Percutaneous Harvest of Calcaneal Bone Autograft: Quantification of Volume and Definition of Anatomical Safe Zones

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Statement of Purpose

The purpose of this poster is to present an efficient technique for the harvest of calcaneal bone graft and quantify cancellous autograft volume from the calcaneus while simultaneously defining the anatomical safe zone and identifying anatomical structures at risk.

Introduction and Literature Review

Bone grafts are commonly used in orthopedic surgery to augment arthrodesis and non-union revision, enhance fracture healing, and treat osseous defects [1,2,3]. Despite the increasing availability of allograft bone and bone graft substitutes, autogenous bone graft has been shown to be superior in its ability to enhance bone healing [2] and remains the gold standard for reconstructive procedures in the foot and ankle [4]. Unlike bone allograft, autogenous bone graft has properties which make it vital to bone healing, stimulation and growth. Autograft bone is osteoconductive in that it provides a scaffold for osseous and fibrovascular ingrowth and proliferation. It is also osteoinductive in nature as it promotes growth factors and matrix proteins, which help modulate cellular processes essential to bone growth. Additionally, bone autograft is osteogenic as it provides osteoblasts, osteocytes, and precursors that can actively form bone [5,6].

Some of the challenges of autogenous bone grafting include the potential for complications at the harvest site. Due to complications associated with iliac crest graft harvesting, like persistent donor site pain [3], alternative harvest sites in the lower extremity have been utilized including the greater trochanter, distal and proximal tibial metaphysis and the fibula, as well as the calcaneus [7]. Iliac crest graft harvest is associated with persistent pain which is commonly associated with a host of other complications including hematoma, wound infection, incisional pain, nerve injury, and/or stress fracture. Proximal tibial harvests have documented complications such as iatrogenic fracture and hematoma formation [3,6].

In the foot and ankle, the calcaneus is a convenient harvest site from which autograft can be obtained with documented success and low complications rates [2,8]. The calcaneus is a great source of richly cellular cancellous and cortico-cancellous autograft [8,9]. Cancellous bone grafts possess an inherent quality of rapid revascularization and demonstrate complete incorporation over time through the process of creeping substitution [10]. It is typically used in areas that do not require significant structural support, such as filling small defects or applying it to prepared joint surfaces to aid in joint fusion. Some advantages of cancellous bone graft harvest are that it requires a minimal incision and has low morbidity with minimal cost [11]. Additionally, the calcaneus' relative thin soft tissue envelope at its posterolateral aspect makes dissection comparatively easy to more proximal harvest sites.

The adjunct use of calcaneal autografts in forefoot arthrodesis has limited complications due to minimally invasive technique and the small amount of harvested bone. The complications and morbidity associated with calcaneal autograft harvest is not widely studied, however theoretical disadvantages include the limited volume of available graft, the unknown quality of harvested bone, potential sural nerve injury and iatrogenic calcaneal fracture. A study evaluating calcaneal bone-graft outcomes in 210 patients treated by six surgeons found that 86.2% experienced no complications, 2.9% indicated only incisional nerve sensitivity, 1.9% experienced only incisional pain, 2% reported only shoe limitations, and 4.8% of responders had a combination of symptoms. Only 3 patients (1.4%) showed more significant complications including fracture of the graft site and calcaneal stress fracture and 1 patient with permanent numbness along the sural nerve distribution [12].

These complications could very likely be a result of differing harvest techniques [5,8,10]. Another case study on incidental CT imaging four years after calcaneal graft harvest for foot arthrodesis demonstrated the failure however with this approach, the medial and lateral calcaneal cortices were purchased, theoretically increasing neurovascular insult and iatrogenic fracture [8]. In 2006, Roukis et al. described a similar approach using this 8mm trephine without penetrating the medial cortex [5]. Similar complications are associated with this technique and specialized surgical instrumentation is also required. In 2006, DiDomenico and Harrow described a technique in which a 3.5mm drill was used to breach the lateral wall and then a bone curette was utilized to harvest cancellous bone to achieve the desired amount of graft [15].

The current study aims to present a variation of the technique described by DiDomenico and Haro, identify the potential complications from the calcaneal donor site, and to define the anatomical safe zones for efficient execution of graft harvest. This modified percutaneous technique for harvesting calcaneal cancellous autograft requires no additional surgical equipment or power instrumentation, thereby increasing operating room efficiency and decreasing costs associated with allograft use.

Figure 1: Measurement of bone graft with 3cc syringe

Materials and Methods

Specimen Preparation

Nine matched-pairs of fresh frozen human cadaveric below-knee limbs were obtained and thawed at room temperature prior to the procedure. All donors were matched to sex (6 Female, 3 male), general medical comorbidities, and age range (62.4 years). Donor criteria included a history free from previous foot and ankle surgery or systemic musculoskeletal disease (osteoporosis, inflammatory arthropathies, spondylopathies, etc.). Calcaneal autograft was obtained via the senior author's technique (DJE). Bone graft was quantified by podiatric medical students (BR and JT) utilizing a 3cc syringe and plunger to pack and measure (Figure 1). An independent professor of lower extremity anatomy (KS) meticulously dissected the lateral calcaneal soft tissue envelope to determine rates of neurovascular compromise (Figure 2). Anatomical safe zones were defined by measurement of the harvest site compared to vital anatomical structures (Figure 3). An L-shaped lateral extensile incision was performed and all soft tissue reflected off of the lateral calcaneus. The diameter of the cortical breach, any break in the cortex of lateral calcaneal wall, and location of the opening was measured and recorded (Table 1).

Surgical Technique

The instrumentation necessary for adequate harvest includes: straight bone curettes, curved mosquito hemostat, #10 blade, sterile cup (Figure 4). The incision should be made inferior to the sural nerve and peroneal tendons on the posterolateral aspect of the heel. The incision is placed at the bisection of imaginary lines drawn between the distal tip of the fibula and posterior/inferior calcaneus and the cranial and caudal borders of the lateral calcaneus (Figure 5). It is vital that the harvest site be located within the midsubstance of the posterior tubercle of the calcaneus. This ensures a maximum amount of graft harvest while avoiding the important weight bearing architecture of the anterior and posterior calcaneus.

Figure 2: Dissection of the lateral hindfoot

Once the site is located, a small stab incision is made parallel to the sural nerve with a #10 blade (Figure 6). The incision is carried down to the lateral wall of the calcaneus. A curved mosquito hemostat may be used if blunt dissection is necessary. Next, a small straight bone curette is inserted into the lateral wall of the calcaneus. The curette is spun back and forth with the surgeon's fingers mimicking a "hand drilling" technique. Once the lateral wall is punctured the first curette is removed and a slightly larger curette is inserted and the process is repeated.
Once a large enough curette is used (usually 3-4mm) the surgeon can safely harvest cancellous bone graft in an efficient manner. One must be able to visualize the three-dimensional orientation of the calcaneus within his or her mind's eye. Cancellous bone is then curetted utilizing an "ice cream scoop" technique, with care to not violate the medial calcaneal wall (Figure 7). Once cancellous bone is extirpated it is placed into a sterile container for later use at the fusion site (Figure 8).

Figure 3: Harvest site is marked with an 18G needle. Anatomical structures of the lateral hindfoot are identified and distance from harvest site is measured and recorded.

Figure 4: Instrumentation for percutaneous calcaneal bone graft harvest

Results

The average calcaneal cancellous autograft obtained was **0.85cc** through an average cortical opening of **0.77cm**. Incision placement was noted to be within the midsubstance of the posterior calcaneal tuber on all occasions. Distance of harvest site from the sural nerve was on average **1.85cm**. Distance of harvest site from the inferior calcaneus was on average **1.64cm**. Distance of harvest site from the tip of the lateral malleolus was on average **3.08cm**. Distance of harvest site from the posterior calcaneus was on average **2.24cm**. Distance of harvest site from the peroneal tendons was on average **2.18cm**. The medial calcaneal cortical wall remained intact on all limbs, and only 1 case of neurovascular compromise was noted. In that case, the nerve transected was identified as the lateral calcaneal branch of the sural nerve.

Specimen	Age	Sex	Volume of Graft (Cubic Centimeters)	Neurovascular Injury?	Diameter (cm)	Distance from Lateral Malleolus (cm)	Distance from Inferior Calcaneus (cm)	Distance from Posterior Calcaneus (cm)	Distance from Sural Nerve (cm)	Distance from Peroneal Tendons (cm)
1	65	Male	0.7	No	0.5	4	1.5	2.2	1.8	2.8
	65	Male	1	No	0.6	3.2	2.3	3.4	3	2.1
2	54	Male	0.5	Yes	0.9	3.7	1.5	2.5	2.1	3
	54	Male	0.8	No	0.8	2.5	2	2.5	1.6	2
3	63	Female	0.8	No	0.9	3.4	1.5	1.8	1.7	1.5
	63	Female	0.8	No	1.5	2.9	1.2	1.1	1.4	1.8
4	70	Male	1.6	No	0.9	3.5	1.8	1.9	1.8	2.5
	70	Male	0.4	No	1	2.5	2.3	3.3	1.5	1
5	59	Female	0.9	No	0.7	2.4	1.7	2.4	1.4	1.8
	59	Female	0.8	No	0.7	1.9	1.6	2.1	1.3	2.4
6	63	Female	1.2	No	0.7	2.7	1.4	1.8	1.9	1.5
	63	Female	0.7	No	0.8	2.8	1.4	1.7	1.9	2
7	60	Female	0.5	No	0.7	3	1.7	2.2	2.1	2.1
	60	Female	0.7	No	0.45	3.3	1.2	2.3	1.7	2.3
8	66	Female	1.1	No	0.7	3.8	1.4	2.2	1.9	2.8
	66	Female	0.7	No	0.7	2.9	2	2.5	1.8	2.6
9	62	Female	1.3	No	0.6	3.8	1.3	2.4	2.4	2.7
	62	Female	0.9	No	0.7	3.2	1.7	2	1.8	2.4
Mean	**62.44**		**0.86**		**0.77**	**3.08**	**1.64**	**2.24**	**1.84**	**2.18**

Table 1: Raw Data from 18 cadaveric limbs. Graft Volume and distance of anatomic structures to harvest site are listed.

Figure 5: Identification of graft harvest site

Figure 6: Incision with #10 blade parallel to the sural nerve.

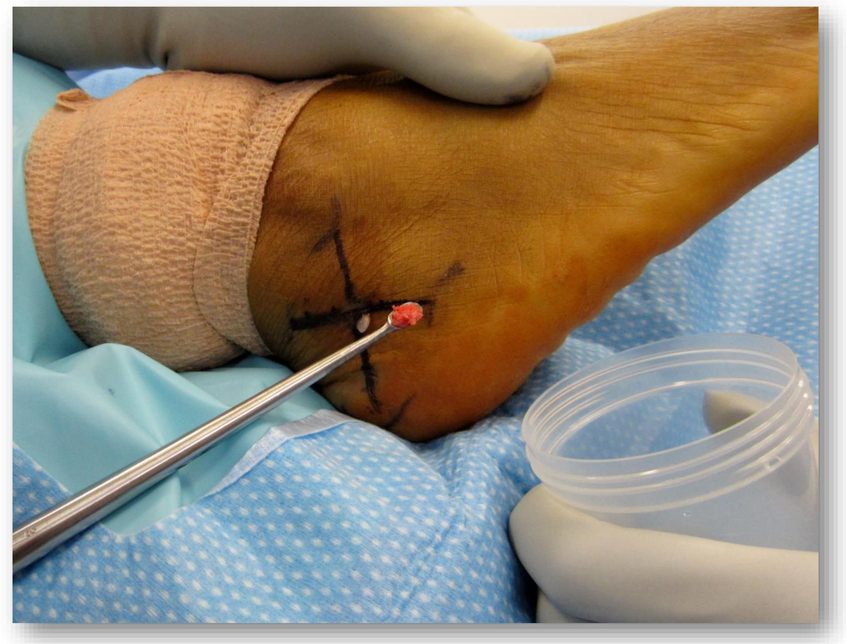

Figure 8: Bone graft is harvested and placed into a sterile container

Discussion

Using the above-described surgical approach, foot and ankle surgeons can feel confident that adequate bone harvest can be completed with little to no associated morbidity to the patient. Additionally, when following this technique, the surgeon does not need to rely on intra-operative fluoroscopy to guide incision placement. This ultimately saves operative time and cost, and limits exposure of the surgeon, staff, and patient to unnecessary ionizing radiation.

In this study, we determined the average graft volume to be 0.85cc. The senior author has found this volume to be ideal for primary 1st MPJ arthrodesis and Lapidus arthrodesis cases. This volume can also be useful for digital arthrodesis procedures as well. The nearest structure of concern to the harvest site was identified as the sural nerve, which was on average 1.85cm away from the incision. In no instances was the sural nerve violated, however there was one instance of transection of the lateral calcaneal branch. Additionally the cortical deficit was on average 0.77cm in size. This is slightly bigger than the largest curette used for harvest. At our institution we have access to weight bearing CT imagery. Many of our patients have participated in other research projects, and have been scanned after having calcaneal bone graft harvested in this fashion. We have anecdotally noticed that the medullary void is far greater in size than the small cortical deficit (Figure 7).

Harvesting of autogenous bone graft continues to be a reliable adjunctive procedure in many orthopedic surgical cases. Within the realm of the foot and ankle, the calcaneus has been identified as a viable source for autogenous bone graft [2,8,9]. Traditionally, the techniques employed for harvest of calcaneal bone graft required open procedures, or the need for power instrumentation [5,9]. To our knowledge, this is the first report of the quantification of graft volume, as well as evaluation of anatomical safe zones for performance of calcaneal autograft bone harvest without the need of power instrumentation or operative fluoroscopy.

Figure 7: CT imaging of a post-operative patient. Note the large medullary void with minimal lateral wall puncture. The medial wall was not violated.

The limitations of this study revolve around the use of cadaveric specimens as a data source. Although we did evaluate the anatomical structures at risk, an a clinical cohort would be necessary to properly evaluate subjective complaints from the patient, as well as other objective complications such as scaring and wound breakdown. Additionally, the use of fresh-frozen cadavers could slightly alter the quality of bone available for harvest, therefore skewing the volume results we obtained. To limit this, limbs were thawed only once prior to graft procurement. A study on living patients would ultimately be necessary to eliminate this confounder.

Given the simplicity of our proposed technique and the anatomically sound safety profile, percutaneous harvest of calcaneal bone graft should be a technique that all foot and ankle surgeons should be familiar with. Our study has demonstrated adequate volume for small joint procedures, and little risk to surrounding anatomical structures.

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