Clin Orthop Relat Res (2015) 473:1765–1774
DOI 10.1007/s11999-014-4052-5

Clinical Orthopaedics and Related Research®
A Publication of The Association of Bone and Joint Surgeons®

CLINICAL RESEARCH

Incidence and Risk Factors of Allograft Bone Failure After Calcaneal Lengthening

In Hyeok Lee MD, Chin Youb Chung MD, Kyoung Min Lee MD, Soon-Sun Kwon PhD, Sang Young Moon MD, Ki Jin Jung MD, Myung Ki Chung MD, Moon Seok Park MD

Received: 13 July 2014 / Accepted: 3 November 2014 / Published online: 14 November 2014

Abstract

Background Calcaneal lengthening with allograft is frequently used for the treatment of patients with symptomatic planovalgus deformity; however, the behavior of allograft bone after calcaneal lengthening and the risk factors for graft failure are not well documented.

Questions/purposes (1) What proportion of the patients treated with allograft bone had radiographic evidence of graft failure and what further procedures were performed? (2) What are the risk factors for radiographic graft failure after calcaneal lengthening? (3) What patient factors are associated with the magnitude of correction achieved after calcaneal lengthening?

Methods Between May 2003 and January 2014, we performed 341 calcaneal lengthenings on 202 patients for planovalgus deformity, the etiology of which included idiopathic, cerebral palsy, and other neuromuscular disease. Of these, 176 patients (87%) had adequate followup for graft evaluation, defined as lateral radiographs taken before and at least 6 months after the index procedure (mean, 18 months; range, 6–100 months) and 117 patients (58%) had adequate followup for the assessment of the extent of correction, defined as weightbearing anteroposterior and lateral radiographs taken before and at least 1 year after the index procedure (mean, 24 months; range, 12–96 months). These patients' results were evaluated retrospectively. The Goldberg scoring system was chosen for demonstration of allograft behavior. A score lower than 6 at 6 months after surgery was defined as radiographic graft failure; the highest possible score was 7 points, and this represented graft incorporation with excellent reorganization of the graft and no loss of height. The patient age, sex, diagnosis, graft material, ambulatory status, and use of antiseizure medication were evaluated as possible risk factors, and we controlled for the interaction of potentially confounding variables using multivariate analysis. Additionally, six radiographic indices were analyzed for their effects on the extent of correction.

Results The mean estimated Goldberg score was 6 (SD, 1.14) at 6 months after calcaneal lengthening with 11 feet (4%) classified as radiographic graft failure (Goldberg score < 6). Of these, four feet (1%) underwent reoperation using an iliac autograft bone resulting from pain and loss of correction. Multivariate analysis showed that the tricortical iliac crest allograft was superior to the patellar allograft (odds ratio [OR], 3.2; 95% confidence interval [CI], 1.1–9.8; p = 0.038) and the possibility of radiographic graft failure was found to increase along with age (OR, 1.2; 95% CI, 1.0–1.3; p = 0.006). Radiographically, the extent of correction was found to decrease with patient age, as

Each author certifies that he or she, or a member of his or her immediate family, has no funding or commercial associations (eg,consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research*® editors and board members are on file with the publication and can be viewed on request.

I. H. Lee, C. Y. Chung, K. M. Lee, S. Y. Moon, K. J. Jung, M. K. Chung, M. S. Park (✉)
Department of Orthopaedic Surgery, Seoul National University Bundang Hospital, 300 Gumi-Dong, Bundang-Gu, Sungnam, Kyungki 463-707, Korea
e-mail: pmsmed@gmail.com

S.-S. Kwon
Biomedical Research Institute, Seoul National University Bundang Hospital, Sungnam, Kyungki, Korea

observed at the anteroposterior talus-first metatarsal angle ($p < 0.001$), lateral talocalcaneal angle ($p < 0.001$), lateral talus-first metatarsal angle ($p < 0.001$), and relative calcaneal length ($p = 0.041$).

Conclusions Graft failure can occur after calcaneal lengthening using allograft. Our study showed that the tricortical iliac allograft was superior to the patellar allograft, and further studies are warranted to further elucidate the effects of age on radiographic graft failure.

Level of Evidence Level III, therapeutic study.

Introduction

Planovalgus deformity is characterized by hindfoot valgus, decreased medial longitudinal arch, and forefoot abduction. If these deformities progress, prominent talar head, pain, and gait disturbances may occur [10, 21]. Many surgical options such as medial displacement osteotomy of calcaneus, subtalar extraarticular arthrodesis, lengthening of the lateral column, and triple arthrodesis have been suggested for this condition [10, 14, 15, 21, 29]. Among these, calcaneal lengthening osteotomy is most commonly used to correct planovalgus deformity without sacrificing joint motion.

Mosca described that calcaneal lengthening was indicated for idiopathic planovalgus when prolonged attempts at conservative management failed to relieve the pain under the head of the plantarflexed talus or the sinus tarsi area [21]. However, in patients with cerebral palsy, it is additionally indicated for the relief of flexible lever arm dysfunction and is usually performed as part of a single-event multilevel surgery [33].

Calcaneal lengthening was introduced by Evans in 1975 [10]. The Evans technique was modified by Mosca in 1995 [21]. The Mosca technique requires allograft to fill the created bone defect, and the tricortical iliac allograft bone is frequently used. Tricortical iliac allograft bone has the advantages of being widely available, does not require additional surgery for harvesting, and has satisfactory bone incorporation, similar to that of autograft [20]. Nevertheless, allograft has certain risks, including infection, disease transmission, and rejection [2, 4]. However, the rates of infection and disease transmission can be decreased by using demineralized freeze-dried allograft bone [30]. There have been several reports describing graft failure after allograft for other indications, including procedures on the spine, humerus, and tibia [8, 24, 31, 34]; however, to our knowledge, the incidence and risk factors of allograft bone failure after calcaneal lengthening has not been characterized in other studies. Although one might speculate that graft failure is less common in the calcaneus because it contains more cancellous bone than other bones, the frequency of and risk factors for graft failure are not completely understood [12].

We therefore sought to determine the following: (1) What proportion of patients treated with allograft bone shows radiographic evidence of graft failure, and what further procedures were performed? (2) What are the risk factors for radiographic graft failure after calcaneal lengthening? (3) What patient factors are associated with the magnitude of correction achieved after calcaneal lengthening?

Patients and Methods

Our retrospective study was approved by the institutional review board of our hospital. The need for informed consent was waived because of the retrospective nature of the study.

Inclusion criteria for study patients were that they be aged 20 years or younger and have undergone calcaneal lengthening for planovalgus deformity between May 2004 and January 2014. A followup of more than 6 months and pre- and postoperative lateral foot radiographs were also required. Exclusion criteria included concurrent medial column procedures such as medial cuneiform osteotomy, talonavicular capsular plication, tibialis posterior reefing, and talonavicular fusion or incomplete medical records or inadequate foot radiographs for measurement. Patient age, sex, diagnosis, side (right or left) of the feet, type of allograft material, ambulatory status, use of antiseizure medication, and dates of radiography were obtained by medical record review. The patients were classified as idiopathic, cerebral palsy, and other neuromuscular disease. Those under "others" were the patients whose feet were affected as a result of neuromuscular disease other than cerebral palsy such as hereditary spastic paraplegia and Guillain-Barré syndrome.

During that period, we performed 341 calcaneal lengthening operations on 202 patients for planovalgus deformity in patients younger than 20 years of age. Of them, 176 (87%) had adequate followup, defined as AP and lateral radiographs taken before and at least 6 months after the index procedure (mean, 18 months; range, 6–100 months). A total of 304 feet (176 patients) were included in our study, and 961 lateral foot radiographs were assessed using the Goldberg scoring system for graft behavior (Fig. 1). A total of 158 feet were in patients diagnosed with cerebral palsy, 117 feet were classified as having idiopathic planovalgus deformity, and 29 feet were classified as other neuromuscular disease. A total of 186 of the feet were in male patients and 118 were in female patients. Mean patient age at time of surgery was 11.3 ± 3.4 years (range, 5.4–20 years) and mean duration of patient followup was

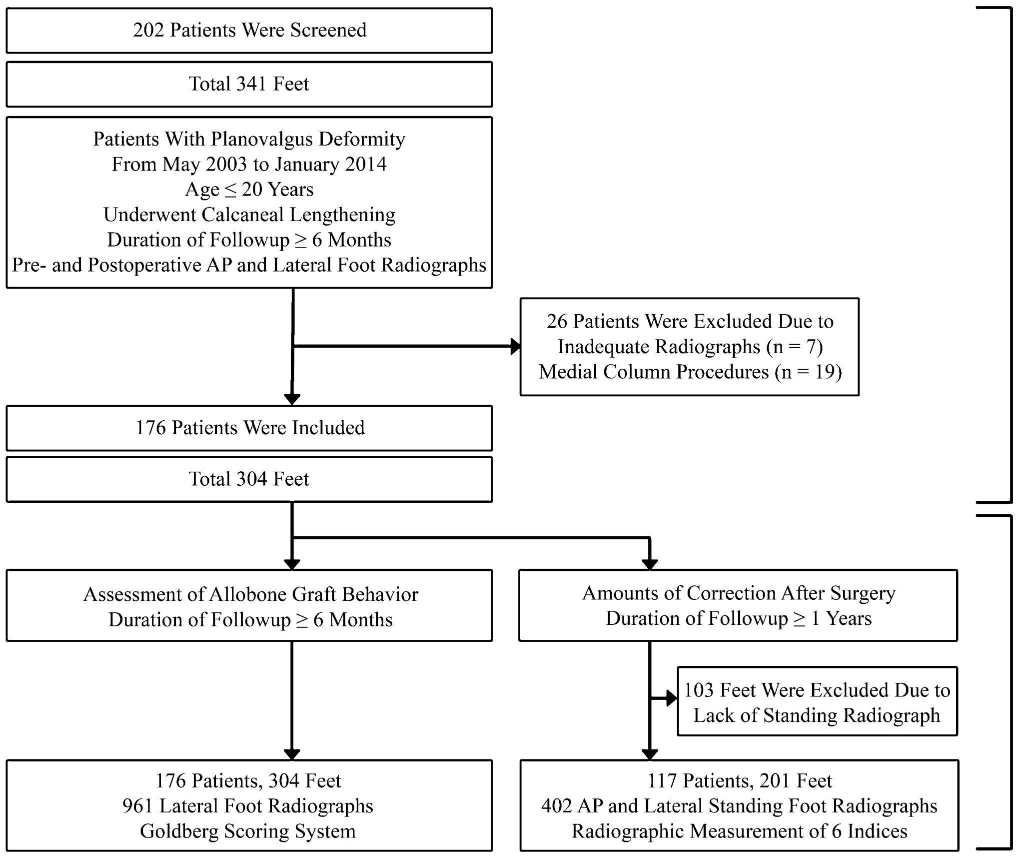

Fig. 1 Inclusion and exclusion criteria for the study population are shown.

Table 1. Demographics of study patients

Characteristic	Number (feet)
Sex (men/women)	186/118
Patient age at the time of operation (years)*	11 ± 3
Followup (years)*	1.6 ± 1.7
Diagnosis (idiopathic/cerebral palsy/other neuromuscular disease)	117/158/29
Type of graft material (ilium/patella)	281/23
Total number of feet	N = 304

* Data are presented as mean ± SD.

1.6 ± 1.7 years (range, 0.6–8.3 years). Tricortical iliac allograft bone was used in 281 feet, whereas machined wedge patellar allograft bone was used in 23 feet (Table 1). Furthermore, 117 patients (58%) had adequate followup for assessment of the extent of correction, defined as weight-bearing AP and lateral radiographs taken before and at least 1 year after the index procedure (mean, 24 months; range, 12–96 months). A total of 201 feet underwent radiographic evaluation of the extent of correction (Fig. 1).

Calcaneal lengthening was performed by two pediatric orthopaedic surgeons (CYC, MSP). The surgical procedure used was a minor modification of the Mosca technique [21]. Transverse osteotomy was performed with an oscillating saw between the anterior and middle facets of the calcaneus 1.5 cm proximal to the calcaneocuboid joint. The osteotomy sites of the proximal and distal calcaneal fragments were distracted by a laminar spreader until anatomic reduction of the subtalar and talonavicular joints was achieved. Allograft bone was trimmed into a trapezoidal shape, matched in size to fit the osteotomy site, and was then inserted in the distracted area. Stabilization of the graft or the calcaneocuboid joint was not performed. The peroneus brevis tendon was lengthened by Z-plasty, whereas the peroneus longus tendon was not lengthened. In patients with equinus deformity, tendo-Achilles lengthening for the soleus and gastrocnemius contracture or gastrocnemius recession for isolated gastrocnemius contracture were performed concomitantly. Normalization of the radiographic measurements was confirmed in every patient using a C-arm during surgery. After surgery, each patient was immobilized in a short-leg cast and remained nonweightbearing for 5 to 6 weeks. Standing and weightbearing were resumed with a leaf spring-type ankle-foot orthosis, which was worn for 2 to 3 months.

During the period in question, we generally used the tricortical iliac crest allograft bone, whereas patellar

Goldberg scoring system for calcaneal bone graft

Check list		
Index	point	Check
1. Graft appearance		
Resorbed	0	
Mostly resorbed	1	
Largely intact	2	
Reorganizing	3	
2. Bony union (Proximal or posterior)		
Nonunion	0	
Possible union	1	
Radiographic union	2	
3. Bony union (Distal or anterior)		
Nonunion	0	
Possible union	1	
Radiographic union	2	
Total		

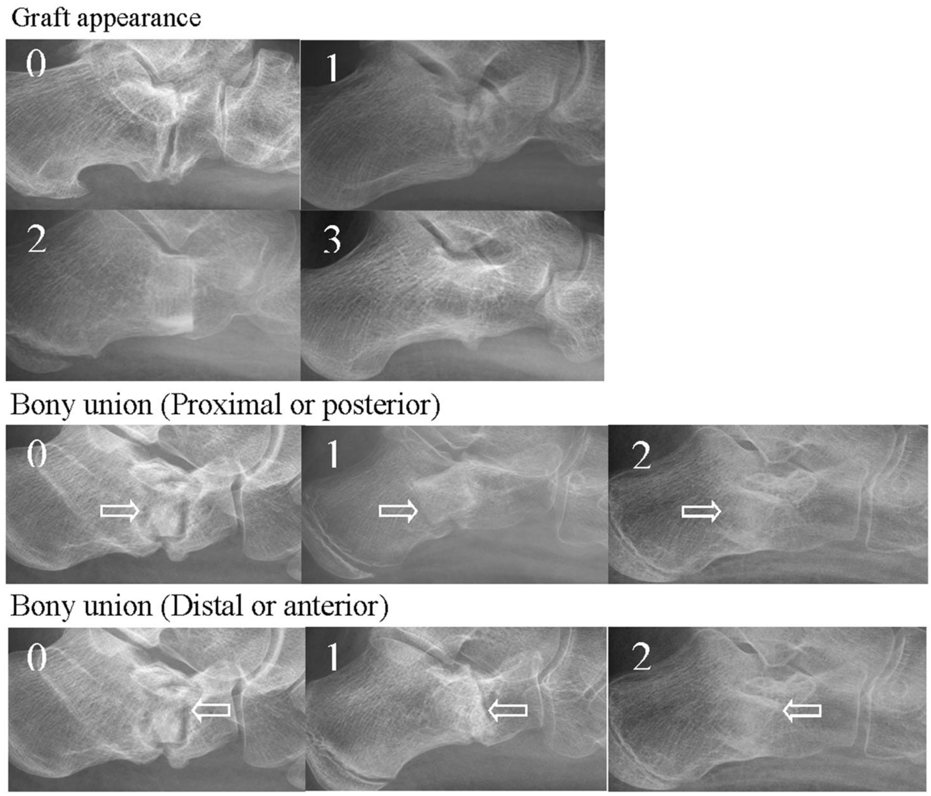

Fig. 2 Indices of the Goldberg scoring system are shown. The postoperative lateral foot radiograph is used for the checklist. The first index is evaluation of graft appearance. The second and third indices are evaluation of bony union. Modified from Goldberg VM, Powell A, Shaffer JW, Zika J, Bos GD, Heiple KG. Bone grafting: role of histocompatibility in transplantation. *J Orthop Res.* 1985;3:389–404. Copyright © 1985 Orthopaedic Research Society [13].

allograft bone was used during a certain period without specific indication owing to the supply of the tricortical iliac crest allograft being insufficient. During that period, no patients were treated with autograft of any kind as part of initial calcaneal-lengthening surgery.

Foot radiographs were obtained using a UT 2000 x-ray machine (Philips Research, Eindhoven, The Netherlands) at a source-to-image distance of approximately 100 cm with the patient standing or supine with respect to his or her condition. The x-ray machine settings were 46 to 50 kVp and 4.5 to 5 mAs, depending on patient body size. All conventional radiographic images were digitally acquired with picture archiving and communication software (INFINITT Healthcare, Seoul, Korea), which was subsequently used to conduct measurements.

Consensus-building of Radiographic Measurements

Before the radiographic measurements, a consensus-building session was held by all examiners. Previous studies were reviewed, and one of the authors (IHL) defined the measurements that we believed would be relevant to evaluate graft incorporation after bone grafting. Standards of measurement were chosen based on a consensus among three orthopaedic surgeons, who constituted a consensus development panel. As a result, three indices of the Goldberg scoring system were chosen [13]. On lateral foot radiographs, the first index is evaluation of graft appearance, which receives a score of 0 for resorbed, 1 for mostly resorbed, 2 for largely intact, and 3 for reorganizing. The second and third indices are evaluation of bony union, which receives a score of 0 for nonunion, 1 for possible union, and 2 for radiographic union at the proximal and distal ends of the graft, respectively (Fig. 2). A score lower than 6 at 6 months after surgery was defined as radiographic graft failure; the highest possible score was 7 points, and this represented graft incorporation with excellent reorganization of the graft and no loss of height. Both weightbearing and nonweightbearing lateral foot radiographs were used to obtain these measurements, because a weightbearing condition is not necessary for serial assessment of the graft incorporation by the Goldberg score. For our study, radiographic graft failure was defined as absence of graft incorporation by 6 months after calcaneal lengthening. Graft incorporation was determined based on the appearance of the graft material and state of union. To evaluate the allograft bone behavior, the Goldberg score was measured according to the followup period on all serial radiographs.

In addition, radiographs were measured for extents of correction. On lateral foot radiographs, the calcaneal pitch angle, lateral talocalcaneal angle, lateral talus-first metatarsal angle, calcaneal length, and calcaneocuboid subluxation were measured, whereas on AP foot radiographs, the AP talus-first metatarsal angle was measured, all of which have been described in the literature [27, 33]. Only weightbearing AP and lateral foot radiographs were used for obtaining these measurements. The measurements were carried out when followup continued for more than 1 year.

After consensus-building, reliability testing was conducted before the main measurements were performed. Interobserver reliability was determined with the use of intraclass correlation coefficients (ICCs). Three orthopaedic surgeons (IHL, SYM, MKC), with 5, 8, and 4 years of experience, respectively, who were not involved in treatment and who were blinded to the other measurements and to all data randomly and independently assessed the selected study patient radiographs. A prior sample size estimation by precision analysis indicated that a minimum of 36 radiographs of the feet should be assessed. A research assistant (HMK), who did not otherwise participate in the study, collected all the measurements.

After reliability testing, all measurements on the preoperative and followup radiographs were performed by one of the authors (IHL) with 5 years of orthopaedic experience. Statistical analysis was performed by one of the authors (S-SK), who has a PhD in statistics and 6 years of biostatistical experience.

In our study, reliability was assessed with the use of ICCs and a two-way mixed-effect model, assuming a single measurement and absolute agreement [19, 32]. With an ICC target value of 0.8, a Bonett approximation was used with 0.2 set as the width of 95% confidence intervals [3]. The minimal sample size (number of radiographs needed) was calculated to be 36. When the ICC was more than 0.8, the reliability was regarded as excellent. In terms of the interobserver reliability, the Goldberg score demonstrated excellent reliability (ICC, 0.924) as did all other radiographic measurements (Table 2).

Descriptive statistics were used to summarize the patient demographics and radiographic measurements. Because some data were from both feet of the same patient, a generalized estimating equation (GEE) and a linear mixed model were adopted to ensure statistical independence [26].

Table 2. Interobserver reliability of radiographic indices

Measurement	ICC	95% CI
Goldberg score	0.924	0.874–0.958
AP talus-first metatarsal angle	0.953	0.920–0.974
Calcaneal pitch angle	0.944	0.905–0.969
Lateral talocalcaneal angle	0.809	0.645–0.900
Lateral talus-first metatarsal angle	0.832	0.695–0.910
Relative calcaneal length	0.833	0.732–0.904
Calcaneocuboid subluxation	0.816	0.707–0.894

ICC = intraclass correlation coefficient; CI = confidence interval.

Associations between the risk factors and Goldberg score were assessed using a GEE to calculate the adjusted odds ratios (ORs) and confidential intervals (CIs). Multivariate analysis using a GEE was used to determine the risk factors that significantly affected the Goldberg score. The response variable was adjusted according to multiple factors using a GEE with patient age, sex, graft material, and diagnosis as the fixed effects and individual subjects and side of the body as the random effects. The working covariance structure can assume different types according to the model but assumed compound symmetry for our study.

In addition, we analyzed the extent of correction between the preoperative and postoperative radiographic measurements; and the radiographic measurements for extent of correction were adjusted by multiple factors using a linear mixed model with age, sex, and diagnosis as the fixed effects and individual subjects and body side as the random effects. The estimates were fitted using the restricted maximum likelihood estimation method to produce unbiased estimates. To construct an appropriate model accounting for possible additional effects on correction after surgery, multivariate analysis was performed after the univariate analysis.

Statistical analyses were conducted using R Version 2.15.2 software with the Nonlinear Mixed-Effect package 20 (R Foundation for Statistical Computing, Vienna, Austria). All statistics were two-tailed, and p values < 0.05 were considered significant.

Results

Although most grafts healed, using our definition of graft incorporation as well as that based on the Goldberg system, some grafts did not. The mean estimated Goldberg score was 6 (SD, 1.14) at 6 months after calcaneal lengthening (Fig. 3). Eleven feet (4%) were classified as radiographic graft failures (Goldberg score < 6). Of these, four feet (1%) underwent reoperation using an autogenous iliac bone

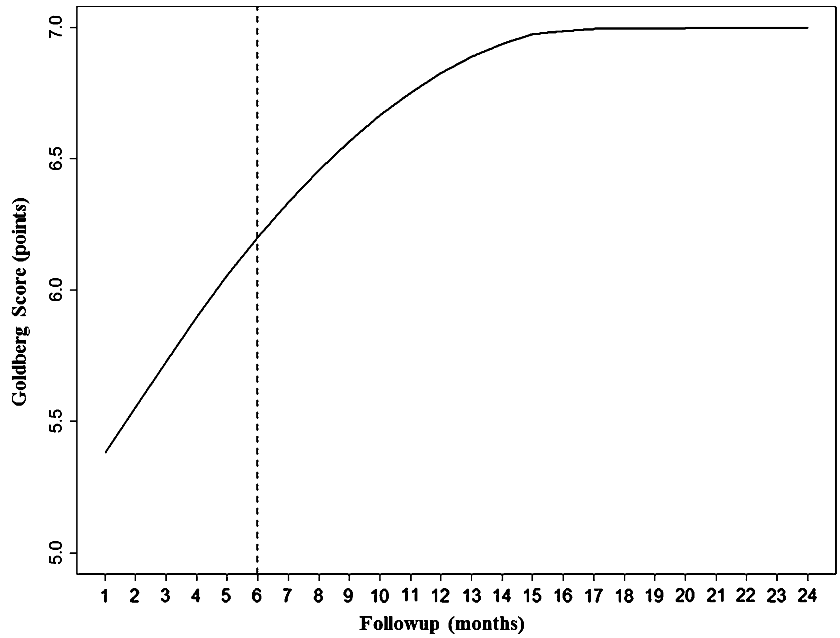

Fig. 3 Graph shows the mean Goldberg score according to followup duration. The slope increased over time. The mean estimated Goldberg score was 6 at 6 months after surgery.

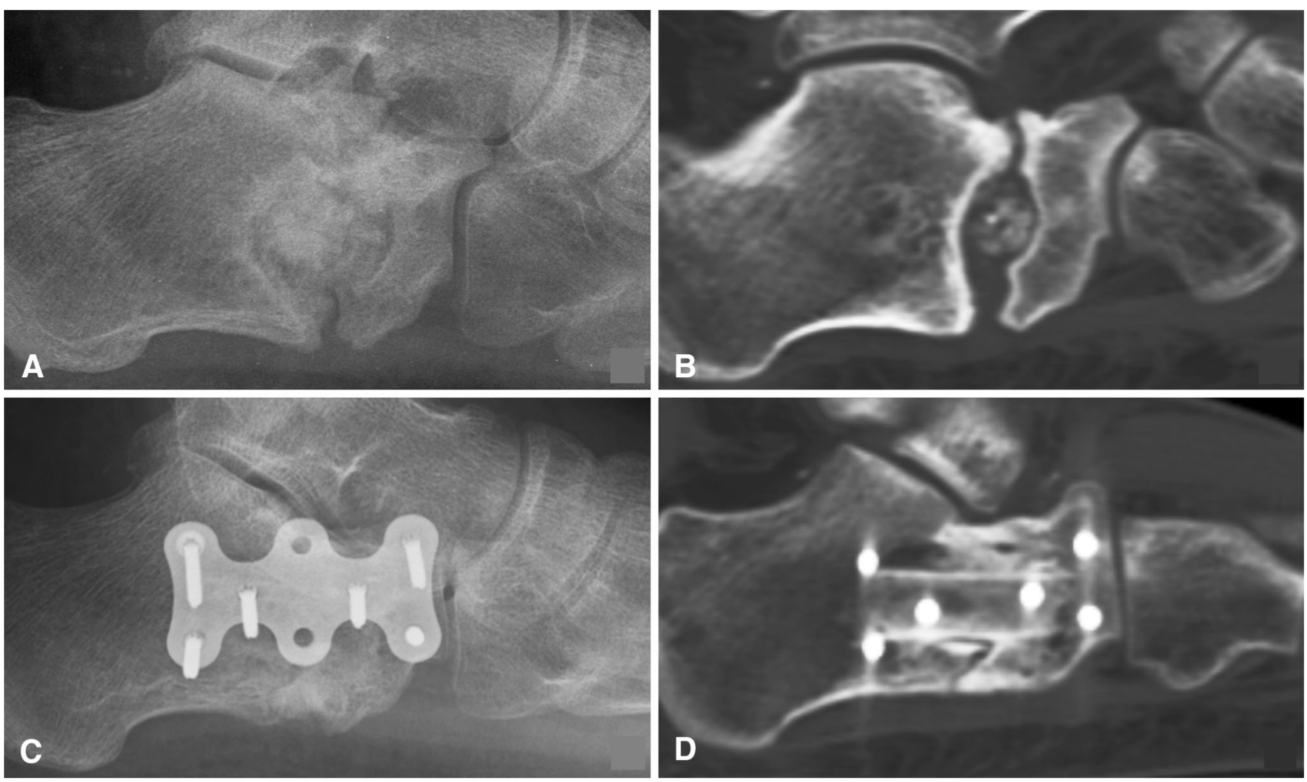

Fig. 4A–D (**A**) Preoperative lateral foot radiograph and (**B**) sagittal CT scan show graft failure in a 16-year-old girl who underwent unilateral calcaneal lengthening 6 months previously. She was diagnosed with idiopathic planovalgus deformity. The radiograph (**A**) shows loss of correction, whereas the CT scan (**B**) shows resorption of the graft material. In addition, (**C**) the postoperative lateral foot radiograph and (**D**) sagittal CT scan show graft incorporation. The patient underwent plating with a unilateral autogenous tricortical iliac bone graft. The radiograph (**C**) shows plating fixation, whereas the sagittal CT scan (**D**) shows complete graft incorporation.

graft as a result of radiographic graft failure associated with patient pain and loss of correction (Fig. 4).

Multivariate analysis showed that tricortical iliac crest allograft was superior to the patellar allograft (OR, 3.2; 95% CI, 1.1–9.8; p = 0.038), and the risk of radiographic graft failure, as determined by the Goldberg score, was found to increase along with age (OR, 1.2; 95% CI, 1.0–1.3; p = 0.006) (Table 3). Other factors such as sex, body side, diagnosis (cerebral palsy, idiopathic planovalgus, or other neuromuscular disorders), ambulatory status (p = 0.320), and the use of antiseizure medication (p = 0.105) were not associated with the Goldberg score.

Radiographically, the extent of correction was found to be decrease with age at the AP talus-first metatarsal angle ($p < 0.001$), lateral talocalcaneal angle ($p < 0.001$), lateral talus-first metatarsal angle ($p < 0.001$), and relative calcaneal length (p = 0.041). We found that younger patients had a greater extent of correction than older patients with planovalgus deformity (Table 4).

Table 3. Potential risk factors for radiographic graft failure

Factor	Adjusted OR (95% CI)	p value
Age (per year)	1.2 (1.0–1.3)	**0.006**
Sex (male)	1.4 (0.7–2.8)	0.330
Body side (right)	1.2 (0.7–2.1)	0.492
Graft material (patellar allograft)	3.2 (1.1–9.8)	**0.038**
Diagnosis		
Idiopathic planovalgus (reference group)	1.0	–
Cerebral palsy	1.3 (0.6–2.7)	0.060
Other neuromuscular disease	0.9 (0.3–2.1)	0.710

Probability values in bold are significant; multivariate analysis using generalized estimation equation is used to calculate the ORs and CIs; OR = odds ratio; CI = confidence interval.

Discussion

Calcaneal lengthening is indicated for patients with idiopathic planovalgus with unresolved pain by conservative treatment and, in patients with cerebral palsy, it is moreover indicated for relief of flexible lever arm dysfunction. Allograft bone is commonly used in calcaneal lengthening. However, graft failure after calcaneal lengthening has not been well studied; hence, we performed the present study to investigate the incidence of radiographic allograft failure and its risk factor and to radiographically evaluate the extent of correction after calcaneal lengthening. The rate of radiographic graft failure was found to be 4%, and 1% of all patients underwent reoperation. In terms of the risk factors, the use of tricortical iliac allograft was found to be superior to patellar allograft, and the risk of radiographic graft failure was found to increase along with age. In terms of the extent of correction, our findings are comparable to those of the previous studied on the topic [1, 5, 23, 25, 33, 37, 38].

This study had a number of limitations. First, we should consider that there are several different techniques for calcaneal lengthening such as fixing the calcaneocuboid joint or graft, which could lead to different results [1, 7]. In this study, we did not perform any fixation, and further studies are needed to evaluate the effects of fixation on radiographic graft failure. Second, the results of the calcaneal lengthening might be affected by the ambulatory

Table 4. Estimation of extent of correction

Factor	AP talus-first metatarsal angle		Calcaneal pitch angle		Lateral talocalcaneal angle		Lateral talus-first metatarsal angle	
	Estimation (degrees) (95% CI)	p value	Estimation (degrees) (95% CI)	p value	Estimation (degrees) (95% CI)	p value	Estimation (degrees) (95% CI)	p value
Intercept	−29.1	–	5.8	–	−15.2	–	−26.3	–
Age (per year)	0.8 (0.4–1.2)	**< 0.001**	−0.1 (−0.4 to 0.1)	0.391	0.8 (0.5–1.1)	**< 0.001**	1.2 (0.8–1.6)	**< 0.001**
Sex (male)	1.0 (−1.9 to 3.9)	0.507	−0.7 (−2.3 to 0.9)	0.406	−1.7 (−3.9 to 0.4)	0.109	−0.9 (−3.6 to 1.8)	0.506
Body side (right)	−0.4	–	0.3	–	−0.1	–	−0.4	–
Diagnosis								
Cerebral palsy (reference group)	–	–	–	–	–	–	–	–
Idiopathic	2.2 (−0.8 to 5.2)	0.145	−1.0 (−2.7 to 0.7)	0.230	1.0 (−1.2 to 3.2)	0.376	1.9 (−0.9 to 4.7)	0.175
Others	5.2 (−0 to 10.4)	0.051	−1.1 (−4.0 to 1.9)	0.473	−0.0 (−3.9 to 3.8)	0.980	−0.3 (−5.3 to 4.6)	0.895

Probability values in bold are significant; Intercept = mean for the response when all of the explanatory variables take on the value 0. That is, if the age is 10, we can expect that the extent of correction ($29.1 - 10 \times 0.8 = 21.1$) will be 21.1° in AP talus-first metatarsal angle; multivariate analysis using the linear mixed model is used to calculate the estimates and the CIs, CI = confidence interval.

Table 5. Studies on radiographic measurements after calcaneal lengthening

Study	Etiology (number of subjects)	Radiographic parameter	Preoperative (degrees)*	Postoperative (degrees)*	p value
Our study	Cerebral palsy (94)	AP talo-1MT	26 ± 11	9 ± 12	< 0.001
	Idiopathic (65)	Lateral talo-1MT	25 ± 12	13 ± 10	< 0.001
	Other (17)				
Adams et al. [1]	Cerebral palsy (42)	AP talo-1MT	20 ± 8	1 ± 10	< 0.05
		Lateral talo-1MT	29 ± 10.5	10 ± 11.5	< 0.05
Danko et al. [5]	Cerebral palsy (62)	AP talo-1MT	18	7	< 0.0001
	Idiopathic (23)	Lateral talo-1MT	29	20	0.0001
	Other (11)				
Noritake et al. [23]	Cerebral palsy (16)	AP talo-1MT	21 ± 10	1 ± 9	< 0.0001
		Lateral talo-1MT	37 ± 13	15 ± 13	< 0.0001
Park et al. [25]	Cerebral palsy (22)	AP talo-1MT	28 ± 10	10 ± 8	< 0.0001
		Lateral talo-1MT	29 ± 13	5 ± 4.5	> 0.05
Sung et al. [33]	Cerebral palsy (75)	AP talo-1MT	22 ± 11	2 ± 14	< 0.001
		Lateral talo-1MT	30 ± 16	12 ± 13	< 0.001
Yoo et al. [37]	Cerebral palsy (56)	AP talo-1MT	23 ± 9	2 ± 10	0.00012
		Lateral talo-1MT	25 ± 9	5 ± 8	0.00021
Zeifang et al. [38]	Cerebral palsy (32)	AP talo-1MT	25 ± 9	10 ± 7	< 0.0001
		Lateral talo-1MT	33 ± 14	18 ± 12.5	< 0.0001

* Data presented as mean ± SD; 1MT = first metatarsal.

level of the patients. It is well known that a nonambulatory status is associated with poor outcomes after calcaneal lengthening in regard to the deformity correction [9, 23, 38]. However, this does not necessarily correlate with graft failure. In the present study, no statistical significance in terms of graft incorporation was observed, and further studies are thus needed to evaluate the correlation between ambulatory status and graft failure. Third, each patient was immobilized in a short-leg cast and remained nonweight-bearing for 5 to 6 weeks after surgery. Previous studies have reported on various cast durations, ranging from 4 to 8 weeks [1, 9, 10, 16, 21, 33, 37]. However, in these previous studies, graft failure did not seem to be associated with cast duration. In the future, studies aimed at evaluating the correlation between cast duration and graft failure are warranted. Finally, there is a risk of transfer bias, because patients who had incomplete followup may not have done as well as those who returned for their followup appointments.

We found that a high proportion of young patients undergoing corticocancellous allografting as part of calcaneal lengthening healed their grafts. Structural bone allograft have been used in orthopaedic surgery since the 1950s [36]. Mosca, in 1995 [21], described the use of tricortical iliac crest allograft for calcaneal lengthening. Vining et al. [35] reported that corticocancellous autograft bone and allograft bone do not differ significantly and concluded that the main advantage of structural allograft is that they are highly resistant to compressive load failure while allowing for loadbearing after surgery [18]. Moreover, Myerson et al. [22] reported successful union after calcaneal osteotomy with fresh-frozen structural allograft in 11 feet with an average time to union of 10 weeks. John et al. [17] found in their study of anterior calcaneal osteotomy that allograft incorporated within 9.1 weeks in adolescents and 9.8 weeks in adults after surgery resulted in a bony union rate of 100% in adolescents and 90% in adults. Furthermore, Dolan et al. [6] performed a study comparing allograft and autograft in planovalgus deformity. Their study included 33 feet in 31 patients with 18 randomized to receive allograft and 15 to receive autografts. In both group, all patients had healed by 12 weeks. However, unlike in the mentioned previous studies, a few studies have reported graft failure after calcaneal lengthening using allograft. Philbin et al. [28] studied 28 feet in 26 patients who underwent correction of planovalgus deformity using a lateral column lengthening with allograft tricortical iliac crest stabilized with a cervical plate. Graft incorporation occurred in all but one patient, and the average time to union was 10 weeks. Because graft failure was such a rare event in these previous studies, it was not possible to determine the incidence and risk factors. Therefore, we aimed to determine the incidence of graft failure in our large series by using objective measurements such as the Goldberg score.

In our study, all patients were treated with a corticocancellous allograft. Tricortical iliac allografts were used most often, whereas patellar allografts were used in 23 feet during a certain period without specific indication, owing to insufficient iliac crest allograft bone during this period. Although the previous studies on the topic could not specify the risk factor for graft failure, our results showed that use of patellar allograft was a significant risk factor for graft failure. It is speculated that the cancellous part of patellar allograft is too dense to be incorporated with the host bone. However, further studies will be needed to clarify this issue. Furthermore, another risk factor for graft failure is age, and our study accordingly showed that the Goldberg score was decreased with increasing age, confirming that older patients may require more time for graft incorporation [11] and have a higher probability of graft failure.

Our study measured the degree of correction after calcaneal lengthening by using six radiographic indices, which, in previous studies [1, 5, 23, 25, 33, 37, 38], have been reported to be improved after calcaneal lengthening, and we obtained comparable results (Table 5). In addition, we also investigated the risk factors affecting the extent of correction. Among the risk factors, age affected some indices in the multivariate analysis, including the AP talus-first metatarsal angle, lateral talocalcaneal angle, lateral talus-first metatarsal angle, and relative calcaneal length. As a result, younger patients maintained greater correction than did older patients with planovalgus deformity. Although previous studies have reported the severity of initial deformity [33] and ambulatory status [9, 23, 38] as factor affecting extent of correction, the effects of age on the extent of correction have not been well documented. We speculate that the more rigid the feet are, the lower the extent of correction achieved by calcaneal lengthening will be; and, because older patients may be more rigid, older age may hence result in a reduced extent of correction after the surgery. However, this hypothesis will need to be confirmed in future studies.

In conclusion, we found that graft failure can occur after calcaneal lengthening using allograft. Our study showed that the tricortical iliac allograft appears to be superior to the patellar allograft in terms of the graft failure rate, and further studies are warranted to elucidate the effects of age on graft failure.

Acknowledgments We thank Hyun Mi Kim BS, for data collection.

References

1. Adams SB Jr, Simpson AW, Pugh LI, Stasikelis PJ. Calcaneocuboid joint subluxation after calcaneal lengthening for planovalgus foot deformity in children with cerebral palsy. *J Pediatr Orthop.* 2009;29:170–174.
2. Bauer TW, Muschler GF. Bone graft materials. An overview of the basic science. *Clin Orthop Relat Res.* 2000;371:10–27.
3. Bonett DG. Sample size requirements for estimating intraclass correlations with desired precision. *Stat Med.* 2002;21:1331–1335.
4. Cypher TJ, Grossman JP. Biological principles of bone graft healing. *J Foot Ankle Surg.* 1996;35:413–417.
5. Danko AM, Allen B Jr, Pugh L, Stasikelis P. Early graft failure in lateral column lengthening. *J Pediatr Orthop.* 2004;24:716–720.
6. Dolan CM, Henning JA, Anderson JG, Bohay DR, Kornmesser MJ, Endres TJ. Randomized prospective study comparing tri-cortical iliac crest autograft to allograft in the lateral column lengthening component for operative correction of adult acquired flatfoot deformity. *Foot Ankle Int.* 2007;28:8–12.
7. Dunn SP, Meyer J. Displacement of the anterior process of the calcaneus after Evans calcaneal osteotomy. *J Foot Ankle Surg.* 2011;50:402–406.
8. Ehrler DM, Vaccaro AR. The use of allograft bone in lumbar spine surgery. *Clin Orthop Relat Res.* 2000;371:38–45.
9. Ettl V, Wollmerstedt N, Kirschner S, Morrison R, Pasold E, Raab P. Calcaneal lengthening for planovalgus deformity in children with cerebral palsy. *Foot Ankle Int.* 2009;30:398–404.
10. Evans D. Calcaneo-valgus deformity. *J Bone Joint Surg Br.* 1975;57:270–278.
11. Gaston MS, Simpson AH. Inhibition of fracture healing. *J Bone Joint Surg Br.* 2007;89:1553–1560.
12. Gefen A, Seliktar R. Comparison of the trabecular architecture and the isostatic stress flow in the human calcaneus. *Med Eng Phys.* 2004;26:119–129.
13. Goldberg VM, Powell A, Shaffer JW, Zika J, Bos GD, Heiple KG. Bone grafting: role of histocompatibility in transplantation. *J Orthop Res.* 1985;3:389–404.
14. Grice DS. An extra-articular arthrodesis of the subastragalar joint for correction of paralytic flat feet in children. *J Bone Joint Surg Am.* 1952;34:927–940; passim.
15. Horton GA, Olney BW. Triple arthrodesis with lateral column lengthening for treatment of severe planovalgus deformity. *Foot Ankle Int.* 1995;16:395–400.
16. Huang CN, Wu KW, Huang SC, Kuo KN, Wang TM. Medial column stabilization improves the early result of calcaneal lengthening in children with cerebral palsy. *J Pediatr Orthop B.* 2013;22:233–239.
17. John S, Child BJ, Hix J, Maskill M, Bowers C, Catanzariti AR, Mendicino RW, Saltrick K. A retrospective analysis of anterior calcaneal osteotomy with allogenic bone graft. *J Foot Ankle Surg.* 2010;49:375–379.
18. Khan SN, Cammisa FP Jr, Sandhu HS, Diwan AD, Girardi FP, Lane JM. The biology of bone grafting. *J Am Acad Orthop Surg.* 2005;13:77–86.
19. Lee KM, Lee J, Chung CY, Ahn S, Sung KH, Kim TW, Lee HJ, Park MS. Pitfalls and important issues in testing reliability using intraclass correlation coefficients in orthopaedic research. *Clin Orthop Surg.* 2012;4:149–155.
20. Mahan KT, Hillstrom HJ. Bone grafting in foot and ankle surgery. A review of 300 cases. *J Am Podiatr Med Assoc.* 1998;88:109–118.
21. 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;77:500–512.
22. Myerson MS, Neufeld SK, Uribe J. Fresh-frozen structural allografts in the foot and ankle. *J Bone Joint Surg Am.* 2005;87:113–120.
23. Noritake K, Yoshihashi Y, Miyata T. Calcaneal lengthening for planovalgus foot deformity in children with spastic cerebral palsy. *J Pediatr Orthop B.* 2005;14:274–279.
24. Nugent PJ, Dawson EG. Intertransverse process lumbar arthrodesis with allogeneic fresh-frozen bone graft. *Clin Orthop Relat Res.* 1993;287:107–111.
25. Park KB, Park HW, Lee KS, Joo SY, Kim HW. Changes in dynamic foot pressure after surgical treatment of valgus deformity of the hindfoot in cerebral palsy. *J Bone Joint Surg Am.* 2008;90:1712–1721.

26. Park MS, Kim SJ, Chung CY, Choi IH, Lee SH, Lee KM. Statistical consideration for bilateral cases in orthopaedic research. *J Bone Joint Surg Am.* 2010;92:1732–1737.
27. Park MS, Kwon SS, Lee SY, Lee KM, Kim TG, Chung CY. Spontaneous improvement of radiographic indices for idiopathic planovalgus with age. *J Bone Joint Surg Am.* 2013;95:e193.191–198.
28. Philbin TM, Pokabla C, Berlet GC. Lateral column lengthening using allograft interposition and cervical plate fixation. *Foot Ankle Spec.* 2008;1:288–296.
29. Rathjen KE, Mubarak SJ. Calcaneal-cuboid-cuneiform osteotomy for the correction of valgus foot deformities in children. *J Pediatr Orthop.* 1998;18:775–782.
30. Scarborough NL, White EM, Hughes JV, Manrique AJ, Poser JW. Allograft safety: viral inactivation with bone demineralization. *Contemp Orthop.* 1995;31:257–261.
31. Segur JM, Torner P, Garcia S, Combalia A, Suso S, Ramon R. Use of bone allograft in tibial plateau fractures. *Arch Orthop Trauma Surg.* 1998;117:357–359.
32. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychol Bull.* 1979;86:420–428.
33. Sung KH, Chung CY, Lee KM, Lee SY, Park MS. Calcaneal lengthening for planovalgus foot deformity in patients with cerebral palsy. *Clin Orthop Relat Res.* 2013;471:1682–1690.
34. Tomford WW. Bone allografts: past, present and future. *Cell Tissue Bank.* 2000;1:105–109.
35. Vining NC, Warme WJ, Mosca VS. Comparison of structural bone autografts and allografts in pediatric foot surgery. *J Pediatr Orthop.* 2012;32:719–723.
36. Woolf SK, Gross RH. Perceptions of allograft safety and efficacy among spinal deformity surgeons. *J Pediatr Orthop.* 2001;21:767–771.
37. Yoo WJ, Chung CY, Choi IH, Cho TJ, Kim DH. Calcaneal lengthening for the planovalgus foot deformity in children with cerebral palsy. *J Pediatr Orthop.* 2005;25:781–785.
38. Zeifang F, Breusch SJ, Doderlein L. Evans calcaneal lengthening procedure for spastic flexible flatfoot in 32 patients (46 feet) with a followup of 3 to 9 years. *Foot Ankle Int.* 2006;27:500–507.