Bone Grafts: A Radiologic, Histologic, and Biomechanical Model Comparing Autografts, Allografts, and Free Vascularized Bone Grafts

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The introduction of bone-grafting techniques in the late nineteenth century by Barth led to their use in the treatment of nonunions, arthrodesis of joints, filling of bone cavities secondary to infection, replacement of bone loss secondary to trauma or tumor reconstruction, and replacement of joint surfaces. The various techniques have evolved to the following: autogenous bone grafts, allograft bone transplants, and free vascularized bone grafts.

An experimental model was developed to compare the relative merits of corticocancellous matchstick autografts, conventional segmental autografts, free vascularized bone grafts, and fresh segmental allografts with respect to radiologic, histologic, and biomechanical properties in terms of their ability to span a large segmental bone defect in the canine femur.

MATERIALS AND METHODS

Forty-five adult mongrel dogs weighing 25 to 30 kg were used, and in each, skeletal maturity was confirmed by radiologic closure of the femoral epiphyseal plates. The animals were observed for at least 3 weeks prior to surgery and examined to rule out any musculoskeletal abnormalities. Intravenous Nembutal (Abbott) anesthesia was used to perform the operations, and prophylactic penicillin was given intramuscularly preoperatively and for the first 5 days postoperatively.

A schematic drawing of the experimental model is shown in Fig. 1. A medial extraperiosteal approach was employed to expose the entire length of the femur. A modified ASIF 245-mm leg lengthening plate (courtesy of AO International) was then rigidly fixed to the femur with six 4.5-mm cortical screws. The intermediate 7-cm diaphyseal segment was then dissected extraperiosteally from all soft tissue, which included the quadriceps anteriorly and laterally and the adductor magnus and gluteus maximus medially and posteriorly. The 7-cm diaphyseal segment was removed after osteotomy proximally and distally with a Gigli saw. In the distal portion of the incision, the saphenous artery and vein were identified and prepared as recipient vessels. Hemostasis was obtained throughout the incision, and the wound was temporarily packed while the donor rib graft was taken.

Following sterile technique, a right-sided thoracotomy was performed. The ninth rib was exposed from its origin at the costovertebral joint posteriorly around to the osteochondral junction anterolaterally. The intercostal muscles were detached extraperiosteally along the superior border but preserved along the inferior border of the rib, where the intercostal vessels are located. A length of rib was marked off 9 cm anterior from the costotransverse joint, and the anterior end was transected with a bone cutter. Attention was then turned to the intercostal vein and artery at their origin adjacent to the vertebrae in the posterior thorax. The vessels were dissected free deep to the pleura and hemoclipped and divided preserving as long a vascular pedicle as possible. This was usually 1- to 2-cm pedicle limited medially by the aygos vein. The time the vessel
were ligated was recorded as the beginning of graft ischemia. The costovertebral joint was divided, and the rib was removed with its vascular pedicle and immersed in an ice-chilled saline bath at 4°C. Hemostasis was obtained and the thoracotomy was closed over suction drains.

The rib graft was prepared as either a revascularized autograft, a conventional autograft, a corticocancellous matchstick autograft, or an avascular allograft.

**Revascularized Autografts**

There were 14 dogs in this group. The intercostal vascular pedicle of the rib graft was examined under the operating microscope, and side branches were ligated. A spinal branch passing into the intervertebral foramen was a consistent finding and was occluded with a small hemoclip. The vessel ends were dissected free of adventitia and were dilated. The muscle cuff was trimmed 1 cm from each end of the rib graft, leaving 7 cm of rib covered with muscle cuff and 1 cm at each end free of soft tissue to be telescoped into the medullary canal at each end of the femoral defect. The graft was secured into the 7-cm surgically created femoral defect with one of the three screws at each end of the plate, transfixing the plate, graft, and femur as shown in Fig. 1. Microvascular anastomoses of the intercostal artery and vein to the saphenous artery and vein were performed with interrupted 9-0 nylon sutures using an operating microscope. Ischemia time averaged 2 hours.

**Conventional Autografts**

There were 9 dogs in this group. The same procedure was followed as in the vascularized autografts, except that the soft-tissue cuff consisting of the intercostal muscle and neurovascular pedicle was removed from the rib extraperiosteally.

**Corticocancellous Matchstick Autografts**

There were 8 dogs in this group. The rib was harvested as described earlier, and the soft-tissue cuff was removed as in the conventional autograft group. The bone was cut longitudinally into four matchstick pieces and placed in the 7-cm femoral defect.

**Fresh Avascular Allografts**

There were 9 dogs in this group. The rib was harvested as described earlier, but from a non-related dog of similar size on a second operating table, and it was placed in the 7-cm femoral defect and secured with plate and screws after extraperiosteally removing all soft tissue. No attempt was made to match the dogs except for size, and selection was random according to the sequence of delivery from the animal colony.

At the completion of surgery, a percutaneous Achilles tenotomy was performed on each recipient extremity. A short, light-weight, waterproof, fiberglass cast was applied to hold the ankle in full dorsiflexion and thus prevent weight-bearing. This allowed the animal to ambulate on three legs during the initial 3-month period, after which time the cast was removed, allowing progressive, unprotected activity as tolerated. The animals were maintained in individual 4 x 6 ft enclosures throughout the study.

**Roentgenograms**

Roentgenograms were taken of the grafted femurs at 1 week, 3 months, and 6 months postoperatively with a standard 11 x 14 inch radiograph at a 40-inch film-to-tube distance at 72 kV and 15 mAs in both an anteroposterior and a
lateral projection. For constant positioning, the
dog was sedated and placed on a table that was
modified to hold the thigh flat. The criteria used
to assess the radiologic healing of the graft are
shown in Table I. Both graft-femur junctions
and the midsection of the graft were analyzed
and given a radiologic score at the three time
intervals. A maximum score of 18 could be
achieved if the defect was fully reconstituted and
remodeled to the size of the original femur. If
the roentgenogram disclosed loss of rigid fixation
with graft fracture or loosening of the plate or
screws, these animals were excluded from the
average radiologic scores and mechanical testing
and considered as complications.

Arteriography

In the revascularized autograft group, arteri-
ography was performed at 1 week, 3 months,
and 6 months. The femoral artery of the grafted
extremity was punctured with an 18-gauge
Quick-cath plastic cannula and 15 cc of Conray-40
was injected over 5 seconds. A single antero-
posterior exposure was taken as the injection was
completed. The criteria used to judge graft-ar-
terial patency was a continuous column of con-
trast medium extending from the saphenous ar-
tery to the intercostal pedicle along the medial
margin of the rib graft.

Fluorochrome Labeling

At the same intervals at which radiographs
were taken, fluorochrome bone markers were
administered to indicate new bone formation.
These consisted of oxytetracycline (yellow), 25
mg/kg of body weight, given on the first day
postoperatively; Alizarin complexone (red), 25
mg/kg of body weight, at 3 months; and DCAF
(green), 20 mg/kg of body weight, at 6 months
postoperatively.

<table>
<thead>
<tr>
<th>TABLE 1</th>
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<tbody>
<tr>
<td>X-Ray Rating System</td>
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<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Proximal/Distal Junction</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>0 Complete resorption/pseudarthrosis</td>
</tr>
<tr>
<td>1 Severe resorption</td>
</tr>
<tr>
<td>2 Mild resorption</td>
</tr>
<tr>
<td>3 Resembling postoperative</td>
</tr>
<tr>
<td>4 Early union</td>
</tr>
<tr>
<td>5 Solid union</td>
</tr>
<tr>
<td>6 Remodeled to size of femur</td>
</tr>
</tbody>
</table>

Specimen Preparation

At 6 months, animals were sacrificed with a
barbiturate overdose. To prepare the specimens
for microangiography, Micropaque (Picker) was
infused through a catheter into the left femoral
artery. Micropaque is a radiopaque aqueous sus-
pension of barium sulfate with a particle size of
7 to 15 μm, allowing visualization of vessels as
small as 10 μm. The infusion technique was mod-
ified, but similar to that of Rhinelander et al.11
A 10% by weight suspension of Micropaque in
normal saline was infused from a 500-cc reservoir
pressurized by a manual bulb pump maintaining
a pressure of 110 to 120 mmHg as recorded on
a blood pressure manometer connected in par-
allel with the system. After infusion of 250 cc of
the preceding solution, 250 cc of a second solu-
tion of 30% Micropaque in saline was infused,
and finally, a third solution of 30% Micropaque
in 10% buffered Formalin was infused. The last
infusion appeared to cause vasospasm and was
maintained under pressure for 10 minutes, but
usually, only 10 to 25 cc of this final solution
could be infused. The operated and control fe-
murs were then harvested, preserving a 1-cm
soft-tissue cuff around the grafted area. The
plate and screws were removed, and specimens
were radiographed on a detail screen film at 60
kV and 5 mAs at 40 inches.

Mechanical Testing

The femurs were prepared for mechanical
testing by potting both ends in a MMED mate-
rials testing apparatus using self-curing methyl
methacrylate cement. The bone was tested at a
rate of 19 degrees of torsional rotation per sec-
ond; angular torque registered in newton-meters
and torsional displacement in degrees were si-
multaneously plotted on an x-y recorder. Testing
was performed to ultimate strength at fracture,
recording the mechanical stiffness and energy to
failure from the plotted curves. Both the oper-
ated and control femurs were tested in all animals
as well as several control ribs. After failure, spec-
imens were again x-rayed to delineate the nature
and location of the fracture in the graft. The 7-
cm length of rib graft provided a constant length
of specimen situated between the relatively rigid
femur at both ends of the graft for mechanical
testing. During mechanical testing, the bones
were wrapped with a moistened towel to prevent
dehydration. The process, from sacrifice through completion of mechanical testing and
sectioning of specimens for histology, took less than 2 hours, ensuring analysis of specimens in their fresh state.

**Histology and Microangiography**

Cross-sectional specimens were taken as shown in Fig. 1 after mechanical testing was completed. From the midsection of the graft, one group of samples was fixed in Formalin, decalcified in RDO rapid bone decalcifier (DuPage Kinetic Laboratories, Naperville, Illinois), and processed to a standard 6-µm paraffin section stained with hematoxylin and eosin. For microangiograms, similar 2.4-mm-thick cross-sectional slices of the graft were decalcified and x-rayed on Kodak high-resolution XTL-2 film for 2 minutes at 15 kV and 3 mA.

The criteria used to assess the microangiograms were size of new vessels in the graft, pattern of vascularity across the bone from endosteum to periosteum (highly vascular areas indicating active osteogenesis), and areas of nonfusion. These patterns were correlated with the sequential fluorochrome bone labels.

A third group of cross-sectional samples from the midsection of the graft were fixed in alcohol and embedded in plastic without decalcification. These were cut to 125-µm sections and viewed under incident fluorescent light to record the spatial patterns of the fluorochrome labels.

**RESULTS**

Of the 45 dogs studied, 14 were excluded because of complications, leaving 31 animals followed for a minimum of 6 months (Table II). Three dogs in the vascularized autograft group were followed for 1 year. Ten complications relating to the graft all involved loss of internal fixation, while the remaining four dogs were sacrificed because of pneumonia or parasitic skin infections. There were no surgical wound infections in this series.

**Roentgenograms**

Radiologic assessment of bony union at the graft-host junctions and evaluation of the body of the graft according to the x-ray rating system in the vascular autografts.

**TABLE II**

Distribution of Dogs in Groups and Complications

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Dogs</th>
<th>Complications Not Related to Graft (No. of Dogs)</th>
<th>Complications Related to Graft (No. of Dogs)</th>
<th>Followed to 6 Months (No. of Dogs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avascular autograft</td>
<td>9</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Matchstick autograft</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Avascular allograft</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Vascular autograft</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>13</td>
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<tr>
<td>Practice</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>0</td>
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<tr>
<td>TOTAL</td>
<td>45</td>
<td>4</td>
<td>10</td>
<td>31</td>
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</table>
groups studied. By 6 months, 25 of 26 autografts showed union at both ends of the graft, while only 2 of 5 allografts were united proximally and distally. These results are summarized in Table III.

Evaluation of hypertrophy of the graft, as reflected by the numerical score of the midportion of the graft, revealed a trend for more frequent hypertrophy in the vascular autografts, matchstick autografts, avascular autografts, and avascular allografts in decreasing order (Table IV). Bone resorption was not observed in any of the autograft groups but was observed in two of five allografts at 6 months.

Roentgenograms in Fig. 6 illustrate the average appearance of each group with respect to bone union and graft hypertrophy.

**Mechanical Testing**

Mechanical strength testing results are shown in Table V and Fig. 7. There was considerable variation within each group and overlap between groups. However, on average, the grafts' strength to fracture ranked in decreasing order as follows: vascular autografts, avascular autografts, matchstick autografts, and avascular allografts.
Fig. 6. (Above, left) Anteroposterior and lateral roentgenograms of a vascular autograft at 6 months. The plate and screws have been removed to show the graft clearly. Solid incorporation of the graft proximally and distally and moderate new bone formation on the medial and posterior surfaces is apparent. Postmortem barium infusion for microangiography shows patent intercostal artery. (Above, right) Anteroposterior and lateral roentgenograms of an avascular (conventional) autograft at 6 months. The plate and screws have been removed to show the graft clearly. There is union of the graft at both ends. (The fracture located proximally was produced during mechanical testing.) Hypertrophy is apparent on the concave (posterior) side of the rib graft. (Below, left) Anteroposterior and lateral roentgenograms of a matchstick autograft at 6 months. The plate and screws have been removed to show the graft clearly. Solid incorporation of the graft proximally and distally and new bone formation around the body of the graft are seen. (Below, right) Anteroposterior and lateral roentgenograms of an avascular allograft at 6 months. The plate and screws have been removed to show the graft clearly. Union of the graft has taken place proximally and distally, but significant resorption and osteopenia is apparent in the body of the graft.
TABLE V
Average Graft Fracture Torque (Newton-Meters)

<table>
<thead>
<tr>
<th>Group</th>
<th>Average</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>Vascular autograft</td>
<td>11.0</td>
<td>2.8–24.1</td>
</tr>
<tr>
<td>Avascular autograft</td>
<td>8.4</td>
<td>0–14.0</td>
</tr>
<tr>
<td>Matchstick autograft</td>
<td>4.3</td>
<td>0–11.4</td>
</tr>
<tr>
<td>Avascular allograft</td>
<td>1.9</td>
<td>0–4.6</td>
</tr>
<tr>
<td>Control femur</td>
<td>57.8</td>
<td>40.6–76.2</td>
</tr>
<tr>
<td>Control rib</td>
<td>1.9</td>
<td>1.0–5.2</td>
</tr>
</tbody>
</table>

FRACTURE TORQUE

Fig. 7. The graph illustrates mechanical strength testing results to fracture of the four experimental groups. As can be seen, there was considerable variation within groups, but the vascular autografts achieved the highest strength to fracture.

TABLE VI
Arteriography in Vascular Autografts

<table>
<thead>
<tr>
<th>Dog</th>
<th>Arteriography, Months Postoperative</th>
<th>Arteriography, Sacrifice</th>
<th>Anastomosis Patency</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>3</td>
<td>6</td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td>19</td>
<td>—</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>21</td>
<td>O</td>
<td>O</td>
<td>—</td>
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<tr>
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<td>—</td>
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<td>X</td>
<td>X</td>
</tr>
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<td>29</td>
<td>O</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>30</td>
<td>O</td>
<td>O</td>
<td>—</td>
</tr>
<tr>
<td>48</td>
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<td>51</td>
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<td>62</td>
<td>O</td>
<td>—</td>
<td>O</td>
</tr>
<tr>
<td>63</td>
<td>O</td>
<td>—</td>
<td>O</td>
</tr>
</tbody>
</table>

* O = Anastomosis open; X = Anastomosis closed; — = vessel not identified.

Arteriography

Arteriograms were performed only in the vascular autograft group (Table VI). While immediate postoperative arteriograms were not done in the first five animals, the final eight vascular autografts showed 100 percent patency at 1 week after surgery (Fig. 8). At 3 months, six arteriograms demonstrated patent vessels, and five did not. With one exception (dog 48), the arteriograms performed at 6 months showed the same results as the previous 3-month arteriograms. At 6-month sacrifice, by taking x-rays of the resected femur after the injection of Micropaque for microangiograms, visualization of the intercostal artery along the margin of the graft was possible. Seven patent intercostal arteries were seen, while six were not. This observation did not correlate well with the presacrifice arterio-

grafts. As is evident, no graft approached the mechanical strength of the contralateral femur, but the microsurgically revascularized rib autografts were clearly the strongest, averaging 11.0 newton-meters to fracture, which was, however, only 19 percent of the control femurs.

Fig. 8. Anteroposterior arteriogram showing patent intercostal artery along the body of the graft (two arrows). The saphenous artery can be seen branching off the femoral artery to the left of the midportion of the plate (arrow) and passing to the area of the microarterial anastomosis (behind plate) and looping back into the intercostal artery along the rib graft to the right side of the plate.
grams and may be due to inadequate filling of small vessels or recanalization of previously occluded vessels. At sacrifice, evaluation of the anastomoses was performed with the operating microscope. Nine arterial anastomoses were examined, and all were found to be patent, while seven of eight venous anastomoses were patent. The anastomoses in four animals were not examined.

Histology

All four experimental groups, including the vascularized autografts, demonstrated a similar histologic appearance with areas of viable cortex surrounding areas of necrotic bone and peripheral new bone deposition. However, the extent of new peripheral bone deposition and cortical viability was characteristic for each of the groups. Revascularization by "creeping substitution" was most marked in the avascular block autografts and least apparent in the avascular allografts.

The histologic appearance of the bone marrow gave the clearest demonstration of viability of the graft. At 6-month sacrifice, all avascular autografts and allografts showed diffuse marrow fibrosis, indicating death of the original marrow and subsequent revascularization (Fig. 9). By contrast, the microsurgically revascularized autografts all showed normal marrow at 6 months with a fine reticular, largely adipose network (Fig. 10). The nutrient artery in the marrow was patent and filled with Micropaque in all vascular autografts.

Persistence of original dead cortex was greatest in the avascular allografts, where over half the original cortex was devoid of osteocytes and demonstrated little evidence of revascularization (Fig. 11). In the avascular autografts, approximately 25 percent of the original cortex remained with osteons devoid of osteocytes. The matchstick autografts also showed small islands of bone where the original segment of dead cortex remained surrounded by fibrous tissue (Fig. 12), while the vascularized autografts demonstrated the greatest degree of cortical viability.

Fluorochrome Bone Labels

The tetracycline marker given on the first day after surgery was seen in the undecalcified sections in 11 of 13 vascularized autografts and in none of the other groups. Concentration was noted in the central cancellous trabeculae and periosteum, with little tetracycline labeling visualized in the cortex. Similarly, normal control cortical ribs examined showed only a few labeled osteons in the cortex, indicating relatively little new bone formation. The 3-month Alizarin labels most clearly demonstrated the difference in

Fig. 9. Photomicrograph of an avascular autograft at 6 months showing replacement of the marrow with fibrous tissue (H&E; ×100).
new bone formation between the four groups. Intense areas of uptake were seen throughout the cortex and cancellous portions of the vascularized grafts. The avascular autografts also demonstrated active new bone formation throughout the cortex and cancellous portions of the grafts, while the avascular allografts showed scant new bone formation at the periosteal surface only.

**Fig. 10.** Photomicrograph of vascular autograft at 6 months illustrating normal marrow with a fine reticular, largely adipose stroma and a patent nutrient artery filled with Micropaque seen in the center (H&E; ×100).

**Fig. 11.** Photomicrograph of an avascular allograft at 6 months demonstrating marrow fibrosis and necrotic cortex. Over 50 percent of the cortex is devoid of osteocytes in their lacunae (H&E; ×100).
The matchstick autografts typically showed minimal new bone formation around one or two segments of the original graft cortex. Six-month labeling with DCAF generally exhibited much less new bone activity in the autografts than seen with the 3-month Alizarin label. Allografts demonstrated new bone formation at the peripheral portions of the rib cortex, but this was generally incomplete at 6 months.

Microangiograms

Microangiograms of the three autograft groups all demonstrated excellent vascularization throughout the graft at 6 months. However, only in the microsurgically revascularized autografts was a well-developed medullary artery apparent. While revascularization was demonstrated in the allografts, it was confined to the outer cortex with no evidence of vascularization in the endosteal or medullary areas.

Discussion

In this experimental model, microsurgically revascularized autografts were superior to all other groups with the least complications, earlier union at the juncture sites, earlier hypertrophy rates, and the highest mechanical strengths. In the vascularized group, there were no failures due to loss of internal fixation. By contrast, loss of fixation in the avascular block autografts and fresh allografts (five dogs), once initiated, always progressed to resorption of the graft, fracture, and loss of function of the extremity.

Union of the bone graft to the recipient femur at the proximal and distal junctures was achieved by 6 months in 25 of 26 autografts. No difference in union rate was seen within the autograft group at this time interval, but it was apparent in 9 of 13 dogs with vascular autografts at 3 months. However, only two of five allografts followed for 6 months achieved bony union to the recipient site, indicating a superiority of autografts over fresh allografts in this respect. Fresh-frozen or freeze-dried allografts are currently being employed by many surgeons for the reconstruction of bony defects with excellent clinical results. They have a markedly decreased antigenicity when compared with fresh allografts, and there is no doubt that the results obtained in the allograft group of experimental animals would have been better if they were used instead of fresh allograft preparations.

The rigid internal fixation employed to secure the rib grafts within the 7-cm segmental femoral defect in this experimental model provided considerable stress protection to the grafts in all four groups, thereby creating a most unfavorable environment for the incorporation and hypertrophy of the four experimental grafts performed. Our goal was to evaluate conventional bone-
grafting techniques with respect to vascularized bone grafts in a difficult experimental situation. In clinical practice, conventional autografts, matchstick autografts, and allografts play a significant role in the reconstruction of skeletal defects.

Mechanical testing revealed considerable variation within each group and overlap between groups. No clear difference between groups was found, and the results obtained were not statistically significant. While the vascularized autografts demonstrated only 19 percent of the control femurs' mechanical strength to fracture, they did show greater evidence of hypertrophy upon radiographic evaluation than the other three groups. If internal fixation was removed once union of the graft occurred, differences in the rate of hypertrophy most likely would have been observed if partial weight-bearing could have been controlled. This was not considered feasible in the present experiment because of cost factors and an inability to control partial weight-bearing in the animals.

Arteriography, microangiography, fluorochrome, and histologic studies all supported the concept that microsurgically revascularized grafts, when successful, maintain their viability. The increased incorporation rate (at 3 months; see Table III) of the vascular autografts compared with the avascular autografts can be attributed to the technique of microsurgical revascularization and continued viability of the graft, as can the observed graft hypertrophy (Table IV) and greater mechanical strength to failure (Table V and Fig. 7). Correlation of graft hypertrophy with union at both ends of the graft revealed that hypertrophy of the graft occurred only after solid union at both ends had been achieved.

The premise that all osteocytes survive in a successfully revascularized bone graft is open to question. While the decalcified sections showed that all microsurgically revascularized grafts maintained normal viability in the central marrow and cancellous portions compared with the other three groups in this study, all of which underwent marrow fibrosis after revascularization by creeping substitution, the viability of cortical bone in the vascularized autografts was less clear. The undecalcified fluorochrome-labeled sections suggested that circulation was not preserved in all portions of the cortex in the microsurgically revascularized autografts, and creeping substitution was observed, although to a lesser degree than in the avascular (conventional) autografts and matchstick autografts. Revascularization of the conventional autografts proceeded in a centripetal direction, and in the 2- to 3-mm rib cortex, revascularization was generally completed by 3 months. For the fresh allografts, the process was not complete at 6-month sacrifice.

CONCLUSIONS

The animal model employed in this study enabled us to evaluate the efficacy of avascular autografts, avascular matchstick autografts, fresh avascular block allografts, and microsurgically revascularized autografts in the reconstruction of a 7-cm segmental bone defect created in the dog femur. Of the three most commonly used bone-grafting techniques employed to reconstruct massive bone defects, autografts and matchstick autografts were clearly superior to the fresh allografts. The two types of avascular autografts behaved similarly, while the allografts were inferior with respect to delayed or absent incorporation and frequent bone resorption.

The autografts revascularized by microsurgical techniques demonstrated a high rate of vascular patency and bone survival, especially in the central portions of the graft. The vascularized grafts were more successful than the other three types in terms of early bone union, hypertrophy, and greater mechanical strength to failure.

SUMMARY

We developed an experimental model to compare the efficacy of free vascularized bone grafts, conventional segmental autografts, matchstick autografts, and fresh segmental allografts in terms of their ability to reconstruct a 7-cm segmental diaphyseal defect created in the canine femur. Forty-five adult mongrel dogs were studied and followed for 6 to 12 months prior to sacrifice. Evaluation included radiologic assessment of graft incorporation and hypertrophy, histology, and biomechanical testing.

These studies indicated that microsurgically revascularized autografts were superior to all other groups in terms of early incorporation, hypertrophy, and the highest mechanical strength to failure. Union of the bone graft to the recipient femur was achieved by 6 months in 25 of 26 autografts, and no difference in union rate was seen within the autograft group. However, only two of five allografts achieved bony union during this time interval. Arteriography, microangiography, fluorochrome, and histologic
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studies all supported the concept that microsurgically revascularized grafts, when successful, maintain their viability. However, the premise that all osteocytes survive in a successfully revascularized bone graft is open to question. While decalcified sections showed that all microsurgically revascularized grafts maintained normal viability in the central marrow and cancellous portions compared with the other three groups, the viability of cortical bone in the vascularized autografts was less clear. Decalcified fluorescentochrome sections suggested that circulation was not preserved in all portions of the cortex. Revascularization of the nonvascularized autografts was complete at 3 months, while, in the avascular allografts, the process was not complete at 6 months.

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