dislocation of carpus, 2 weeks after injury.

Fig. 14. Case 403756. Lateral radiograph, 2 years post-fusion.
joint was rigid but approximately 15° of flexion was possible at the lower carpal joints. Radiographs showed a total radio-carpal fusion (Fig. 14).

Case 401625. Rough Collie, female, 6 years old; body weight 20 kg.

The left carpus had been injured 5 months previously when the dog jumped out of a first-floor window. Although the joint was painful and swollen there was no apparent bone damage. A splint was applied for 3 weeks to immobilize the carpus because the dog was exceedingly active. Thereafter, however, a moderate lameness remained and it was aggravated by any form of activity.

![Image](image_url)

Fig. 15. Case 401625. Lateral radiograph of carpus, 4 years post-fusion.

At the time of referral, the carpus was enlarged and flexion was reduced by half. The foot was angulated medially. The distal radius was displaced anteriorly but there was no laxity in the antero-posterior direction. Radiographs revealed a radio-carpal subluxation with numerous exostoses at the distal end of the radius and ulna, and also on the proximal and distal borders of the accessory carpal bone close to its articulation with the carpus.

A carpal arthrodesis was performed using bone from the iliac crest. The cartilage at the distal end of the radius was severely eroded. A bone plate was applied across the anterior surface of the carpus, held by two screws in the distal radius and one in the radio-carpal bone. A plaster-of-Paris cast was applied from the elbow to the foot.
8 weeks: Limb function was good and the alignment of the foot had greatly improved. The entire carpus was rigid and manipulation caused no discomfort.

16 weeks: Limb function and foot posture continued to be good but one of the screws had loosened and it was necessary to remove the implants. On radiographs the graft was almost completely incorporated into a bone mass fusing the radiocarpal joint.

4 years: During the intervening period the dog had enjoyed complete freedom from lameness despite leading a very active life. A slight lameness had recently occurred but examination of the carpus revealed no swelling or pain. Radiographs showed a well established fusion but there was extensive exostosis formation on the carpal bones (Fig. 15).

![Image](image_url)

**Fig. 16. Case 203520. Lateral radiograph showing subluxation of carpus and non-union of ulna fracture, 2 months after injury.**

*Case 203520. Saluki, female, 2 years old; body weight 20 kg.*

The left carpus was injured when the bitch jumped awkwardly into a grass bank while coursing. The ulna had fractured near its distal end. A cast was applied but 2 weeks later the leg was still being carried and the animal was referred for advice. At this time the carpus was swollen and painful, and flexion was reduced by a third. On radiographs, the ulnar fracture did not appear to be healing, and a small chip had detached from the posterior aspect of the distal radius. A further period of splinting was advised.
2 months: The limb was used very little and the foot tended to deviate laterally from the carpus. Flexion was reduced even further and painful. Radiography now revealed anterior subluxation of the radio-carpal joint, the ulnar fracture was un-united and the bones of the foot were porotic (Fig. 16). Arthrodesis was performed using an iliac crest bone graft, and a bone plate was applied from the radius to the metacarpus.

4 months: Limb use had improved but the dog was still quite lame. Foot alignment and posture was normal and there was little or no local swelling or pain. Radiographs revealed satisfactory fusion and the ulna fracture had healed (Fig. 17).

*Fig. 17. Case 203320. Radiographs showing state of fusion after 9 weeks, and union of ulna.*

*Case 403639. Alsatian, male, 3 years old; body weight 36 kg.*

Both carpal joints were severely injured when the dog jumped about 45 ft down a cliff. External support was provided for each limb but 4 weeks later the dog walked plantigrade and could only manage several yards before collapsing. Radiographs revealed in each limb, a defect of the radio-carpal joint, with a medial displacement of the carpal bones, and a fracture at the head of the fifth metacarpal bone.

An arthrodesis procedure was performed on the left carpus using inlay graft technique, with bone removed from the tibia. The graft was secured with
screws into the radius and third metacarpal bone (Fig. 18). A plaster cast was applied.

12 weeks: Foot posture had improved but the radio-carpal joint was still slightly mobile. A similar procedure was performed on the right carpus.

20 weeks: The carpal joints were stable and weight-bearing caused no hyper-extension of the foot.

24 weeks: With increasing weight-bearing the feet had become more hyper-extended. Radiographs showed incomplete incorporation of the graft in each joint, with fracture of the graft at some screw holes. The owner now decided not to continue with treatment and the dog was destroyed.

DISCUSSION

The histological fate of transplanted bone has been the subject of vigorous controversy ever since detailed consideration was given to the process of regenerative osteogenesis where bone grafts are employed. Early investigators were well aware, from clinical and experimental observations, that an autogenous or homogenous bone graft could provide a replacement where there had been bone loss, or contribute to the healing of a non-union fracture. That new bone developed
at the graft site was not disputed but opinions differed about its cellular source. The main possibilities are, that new bone formation depends on the survival of the bone cells of the graft, or that the graft acts merely as a scaffolding and is involved in a long process of revascularization, absorption and replacement. Barth (1893), and Axhausen (1909), two pioneers in this field of study, were convinced that most of the graft died and underwent replacement, although Axhausen showed that periosteum could survive and provide a source of osteogenesis. This view is shared by the majority of researchers today, and has been supported by the results of experiments in recent times. Chalmers & Sissons (1959) failed to find surviving osteocytes in any autogenous or homogenous grafts, while Ross (1966) found most lacunae empty by 7 days and all empty by 14 days after transfer. There are, nevertheless, some workers who believe that at least some cells of a fresh autograft do survive transfer and are active in the formation of new bone (Campbell et al., 1953; Bonfiglio, 1958).

The process of repair and re-organization is through vascular connective tissue which invades from the periosteum of the host, and also from the surrounding tissues. By transformation this becomes osteoblastic or osteoclastic with subsequent re-organization of the spongiosa and compacta. All re-organization is by resorption and apposition.

The rate at which invasion and replacement of the graft occurs is influenced by a number of factors. The physical nature of the bony element is important in this respect. Cancellous bone is relatively rapidly replaced because it has thin trabeculae and large channels which provide ready entrance for vessels and allow extensive contact with tissue fluid. Cortical bone is very dense and the ingress of vessels has to be via small Haversian canals, which militates against rapid substitution. It is for the same reasons that fractures of spongy bones, such as the ilium, heal more rapidly and with a considerably lower incidence of non-union than fractures of compact bone. Rib compactum falls into a slightly different category because the Haversian spaces are more numerous and larger than in long bone, and access for blood vessels is thereby easier.

Account has also to be taken of the size of the graft and the age of the donor animal. Small fragments, and young bone regenerate more rapidly than large pieces and mature bone because the former are more readily vascularized.

The origin of the transplant and whether it is fresh or dead are also important considerations. The relative merits of fresh autografts, fresh homografts and various types of preserved bone grafts have been the subject of extensive investigation. It has been established that many different forms of graft, viable or dead, may be utilized by the host in the process of osteogenesis. It is generally agreed that the healing process is most rapid with autogenous grafts, whereas with all other grafts resorption and apposition is delayed. So far as autografts and homografts are concerned, however, the difference in the healing rate is not significant enough to affect the use of homografts clinically. Recent experimental studies have tended to re-inforce these opinions. Chalmers & Sissons (1959) compared, in
dogs, fresh autografts with various homografts (fresh, frozen, autoclaved, freeze-dried, decalcified, freeze-dried irradiated) and deproteinized bone. The progress of the grafts was followed microradiographically and histologically for 6–9 months after transfer. Fresh autografts were found to stimulate more new bone formation than fresh homografts. The differences between the behaviour of the other types were unimportant. Similarly, Ross (1966), in experiments using dogs, was unable to distinguish any difference in the healing rate of fresh autogenous, frozen homogenous or plasma-stored homogenous grafts, even in the early stages after transfer.

The implications of these findings are of great importance to the practical application of bone transplantation. The use of homografts rather than autografts avoids the need for two operations, thus reducing surgical hazard and saving the patient discomfort. To be practical, however, graft bone must be readily available which means it has to be preserved and stored in sterile conditions. Interest in storing bone dates back to early this century but the concepts of a bone bank emerged largely from the work of Inclan (1942) who successfully used bone preserved at low temperature in sterile jars of citrated blood or Ringer’s solution. The method was developed by Bush (1947) and Wilson (1947), the bone being stored at −20°C in sealed containers, and this technique is still widely used today. Proof that refrigerated homografts are well tolerated by the host has been provided by several clinical studies in human beings. Bush & Garber (1948) had only four complications out of 126 operations. Wilson (1951) reported a success rate of 80% in 214 people, with only four infections, and loss of the graft in two cases. At a temperature of −25°C it is believed that bone may be preserved indefinitely. Storage in merthiolate solution, and the freeze-dried technique have also been successful.

Obtaining homogenous bone of sufficient quantity and quality presents difficulties in human medicine. In small animal practice, however, there should be no problem in obtaining a ready supply from dogs after euthanasia, so setting up a bone bank ought to be a feasible proposition. Samples would have to be collected aseptically and stored in deep freeze. The author has so far used refrigerated homografts in only one dog; sections of rib were used in the treatment of a non-union fracture of the radius-ulna in a Toy Poodle, but the final outcome of this is not yet known. An alternative method would be to delay the operation until a suitable donor dog was available and then to use fresh homogenous bone.

Heterogenous bone is generally considered to be inferior to autogenous and homogenous bone for grafting because it is much less readily incorporated into the host bone. Success with specially treated, or stored, heterogenous grafts has, however, been reported. Screws prepared from bovine bone have been used in human surgery for many years; this bone usually disappears in time and the gap eventually fills in. At one time the use was advocated of cadaveric human and animal bone with its protein extracted and boiled, material which became known as Os purum (Orell, 1937). Guilleminet, Stagnara & Perret (1953) prepared rods
of cortical bone and cubes of cancellous bone from calves 6–8 months old. The bones were removed and prepared under strict aseptic precautions, and stored at $-35^\circ\text{C}$. In calf-to-dog experiments and in a clinical study of calf-to-man the results were comparable to those seen with autografts although incorporation of the graft was a little slower. Satisfactory results with the clinical use of heterografts in animals have also been reported. Temizer (1956) used pins prepared from dried horse bone and autoclaved. Banic (1971) has repaired a large defect in the femur of a dog with calf metatarsal bone.

The decision as to whether a graft of cortical or cancellous bone should be used depends largely on the purpose for which it is required. Rectangular strips of cortical bone possess rigidity and strength and can serve a dual purpose, providing stability as well as furnishing osteosynthesis. Their disadvantages are that they seldom survive in the presence of infection and are extruded as sequestra, and that once their density is reduced by the repair process they are vulnerable to injury and are liable to fracture. In human surgery they are used as inlay, onlay and sliding-inlay grafts in the treatment of non-union fractures. In dogs non-union fractures are most common in the radius–ulna of small breeds and the techniques involved with compact bone grafting are not practical in bones of such small diameter. Cortical grafts appear to have an application in fusion of the carpus in medium to large sized dogs. Judged, however, by the unsuccessful case described in this paper reliance should not be put on the strength of the graft alone, and supplementary fixation with a plate is needed to safeguard against breakdown due to inordinate limb use.

Cancellous bone chips possess a high degree of viability in the presence of infection but they provide no stability and some form of internal fixation is essential to ensure immobilization. The author has found them of special value in the treatment of non-union fractures of the radius–ulna and femur. In very small dogs an intramedullary pin is used to provide stability and alignment, but plates are preferred for larger dogs. For this purpose bone has been taken from the iliac crest; this is not entirely cancellous but the covering of compactum is extremely thin. No lameness or disfigurement of pelvis contour has resulted from this technique. Nestle (1964) has reported success with frozen bone chips placed around a fracture of the radius–ulna in a Chihuahua without an implant, but external support was provided. Another purpose for which cancellous bone is indicated is to pack bone cavities, as in bone cysts or benign bone tumours.

For the replacement of large sections of long bones in dogs, rib grafts offer the best solution. They have been used in the repair of badly comminuted shaft fractures (Walker, 1966b) and for replacing diseased bone (Owen & Walker, 1963). Ribs are unfortunately curved in two planes and only in large dogs is it possible to obtain reasonable lengths of relatively flat, straight bone. Ribs are not as brittle as compact bone and in medium and large size dogs will accept screws without splitting.

Injury to the carpus, resulting in instability, displacement or severe arthritis,
produces a lameness which can best be remedied by arthrodesis. The technique of inserting a wedge of bone from the iliac crest to stimulate osteogenesis at the site of fusion is similar to that described by Hurov et al. (1966), but the latter merely débrided the articular surfaces instead of removing them, and did not use internal fixation to secure the joint components together. The indication for fusion in their cases, however, was to improve foot posture in dogs with radial paralysis and the carpus was basically normal. With the type of chronic carpal lesion described here, additional stability is needed to keep the bones in apposition and alignment.

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Résumé. L'auteur donne un aperçu des possibilités de recours aux autogreffes osseuses pour la réparation des fractures avec désunion et dans le traitement des lésions carpiennes graves chez le chien. Il décrit les méthodes d'obtention de greffons des côtes, de la crête iliaque et du cortex tibial, ainsi que les techniques de mise en place au site des fractures et en vue du fusionnement carpien. Chaque procédé est illustré par quatre comptes rendus de cas. Le sort des os greffés l'importance d'une banque des os et l'emploi d'homogreffes et d'hétérogreffes font l'objet d'importantes considérations théoriques.