Foot and Ankle Surgery 20 (2014) 120–124

Contents lists available at ScienceDirect

Foot and Ankle Surgery

journal homepage: www.elsevier.com/locate/fas

Non-irradiated frozen structural allograft in reconstructive surgeries of the hindfoot and midfoot

Juan Manuel Yañez Arauz [1], Jorge Javier del Vecchio *, Ricardo Tito Amor [2], Diego Amadeo Piazza [3]

Department of Orthopaedic Surgery, Austral University Hospital, Buenos Aires, Argentina

ARTICLE INFO

Article history:
Received 21 June 2013
Received in revised form 17 December 2013
Accepted 5 January 2014

Keywords:
Structural Allograft
Hindfoot
Midfoot
Reconstruction

ABSTRACT

Background: A few studies investigating the use of structural allograft in foot and ankle surgery are available. The purpose of this study is to analyze the clinical, functional and radiological results of patients treated with non-irradiated frozen structural bone allograft.

Methods: We analyzed 20 reconstructive surgeries of the hindfoot and midfoot performed between April 2004 and April 2010. The mean follow up period was 45.4 months. The results were evaluated according to AOFAS score, X-ray (allograft consolidation, alignment preservation, and allograft collapse or re-absorption), and complications.

Results: We observed a 48-point mean improvement of AOFAS ankle and hindfoot score (17 cases), and a 53-point mean improvement of AOFAS midfoot score (3 cases). The mean bone consolidation time was 75 days. No graft fracture and no cases of non-union were seen.

Conclusion: This treatment is a good option to treat severe defects or fill sequelae deformities.

1. Introduction

Bone is one of the most frequently transplanted types of tissue [1]. It is used to provide bone stability, cavity filling, and to achieve bone consolidation in multiple situations such as consolidation delay and pseudoarthrosis, sequelae bone defects, tumor surgery, arthrodesis.

In general, grafts offer an osteogenesis source and act as a mechanical support. Osteogenesis is defined as bone synthesis mediated by either the graft cells or host cells.

Osteoinduction is described as the grouping of mesenchymal stem cells of the surrounding tissue which are differentiated from osteoblasts. The grouping and the differentiation of these cells are modulated by molecular low-weighted peptides such as glycoproteins, morphogenetic protein and various growth factors.

Osteoinduction refers to the growing process of the arterial capillaries, perivascular tissue and osteoprogenitor cells of the host inside the graft [2,3].

There are four types of bone grafts that may be transplanted:

A. *Autograft:* it is transplanted from a donor site to a receptor site.
B. *Isograft:* it is transplanted from one individual to another with an identical genetic pattern (identical twins).
C. *Allograft*: it is transplanted from one individual to another with a different genetic pattern.
D. *Xenograft:* it is transplanted from one species to another [2,3].

In the field of ankle and foot surgery, autografts and allografts are the most frequently used types of grafts. Also, cancellous bone and the small cortical-cancellous pieces of the allograft are most frequently used. There are different presentations: cancellous or structural, variations of fresh-frozen processing, cryopreserved, lyophylized and demineralized [2–4].

Bone grafts may be cortical, cancellous or cortical-cancellous [5]. The cortical and cortical-cancellous (structural) bone is usually used in areas of greater mechanical demand since it provides support and rigid fixation [6]. Traditionally, cortical-cancellous bone has been obtained from the iliac crest [1,7] and although ankle and foot defects were refilled with this type of graft, a great number of complications have been reported [8,9].

Many researchers have reported similar results when replacing autograft with allograft [1,4,7,10]; however, there are few studies

* Corresponding author at: Arenales 1722 10th Floor "B", Martinez, CP 1640, Buenos Aires, Argentina.
E-mail addresses: jmyanez@cas.austral.edu.ar (J.M. Yañez Arauz), javierdv@mac.com (J.J. del Vecchio).
[1] Address: General Urquiza 340, Acassuso, Buenos Aires, CP 1641, Argentina. Tel.: +54 1147988613.
[2] Address: Nueva York 3520, Capital Federal, CP 1419, Argentina.
[3] Address: Libertador Ave., 1080 4th Floor "D", Capital Federal, CP 1423, Argentina.

1268-7731/$ – see front matter © 2014 European Foot and Ankle Society. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fas.2014.01.001

evidencing the use of allograft in foot and ankle surgery [10–12], even less in hindfoot and midfoot reconstruction surgeries specifically [6,11,13].

The purpose of this study is to analyze the clinical, functional and radiological outcome of patients treated with non-irradiated frozen structural bone allograft as well as to evaluate the usefulness and possible advantages of using this type of graft in hindfoot and midfoot reconstructive surgery.

2. Materials and methods

Between April 2004 and April 2010, 20 reconstructive surgeries of the hindfoot and midfoot were performed in 19 patients requiring a structural graft. Nine patients were female and 10 were male. Four surgeries were performed in the midfoot and 17 in the hindfoot. Patients' mean age was 48 years old, being 18 the minimum age and 66 the maximum age. In all these surgeries it was necessary to use bone graft due to lack of structure, subsequent deformity or severe trauma with bone destruction. For that reason, non-irradiated frozen structural (associated or not with cancellous graft) cadaveric graft was used.

The clinical diagnosis leading to the surgery included: calcaneus fracture, valgus flatfoot (Figs. 1–3), failed subtalar arthrodesis (pseudoarthrosis), rheumatoid arthritis of the hindfoot (Figs. 4–6), neurological sequelae supinated equinovarus foot due to tumor surgery of ipsilateral knee, neurological sequelae of the hindfoot, Lisfranc fracture, flat midfoot, comminuted fracture of the navicular bone, and destructive arthritis of the first cuneometatarsal joint (Table 1).

Except for the comminuted fracture of the navicular bone treated in the acute stage, the rest of the surgeries were performed in the chronic stage of the disease (sequelae stage).

All patients showed clinical symptomatology and/or objective alteration of the preoperative physical examination, summarized in one or more of the following conditions: pain in the subtalar area, anterior impingement of the painful ankle, posterior impingement of the hindfoot and/or ankle, hindfoot deformity, loss of the medial longitudinal arch, cuneometatarsal pain and deformity of the first ray, Achilles insufficiency, severe gait disorder and loss of height in the calcaneus with widening of this bone and peroneo-calcaneus impingement. In the case of the navicular fracture, also a cuboid fracture and metatarsal–tarsal fracture-dislocation of the medial and lateral column was present with the corresponding clinical disability.

Non-irradiated frozen (−80 °C) structural allograft was used in all cases. This allograft was provided by the Tissue Bank complying with international recommendation patterns. Donor parts consisted of tricortical cuneiform fragments derived from the processed iliac crest. These fragments were taken from cadaveric donors (14 were male and 7 were female). Donors' mean age was 33 years old, ranging from 18 to 54. It is important to mention that only 4 donors were above the age of 40. For subtalar correction, trapezoidal grafts where used with a height ranging between 8 and 11 mm (mean 9.6) in the mayor axis depending on the improvement required. For midfoot correction the grafts were carved for each specific case. The aim was to achieve a neutral and plantigrade foot. The osteosynthesis used in all cases was 3.5, 4.5 and 6.5 mm compressive partial threaded screws.

The surgical use of the structural graft was divided into:

1. three cases of graft in calcaneus varus osteotomies
2. twelve cases of graft in subtalar arthrodesis
3. two cases of calcaneocuboid joint arthrodesis
4. two cases of cuneometatarsal arthrodesis of the first ray, and
5. one case of talar-cuneiform arthrodesis.

The mean follow-up was 45.4 months with a minimum of 29 months and a maximum of 72 months.

A retrospective analysis was made based on:

1. Follow-up files with the score of the American Orthopaedic Foot and Ankle Society (AOFAS) for hindfoot and ankle or for midfoot [12] as the case may be, both of the preoperative

Fig. 1. Case 4 (O.V.R. (LF)*. Valgus flatfoot. Preop.

Fig. 2. 3 months Postop. X-ray.

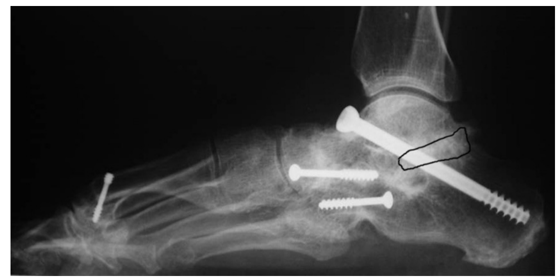

Fig. 3. The healed fusion after 7 months.

Fig. 4. Case 5 (B.G.). Rheumatoid arthrosis. Lateral view.

Fig. 5. Sagittal CT scan.

and long term postoperative periods (after a period of more than 18 months). In arthrodesis cases, the maximum score to be compared was 94 points, since the subtalar movement was not considered, clinical follow-up data protocolised in the computerized case records of our Institution evaluating the following:

(a) immobilization time with plaster not allowing weight bearing (for 6–8 weeks depending on bone quality and patient's age),
(b) After a), immobilization with a Walker boot allowing partial weight bearing (for another 2 weeks),
(c) time when weight-bearing was authorized,
(d) social activity, pain and gait disorders during the preoperative and long term postoperative periods,
(e) complications such as scar infection and/or dehiscence,
(f) foot alignment in the posterior and medial view,
(g) joint- and gait-related movement,

2. AP, lateral, Harris and Broden X-ray images taken 6 weeks, 3–6 months and 1 year or more after the surgery. The maintenance of the achieved correction, graft consolidation, the re-absorption signs with height loss measured in mm, the consolidation delay or pseudoarthrosis, and the preservation of the axis or allograft collapse were evaluated. The X-ray evaluation was made on an observation basis, and based on the X-ray analysis of three different observers who were not together at the moment of evaluating the images.

Fig. 6. The fusion and correction after 9 months.

The criterion used to determine the graft consolidation to the receptor bone was the presence of trabeculation where the allograft joins the patient's bone, both in arthrodesis and osteotomies. Trabeculation had to appear in both contact surfaces of the graft.

According to Mark Myerson's [13] criteria, a consolidation delay was considered when no bone consolidation signs were observed more than 4 months after the postoperative period.

3. Results

According to the evaluation of the AOFAS rating system: of a total value of 94 points as a maximum score for hindfoot, a mean value of 33.3 AOFAS points was observed preoperatively. Also for midfoot, a mean value of 30.3 AOFAS points was seen before surgery. The postoperative mean value for the hindfoot was 81.45 AOFAS points of a total value of 94 points. The postoperative AOFAS mean value for the midfoot was 83.8 points over a total value of 100 points. As regards the AOFAS rating system for ankle and hindfoot, sixteen patients (seventeen surgeries) were evaluated and a 48.15-point mean improvement (over a total of 94 possible points) was observed during the long term postoperative period (more than 18 months) compared to the preoperative period. As regards the AOFAS rating system for midfoot, 4 patients were evaluated and a 53.5-point mean improvement (of a total of 100 points) was observed during the long term postoperative period (more than 18 months). The mean immobilization time with plaster was 44.9 days (30–60) and the mean time for weight

Table 1
Evaluated patients. Age, sex, etiology, surgery, follow-up.

N	Patient	Age	Sex	Etiology	FU (months)	Surgery – graft
1	M.R.	47	M	Pseudoarthrosis – subtalar arthrodesis	48	Hindfoot
2	S.M.	37	F	Pseudoarthrosis – subtalar arthrodesis	49	Hindfoot
3	O.V.R. (RF)[a]	47	F	Valgus flatfoot	53	Hindfoot
4	O.V.R. (LF)[a]	47	F	Valgus flatfoot	48	Hindfoot
5	B.G.	42	F	Rheumatoid arthrosis	46	Hindfoot
6	T.F.	18	F	Neurological foot (supined equinovarus)	52	Hindfoot
7	R.C.	57	M	Neurological foot	50	Hindfoot
8	L.A.	66	F	Sequelae – calcaneus fracture	50	Hindfoot
9	C.B.	66	F	Valgus flatfoot	49	Hindfoot
10	L.O.	63	M	Flat midfoot	46	Midfoot
11	M.T.	44	M	Cuneometatarsal arthritis	57	Midfoot
12	T.R	29	F	Psoriatic arthritis	72	Hindfoot
13	R.A.	63	M	Navicular fracture	42	Midfoot
14	DV.J.	38	M	Sequelae – calcaneus fracture	54	Hindfoot
15	ML.T.	48	M	Sequelae – calcaneus fracture	24	Hindfoot
16	C.V.	57	F	Valgus flatfoot	35	Hindfoot
17	L.M.	47	M	Sequelae – calcaneus fracture	29	Hindfoot
18	GD.M.	60	F	Valgus flatfoot	39	Hindfoot
19	G.J.	36	M	Sequelae – calcaneus fracture	34	Hindfoot
20	M.D.	46	M	Sequelae – calcaneus fracture	32	Hindfoot
		48			45.45	

[a] RF, right foot; LF, left foot.

bearing was 56 days (42–60). The average immobilization-protection time with a Walker boot after using plaster was 36.2 days. One patient was excluded because of tumor surgery sequelae, and he used a Walker boot for 9 months.

Three cases showed, signs of graft re-absorption, and collapse with loss of correction over 5 mm with no clinically significant or relevant differences compared to other patients but with presence of flattening of the foot arch on lateral X-rays. No X-ray signs of graft re-absorption were found in 12 cases, and a mean 1.1 mm graft height loss (0.5–2 mm) was observed in the 5 remaining cases as shown in the X-ray images. The mean bone consolidation time was 75 days (49–140). No graft fractures were observed in these cases.

The complications were the following:

(a) A case of severe infection during the postoperative period leading to the removal of the osteosynthesis material as well as the bank graft 17 days after surgery. This was a cancer patient who had undergone many previous surgeries, which increases the normal infection risk. The bacteria culture showed the presence of methycillin-resistant *Staphylococcus aureus* (MRSA) located in the allograft which was treated with the mentioned surgery toilette and the specific antibiotic therapy. The patient finally had an *in situ* ankylosis–arthrodesis but did not need a new surgery. This case is not included in the X-ray evaluation regarding the consolidation and incorporation of bank graft.
(b) A case of superficial infection treated with the corresponding antibiotic therapy and local treatment.
(c) Three wound dehiscences with a good outcome.
(d) Two consolidation delays (more than 16 weeks).

4. Discussion

Although there are publications related to the use of allografts in different skeletal locations, few studies focus on the usefulness of allografts in hindfoot and midfoot surgery [5–7,13].

The autograft transports live cells and provides an effective structure for the reconstruction of bone defects, and the incorporation in the recipient's site is faster than in the allografts. However, its use is not free from complications and limitations. Within these complications, many authors [14,15] mention the difficulty in obtaining the autograft, the deficit of the exact modeling according to the need, the longer surgical time and the added morbidity (bleeding, pain, nervous injury, among others). Some comparative features between the autograft and allograft are shown in Table 2 [5].

Evans et al. [16] conducted a mechanical study about the features and properties of cadaveric bone. They concluded that the bones from cadaveric donors in a 20–40 year old age group kept 100% of their physical properties regarding compression resistance, inclination resistance and torsion resistance compared to the normal bone. They also kept 100% of their tensile properties. In the study in question, grafts belonging to cadaveric donors whose mean age was 32 years old were used. This provided the recipient with good support and resistant structure.

Table 2
Descriptive comparison between allograft and autograft.

	Autograft	Allograft
Immunogenicity	No	Yes
Osteogenesis	Yes	No
Osteoconduction	Yes	Cancellous
Osteoinduction	Yes	Demineralized
Consolidation	Fast	Slow
Donor site morbidity	Possible	None
Quantity	Limited	Unlimited
Mechanical support	Yes (cortical)	Yes (cortical)
Disease transmission	None	Possible
Vascularization	No*	No[a]

[a] Excluding vascularized bone transplant.

Triantafyllou et al. [17] studied the characteristics of graft sterilization systems and concluded that irradiated bone features significant alterations in the graft biomechanical properties such as a 50–75% decrease in the axial compression resistance and tensile strength. In this study, a non-irradiated frozen bone was used due to the alteration caused by irradiation. This could be a relevant factor regarding the absence of fractures observed in our series.

According to Pelker et al. [18], the preservation of the graft by means of lyophylization alters the bone biomechanical properties remarkably featuring a 39% decrease in s torsion resistance and a 55% decrease in bending resistance. In our series no lyophylized grafts were used, only fresh-frozen grafts.

Pelker et al. [19] report that the graft incorporation as well as its consolidation depends on several factors such as: patient's immune response, graft preservation techniques, the sterilization technique used, and the mechanical properties of the donor bone, among others. In general, all grafts (either autograft or allografts) feature five stages in their consolidation: inflammation, revascularization, osteoinduction, osteoconduction and re-modeling. In the case of allografts, they show an exaggerated inflammatory phase with a poor or null osteoinductive stage. This immunological phenomenon between the graft and the host might be the main reason why the allograft has a slower incorporation compared to the autograft [20]. We believe that this accounts for the longer consolidation time observed in our analysis.

Based on this and according to Murphy et al. [21], the allograft consolidation time is longer than that observed when an autograft is used. In the series analyzed in this study, the allograft consolidation time, although longer than that observed when autografts are used, was shorter than the times reported by other authors [13]. The reason might be the use of grafts with other preservation and sterilization techniques such as lyophilized and/or irradiated grafts.

Goldberg et al. [22] report in their study that the histocompatibility tests between the donor and recipient's bones may determine a greater success rate regarding the use of allografts and its results. In our study no histocompatibility test was conducted between the donor and recipient's bones.

For a period of about 6 months after transplant, cortical allografts are more fragile than autografts so they must be protected for a longer period to avoid fractures or failures. However, fresh cortical allografts which are stabilized under compression may normally feature osteoinduction even before an immune reaction [22]. This determines less fault risk and after one year this kind of allografts features mechanical and structural properties similar to those corresponding to autografts. During this study, the allografts used in all cases were fresh, frozen, structural, and were placed under compression in the recipient's area with compressive osteosynthesis. This could determine the low incidence of consolidation delay as well as the absence of pseudoarthrosis or fractures in those grafts.

As for the pseudoarthrosis rate when using structural allografts, different studies [6] have reported that this rate is not significantly higher as compared to those reported when using structural autografts. In the series studied, no pseudoarthrosis was observed

As far as complications are concerned, Tomford et al. [23] report that the disease transmission rate is very low. In his study including 303 cases, only one patient developed a disease related to the graft. According to an American official report [24] the possibility of transmitting viral infectious diseases was 1/

8,000,000. In the series analyzed, no disease directly related to the allograft was detected.

5. Conclusions

Some direct consequences are observed when using non-irradiated frozen structural allografts:

1. Availability of different sizes according to the case to be treated.
2. Availability of the quantity of grafts needed (more than one wedge).
3. Possibility of exactly modeling of the graft to be used according to the recipient's site.Reduced surgical time, less bleeding and shorter time under anesthesia.
4. No morbidity in patient's donor sites, thus avoiding possible intra- and post-surgical complications and discomfort during the post-operative period.
5. As it is not irradiated, the graft maintains the biomechanical properties. This might lead to a better structural function and a higher consolidation rate as compared to the grafts undergoing a different processing and sterilization type.

A main disadvantage found in the study is the fact that the allograft consolidation and integration time is longer than that of the autograft. We think that the collapse seen in the few patients may be solved by adding positional screws (not compressive alone) or new blocking plates (hind/midfoot).

No complications directly related to the use of the allograft such as disease transmission were found.

Therefore, we believe that using the non-irradiated frozen structural cadaveric allograft is a good option to treat severe defects or to fill sequelae deformities. This leads to lower morbidity during the intra-operative period and low rate of consolidation delay and pseudoarthrosis in our series.

Disclosure statement

The authors disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three (3) years of beginning the work submitted that could inappropriately influence (bias) our work.

Acknowledgments

The authors would like to thank Walter Parizzia, MD (Tissue Bank Coordinator) for providing the allografts and Facundo Bilbao, MD for his assistance during the surgeries and Gabriela Franke for the translation assistant.

References

[1] Lane JM, Sandhu HS. Current approaches to experimental bone grafting. Orthop Clin N Am 1987;18(April (2)):213–25.
[2] Burwell RC. Studies on the transplantation of bone. The fresh composite homo-autograft of cancellous bone. An analysis of factors leading to osteogenesis in marrow transplants and in marrow containing bone grafts. J Bone Joint Surg 1964;46B:110–27.
[3] Burwell RC. The fate of bone grafts. In: Apley AG, editor. Recent advances in orthopaedics. London: Churchill Livingston; 1969. p. 115.
[4] Michelson JD, Curl LA. Use of demineralized bone matrix in hindfoot arthrodesis. Clin Orthop Relat Res 1996;325(April):203–8 [Review].
[5] Catanzariti A, Karlock L. The application of allograft bone in foot and ankle surgery. J Foot Ankle Surg 1996;35(September–October (5)):440–51 [Review].
[6] Easley ME, Trnka HJ, Schon LC, Myerson MS. Isolated subtalar arthrodesis. J Bone Joint Surg Am 2000;82(May (5)):613–24.
[7] McGarvey WC, Braly WG. Bone graft in hindfoot arthrodesis: allograft vs. autograft. Orthopedics 1996;19(May (5)):389–94.
[8] Arrington ED, Smith WJ, Chambers HG, Bucknell AL, Davino NA. Complications of iliac crest bone graft harvesting. Clin Orthop Relat Res 1996;329(August):300–9.
[9] Banwart JC, Asher A, Hassanein RS. Iliac crest bone graft harvest donor site morbidity. A statistical evaluation. Spine 1995;20(May (9)):1055–60.
[10] Flemister Jr AS, Infante AF, Sanders RW, Walling AK. Subtalar arthrodesis for complications of intra-articular calcaneal fractures. Foot Ankle Int 2000;21(May (5)):392–9.
[11] Kitaoka HB, Alexander IJ, Adelaar RS, Nunley JA, Myerson MS, Sanders M. Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. Foot Ankle Int 1994;15(July (7)):349–53.
[12] Mosca VS. Calcaneal lengthening for valgus deformity of the hindfoot. Results in children who had severe, symptomatic flatfoot and skewfoot. J Bone Joint Surg Am 1995;77(April (4)):500–12.
[13] Myerson MS, Neufeld SK, Uribe J. Fresh-frozen structural allografts in the foot and ankle. J Bone Joint Surg Am 2005;87(January (1)):113–20.
[14] Fowler BL, Dall BE, Rowe DE. Complications associated with harvesting autogenous iliac bone graft. Am J Orthop 1995;24(December (12)):895–903 [Review].
[15] Younger EM, Chapman MW. Morbidity at bone graft donor sities. J Orthop Trauma 1989;3:192–5.
[16] Evans FG. Mechanical properties of bone. Springfield, IL: Charles C. Thomas; 1973.
[17] Triantafyllou N, Sotiorpoulos E, Triantafyllou J. The mechanical properties of lyophylized and irradiated bone graft. Acta Ortoph Belg 1975;41:35–44.
[18] Pelker R. Biomechanical properties of bone allograft. Clin Orthop Relat Res 1993;174:54–7.
[19] Pelker RR, McKay J, Panjabi MM. Biomechanical evaluation of allograft incorporation. Trans Ortop Res Soc 1986;11:272.
[20] Burchardt H. The biology of bone graft repair. Clin Orthop 1983;174:28–42.
[21] Murphy MD, Sartoris D, Branch JM. Radiographic assessment of bone grafts. In: Habal MB, Reddi AH, editors. Bone grafts and bone substitutes. Philadelphia: Saunders; 1992. p. 9–36.
[22] Goldberg VM, Powell A, Shaffer JW, Zika J, Bos GD, Heiple KG. Bone grafting: role of histocompatibility in transplantation. J Orthop Res 1985;3:389.
[23] Tomford WW, Starkweather RJ, Godman MH. A study of the clinical incidence of infection in the use of banked allograft bone. J Bone Joint Surg Am 1981;63:244–8.
[24] Tom A. Soft tissue allograft for knee reconstruction in sport medicine. Clin Orthop Relat Res 2002;402:135–52.