CHAPTER 14

AUTOLOGOUS DISTAL TIBIA BONE GRAFT HARVEST: Results in 77 Patients

John Anderson, DPM
Amir Hajimirsadeghi, DPM

INTRODUCTION

The history of bone grafting is as old as the history of orthopedics. Until the early 1900s, bone grafting was for the most part unsuccessful.[1] In 1911, Fred Albee started to perform bone grafting by using the same principles used in grafting fruit trees.[2]

The current gold standard for bone grafting is the autograft, in which bony tissue is harvested from the patient, usually from the iliac crest, proximal anteromedial tibia, distal anteromedial tibia, fibula, calcaneus, greater trochanter, distal femur, and ribs.[3-7]

Autologous bone graft is an ideal tissue because it possesses the 3 characteristics necessary for new bone growth. First, it serves as a scaffold for vascular ingrowth and extensive surface area for cell adhesion and tissue development (osteoconduction) (Figure 1).[6] The term creeping substitution was used by Phemister[7] and Axhausen[8] to describe the ingrowth of new vessels across the graft enabling production of new viable bone. Second, it contains macromolecules (bone morphogenic proteins) that stimulate bone formation (osteoinduction).[9] The theory of osteoinduction was first proposed by Barth in 1893[10] and it was further supported in 1952 by Urist and McLean.[11] Urist is also credited with describing chemical mediators of bone healing known as bone morphogenic protein (BMP).[12] Finally, it may also have some precursor cells that will survive transplantation, differentiate into osteoblasts, and carry forth with the various stages of bone regeneration (osteogenesis).[13] The osteogenic potential of transplanted bone marrow was originally documented by Goujon in 1869.[14] These processes are also influenced by the vascularity and composition of the host bed. Thus, the interaction of the host and the bone graft determines the success of these procedures, which ultimately is to provide a mechanically efficient support structure.[15] Since autologous bone grafts are not immunogenic they incorporated well into the receiving site and the results are more predictable.[4]

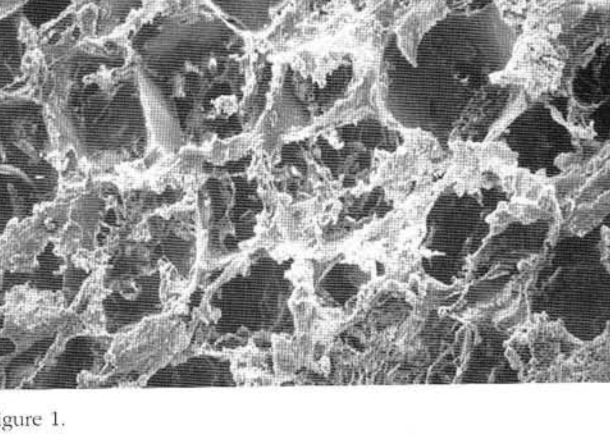

Figure 1.

Autologous bone is used to help promote bone healing and to provide structural support in reconstructive surgery, limb salvage surgery, reconstruction of failed arthroplasties, acute comminuted fractures, nonunions, and the correction of significant bone loss associated with joint replacement or bone tumors.[4,16-19] Other types of bone grafts such as allografts, xenografts, and synthetic grafts are also used in such procedures.[5] However, complications due to use of non-autologous bone grafts drive most surgeons to employ autografts as a reliable source. Taken from donors or cadavers, allografts circumvent some of the shortcomings of autografts by eliminating donor site morbidity and issues of limited supply. However, allografts present risks of disease transmission as well.[20] Allografts are more slowly and less completely replaced by host bones because they invoke both local and systemic immune responses that diminish or destroy the osteoinductive and conductive processes. Most bone substitutes, such as calcium sulfate, coralline substitutes, ceramics, and collagen, are osteoconductive, but not osteoinductive.[7] Scranton published an article about his success with several different bone substitute products that are used in foot and ankle reconstructive cases. As these options become more varied, it becomes more difficult to know which product to select.[21]

The sources of the bone graft raise changeable questions in regard to complications. The ability to harvest iliac crest bone is a well-established skill in the surgical armamentarium of the orthopedic surgeon. As with any surgical procedure, this operation has its own set of complications. When compared with cited complications from iliac crest, distal tibial bone graft harvesting has fewer complications. Bone graft complications can be divided into minor complications and major complications. Minor complications include wound erythema, sensory disturbance, and pain that do not require further operative treatment or pain medication. Major complications include wound dehiscence, cellulitis, severe pain, and fracture that need a further hospital stay and might need additional surgery, intravenous antibiotic therapy, and pain medication. Also, non-union at the recipient site is another complication that should be considered.[8] Approximately 5.8% of the iliac crest bone grafts can be associated with major complications including herniation of abdominal contents through massive bone graft donor sites, vascular injuries, deep infections at the donor site, neurologic injuries (lateral femoral cutaneous nerve, superior cluneal nerves, ilioinguinal nerve), vascular injuries (superior gluteal injury), deep hematoma formation requiring surgical intervention, cosmetic deformity, and iliac wing fractures.[4] The complication rates associated with iliac crest bone graft ranges from 10 to 49%.[22,23]

Complications with allografts include disease transmission and immune response. These are avoided by using locally obtained distal tibia autograft for use in any foot and ankle procedures including arthrodeses.[24]

In the field of podiatry, unfortunately due to limitation of scope of practice, obtaining grafts from ribs, iliac crest, greater trochanter, femur, and even proximal tibia is a challenge. Podiatric surgeons are required to employ another surgeon to harvest bone graft from the above sites. Thus, due to the above challenges it is very important to expand our understanding of bone grafting from the ipsilateral distal tibia.

METHODS

Between the years 2001 to 2005, 77 patients went through an ipsilateral distal tibia bone graft harvesting to augment healing in varieties of forefoot and rearfoot surgeries. The average age was 55.6 years of age, varying from 17 to 80 years old. There were 38 right and 39 distal tibias that bone grafts were harvested from. The same surgeon performed all procedures for consistency of techniques. The inclusion criteria were patient acceptance, vascular qualification, neurological qualification, lack of active osteomyelitis, lack of active soft tissue infection, and elective reconstructive surgery as well as trauma with a large defect. The exclusion criteria were patient lack of acceptance, active osteomyelitis, active soft tissue infection, ischemia, neurologic impairment, active Charcot neuroarthropathy and open growth plates. The procedures included tarsometatarsal joint fusions, Lapidus, tarsal bones fusions, talonavicular joint fusion, subtalar joint fusions, first metatarsophalangeal joint fusion, nonunion fractures, and bone voids secondary to traumas or bone infections. The donor site was then prepared. According to the size of the measured defect and the amount and the type of bone graft needed, the distal aspect of tibia was then approached and the bone graft was harvested (Figures 2, 3).

The amount of the collected cancellous bone graft was approximated using an empty syringe to collect the harvested bone graft. The empty space in the tibia was then filled with bone substitutes of various types, such as calcium phosphate, calcium sulfate, and demineralized bone matrix. Patients were followed for 48-hours, 2-weeks, and 6-months postoperatively and the amount of the pain from the harvested area was assessed based on a visual analog pain scale ranging from 0-10 with 0 = no pain and 10 = severe pain. The pain of each patient's harvest site was questioned separately from the remaining operated limb as a whole.

Technique

The position of the patient on the operating table was based on the type of the procedure. A proximal to distal, linear incision was placed over the anteromedial aspect of the medial surface of the tibia, just above the medial malleolus. If more cortical bone

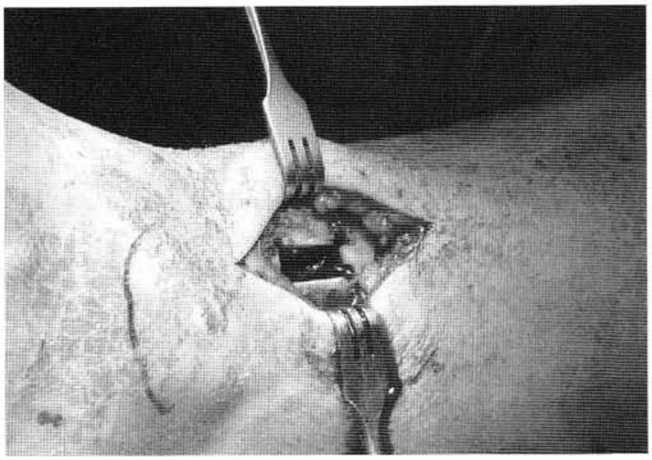

Figure 2.

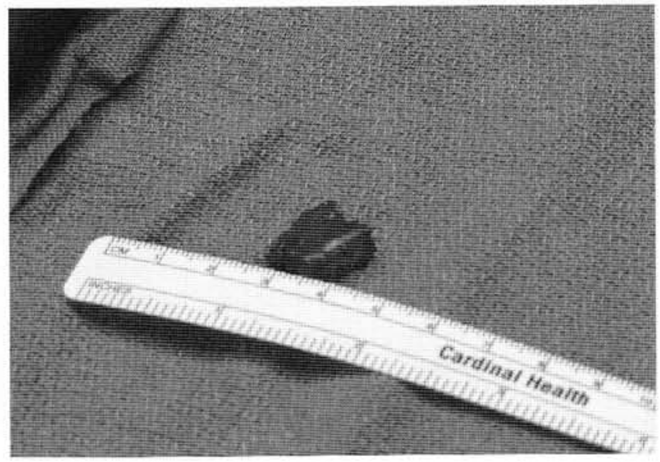

Figure 3.

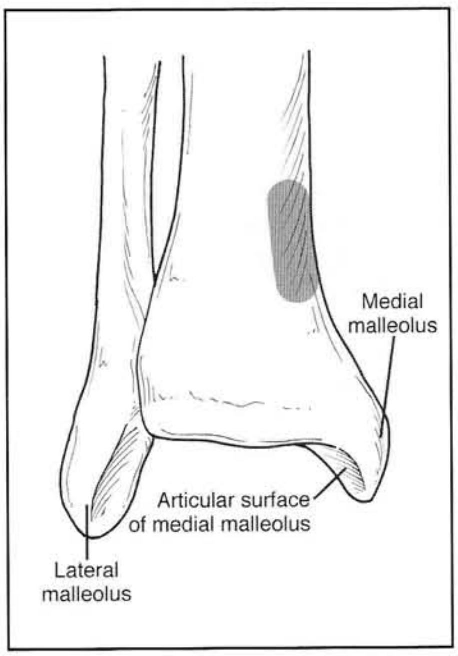

Figure 4.

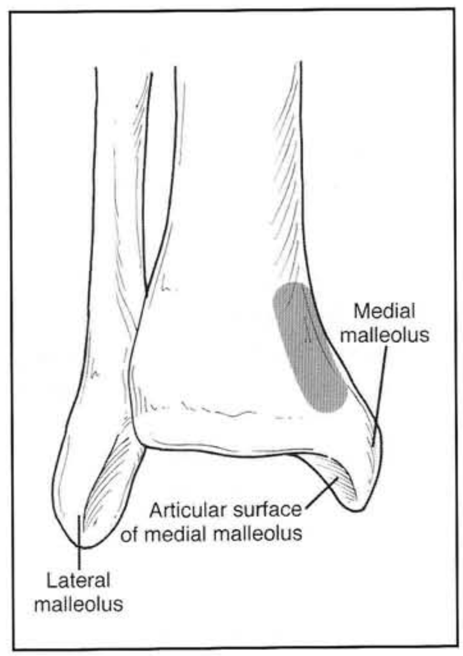

Figure 5.

was needed, then the bone window was placed slightly above the metaphyseal-diaphyseal junction (Figure 4). However, if mainly cancellous bone was needed, the bone window was placed over the metaphyseal-diaphyseal junction (Figure 5).

The incision length was between 4 to 6 centimeters. The incision was carefully deepened to the level of the periosteum. The periosteum was then incised and elevated. A 0.045-inch Kirschner-wire or a 1.5mm was used to drill the four corners of a rectangular shape bone window to prevent stress fracture. Using a small oscillating saw in an inverted fashion, the four corners were connected and a window created. The inverted cuts will create beveled inward edges and will further prevent migration of the cortical window. The cortical window with attached cancellous bone was then harvested. Using a 3 or 4 mm curved curette, the extra cancellous bone was harvested as needed. Care was taken to prevent harvesting bone distally, which might penetrate the articular surface of the distal tibia as well as penetrating the lateral wall of the distal tibia where the syndesmosis ligament is attached. The surgeon should consider using fluoroscopy for better visualization and prevention of any osseous damage. Also, attention was taken not to use the edges of the window as a lever arm for the curette, which might further create a fracture. After achieving the desired amount of the bone graft, the void was filled with any source of synthetic bone graft. The removed cortical window was then replaced if not used. The periosteum and subcutaneous tissues were sutured with absorbable suture materials. The skin was closed using absorbable suture in a subcuticular fashion. The surgical site was then dressed with a mild compressive dressing.

RESULTS

The cortical window was approximately 1 x 2 centimeter in maximal dimensions. The collected cancellous bone graft varied from 4 ml up to 15 ml with an average of 7.2 ml. Based on the review of the patient charts at 48 hours, the average pain was 1.4 out of 10. At 2 weeks the average pain was reported to be 1 out of 10. This was then reduced to 0.44 out of 10 at 6-months postoperatively. Serial radiographs were taken from the donor and receiving sites to evaluate for bone graft incorporation at both sites. The time to heal varied from 3 months to 16 months with an average of 5.2 months. This was determined when the new trabecular bone pattern was across more than 50% of the original defect on radiograph. From a clinical standpoint, a bone graft has been incorporated successfully when the host-graft interface unites and the graft-host bone construct tolerates physiologic weightbearing without fracture or pain.[7] The larger the amount of bone graft collected, the more time needed for healing. Also, the younger the patients were, the earlier the time to fill the void at the donor site. Postoperative complications were all minor, including 1 patient with superficial dehiscence, 1 patient with superficial dehiscence and cellulitis, and 1 patient with saphenous neuritis. In the case of the superficial dehiscence, patients were treated with local wound care as an outpatient and the cellulitis was treated with oral antibiotics. The patient with saphenous neuritis was treated with oral non-steroidal antiinflammatories. This patient started with a 5 on the visual analog scale for pain, which was then reduced to a 3 on the visual analog scale at 2 weeks postoperatively. The rate of complications at the donor site was 3.9% postoperatively. The post-operative weight-bearing status was determined based on the primary procedure.

Instrumentation

Other methods and techniques for distal tibia bone graft harvesting are also descried in the literature. Brown described a technique for obtaining morselized cancellous bone graft from the distal tibia using Acumed system (Acumed, Inc., Hillsboro, OR) through a small incision site.[25] Raikin and Brislin described using a 9-mm diameter trephine from Wright Medical to remove a core of distal tibial metaphysial bone.[8] Donley and Richardson also, described a trephination technique from distal tibia.[26] The success with using different methods and instrumentation are all dependent on the surgeon's experience and previous training.

LITERATURE REVIEW

The most common referenced donor sites are the iliac crest, distal tibia, and calcaneus.[1-14,16-19,22,27-32] These all have demonstrated limitations, the high morbidity rate associated with the iliac crest and the poor quantity of graft from distal sources. In an study by Silber et al he concluded that following anterior iliac crest bone graft harvest, 134 out of 187 total patients reported symptoms as the following rates; ambulation difficulty, 50.7%; extended antibiotic usage, 7.5%; persistent drainage, 3.7%; wound dehiscence, 2.2%; and incision and drainage, 1.5%. Also, 11.2% of patients chronically used pain medication. About 15.7% of the patients reported abnormal sensations at the donor site.[27]

Many experiments have been done in using the ipsilateral tibial graft as a reliable and fast source of bone grafts. Raikin and Brislin studied 70 patients, who had under gone bone graft harvesting from the ipsilateral distal tibia. The patients were followed postoperatively for an average of 16 (range 5 to 28) months and were evaluated for minor and major complications, satisfaction, and healing rates. There were no major complications. Ten patients (8.7%) had minor complications including initial incisional sensitivity or local numbness, none of which affected function or required additional treatment. Satisfaction rate for the procedure was 100%. He concluded that it is safe and reliable for operative procedures of the foot and ankle.[8] Saltrick et al reviewed 16 patients with distal tibial bone grafts as a source of corticocancellous bone. He described donor site possible complications as increased

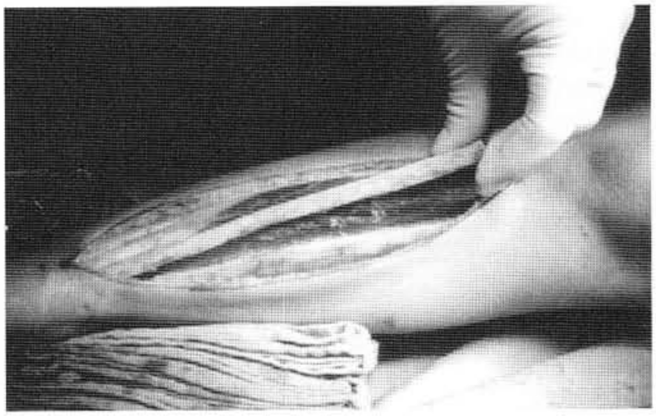

Figure 6.

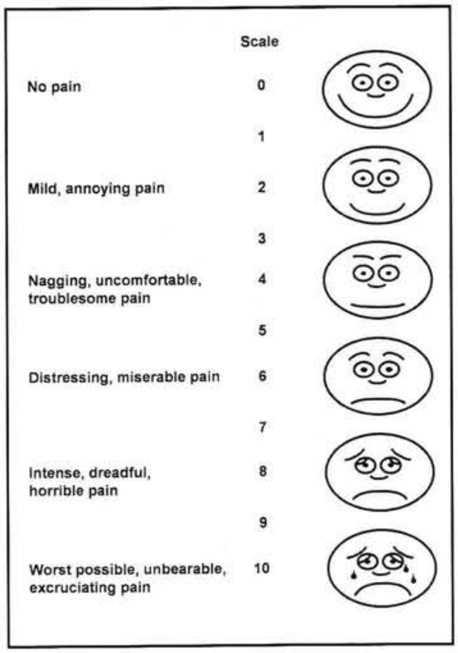

Figure 7.

postoperative morbidity, fracture at the donor site, additional surgical procedure, increased operative time, excessive blood loss, hematoma, increased relative cost (OR time). However he concluded that the distal tibia is a readily available source, effective, has limited morbidity and is an excellent source of corticocancellous bone for grafting.[33] O'Malley and Conti in their retrospective study of 100 patients undergoing triple, STJ, TN arthrodesis using ipsilateral distal tibial bone graft investigated fusion rates at the recipient site and complications at the donor site. They realized that fusion rates were no less than other fusion rates where the bone was harvested from other sites. Minor (erythema and hematoma 13%) and major complications (non-union 3%, fracture 1%) were 17%. And if excluding erythema and hematoma the complication rate was only 4%. This is almost the same complication rate that was concluded from our study (3.9%). One patient out of 100 had a fracture at the donor site which was healed after 4 weeks of nonweight-bearing. This happened in a 78-year-old female 4 weeks after she had been removed from the cast with a healed subtalar fusion and had started progressive weight-bearing ambulation training. They concluded that the distal tibia is not a good source of cortical bone. This might have been due to their technique or placement of the bone window in relation to the metaphyseal-diaphyseal junction. However, at the end they added that the distal tibia is a safe and effective source for cancellous bone with sufficient quantity and quality for hindfoot arthrodesis procedures.[34]

Other studies in regard to harvesting bone grafts from the distal tibia have been described throughout the literature. In these studies they all agreed that distal tibia is a good source of bone graft for foot and ankle procedures and will provide enough cancellous bone materials.[24] In comparison with allografts, autogenous bone grafts have always been reported to have a better union rate.[35] In an animal study by Ishikawa et al cortico-cancellous bone graft harvested from the tibia of an Akita dog was successfully augmented to repair its cleft palate.[36] Even in the field of dentistry, autologous bone graft from tibia has served dentists equally in comparison with the iliac crest bone graft.[37,38] Mendicino et al used autologous bone grafts in arthrodesis or for revision of malunions or non-unions. He concluded that the lower extremity provides a good source for obtaining cortical, corticocancellous, and cancellous bone for use in foot and ankle surgery.[39] Yu et al in their retrospective study using autogenous tibial strut graft realized that autogenous tibial strut grafts provided physical advantages over commonly used iliac crest, rib, and fibula grafts. The tibia provides dense cortical bone with ample length and mechanical strength with virtually no donor-site morbidity (Figures 6,7).[40]

DISCUSSION

The most common referenced donor sites are the iliac crest, tibia, and calcaneus.[41] These all have demonstrated limitations, the high morbidity rate associated with the iliac crest and the poor quantity of graft from distal sources.[12] Other autologous sites for bone harvest are available to the surgeon, and she or he should be aware of these in terms of location, limitations of use, harvest technique, and potential pitfalls. The foot and ankle surgeon almost always needs less bone graft than other colleagues in orthopaedic surgery, so these other sites may be more suitable than the iliac crest for obtaining bone graft. Harvesting the autograft requires an additional surgery at the donor site that can result in its own complications that occasionally outlasts the pain of the original surgical procedure. Quantities of bone tissue that can be harvested are also limited, creating a supply problem as well.[15]

This study showed that the distal tibia can be a good source of bone graft when autogenous bone is needed. It provides enough volume for almost all of the routine foot and ankle procedures that may need bone graft. As discussed earlier, certain morbidity exists when performing distal tibial bone graft harvest. Fortunately, several large series in the recent literature can help the surgeon understand the incidence and occurrence of various complications associated with tibial bone graft procedures. Understanding the anatomy of tibia, nerves and vessels in the area of the procedure can minimize complications related to pain, neuropathy, and hemorrhage. Being aware of unusual complications, such as fracture, hematoma formation, or infection can help the surgeon treat them more quickly and effectively. Fracture risk can be minimized by avoiding harvesting excessive quantities of bone and by avoiding placement of the bone harvest too close to the distal articular surface of tibia.[7]

In average, distal tibia can provide between 8.6 to 11.3 ml of bone graft which are enough amounts to fill most of the defects in foot and ankle procedures.[37] The mean graft volume for iliac crest bone graft is about 55.12 ml which is approximately 5 times more than the amounts of bone graft from distal tibia.[42] Of course, iliac bone graft is associated with complication rates from 10% to 49% in comparison to distal tibial bone graft which shows minor complications in 1.8% to 15% of patients and major complications in 1.2 to 21.5%.[8]

Relative contraindications to the procedure include concomitant clinically significant peripheral neuropathy and severe osteopenia.[34] Since cortical bone is not fully available from the distal tibia, procedures requiring corticocancellous strut or block grafts cannot rely solely on distal tibial grafting, although this procedure can be used to supplement iliac crest grafting when necessary.[34] Crushing or avulsion injuries with jeopardized lower limb vascularization (high risk of failure of vascular anastomosis), crushing or avulsion injuries with severe motor and sensitive nerve damage, severe multiple lower limb joint compromise, severe bilateral lower limb fractures (no safe donor area available), total amputations in which the segment may be re-implanted first and, if shortened, only then subsequently lengthened are other contraindication for the use of distal autologous tibial bone graft. Also, ankle fusions are another contraindication to the bone graft from distal tibia since this could weaken the internal or external fixation necessary for fusion.[43,44]

Use of autologous bone graft harvested from the ipsilateral distal tibia is a safe, effective, and reliable source of obtaining cancellous bone, alternative to iliac crest. It provides sufficient quantity and quality of cancellous bone. This study showed that distal tibial bone grafts are ideal because they possesses all of the characteristics necessary for new bone growth, namely osteoconductivity, osteogenicity, and osteoinductivity. Distal tibia as a source of bone graft will power foot and ankle surgeons to perform surgeries without other surgeon's assistance to harvest from other sources. This will speed up the procedures. It also has less complications and less pain postoperatively. Fusion rates using this bone graft are no less than those reported in the literature using autologous bone obtained from other sites. The 1% fracture at the donor site as a significant complication of the donor site is low and can be prevented with proper technique and postoperative care.

Although autologous grafts provide the ideal combination of high osteoinduction and osteocoduction, good structural support, and low immunogenicity, these benefits come at the expense of donor site morbidity. Non-autogenous alternatives are becoming increasingly available as a way to decrease morbidity and operating times.[15] Allgraft or synthetic substitutes should be considered with proper understanding of the potential benefits and disadvantages of these products. Understanding the biology of bone grafting provides the surgeon with the knowledge that is needed to make an informed choice when selecting a bone grafting option. Before choosing an alternative graft material, the surgeon should also investigate how the graft material has performed in cases similar to his or her patient's needs. In the future, with continued research, the fields of tissue engineering and gene therapy will provide even better options for non-autogenous bone graft material.[45]

REFERENCES

1. Janeway HH. Autoplastic transplantation of bone. *Ann Surg.* 1910;52:217.
2. Albee FH. Bone graft surgery. Philadelphia: Saunders; 1915.
3. Boone DW. Complications of iliac crest graft and bone grafting alternatives in foot and ankle surgery. *Foot Ankle Clin* 2003;8:1-14.
4. Arrington ED, Smith WJ, Chambers HG, et al. Complications of iliac crest bone graft harvesting. *Clin Orthop* 1996;329:300-9.
5. Santanelli F, Grippaudo FR. Lower extremity reconstruction, Tibia. URL: www.emedicine.com.
6. Friedlaender GE. Current concepts review bone grafts. *J Bone Joint Surg Am.* 1987;69:786.
7. Blitch EL. Pachuda NM. Karlock LG. Mahan KT. Bone grafts. *Foot Ankle Surg* 2001;43:1465-86.
8. Raikin SM. Brislin K. Local bone graft harvested from the distal tibia or calcaneus for surgery of the foot and ankle. *Foot Ankle Int* 2005;26:449-53.
9. Blitch El, Ricotta PJ. Introduction to bone grafting. J Foot Ankle Surg 1996;35:458. (Burchardt H. Biology of bone grafting. *Orthop Clin North Am* 1987;18:187.
10. Barth A. Histologische unterschungen uber Kochen-implantationer. *Beitr Pathol Anat.* 1895;17:65-142.
11. Urist MR. McLean FC. Osteogenic potency and new-bone formation by induction in transplants to the anterior chamber of the eye. *J Bone Joint Surg Am* 1952;34:443-67.
12. Geideman W, Early JS, Brodsky J. Clinical results of harvesting autogenous cancellous graft from the ipsilateral proximal tibia for use in foot and ankle surgery. *Foot Ankle Int* 2004;25:451-5.
13. Lane JM, Bostrom MPG. Bone grafting and new composite biosynthetic graft materials. AAOS Instructional Course Lectures 1998;47:525-34.
14. Goujon E. Researcheres experimentales Sue Les Proprieties. *J L Anat* 1869;6:399-412.
15. Goldberg VM, Stevenson S. Natural history of autografts and allografts. *Clin Orthop Relat Res* 1987;225:7-16.
16. Campbell M, Seligson D. The history of the bone grafting. *Tech Orthop* 1992;7-2:1.
17. Hofbauer MH, Delmonte RJ, Scripps ML. Autogenous bone grafting. *J Foot Ankle Surg* 1996;35:386.
18. Rodriguez JA, Huk OL, Pellici PM, et al. Autogenous bone grafts from the femoral head for the treatment of acetabular deficiency in primary total hip arthroplasty with cement. long-term results. *J Bone Joint Surg Am* 1995;77:1227.
19. Sculpo TP, Choi JC. The role and results of bone grafting in revision total knee replacement. *Orthop Clin North Am* 1998;29:339.
20. Laurencin CT. Pratt LT. Khan Y. Bone graft substitute materials. URL: www.emedicine.com.
21. Scranton PE,JR. Results of arthrodesis of the tarsus: talocalcaneal, midtarsal, and subtalar joints. *Foot Ankle* 1991;12:156-64.
22. Younger EM, Chapman MW. Morbidity at bone graft donor sites. *J Orthop Trauma* 1989;3:192-5.
23. Schulhofer SD, Oloff LM. Iliac crest donor site morbidity in foot and ankle surgery. *J Foot Ankle Surg* 1997;36:155-60.
24. Danziger MB, Abdo RV, Decker JE. Distal tibia bone graft for arthrodesis of the foot and ankle. *Foot Ankle Int* 1995;16:187-90.
25. Brown CH. A technique for distal tibial bone graft for arthrodesis of the foot and ankle. *Foot Ankle Int* 2000;21:780-1.
26. Donley BG, Richardson EG. Bone grafting in foot surgery. *Foot Ankle Int* 1996;17:242.
27. Silber JS et at. Donor site morbidity after anterior iliac crest bone harvest for single-level anterior cervical discectomy and fusion. *Spine* 2003;28:134-9.
28. Fernyhough JC, Schimandle JJ, Wiegel MC, Edwards CC, Levine AM. Chronic donor site pain complicating bone graft harvesting from the posterior iliac crest for spinal fusion. *Spine* 1992;17:1474-80.
29. Meekeren JV. Heel en geneeskonstigi-aanmerkingen. Amsterdom: Commelign; 1668). Vonn Walter performed the first recorded autograft implant in 1821 (Burchardt H, Enneking WF. Transplantation of bone. *Surg Clin North Am* 1978;58:403-27.
30. Macewen W. Observation concerning transplantation on bone. *Proc R Soc Lond* 1881;32:232-47.
31. Albee FH. Fundamentals in bone transplantation: experiences in three thousands bone graft operations. JAMA 1923;81:1429-32.
32. Chase SW. Herndon CH. The fate of autogenous and homogenous bone grafts: a historical review. *J Bone Joint Surg Am* 1955;37:809-41.
33. Saltrick KR, Caron M, Grossman J. Utilization of autogenous corticocancellous bone graft from the distal tibia for reconstructive surgery of the foot and ankle. *Foot Ankle Surg* 1996;35:406-12.
34. O'Malley DF Jr, Conti SF. Results of distal tibial bone grafting in hindfoot arthrodeses. *Foot Ankle Int* 1996;17:374-7.
35. McGarvey WC, Braly WG. Bone graft in hindfoot arthrodesis: allograft vs autograft. *Orthopedics.* 1996;19:389-94.
36. Ishikawa Y, Goris R, Nagaoka K. Use of a cortico-cancellous bone graft in the repair of a cleft palate in a dog. Veterinary Surgery 1994;23:201-5.
37. Marchena JM, Block MS, Stover JD. Tibial bone harvesting under intravenous sedation: Morbidity and patient experiences. *J Oral Maxillofac Surg* 2002;60:1151-4.
38. Sivarajasingam V, Pell G, Morse M, Shephero JP. Secondary bone grafting of alveolar clefts: a densitometric comparison of iliac crest and tibial bone grafts. Cleft Palate-Craniofacial J 2001;38.
39. Mendicino RW, Leonheart E, Shromoff P. Techniques for harvesting autogenous bone graft of the lower extremity. *J Foot Ankle Surg* 199635:428-35.
40. Yu WD, Bernstein RM, Watts HG. Autogenous tibial strut grafts used in anterior spinal fusion for severe kyphosis and kyphoscoliosis. *Spine* 2003;28:699-705.
41. De Boer HH. The history of bone grafts. *Clin Orthop Relat Res* 1988;226:292-8.
42. Ahlmann E, et al. Comparison of anterior and posterior iliac bone grafts in terms of harvest-site morbidity and functional outcomes. *J Bone Joint Surg Am* 2002;84:5.
43. Anthony JP, Rawnsley JD, Benhaim P, et al. Donor leg morbidity and function after fibula free flap mandible reconstruction. *Plast Reconstr Surg* 1995;96:146-52.
44. Babovic S, Johnson CH, Finical SJ: Free fibula donor-site morbidity: the Mayo experience with 100 consecutive harvests. *J Reconstr Microsurg.* 2000;16:107-10.
45. Burchardt H, Enneking WF. Transplantation of bone. *Surg Clin North Am* 1978;58:403-27.