OSTEOCHONDRAL GRAFTS AND BONE TRANSPLANTS

Tom Merrill, D.P.M.
E. Dalton McGlamry, D.P.M.
Kieran Mahan, D.P.M.

Introduction

The use of bone graft materials has greatly enhanced the surgical procedures available for the reconstruction of the foot and leg. Bone grafts are now commonly used in many podiatric procedures including the Evans calcaneal osteotomy, facilitation of arthrodesis procedures, packing of bone cysts, and repair of nonunions. As new bone graft materials are being introduced, new reconstructive procedures are being developed.

An in-depth study of bone graft healing physiology and the complex research currently being done is unfortunately not within the scope of this text. We will provide a ground work of useful information and highlight several areas of clinical interest. Prior to a discussion concerning the evolution of bone graft technology, we will first outline some basic terminology.

Grafts containing only bone are intercalary grafts and those containing bone and cartilage are osteochondral grafts (1). Bone that is harvested and used within the same individual is an autograft (noun) or an autogeneic (adj) bone graft. Bone that is harvested from a cadaver for use in another individual is an allograft (noun) or an allogeneic (adj) bone graft (2). Autogeneic bone grafts are fresh and unprocessed. Allogeneic bone grafts are available either frozen or freeze dried. Several other bone graft processing methods and materials are being used experimentally (3-7).

History

The idea of removing a damaged structure from a human being and rebuilding the body with a replacement part from another individual or even a cadaver has enchanted society for centuries. Today we are still struggling with the possibilities.

The first experimental investigation of autografts was with skull trephination defects by Merrem in 1810. Ollier first suggested transplanting skin, periosteum, and bone in 1867 even before Pasteur's "germ theory of disease" in 1878. Macewan studied under Joseph Lister and in 1881 documented the first successful aseptic fresh bone allograft (8).

Barth, Marchand, and Athausen each individually outlined various theories describing bone healing at the turn of the century. This description of the invasion of the fresh allogeneic bone by the host cells became the "creeping substitution" theory that in part remains essentially unchanged today (2). In 1908 Judet first reported the implantation of osteochondral grafts in experimental animals(9), and by 1925 Lexer had documented 34 hemi or whole knee allogeneic implants in humans. Lexer followed up the patient results in 1923 and claimed a 50% success rate (10, 11).

Limited availability and complications associated with allogeneic bone harvesting stimulated research in preservation and storage of bone and cartilage. Bauer in 1910 with his canine studies and Inclan in 1942 with his human studies outline the process of sterilization and delayed implantation of bone (2). Bone bank research continued with equipment technology advances almost yearly. The process of freeze drying was developed during world war II and applied to tissue transplants (12).

Precise microscopic documentation with animal models evaluated these new bone and cartilage preservation techniques. The exact cellular stages of revascularization of allogeneic vs autogeneic bone grafts were compared in numerous studies (13-16). Herndon and Chase in 1952 discussed whole joint reimplantation in 56 dogs with autogeneic, fresh allogeneic, and frozen allogeneic osteochondral grafts. All the osseous graft sites appeared to unite within 6-8 weeks with no appreciable difference in function. At 5 to 6 months however, the fresh allogeneic and frozen allogeneic grafts began to show increased density of the subchondral bone area. The allogeneic joints eventually deteriorated. The immune reaction of the host seemed to ignore the transplanted cartilage and instead invaded the subchondral bone (17).

As technology advanced, the problems of immune reaction, subchondral bone invasion, and cartilage preservation were addressed (18). In the 1960's hundreds of dogs underwent metacarpophalangeal joint, femoral condyle, and femoral head transplants (13, 14, 19, 20).

As early as 1948 Graham described the reconstruction

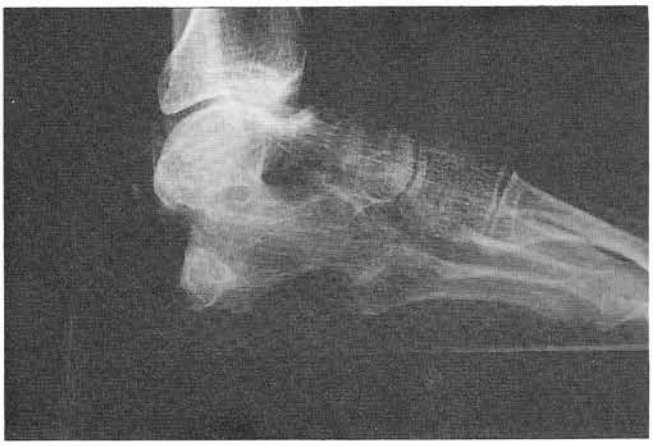

Fig. 1. Preoperative radiograph shows extensive osseous structural loss in rearfoot of this 34 year old female.

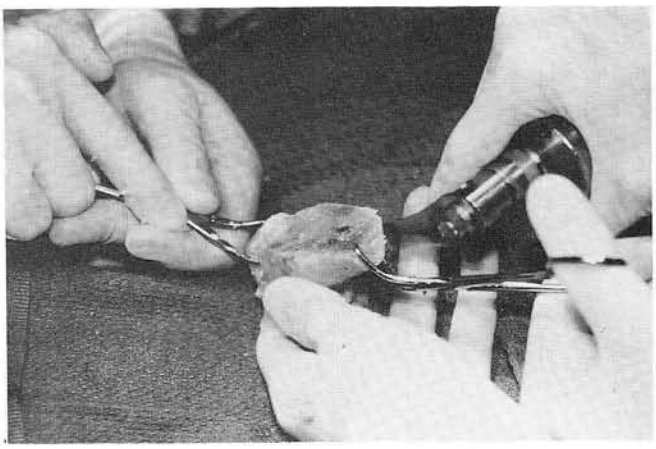

Fig. 2. This intra-operative photograph shows fresh frozen intercalary allogeneic calcaneal graft being remodeled prior to insertion.

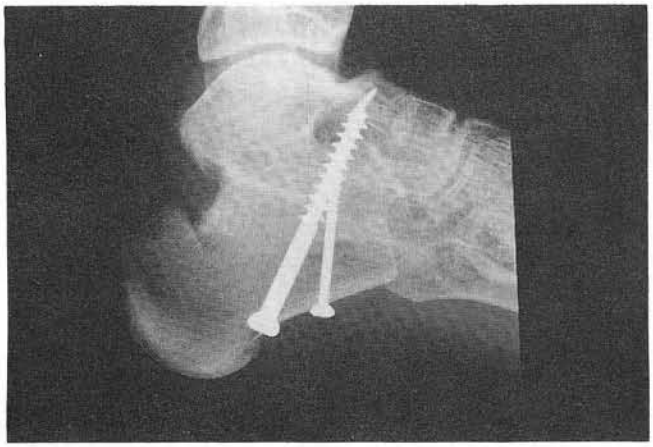

Fig. 3. Postoperative radiograph taken showing restored structure of rearfoot with calcaneal graft intact.

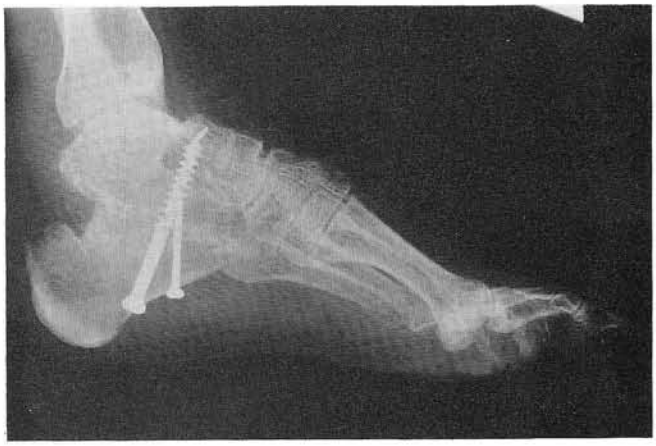

Fig. 4. Radiograph taken six months postoperative with removal of internal fixation devices. Trabecular pattern appears to cross graft interface throughout.

of the metacarpophalangeal joint in a human with an autogeneic metatarsal transplant in five patients (21). The fourth and fifth metatarsals have since been commonly used for metacarpal replacement or mandibular condyle reconstruction (22-25).

The replacement of a calcaneus in a 34 year old female with a fresh frozen allogeneic calcaneal graft at Doctors Hospital by ED McGlamry, D.P.M. has set another milestone in bone graft utilization. The patient's calcaneus had been removed during surgical debridement of osteomyelitis over 15 years previously. (Fig 1). A whole calcaneus was procured under sterile conditions and transported to Doctors Hospital in a frozen state (Fig 2). The graft was remodeled and inserted with AO/ASIF fixation and reattachment of the tendo achillis (Fig 3). The subsequent postoperative management is ongoing and has provided a foundation for further surgical advancements (Fig 4).

Current Bone Graft Utilization

At Doctors Hospital we are currently using bone prepared by three different methods. Allogeneic freeze dried bone is the most frequently used. Autogeneic bone grafts are commonly used, and fresh frozen allogeneic bone grafts are used when appropriate.

Allogeneic Freeze Dried Bone

Allogeneic freeze dried bone has proven its usefulness on many occasions. The desired shape and size of cancellous or cortical bone can be easily stored and remodeled to the individual patient's needs (Fig 5). At Doctors Hospital we currently stock between 20 and 50 allogeneic freeze dried bone grafts of various sizes. We commonly order a truncated iliac crest wedge of approximately 3.5 cm x 1.6 cm x 12 cm for the Evans calcaneal osteotomy procedure (Fig 6).

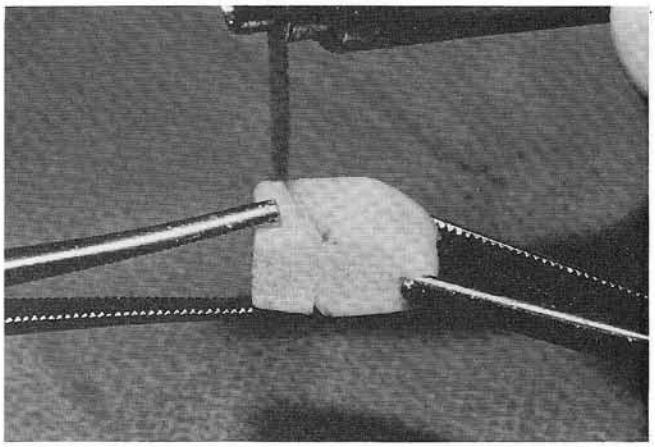

Fig. 5. Freeze-dried bone can be remodeled intra-operatively to specific demands of procedure.

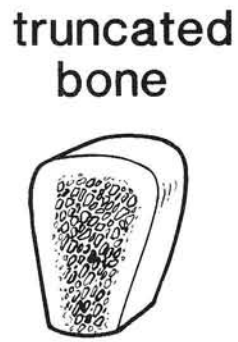

Fig. 6. Truncated iliac crest wedge with three sides of cortical bone and filling of cancellous bone is ideal for Evans calcaneal osteotomy.

The dehydration process has been used for centuries for the preservation and storage of food. Modern techniques have provided a freeze-drying process that can store tissue in a sterile vacuum sealed container indefinitely (26, 27) (Fig 7).

In the freeze-drying process the bone is procured under sterile conditions or secondarily sterilized with ethylene oxide or gamma irradiation. The sterile bone graft is then placed in a liquid nitrogen storage tank (-70 degrees F.) (12). The low temperatures of the liquid nitrogen crystallize the moisture in the bone (Fig 8). The frozen graft is then moved onto the shelf of the freeze-dryer. The doors are closed and the vacuum pumps are turned on. The vacuum in the chamber is maintained at 100 millitorr or below throughout the 14 day cycle (Fig 9). The ice crystals are directly vaporized in the vacuum environment without passing through the intermediate liquid state, thus the term "freeze-dried". The water vapor is drawn away from the bone and into a condenser. At the end of the cycle the containers are sealed, maintaining the sterile vacuum and the low moisture environment. The initial drying of the bone depends on the vacuum. The higher the vacuum the faster the freeze-drying, but the total water removed depends mainly on the length of the freeze-drying cycle. The longer the bone is exposed to the vacuum and low temperature environment, the more moisture is removed and the lower the residual water level. Studies show a 14 day cycle can usually produce a freeze-dried bone graft of less than 5 gm% residual water. Quality control is constantly maintained with 10% of the final product being sacrificed for biological testing prior to the release of the bone graft material.

The donor selection process is the most important aspect of any tissue bank requirements and strict criteria are established (Jones CH, Rutledge WS: Atlanta Regional Tissue Bank. Tissue Donation Criteria, 1987).

1. Tissue donation must occur within 24 hours of death.

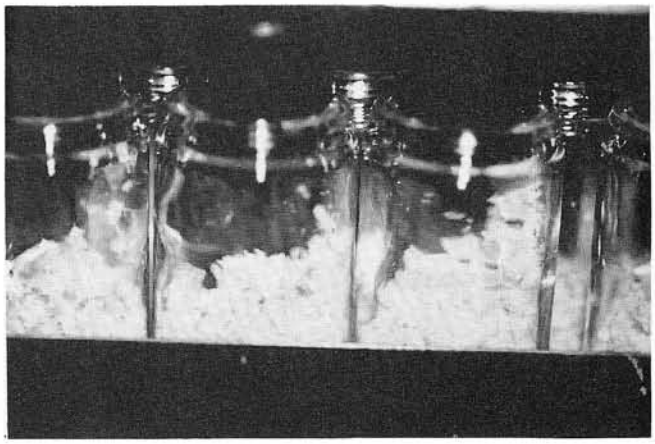

Fig. 7. Freeze-dried bone can be ordered in many shapes and sizes and stored indefinitely until needed.

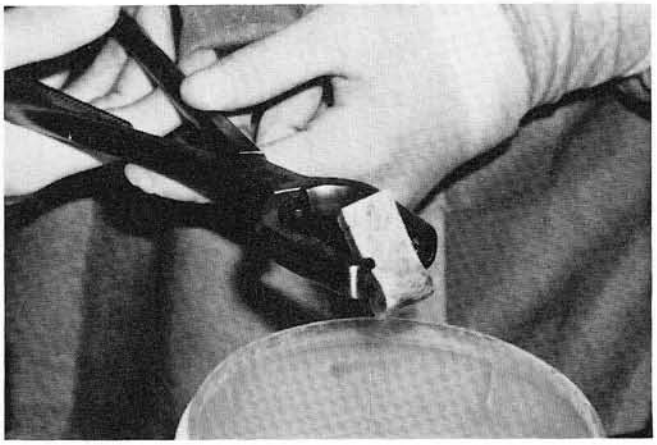

Fig. 8. Liquid nitrogen (-70 degrees F.) crystallizes water moisture of bone, making water easy to remove in freeze-drier.

2. If tissue donation is delayed more than 12 hours after death, the body must be refrigerated.
3. The cause of death must be known.
4. The following factors exclude tissue donation:
   a. Sepsis
   b. Uncontrolled wide spread infection
   c. Extra-cranial malignancies
   d. Hepatitis
   e. current I.V. drug abuse
   f. auto-immune disease
   g. transmissible disease or infection
   h. tissue irradiation
   i. chronic steroid therapy
   j. Pre-existing bone disease
5. Age limits for intercalary grafts
   Male—15 to 50 years
   Female—15 to 40 years
6. Age limits for osteochondral grafts
   Male and female to 35 years.

Freeze-dried bone has been a mainstay for Evans calcaneal osteotomies and the packing of unicameral bone cysts of the calcaneus (28, 29) (Figs 10-12). In over 200 uses at Doctors Hospital there have been no infections associated with allogeneic freeze-dried bone grafts.

Autogeneic Bone Grafts

Autogeneic bone grafts have been useful especially in nonunion sites and in arthrodesis procedures (Fig 13). Freshly harvested autogeneic bone has a faster incorporation time and remodels quickly compared to allogeneic frozen bone or freeze-dried bone. Antigenetic reaction is not a problem. The most common donor sites include the iliac crest, calcaneus, or tibia (30).

The choice of the donor site depends on the size and context of bone needed and the particular surgical procedure involved. The procurement of bone from each area presents different surgical considerations. At Doctors Hospital we have used autogeneic grafts for first metatarsal nonunions, Lisfranc arthrodesis procedures, triple arthrodesis enhancement, and other reconstructive surgeries with a high percentage of success. The complications associated with the donor sites include hematoma, pathologic fracture, slow healing, or persistent postoperative pain.

Fresh Frozen Allogeneic Bone

Fresh frozen allogeneic bone has been used at Doctors Hospital and appears to have an encouraging future. The problems of donor availability and sterile transportation of the bone graft must be handled. There is a shortage of acceptable tissue and organ donors and bone is often difficult to obtain. The surgery schedule is crucial as the fresh allogeneic graft should be implanted within 48 to 72 hours. Fresh allogeneic grafts can be intercalary or osteochondral with the preservation techniques being different for each. In addition to the standard organ donor criteria previously outlined, the following clinical tests are required for fresh allogeneic bone grafts (Jones CH, Rutledge WS: Atlanta Regional Tissue Bank. Tissue Donation Criteria, 1987):

1. ABO blood type
2. Rh factor
3. Blood cultures x 2 (15 minutes apart) aerobic and anaerobic
4. Gram stain of graft at retrieval
5. Aerobic, anaerobic, and fungal cultures of graft at retrieval
6. HAA (hepatitis A antibody)
7. RPR (rapid plasma reagin, syphilis)
8. HTLV III antibody (AIDS)

The fresh allogeneic graft is removed from a suitable donor in the sterile atmosphere of an operating room. The tissue is wrapped in a sterile lap sponge, placed in saline or Ringers lactate solution at +4 degrees C, double wrapped with sterile intestinal bags, then placed in a cooler separated from the ice by a towel. At no time does the tissue come in direct contact with the ice. Osteochondral grafts are not frozen, but are kept at the temperature of +4 degrees C.

Intercalary grafts can be maintained at −70 degrees F. with liquid nitrogen as a preservative. Fresh allogeneic grafts should be implanted within 48 to 72 hours so the scheduling of the patient is crucial.

Osteochondral Grafts

Osteochondral grafts have become more common with recent research showing encouraging results. Several chemicals have been studied to enhance cartilage cell preservation: dimethyl sulfoxide (DMSO, Me2SO), glycerol, 5% glutaraldehyde, and 0.2% Na borohydride (31). At +4 degrees C. with hypothermia as a preservative about 80% of the chondrocytes remain viable for up to 8-10 days without cryoprotectants.

Bone Graft Evaluation

Osseous remodeling and graft incorporation is assessed by:

1. Standard x-ray films
2. Technetium 99 bone scan (Fig. 14)
3. Angiogram
4. Tetracycline labeling

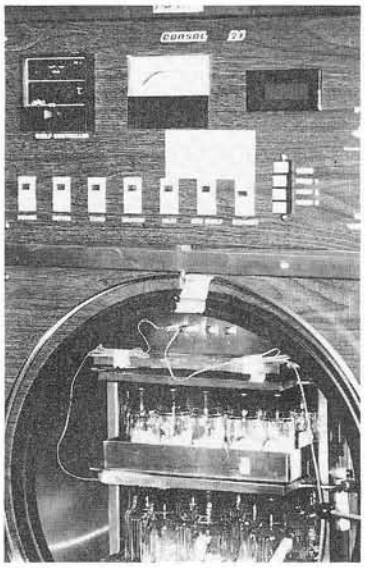

Fig. 9. Vacuum chamber is maintained at 100 millitorr and at -35 degrees F. throughout 14 day freeze-drying cycle.

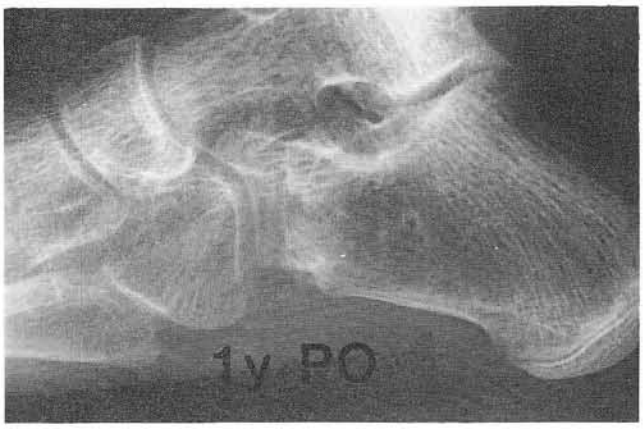

Fig. 11. Radiograph shows incorporation of allogeneic graft one year postoperatively.

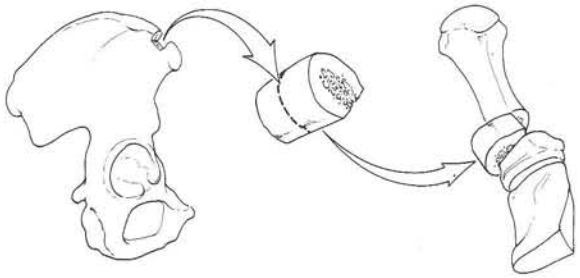

Fig. 13. Iliac crest is common donor site for autogeneic bone graft to be used in nonunion procedures or arthrodesis.

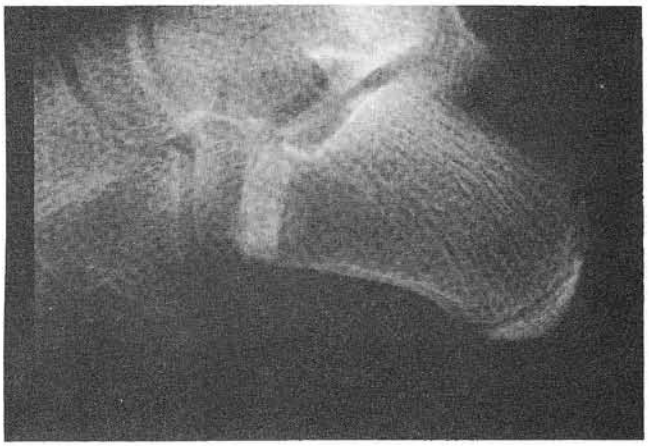

Fig. 10. Radiograph shows initial postoperative position of freeze-dried iliac crest wedge.

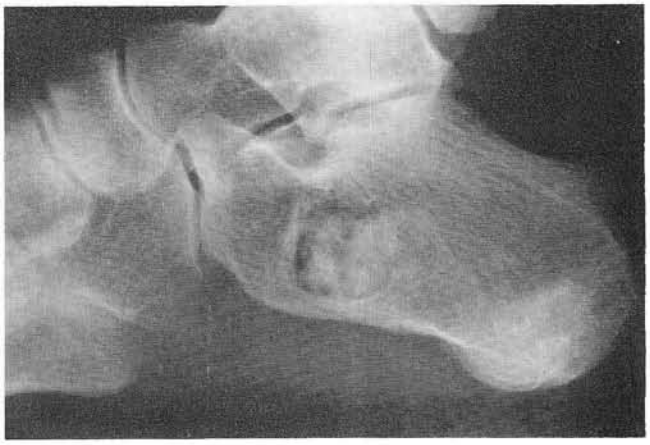

Fig. 12. Initial postoperative radiograph shows cancellous bone chips packed within unicameral bone cyst of calcaneus.

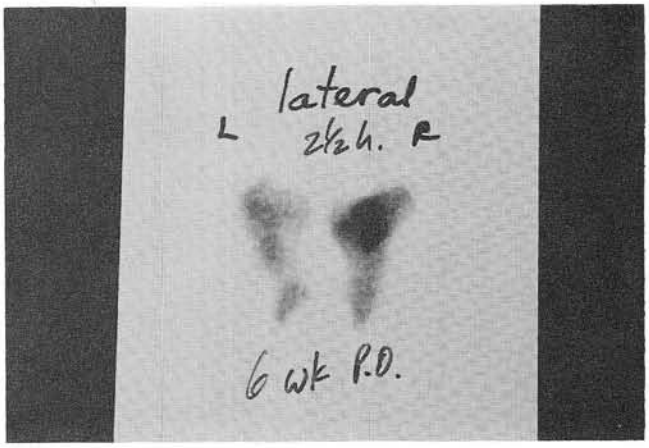

Fig. 14. A technetium 99 bone scan taken postoperatively shows active vascular interface between bone graft and host.

Cartilage viability is assessed by (31):

1. Standard X-ray films
2. Safranin-O staining light microscope
3. Nematoxylin and eosin staining light microscope
4. Labeled 3H-cytidine uptake
5. Labeled 3H-proline uptake
6. Labeled 35S-sulfate autoradiography

The postoperative management and long term followup of bone graft procedures is crucial to the surgical outcome. Non weightbearing of lower extremity bone grafts is the standard.

Summary

The use of bone graft materials in podiatric surgery has greatly enhanced the reconstructive procedures available. New technology and research will increase the availability of freeze-dried grafts, frozen allogeneic bone grafts, and osteochondral grafts. Friends, relatives, and patients should be educated in the organ donor programs because at present the shortage of graft material is due to the shortage of acceptable donors. New procedures and techniques are being developed for reconstructive surgery of the foot and leg and the use of osteochondral grafts is of particular interest at present.

References

1. Mankin HJ, Friedlaender GE: Perspectives on bone allograft biology. *In Osteochondral Allografts*. Little, Brown Co, Boston, pp 3-5, 1982.
2. Prolo DJ, Rodrigo JJ: Contemporary bone graft physiology and surgery. *Clin Orthop* 200:322-342, 1985.
3. Lindholm TS, Urist MR: A quantitative analysis of new bone formation by induction in compositive grafts of bone marrow and bone matrix. *Clin Orthop* 150:288-300, 1980.
4. Holmes RE, Bucholz RW, Mooney V: Porous hydroxyapatite as a bone graft substitute in metaphyseal defects. *J Bone Joint Surg* 68A:904-911, 1986.
5. Sartoris OJ, Gershuni DK, Akeson WH, Holmes RE, Resnick D: Coralline hydroxyapatite bone graft substitutes. *Radiology* 159:133-136, 1986.
6. Hollinger JO, Battistone GC: Biodegradable bone repair materials. *Clin Orthop* 207:290-305, 1986.
7. Pilliar RM, Lee LM, Maniatopoulos C: Observations on the effect of movement on bone ingrowth into porous-surfaced implants. *Clin Orthop* 208:108-113, 1986.
8. Peltier LF, Macewen W: Introduction: the growth of bone. *Clin Orthop* 174:5, 1983.
9. Eutin MA, Baird RM: Experimental and clinical transplantation of autogenous whole joints. *J Bone Joint Surg* 44A:1518-1536, 1962.
10. Lexer E: Joint transplantation and arthroplasty. *Surg Gynecol Obstet* 40:782-789, 1925.
11. Mankin HJ, Doppelt S, Tomford W: Clinical experience with allograft implantation, the first ten years. *Clin Orthop* 174:69-86, 1983.
12. Malinin TI, Wu NM, Flores A: Freeze-drying of bone for allotransplantation. In Friedlaender GE, Mankin HJ, Sell KW (eds): *Osteochondral Allografts*. Little, Brown Co, Boston, pp 181-192, 1982.
13. Herndon CH, Chase SW: Experimental studies in the transplantation of whole joints. *J Bone Joint Surg* 34A:564-578, 1952.
14. Chase SW, Herndon CH: The fate of autogenous and homogenous bone grafts. *J Bone Joint Surg* 37A:809-815, 1955.
15. Smith TF: Bone graft physiology, survival and incorporation of the graft. In Schlefman B (ed): *Doctors Hospital Podiatry Institute Surgical Seminar Syllabus*. Doctors Hospital Podiatry Institute, Tucker, GA, pp 57-61, 1982.
16. Burchardt H: The biology of bone graft repair. *Clin Orthop* 174:28-42, 1983.
17. Rabin EL, Rose RM: Role of subchondral bone in the initiation and progresssion of cartilage damage. *Clin Orthop* 213:24-40, 1986.
18. Johnson CA, Brown BA, Lasky LC: Rh immunization caused by osseous allograft (letter to editor). *N Engl J Med* 312:121-122, 1985.
19. Erdelyi R: Experimental autotransplantation of small joints. *Plast Reconst Surg* 31:129-139, 1963.
20. Campbell CJ, Ishida H, Takahashi H, Kelly F: The transplantation of articular cartilage. *J Bone Joint Surg* 45A:1579-1592, 1963.
21. Graham WC, Riordan DC: Reconstruction of a metacarpophalangel joint with a metatarsal transplant. *J Bone Joint Surg* 30A:848-853, 1948.
22. Dingman RO, Grabb WC: Reconstruction of both mandibular condyles with metatarsal bone grafts. *Plast Reconstr Surg* 34:441-451, 1964.
23. Keffelkamp DB, Ramsey P: Experimental and clinical autogenous distal metacarpal reconstruction. *Clin Orthop* 74:129-137, 1971.
24. Rinaldi FT: The use of human cadaver homologous bone grafts in foot surgery. *J Foot Surg* 22:165-189, 1983.
25. Menon J: Reconstruction of the metacarpophalangeal joint with autogenous metatarsal. *J Hand Surg* 8:443-446, 1983.
26. Friedlaender G, Mankin HJ: Guidelines for the banking of musculoskeletal tissues. *Newsletter Am Assoc Tissue Banks* 3:2, 1979.
27. Friedlaender GE, Mankin HJ: Bone banking: current methods and suggested guidelines. *AAOS Instruc-*

tional Course Lecture Series, vol 30. CV Mosby, St Louis, pp 36-55, 1981.
28. Mahan KT: Bone grafting fundamentals. In Schlefman B (ed): *Doctors Hospital Podiatry Institute Surgical Seminar Syllabus*. Doctors Hospital Podiatry Institute, Tucker, GA, pp 53-56, 1982.
29. Jimenez AL: Technical principles and management of bone grafts. In Schlefman B (ed): *Doctors Hospital Podiatry Institute Surgical Seminar Syllabus*. Doctors Hospital Podiatry Institute, Tucker, GA, pp 62-65, 1982.
30. Mahan KT: Bone grafting. In McGlamry ED, McGlamry RC (eds): *Textbook of Foot Surgery*. Williams & Wilkins, Baltimore, pp 646-667, 1987.
31. Friedlaender GE, Mankin HJ, Sell KW (ed): *Osteochondral Allografts; Biology, Banking and Clinical Applications* Little Brown & Co, Boston, pp 203-217, 82.

Additional References

Aston JE: Repair of articular surfaces by allografts of articular and growth-plate cartilage. *J Bone Joint Surg* 68B:29-35, 1986.

Czitrom AA, Langer F, McKee N, Gross AE: Bone and cartilage allotransplantation, a review of 14 years of research and clinical studies. *Clin Orthop* 208:141-145, 1986.

Parrish FF: Treatment of bone tumors by total excision and replacement with massive autologous and homologous grafts. *J Bone Joint Surg* 48A:968-977, 1966.

Tomford WW: Ongoing study presented at Society for Cryopreservation. 23rd Annual Meeting. Augusta, GA. June 17-20, 1986.