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Contemporary Review: Autograft Bone Use in Foot and Ankle Surgery

Jose M. Iturregui, MD[1], Alex M. Moses, MD[2], Glenn G. Shi, MD[1], and Edward T. Haupt, MD[1]

Abstract

Bone autografts are frequently harvested for use in foot and ankle surgery. A commonly used harvest site is the iliac crest; however, because of known morbidity with this site, the tibia and calcaneus are attractive alternatives. There remains limited understanding regarding the osteogenic potential of autografts from each of these locations. In this review, we provided an update of the known data on bone autografts from the iliac crest, tibia, and calcaneus, focusing on the total cells harvested from each site as well as the presence of osteogenic osteoprogenitor cells.

Level of Evidence: Level V, expert opinion.

Keywords: bone autograft, osteoprogenitor cell quantity, iliac crest, tibia, calcaneus

Introduction

Autologous bone grafts are frequently harvested for use in foot and ankle surgery.[8,12,18,22,25,28,32] Bone autografts have been reported to contain osteoconductive, osteoinductive, and osteogenic properties. These provide the scaffold, growth factors, signal proteins, and mesenchymal cells to facilitate healthy bone growth and healing.[8,13,18,22,28] Bone autografts also pose no risk for rejection or disease transmission when compared to allografts.[17,18,25] The combination of these properties and benefits makes autografts an attractive option for adjunctive use in procedures like arthrodesis, with the goal of enhanced bone healing and, therefore, successful fusion.[7,28] Associated donor site morbidity, however, remains the main potential downside to autograft harvest.[5,7,10,17,20]

Historically, the iliac crest was most commonly used to harvest autologous bone graft because of its ease of access and higher quantity of available graft.[3,18] However, iliac crest donor site morbidity and complications remain a concern, with frequent donor site pain and a reported complication rate as high as 49%.[2,5,7,10,18,25] Foot and ankle surgeons have therefore explored the ipsilateral tibia and calcaneus as alternative harvest sites because of their accessibility and potentially lower morbidity.[7,12,13,18,32]

One of the goals of harvesting autologous bone graft is to obtain mesenchymal stromal cells (MSCs), with the underlying rationale being that grafts with higher MSC concentrations combined with the appropriate osteoinductive and osteoconductive environment will differentiate into osteogenic cells and thus promote new bone formation and increase osseous tissue repair and healing.[8,16] There remains limited understanding, however, of the actual osteogenic potential of autografts harvested from the iliac crest, tibia, and calcaneus.

The purpose of this review is to summarize bone autograft harvests from the iliac crest, tibia, and calcaneus for use in foot and ankle surgery.

Autologous Bone Graft Consistency

Autografts used in foot and ankle surgery can be acquired from cancellous bone, cortical bone, or both. Cancellous

[1]Department of Orthopedic Surgery, Mayo Clinic, Jacksonville, FL, USA
[2]Department of Orthopedic Surgery, University of Florida, Jacksonville, FL, USA

Corresponding Author:
Edward T. Haupt, MD, Department of Orthopedic Surgery, Mayo Clinic, 4500 San Pablo Rd, Jacksonville, FL 32224, USA.
Email: haupt.edward@mayo.edu

bone is most frequently used in foot and ankle procedures, as this graft is nonstructural and malleable. In addition, cancellous bone grafts may revascularize and incorporate into host bone with more ease because of its increased porosity.[8] These characteristics are desirable in procedures such as arthrodesis, where molding and filling of small voids is necessary. In contrast, cortical bone grafts are structural but nonmalleable.

Cortical autografts may take longer to revascularize and incorporate into host bone because of the less porous structure but are optimal in procedures where structural support is needed, such as lateral column lengthening or posterior bone block interposition grafting.[8] Cortical bone autografts are considered to have minimal osteogenic potential when compared to cancellous bone autografts.[18]

Liquid bone marrow aspirate (BMA) contains osteoprogenitor cells, and it has been used in procedures with the goal of augmenting tissue repair and bone growth.[8,9,27] Hernigou et al[9] demonstrated more efficacious bone healing in patients with atrophic tibial nonunion when greater concentrations of osteoprogenitor cells were present in the autograft. Although some authors have reported using structural bone allograft in combination with BMA to embed the scaffold with viable osteogenic cells, further research into this technique is needed.[14,30,31]

Autologous Bone Graft Harvest Techniques

The harvest method should match the structural and biological needs of the primary procedure while simultaneously considering the associated risks and potential donor site morbidity. BMA harvests are the least invasive, with percutaneous wounds and the use of a cannulated needle system to enter the intramedullary space to acquire the cells via suction. The yield is a liquid and does not include bone. Accordingly, the harvest may be used to add viable cellular material to a cancellous allograft product. Structural allograft or even porous metallic wedges can also be soaked in the liquid material prior to implantation in an attempt to add autograft cellular material to an otherwise acellular structural piece.

For cancellous bone harvests, the surgical incision is larger than that used for a percutaneous aspirate, but not as large as that required for structural bone harvest. The incision is generally about 1-2 cm in length as cancellous harvests can be performed by breaching the cortex and then using a variety of techniques to excavate cancellous graft from the intramedullary space. Traditionally, a manual harvesting technique (i.e., curettes, osteotomes) has been used. More recently, mechanically powered devices have become available.

Although structural graft can be obtained from several locations, the ilium is the most common harvest site.[8] The harvest is performed via an open approach with an incision that is typically larger than that used for cancellous harvest. The bone is exposed and a segment of cortical bone is cut with an osteotome or saw.

Quantity of Cells Harvested From the Ilium, Tibia, and Calcaneus

The quantity of MSCs harvested may play a role in the osteogenic potential of the bone graft harvest. It is generally thought the amount and concentration of bone marrow MSCs decrease in each extremity from proximal to distal.[11,19,22]

The methodology used in most studies involved identifying all harvested nucleated cells, either manually or using an electronic cell counter, with the assumption that the number of MSCs represented in the population of nucleated cells of harvested graft ranged from 1/10 000 to 1/100 000.[11,19] This assumption may not be an accurate representation, however. These studies simply counted nucleated cells, assuming a constant fraction of the nucleated cells to be osteogenic.[9,11,24] None were able to directly count osteogenic cells. Some studies expanded the harvested nucleated cells into fibroblast colony-forming units (CFUs) to assess the actual proportion of nucleated cells that may be osteogenic.[9,11,24] After the nucleated cells were plated and grown in cell cultures, the resulting CFUs were then manually counted to estimate the osteogenic cell quantity in the sample. CFUs are a surrogate for osteogenic cells as we do not know the true osteogenic significance of their presence. The CFU technique demonstrates that cellular material can create a tissue colony in vitro. Whether or not this corresponds to new bone formation in vivo, however, is unknown.

In addition to the osteogenic cell identification methods, these studies used imperfect cell-counting techniques themselves for quantification either by using a hemocytometer or by counting electronically using cell counter devices. Electronic counters, although easier to use, are subject to error. These devices are able to discriminate cells by size and volume quickly; however, dead cell discrimination, cell clumping, and cell size heterogeneity can result in inaccurate counts.[21,23] In contrast, hemocytometry is a less expensive technique that requires manual cell identification and counting. Hemocytometry, though, is a labor-intensive process that can result in user misuse, bias, and inaccurate counts. Furthermore, sources of error using this technique include samples with too many or too few cells, samples with uneven cell distributions, hemocytometer contamination, variation among users, subjective decisions when using the counter, and hemocytometer filling rate variability.[21]

Chiodo et al[3] performed a histologic evaluation of cancellous bone harvested with a medium curette from the

anterior iliac crest (n=10) and proximal tibia (n=10) in 20 patients. Their analysis demonstrated that anterior iliac bone grafts contain a greater abundance of hematopoietic marrow in comparison to proximal tibia grafts, which predominantly contain medullary fat. It should be noted that this study assumed the percentage of histologically identified hematopoietic tissue was proportional to the quantity of osteogenic cells; however, no direct osteogenic cellular identification and quantification was performed to verify that assumption. This prominent study paved the way for more recent investigations evaluating the cell concentrations within the iliac crest, tibia, and calcaneus harvests.

In a study by Hernigou et al,[9] BMAs of bilateral anterior iliac crests in 60 patients were performed with a beveled needle and syringe. Using a hemocytometer, a manual method of cell counting, the authors found that the average quantity of nucleated cells harvested per aspirate was 18×10^6 cells/mL. Moreover, they found the average quantity of CFUs to be 33 per every 10^6 nucleated cells. The number of CFUs could only be determined after a standard volume of nucleated cells had been cultured and stained, which allowed time for CFUs to incubate and subsequently be quantified under a microscope. From this information, the average yield of progenitor cells obtained in the anterior iliac crest bone marrow harvests was then calculated to be 612 progenitor cells/mL. As previously noted, CFUs are a surrogate for true osteogenic cells, and no actual osteogenic cells were quantified in this study. However, the fibroblastic characteristic of the CFUs was verified by identifying fibronectin and type I and III collagen using immunofluorescence staining and antibodies.

More recent studies have evaluated the quantity of osteoprogenitor cells obtained from different harvest sites. Hyer et al[11] compared BMA samples from the ipsilateral anterior iliac crest, distal tibia, and calcaneus from each of their 40 patients enrolled in the study to determine the yield of osteoblastic progenitor cells obtained from each harvest site. They used an 11-gauge needle and syringe to perform the BMA. After centrifugation, nucleated cells contained in the buffy coat were quantified with a hemocytometer, grown on culture plates to form CFUs, which were then stained with alkaline phosphatase and quantified. Previous work has demonstrated that mesenchymal stem cells staining positive for alkaline phosphatase are within the osteoblast lineage.[29] Based on the alkaline phosphatase–positive cells, the investigators assumed the presence of viable osteoprogenitor cells. The quantified colonies were then used to calculate a yield of osteoprogenitor cells in the harvests. The average concentration of nucleated cells harvested was 15.6×10^6 cells/mL from the anterior iliac crest, 5.8×10^6 cells/mL from the distal tibia, and 7.1×10^6 cells/mL from the calcaneus. The average calculated concentration of osteoprogenitor cells harvested was 898.4 cells/mL from the anterior iliac crest, 32.4 cells/mL from the distal tibia, and 7.1 cells/mL from the calcaneus. These results support the conclusion that MSCs decrease in concentration from proximal to distal in the limb. The authors' data demonstrated a statistically significant difference in osteoprogenitor cell yield when comparing the anterior iliac crest to both the distal tibia and calcaneus ($P < .0001$ for both). No statistical significance was demonstrated in the yields obtained between the distal tibia and calcaneus ($P = .063$).

Pierini et al[24] harvested BMA with a 14-gauge needle and syringe from both the posterior and anterior iliac crests in 22 patients. After gradient separation, mononuclear cells were gathered and grown in culture flasks. An automated cell counter was used to determine the total viable nucleated cell count. Further, mononuclear cells were cultured on plates and after methylene blue staining, the MSC yield was determined from the colony counts. The authors reported an average BMA concentration of 54.7×10^6 nucleated cells/mL from the posterior iliac crest vs 49.0×10^6 nucleated cells/mL from the anterior iliac crest. Although the posterior iliac crest yielded a greater concentration of nucleated cells, this difference was not statistically significant. However, there was a significantly increased prevalence of colony-forming connective tissue progenitors in cultures obtained from the posterior iliac crest (mean, 269.3 progenitors per 10^6 mononuclear cells) compared to the anterior iliac crest (mean, 166.4 progenitors per 10^6 mononuclear cells) ($P = .0001$). The investigators demonstrated that the progenitor cells from each donor site proliferated similarly and determined they had the same biological and functional characteristics.

Marx and Tursun[15] harvested BMA using a trocar, cannula, and syringe and evaluated the quantity of nucleated cells harvested from the tibial plateau, anterior ilium, and posterior ilium. Nucleated cells were counted with an automated cell counter. The authors reported an average nucleated cell concentration of 11.8×10^6 cells/mL in the tibial plateau, 24.4×10^6 cells/mL in the anterior ilium, and 25.1×10^6 cells/mL in the posterior ilium. Thus, the tibial plateau yielded approximately half of the nucleated cell concentration obtained from both the anterior ilium and posterior ilium. No CFUs were quantified in this study.

Narbona-Carceles et al[19] studied BMA samples harvested with an 11-gauge cannulated trocar and syringe from the iliac crest and proximal tibia in 20 patients. Using a cell counter, the average concentration of mononuclear cells obtained was 10.05×10^6 cells/mL from the iliac crest in 20 patients and 1.70×10^6 cells/mL from the proximal tibia in 16 patients ($P < .05$).

Davies et al[4] aspirated bone marrow with an 8-gauge needle and syringe in 10 patients. After centrifugation, a cell count was performed with a cell counter. The investigators found a significant difference ($P = .0007$) in mononuclear

Table 1. Summary of Cell Yields Obtained at Different Harvest Sites Using the Bone Marrow Aspirate Harvest Technique.

Authors	Year	Journal	Harvest Site Location	Nucleated Cell Yield (cells/mL)	Osteoprogenitor Cell Yield (cells/mL)	Osteoprogenitor Cell Yield (cells/10^6 mononuclear cells)
Hernigou et al[9]	2005	*The Journal of Bone and Joint Surgery*	Anterior iliac crest	18.0×10^6	612	–
Hyer et al[11]	2013	*The Journal of Bone and Joint Surgery*	Anterior iliac crest	15.6×10^6	898.4	–
			Distal tibia	5.8×10^6	32.4	–
			Calcaneus	7.1×10^6	7.1	–
Pierini et al[24]	2013	*The Journal of Bone and Joint Surgery*	Anterior iliac crest	49.0×10^6	–	166.4
			Posterior iliac crest	54.7×10^6	–	269.3
Marx and Tursun[15]	2013	*The International Journal of Oral & Maxillofacial Implants*	Anterior ilium	24.4×10^6	–	–
			Posterior ilium	25.1×10^6	–	–
			Tibial plateau	11.8×10^6	–	–
Narbona-Carceles et al[19]	2014	*Injury*	Iliac crest	$10.05 \times 10^{6*}$	–	–
			Proximal tibia	$1.70 \times 10^{6*}$	–	–
Davies et al[4]	2017	*Journal of Orthopaedic Research*	Anterior superior iliac spine	$1.61 \times 10^{6*}$	–	–
			Proximal tibia	$0.63 \times 10^{6*}$	–	–

*Only mononuclear cells were counted.

cells harvested from the anterior superior iliac spine (1.61×10^6 cells/mL) and proximal tibia (0.63×10^6 cells/mL).

Overall, these studies consistently demonstrate higher cell concentrations in bone marrow harvested from the ilium when compared to the tibia and calcaneus (Table 1). Nevertheless, these studies have limitations, most notably in relation to osteogenic cell identification and cell counting. One study assumed the percentage of histologically identified hematopoietic tissue was proportional to the quantity of osteogenic cells; however, no direct cellular identification and quantification was performed to verify that assumption. Other studies expanded harvested cells via culture and counted CFUs; however, CFUs are only a surrogate for true osteogenic cells. The osteogenic nature of CFUs, as well as their osteogenic heterogeneity, is still unknown.

To the authors' knowledge, no recent studies have isolated and provided noncalculated counts of osteoprogenitor cells obtained from the iliac crest, tibia, or calcaneus. The closest available quantification of osteogenic cells has been quantifying CFUs staining for alkaline phosphatase. Therefore, further studies and newer methods are needed to evaluate the quantity of osteogenic cells and their potential for each harvest site more accurately. To this end, a newer method of identification of osteogenic cells using cluster of differentiation (CD) markers and flow cytometry shows promise in this regard.

CD Markers Overview

CD markers are antigens expressed on the surface of cells that allow for identification and classification of different cell populations.[6] By use of flow cytometry, antibodies can target specific CD markers to identify the presence of a particular cell in a collected sample. Identification of known MSC CD markers in harvests from the iliac crest, tibia, and calcaneus can deepen our understanding of the MSC populations present at each harvest site.

For research purposes, the International Society for Cellular Therapy (ISCT) developed standard criteria for characterizing MSCs based on the best available data because of inconsistent definitions of MSC characteristics across the literature. The ISCT states the minimum criteria needed to identify MSCs include MSC plastic adherence under standard culture conditions; expression of the CD105, CD73, and CD90 cell surface markers in $\geq$95% of the MSCs; lack of expression of the CD45, CD34, CD14 or CD11b, CD79α or CD19, and HLA class II cell surface markers ($\leq$2% of the MSCs can be positive); and the ability to differentiate in vitro into osteoblasts, adipocytes, and

chondroblasts.[6] Since the establishment of this criteria, numerous studies have supported the ISCT's position statement. Using flow cytometry and CD markers for cellular identification shows great promise; however, this technology does not provide cellular quantification. Thus, the value of flow cytometry is to confirm the presence of cell markers within a population of cells. Flow cytometry itself does not provide quantitative information without a separate quantitation step.

Following the ISCT guidelines, Li et al[13] identified MSCs positive for CD73, CD90, and CD105 and negative for CD34 and CD45 in BMA specimens collected from the calcaneus of 10 patients. These cells demonstrated mesenchymal lineage differentiation into osteoblasts, chondrocytes, and adipocytes. The authors determined that the calcaneus is a reliable source to harvest MSCs with the capacity for bone regeneration after foot and ankle procedures; however, the quantity of osteogenic cells from the calcaneus was not determined.

Narbona-Carceles et al[19] investigated the expression of CD73, CD90, CD105, CD19, CD14, CD34, CD45, and HLA-DR in BMA cells harvested from the iliac crest and proximal tibia using flow cytometry. In addition, they investigated the VEGF, CD133, CD117, CD71, and CD271 markers because of their utility in identifying MSCs. Both the iliac crest and proximal tibia demonstrated strongly positive MSC phenotype expression for CD73 and CD71, and positive expression for VEGF, CD90, CD271, and CD105. The CD14, CD19, CD117, and CD133 markers were expressed in low levels, and the HLA-DR, CD34, and CD45 markers demonstrated almost no expression. Overall, the investigators found similar phenotypic expression levels between the iliac crest and proximal tibia.

Although flow cytometry can confirm the presence of cells with surface markers consistent with osteoprogenitor cells, the quantity of osteoprogenitor cells still cannot be determined with this method. Although several investigators have sought to identify the presence of cellular progenitors in the sample, difficulties with quantification of total nucleated cells and CFUs remain.

Pierini et al[24] investigated the CD29, CD44, CD146, and CD166 surface adhesion markers, the CD73, CD90, and CD105 mesenchymal cell markers, and the CD34 and CD45 hematopoietic surface markers in harvests from the anterior and posterior iliac crest. The majority of cells from both sites resulted positive for markers CD29, CD44, CD73, CD90, CD105, CD146, and CD166 and negative for markers CD34 and CD45. There was no statistically significant difference in phenotypes between the two harvest sites when comparing the percentage of cells positive for each MSC and hematopoietic marker.

Davies et al[4] evaluated the CD34, CD45, CD73, CD90, and CD105 antigens and found consistent expression of the CD73, CD90, and CD105 MSC surface phenotypes between mesenchymal cells harvested from the anterior ilium and proximal tibia. Their study also demonstrated no difference in the proliferative ability of the harvested cells. The authors therefore concluded that MSC functional abilities from these donor sites do not vary. The authors did conclude that the pelvis is the optimum site to harvest MSCs because of the superior cellular yield, aspirate volume, and CFUs obtained. However, high interindividual variation and a small sample size limit the generalizability of the data. In addition, such variability in MSC yields and CD surface antigen expression among individuals, for reasons that remain unknown, are potential shortcomings when determining the osteogenic potential of bone autograft harvests from different anatomical locations.

Based on known MSC markers, the studies cited above demonstrated the presence of osteoprogenitor cells with comparable phenotypes in the iliac crest, tibia, and calcaneus. However, combining this information with the reported MSC yield at these sites, the current literature indicates that one can expect to harvest MSCs at a decreasing concentration from proximal to distal in the lower extremities. To this end, the iliac crest's extrapolated superior amount of osteogenic nucleated cells in BMA samples demonstrated in the studies by Hernigou et al,[9] Hyer et al,[11] and Pierini et al[24] makes BMA a promising bone graft supplement for fusions when combined with allograft products or structural autograft harvest.

It should be noted that despite flow cytometry's advantages over gross identification of nucleated cells, this technique is still unable to identify the true osteogenic characteristics of the cell regarding bone growth and healing. It assumes that cell surface markers are consistently related to the function and differentiation pathway of that progenitor cell. There is still much to learn about environmental influence on these cells and the growth factors associated with their proliferation, differentiation, and function. Further, this technology has yet to elucidate the quantity of osteoprogenitor cells in bone tissue harvests.

Despite the increasing popularity of BMA harvesting techniques as well as interest in osteogenic cells, the true mechanisms of osteogenic cells to initiate bone healing remains unknown. Osteoprogenitor cells are thought to assist in bone healing; however, the exact mechanism by which the osteoprogenitor stem cell exerts its function to initiate healing and cause bone formation is still under investigation.

Harvest Site Morbidity and Complications

The iliac crest is a commonly used donor site for harvesting bone autograft, both cortical and cancellous.[3,18] However,

pain at the iliac crest donor site is a commonly reported complication of this procedure.[2,5,8,10] Other reported complications include infection, persistent numbness, hematoma, fracture, lateral femoral cutaneous nerve injury, and hernia.[2,5,7,25]

Huang et al[10] used the visual analog scale (VAS) to compare postoperative pain at the anterior iliac crest and proximal tibia harvest sites in 18 patients. Their study demonstrated significantly increased pain levels in those patients undergoing anterior iliac crest harvest at 1, 5, and 14 days postoperatively ($P < .001$). At 4 and 8 weeks postoperatively, however, no significant difference in pain was observed between the groups. Of the 10 patients who underwent iliac crest harvesting, one donor site fracture with hematoma occurred. Of the 8 patients who underwent proximal tibia harvesting, no donor site morbidities were identified.

Elattar et al[7] investigated pain and complications after autograft harvest from the anterior iliac crest in a larger series of 55 patients. Fifty-two patients (94.5%) were satisfied with the procedure and had good to excellent results. Minor complications were reported in 9 patients, which included 4 patients with a hematoma and 5 patients with numbness at the harvest site. All complications resolved except for 1 patient who reported persistent numbness at the harvest site 6 months postoperatively. No major complications resulted from the bone graft harvest. A VAS harvest site pain score greater than 7 was reported in 9 (16%) of patients in the immediate postoperative period. However, only 2 patients reported persistent, nonlimiting harvest site pain that lasted up to 6 months after surgery.

Salawu et al[26] compared complications in 86 patients who underwent iliac crest or proximal tibia harvest (43 patients in each group). One superficial surgical wound infection was reported in the proximal tibia cohort and 3 in the iliac crest cohort. No major complications were reported. The investigators used a numerical scale to assess pain at the donor site. At the 1-month postoperative period, 3 patients had an average numerical pain score of mild severity at the proximal tibia harvest site compared to 12 patients in the iliac crest cohort who had an average score of moderate severity. At the 3-month postoperative period, no patients in the proximal tibia cohort reported pain at the harvest site compared to 2 patients in the iliac crest cohort who had mild pain. Additionally, all 86 patients in this study achieved adequate bone union with either graft for the various procedures performed, and no reoperations were reported.

Jia et al[12] evaluated 9 patients who underwent proximal tibia bone graft harvesting. They reported no harvest site postoperative complications. Utilizing the VAS score, all patients reported tolerable harvest site pain in the immediate postoperative period and no residual pain at their first postoperative visit.

In the study by Hyer et al,[11] the authors reported an average VAS pain score based on a scale of 1-100 assessed at 2, 4, 8, and 12 weeks postoperatively. Although pain was minimal in this cohort, the averaged pain scores over the four postoperative timepoints were significantly greater at the calcaneus (20.8) harvest site compared to both the anterior iliac crest (4.2) and distal tibia (7.7) harvest sites ($P < .05$). The pain scores reported at each harvest site significantly decreased over time, with 12-week scores of 13.9 for the calcaneus, 3.1 for the anterior iliac crest, and 5.3 for the distal tibia. McAlister et al[16] then published a study with 33 patients from Hyer et al's[11] prospective study and reported 1 distal tibia stress fracture at the harvest site due to postoperative weightbearing noncompliance.

Baumhauer et al[1] used the VAS score to investigate postoperative harvest site pain at 3, 24, 36, and 52 weeks of follow-up in 130 patients who underwent either iliac crest (17), proximal tibia (69), distal tibia (24), or calcaneus (20) bone graft harvesting. At 3 weeks postoperatively, there was significantly more pain reported in the iliac crest harvest site compared to the proximal tibia and calcaneus, but not the distal tibia. No significant difference in pain levels were observed at 24, 36, or 52 weeks of follow-up between the cohorts.

In that study by Li et al,[13] the authors reported no postoperative complications of the calcaneus harvest site after bone marrow aspiration in their 10-patient cohort.

Finally, O'Malley et al[20] evaluated 210 patients for morbidity and complications following calcaneus autograft harvest. No complications were reported in 181 (86.2%) patients, whereas 29 (13.8%) patients reported symptoms at the harvest site. There were only 3 (1.4%) major complications reported, including 1 fracture, 1 stress fracture, and 1 case of permanent numbness in the sural nerve distribution. Minor complications included incisional pain (1.9%), incisional sensitivity (2.9%), incisional numbness (1.9%), shoe wear limitations (1.0%), or a combination of these symptoms (4.8%).

Summary

Based on the presence of cells with positive MSC surface markers, osteoprogenitor cells are present in the iliac crest, tibia, and calcaneus. Nevertheless, the precise quantification of the number of cells present remains unknown. In the reviewed studies, iliac crest autograft has been reported to contain the greatest number of nucleated cells, and likely osteoprogenitor cells, when compared to the tibia and calcaneus. Nevertheless, patients undergoing iliac crest harvest should be counseled on the potential pain associated with this procedure, especially in the first few weeks following surgery.

Ethical Approval

Ethical approval was not sought for the present study because this study was a review of the literature.

Declaration of Conflicting Interests

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ORCID iDs

Jose M. Iturregui, MD, https://orcid.org/0000-0001-8120-7967
Glenn G. Shi, MD, https://orcid.org/0000-0001-8764-8886
Edward T. Haupt, MD, https://orcid.org/0000-0002-6198-9233

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