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Increased rates of delayed union after percutaneous Akin osteotomy☆

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ABSTRACT

Background: Akin osteotomy is a well-known surgical procedure in forefoot surgery. When performing percutaneously, we have found a lot of delayed unions on follow up X-rays. The objective of this study was to assess the incidence of delayed union when performing a percutaneous Akin osteotomy.
Methods: We report a series of 26 cases who underwent minimally invasive (percutaneous) Akin osteotomy. The mean follow-up duration was 17.6 (range 12 to 24) months. We analys–24) months. We analyzed the time to fusion using standard weight bearing radiographs. All the procedures were uneventful and we had only two skin burns that healed without sequelae.
Results: All the procedures were uneventful and we had only two skin burns that healed without sequelae. The average time to fusion in our series was 4.69 months (2–11): seventeen of the 26 osteotomies (65.4%) were considered radiographically healed at an average time of 2,94 months (2–5), whereas 9 patients (34.6%) sustained a delayed-union and healed at an average of 8 months (7–11).
Conclusions: Despite few intraoperative complications and satisfactory clinical and radiological outcomes, our data suggest that a delayed union after Akin osteotomy is very common in the daily practice when performing it through a minimally invasive technique.

1. Introduction

Akin osteotomy was described in 1925 as a wedge-shaped proximal phalangeal osteotomy of the big toe with a medially oriented base and a laterally oriented apex. The main indication for this procedure is a hallux valgus interphalangeous deformity [1]. This osteotomy is rarely used as an isolated procedure and is usually performed in conjunction with almost any bunion correction as a complimentary procedure, in which some valgus of the hallux is still present [2–4]. Although Akin osteotomy is generally thought of as a minor procedure, complications do occur, including fracture of the cortical hinge, shortening, under-correction, overcorrection, delayed union and non-union from inadequate bone apposition and stabilization, hardware failure, iatrogenic osteoarthritis, and restriction of the motion of the big toe [2–6].

Delayed union by definition is present when an adequate period of time has passed since the initial injury without achieving bone union; and non-union is defined as the cessation of all reparative processes of healing without bone-union. To define the concept of delayed union or non-union with the Akin osteotomy we must accept that the proximal phalanx osteotomy is comparable to a fracture of the same type, being that the normal healing time is described at 6–8 weeks [7]. Although it is unclear how Orthopedic Surgeons are diagnosing and managing delayed or non-unions in clinical practices, most surgeons agreed that diagnosis should be done of both radiographic and clinical criteria [7].

Being that the degree of soft-tissue injury clearly increases the risk of healing complications [7], the percutaneous or minimally invasive surgical (MIS) techniques in Foot and Ankle was introduced initially to compete with traditional open surgery [8–14]. Percutaneous and minimum incision osteotomies for the management of hallux valgus have received increasing recognition because of the perceived efficacy comparable to traditional open approaches but with fewer costs and higher patient satisfaction [9–11].

This case series is a cohort of 26 patients who were treated with a percutaneous Akin osteotomy. The hypothesis was that percutaneous osteotomy has a higher incidence of delayed union

☆ Level of clinical evidence: IV.

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than open procedures, and the objective of the present study was to assess the incidence of delayed union when performing a percutaneous Akin osteotomy.

2. Patients and methods

From January to December 2013, 31 consecutive patients underwent percutaneous Akin osteotomy. Our institutional review board approved the study, and all patients signed an informed consent form before evaluation.

For this study, the main indications for the Akin osteotomy were painful hallux valgus deformity with interphalangeal angle (IPA) greater than 10° on anteroposterior weight-bearing radiographs, or patients with residual interphalageus valgus following metatarsal osteotomy to correct hallux valgus.

To be involved in this study, the following criteria had to be met:

1. Patients older than 18 year old.
2. Painful hallux valgus refractory to conservative treatment (insoles, shoe modification, activity modification).
3. The ability to understand the study protocol.
4. Provision of written informed consent.

Exclusion criteria were:

1. Prior surgeries in the forefoot.
2. Active infection of peripheral arterial disease (contraindications).
3. Incomplete follow-up.

Twenty-six patients met the inclusion criteria. Pre- and postoperative radiological evaluation was done with conventional radiography of the forefoot (weight-bearing anteroposterior and lateral views). All patients were regularly followed through chart review, clinical examination and radiological evaluation every month. The mean follow-up duration was 17.6 (range 12–24) months.

The primary outcome measure of the present study was complete radiographic fusion of the osteotomy evident by trabecular bridging of ≥2 cortices. The secondary outcomes included the time to fusion and correction of the deformity. Although it has not been generally accepted for this procedure and the literature is sparse, we strictly considered the limit of three months for the phalangeal osteotomy to heal, but, from the practical point of view, we decided the cut of 6 months without radiological bony union, given the clinical variability of the series. We also analyzed technical errors and complications (Table 1).

2.1. Operative technique

All patients were operated on under regional anesthesia (perimetatarsal conduction block). The same surgeon operated on all the patients (MHP). The patient was placed in supine position and no tourniquet was used. All the procedures were performed through minimal incisions and under X-ray control (fluoroscope). In the first step, the first-ray procedure was performed (simple bunionectomy). In the second step, through a minimal incision heading to the base of the proximal phalanx, a lateral capsuloligamentary release of the metatarsophalangeal joint was performed associated with transverse abductor tenotomy by Beaver® blade with a second dorsolateral approach facing the metatarsophalangeal joint-line. In the third step, an Akin osteotomy (varization osteotomy of the first-phalanx) was performed as described by De Prado [10], with a dorsomedial approach of 3 mm, medially to the extensor hallucis longus tendon (Fig. 1). A short straight burr was used for proximal metaphyseal osteotomy of the phalanx with torque multiplication, operating at low speed (max.: 5000 rpm) to avoid burning and bone and skin necrosis, under fluoroscopy, and conserving the lateral cortex. Bone fragments were evacuated under manual pressure, with saline lavage and cleansing by rasps in the workspace. Correction was obtained by medial closure of the osteotomy with the hallux in forced varus (Fig. 2). No osteosynthesis was implanted. Postoperative dressing in slight hypercorrection for 10 days maintained the

Table 1
Demographic data, complications and results of the serie.

No	Age	Sex	Side	BMI	Comorbilities	Technical error	Ost	Complications	Fusion (mo)	FU (mo)
1	27	F	R	31,3	No	No	M	No	3	16
2	38	F	R	30,4	Smoking	Lateral cortex	D	Thermal unjury	2	13
3	56	M	L	25,5	Diabetes, HBP	No	M	No	4	17
4	62	F	R	23,3	No	No	M	No	3	24
5	48	F	L	19,3	Smoking	Lateral cortex	M	No	3	22
6	62	M	L	27	Smoking, HBP	No	M	No	7	16
7	29	M	R	27,6	No	No	M	No	8	17
8	69	F	R	32,3	OP, HBP	No	M	No	8	17
9	67	F	L	31,3	OP, HBP	No	D	No	7	12
10	39	F	R	25,5	Smoking	Lateral cortex	M	No	3	12
11	47	F	R	23,5	No	No	M	No	2	16
12	59	F	R	19,2	HBP, diabetes	No	M	No	7	12
13	62	M	R	23,2	OP, diabetes	No	M	Thermal injury	3	12
14	69	F	L	22	OP, HBP	No	M	No	3	17
15	71	F	R	30,2	OP, diabetes	No	M	No	4	12
16	45	F	R	22	No	Lateral cortex	D	No	11	12
17	55	F	L	25,2	Smoking	No	M	No	3	12
18	56	F	R	27	Smoking	No	M	No	2	24
19	59	F	L	31	Diabetes, HBP	No	M	No	2	18
20	48	M	R	27,2	Smoking	No	M	No	5	24
21	29	F	R	22	No	No	M	No	8	19
22	59	F	L	25,7	Diabetes, HBP	Lateral cortex	M	No	9	24
23	64	F	L	21	OP	No	M	No	2	24
24	60	F	L	19	HBP	No	M	No	3	22
25	38	F	R	22,3	Smoking	No	M	No	3	23
26	69	F	R	26,2	OP, diabetes	Lateral cortex	M	No	7	21

F: female; M: male; R: right; L: left; BMI: body mass index; HBP: high blood pressure; OP: osteoporosis; Lateral cortex: break of the lateral cortex; Ost: osteotomy; M: metaphy; D: diaphysis FU: follow up; mo: month.

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Fig. 1. Dorsomedial approach medially to the extensor hallucis longus tendon, you can see also the dorsolateral approach for the abductor tenotomy.

correction and kept the osteotomies closed. It was then changed for a dressing maintaining first-ray alignment for 1 month.

2.2. Postoperative care

Complete weight-bearing was resumed immediately, with a stiff-soled surgical shoe for the first month. Preventive anti-coagulants were not prescribed except in case of history of deep venous thrombosis or risk factors (coagulation disorder, thrombopathy). Metatarsophalangeal joint mobilization was authorized after the first dressing was put on. All the patients were discharged the same day of the surgery (day surgery) allowing immediate partial weight bearing with the aid of crutches the first two weeks. After two weeks, we removed the sutures and let the patients bear weight completely in a stiff-soled surgical shoe until the bone fused.

2.3. Statistical analysis

Quantitative variables were expressed with means and standard deviations. Qualitative variables were expressed with frequencies and percentages. Proportions between groups were compared using chi square or Fisher exact test when appropriate. An incidental sample was used, and sample power was not calculated before starting the study. Finally, we performed a univariate regression logistic model to estimate the risk of delayed union. The independent variables were age, sex, diabetes, body mass index (BMI), blood pressure, osteoporosis, osteotomy location, technical errors and complications (Table 2).

3. Results

A total of 26 patients were included in the study. There were 5 men and 21 women with an average age of 53,6 years (range, 27–71). The comorbidities were smoking in 8 patients, high blood pressure in 9 patients, obesity (BMI > 30) in 6 patients, osteoporosis in 7 patients and diabetes in 7 patients (Table 1). All the procedures were uneventful and we had only two skin burns that healed without sequelae. The average time to fusion in our series was 4.69 months (2–11): 17 of the 26 osteotomies (65.4%) were considered radiographically healed at an average time of 2,94 months (2–5), whereas 9 patients (34.6%) sustained a delayed union and healed at an average of 8 months (7–11). Table 2 shows the univariate binary regression models to predict delayed union. None of the independent variables were significant predictors of delayed union. We did not find any relation between delayed union and smoking, osteoporosis or diabetes. From the technical point of view, we had 6 breaches of the lateral cortex (3 of them in our 9 delayed unions), but this was without appreciable complication at the end of the follow-up. One case was especially shocking (case 16): a 45 year-old otherwise healthy female. At 4 weeks, although the first radiological test showed no signs of fracture healing, we decided to take out the shoe and let her complete full-weight bearing to promote bone healing. At 3 months follow-up, radiographs showed no signs of osteotomy fusion. The patient complained of continuous, disabling pain, as well as big toe swelling. To rule out a low-grade infection we performed a bone scan and a full blood work, which were completely normal. To reduce swelling, the patient was sent for rehabilitation treatment. At 9 months after surgery, the patient continued with pain and

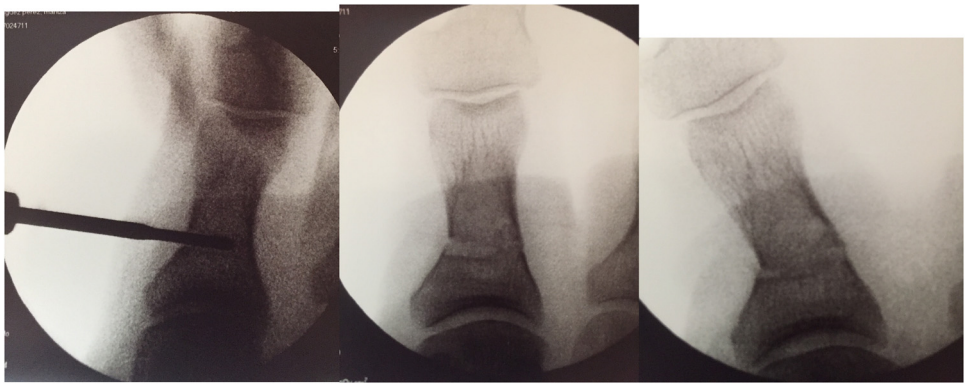

Fig. 2. Surgical steps of percutaneous Akin osteotomy: using the straight burr, incomplete metaphyseal osteotomy and final overcorrection by closing osteotomy in forced varus.

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Table 2
Univariate binary logistic regression models to predict delayed union after surgery.

	OR	95% CI	*P*
Model 1			
Age	1,02	0.961–1.085	0.50
Model 2			
Sex	0,15	0.014–1.632	0.12
Model 3			
Smoking	3.75	0.589–23.867	0.16
Model 4			
IMC groups			0.22
(Reference category: normal weight)			
Overweight	5.33	0.783–36.331	
Obesity	2.66	0.334–21.321	
Model 5			
Diabetes	0.23	0.03–1.538	0.13
Model 6			
Hypertension	0.27	0.049–1.502	0.14
Model 7			
Osteoporosis	0.54	0.095–3.146	0.50
Model 8			
Technical error	0.82	0.132–5.083	0.82
Model 9			
Osteotomy location	2.6059	0.205–32.904	0.46

swelling, and a radiograph showed clear signs of non-union (Fig. 3). With the suspected diagnosis of non-union, reoperation was advised but the patient refused it. Surprisingly, at 11 months of follow-up, the patient began to report less pain and swelling and the X-ray control showed a spontaneous complete union of the osteotomy (Fig. 4).

Fig. 3. X-ray showing delayed union of Akin osteotomy at 6 months PO.

Fig. 4. Spontaneous healing of the osteotomy after 11 months PO.

At the end of the follow-ups all the patients were satisfied, pain free and had a complete correction of the first ray deformity.

4. Discussion

Akin osteotomy is a common procedure in hallux valgus surgery and, although considered a safe procedure, its main complications include: non-union, infection, loss of reduction, overcorrection, under-correction and hardware failure among others [2–5]. Initially, the Akin osteotomy was designed with minimal internal fixation, but over the years multiple fixation methods and devices have been described and used [3–6,15–17]. Neumann et al. report good results in 44 patients treated with staple fixation with a low risk of complications, although three patients reported proximal phalanx tenderness, while one patient had a revision surgery due to persistent deformity [3].

The three most common complications of foot surgery are infection, wound dehiscence, skin ulcers and blisters. To minimize these complications and reduce soft-tissue injury, the so-called minimally invasive surgery (MIS) technique was designed, being nowadays increasingly common.

These techniques have the theoretical advantage of fewer complications compared to open procedures because surgical exposure respects the biology of the osteotomy site with less extensive and gentler soft-tissue dissection [7–11]. Additional advantages include a better cosmesis, as well as the possibility of immediate weight bearing and a faster recovery. However, we still do not have a strong scientific evidence base from randomized controlled trials supporting the clinical superiority of this technique. Maffulli et al. reported that it is not possible to determine clear recommendations regarding the systematic use of minimally invasive surgery for hallux valgus correction. It was also reported that even though preliminary results are encouraging, studies of higher levels of evidence, including large randomized trials, should be performed [7].

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Although there has been concern regarding neurovascular and tendon injury with MIS techniques [7–10], Dhukharam et al. [18] reported their findings in a cadaveric study consistent with minimal risk. This study also reflected the challenges associated with performing the osteotomy in the desired plane, which may be related to the learning curve. However, the study emphasized the need for excellent three-dimensional anatomic knowledge and suggested additional cadaveric training prior to attempting these techniques in clinical practice [11]. In the same way, Yañez Arauz [19] recently have reported in a cadaveric study no nerve injuries, but a partial injury of the flexor hallucis longus tendon sheath in 44% of the samples, so we must consider this the main structure at risk with this technique.

Delayed union, non-union and malunion are well-known complications in forefoot surgery, although specific incidence of this complication with the open Akin osteotomy has not been published [4,5,12]. In recent years, staple fixation techniques have reported very good results (satisfaction rate of 96%) [3], but there is still no consensus about the ideal method of fixation to minimize the risk of these complications, resulting in persistent pain and swelling in the patients, Chacon et al. [20] recently reports the results of a biomechanical analysis comparing 5 commonly used fixation techniques for the Akin osteotomy to determine the strongest method in simulated weight-bearing in sawbone models. Surprisingly, crossed Kirschner wire technique performed significantly better than the other fixation techniques.

We registered a higher rate of delayed union in our series when performing this procedure percutaneously. We tried to find a correlation between this high incidence and comorbidity of our series (Table 2). However, the statistical analysis revealed no significant differences. We have found a recent publication addressing the non-union risks in foot and ankle arthrodesis procedures, which are similar, though not equal, to the non-union risks associated with the osteotomy [21]. In addition, the authors have developed a prediction model (predictive risk assessment model) for the risks associated with non-union. The model is based on the principal risk factors with grade B of scientific evidence: smoking, obesity (BMI > 30), diabetes and the absence of an internal fixation. Smoking and diabetes are clearly related to a delay in the consolidation of fractures and arthrodesis [22,23]. The study by Patel et al. concluded that smokers displayed an increased time in radiological consolidation [22]. In our series, previous comorbidities in patients did not influence the augmentation of the incidence of non-union. Therefore, we should further investigate other mechanical causes that have altered the consolidation process, such as the absence or rigid internal fixation, immediate weight bearing and possible technical defects. From a theoretical point of view, pseudarthrosis or non-union is classified as hypertrophic (due to mechanical causes) and atrophic (due to biological causes). Regarding our series, one may have assumed that the absence of an internal fixation or early mobilization would have great importance as an etiological factor, however, the radiology images we studied revealed that atrophic pseudarthrosis actually relates to a biological disorder of the consolidation process. In three of our delayed unions the technical error was perhaps breaking the lateral cortex of the proximal phalanx, which was described by De Prado as a major risk factor for delayed or malunion [10]. However, we did not find a correlation between this event and an increased incidence of delayed or malunion. Another frequent technical error with this procedure is to perform a mid-diaphyseal osteotomy. This location is likely to take longer to heal than a metaphyseal osteotomy (which is why most of the surgeons try to localize the Akin osteotomy). This fact appears to be obvious, yet we did not find statistical correlation.

With respect to thermal injuries of the skin from high-speed burrs as a cause of bone necrosis, resulting in a biological failure of consolidation, it is very difficult to establish a relationship between thermal injuries and bone necrosis. We did not perform bone biopsies in our study for this particular analysis.

Regardless of the cause, which is most likely multifactorial, in our daily practice we do see many cases of delayed union not only with the Akin procedure but also with other surgical forefoot procedures using MIS technique (first ray osteotomies, metatarsal osteotomies, . . .), most of them clinically asymptomatic, as mentioned in the recent publication by Haque et al. [24]. On the other hand, we find it shocking that in one of our cases the osteotomy fused spontaneously a year after surgery. This perhaps forces us to redefine the concept of delayed union and even non-union in forefoot minimally invasive surgery.

The present study has weaknesses that need to be noted. The most obvious perhaps is the retrospective analysis of our series. We also have a short follow-up and a small patient sample size, without a control group, that may have limited our ability to identify a statistically significant difference in pre and postoperative patients, or between group measurements (a type 2 statistical error). Although we reviewed the recent literature looking for the union time with this procedure and found few references about it [25–27], we did not compare our group with a control group (open Akin osteotomies). Finally, we used plain radiographs to determine the presence of trabecular bridging on more than two views. This was done by only one of us and it would have been ideal to do it with at least two authors. We also did not use CT scan to verify the fusion of the osteotomy.

Akin osteotomy is a safe and reproducible surgical procedure. However, from our series it appears that a delayed union is very common when performing this procedure with a minimally invasive technique, with most of the cases clinically asymptomatic.

5. Conclusions

We have registered an increased rate of delayed union when performing Akin osteotomy with a minimally invasive technique. We cannot attribute this fact to a specific risk factor because we did not have a clear control group and maybe several biological, mechanical and individual factors contribute to this finding. Due to our results, we advise not to perform this procedure indiscriminately and without previous cadaver training experience. If the surgeon is lacking this training experience, we advise to perform a formal open reduction and internal fixation technique. Furthermore, more randomized control trials comparing Akin osteotomy with and without fixation are needed to have a better understanding of the increased risk rates when performing a MIS technique.

Conflicts of interest

The author(s) declared no potential conflicts of interests with respect to the research, authorship, and/or publication of this article.

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References

[1] Arnold H. The Akin procedure as closing wedge osteotomy for the correction of a hallux valgus interphalangeus deformity. Oper Orthop Traumatol 2008;20 (6):477–83.
[2] Cohen M. The oblique proximal phalangeal osteotomy in the correction of hallux valgus. J Foot Ankle Surg 2003;42:282–9.
[3] Neumann JA, Reay KD, Bradley KE, Parekh SG. Staple fixation for Akin proximal phalangeal osteotomy in the treatment of hallux valgus interphalangeus. Foot Ankle Int 2015;36(April (4)):457–64.
[4] McDonald KC, Durrant MN, Drake R, Paolercio NL. Retrospective analysis of Akin-Austin bunionectomies on patients over fifty years of age. J Foot Surg 1988;27(6):545–55.
[5] Frey C, Jahss M, Kummer FJ. The Akin procedure: an analysis of results. Foot Ankle 1991;12(1):1–6.
[6] Roy DP, Tan KJ. A modified suture technique for fixation of the Akin osteotomy. J Foot Ankle Surg 2013;52(2):276–8.
[7] Maffulli N, Longo UG, Marinozzi A, Denaro V. Hallux valgus: effectiveness and safety of minimally invasive surgery. A systematic review. Br Med Bull 2011;97:149–67.
[8] Bauer T, de Lavigne C, Biau D, De Prado M, Isham S, Laffenétre O. Percutaneous hallux valgus surgery: a prospective multicenter study of 189 cases. Orthop Clin North Am 2009;40(4):505–14.
[9] Roukis TS, Schade VL. Minimum-incision metatarsal osteotomies. Clin Podiatr Med Surg 2008;25:587–607 viii.
[10] De Prado M, Ripoll PL, Golanó P. Minimally invasive foot surgery. 1st ed. Barcelona: Masson; 2003.
[11] Giannini S, Faldini C, Nanni M, Di Martino A, Luciani D, Vannini F. A minimally invasive technique for surgical treatment of hallux valgus: simple, effective, rapid, inexpensive (SERI). Int Orthop 2013;37(9):1805–13.
[12] Roukis TS. Central metatarsal head-neck osteotomies: indications and operative techniques. Clin Podiatr Med Surg 2005;22:197–222 vi.
[13] Roukis TS, Schade VL. Minimum-incision metatarsal osteotomies. Clin Podiatr Med Surg 2008;25:587–607 viii.
[14] Roukis TS. Percutaneous and minimum incision metatarsal osteotomies: a systematic review. J Foot Ankle Surg 2009;48:380–7.
[15] Cohen M. The oblique proximal phalangeal osteotomy in the correction of hallux valgus. J Foot Ankle Surg 2003;42:282–9.
[16] Shannak O, Sehat K, Dhar S. Analysis of the proximal phalanx size as a guide for an Akin closing wedge osteotomy. Foot Ankle Int 2011;32(4):419–21.
[17] Goldberg I, Bahar A, Yosipovitch Z. Late results after correction of hallux valgus deformity by basilar phalangeal osteotomy. J Bone Joint Surg 1987;69:64–7.
[18] Dhukaram V, Chapman AP, Upadhyay PK. Minimally invasive forefoot surgery: a cadaveric study. Foot Ankle Int 2012;33(12):1139–44.
[19] Yañez Arauz JM, Del Vecchio JJ, Codesido M, Raimondi N. Minimally invasive Akin osteotomy and lateral release: anatomical structures at risk—a cadaveric study. Foot (Edinb) 2016;27:32–5.
[20] Chacon Y, Fallat LM, Dau N, Bir C. Biomechanical comparison of internal fixation techniques for the Akin osteotomy of the proximal phalanx. J Foot Ankle Surg 2012;51(5):561–5.
[21] Thevendran G, Wang C, Pinney SJ, Penner MJ, Wing KJ, Younger AS. Nonunion risk assessment in foot and ankle surgery: proposing a predictive risk assessment model. Foot Ankle Int 2015;36(8):901–7.
[22] Patel RA, Wilson RF, Patel PA, Palmer RM. The effect of smoking on bone healing: a systematic review. Bone Joint Res 2013;2(6):102–11.
[23] Jiao H, Xiao E, Graves DT. Diabetes and its effect on bone and fracture healing. Curr Osteoporos Rep 2015;13(5):327–35.
[24] Haque S, Kakwani R, Chadwick C, Bowen-Davies M, Blundell CM. Outcome of minimally invasive distal metatarsal metaphyseal osteotomy (DMMO) for lesser toe metatarsalgia. Foot Ankle Int 2016;37(January (1)):58–63.
[25] Kurashige T, Suzuki S. Effectiveness of percutaneous proximal closing wedge osteotomy with Akin osteotomy to correct severe hallux valgus determined by radiographic parameters: a 22-month follow-up. Foot Ankle Spec 2017;10 (April (2)):170–9.
[26] Díaz Fernández R. Percutaneous triple and double osteotomies for the treatment of hallux valgus. Foot Ankle Int 2017;38(February (2)):159–66.
[27] Lam P, Lee M, Xing J, Di Nallo M. Percutaneous surgery for mild to moderate hallux valgus. Foot Ankle Clin 2016;21(September (3)):459–77.

Please cite this article in press as: M. Herrera-Perez, et al., Increased rates of delayed union after percutaneous Akin osteotomy, Foot Ankle Surg (2017), http://dx.doi.org/10.1016/j.fas.2017.04.010