The Foot 41 (2019) 19–23

Contents lists available at ScienceDirect

The Foot

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

Original Article

# Neurovascular structures at risk with percutaneous fixation in tarsometatarsal fusion: A cadaveric study

Eva Lehtonen, Harshadkumar Patel, Sung Lee, John LaCorda, Haley M. McKissack, Sameer Naranje, Ashish Shah*

*University of Alabama at Birmingham, 1313 13th Street South, Birmingham, AL, 35205, USA*

ARTICLE INFO

*Keywords:*
Bunion
Hallux valgus
Neurological injury
Bunion surgery
Modified Lapidus procedure
Lisfranc

ABSTRACT

*Introduction:* First tarsometatarsal (TMT) joint fusion is routinely used for arthritis and deformities. Common fixation methods include a locking plate construct, cross-screws, or combinations of the two. Cross screws have proven effective for union and stability; however, there is a potential for harm to nearby neurovascular structures due to the nature of percutaneous insertion technique. This study assessed risk of damage to the superficial peroneal nerve with percutaneous TMT fusion.

*Methods:* Nine fresh-frozen cadaver specimens were included. A medial incision in the internervous plane was made for TMT joint preparation. Two crossed percutaneous wires followed by 4.0 cc screws were placed in the dorsal aspect of the proximal aspect of first metatarsal and in the medial cuneiform. Both were 10–15 mm from the TMT joint line. The dorsal aspect of the foot was dissected and examined for neurovascular interruptions, particularly branches of the superficial peroneal nerve.

*Results:* Results showed a mean distance of 4.33 mm from the proximal pin to the medial branch of the superficial peroneal nerve. The distal pin had a mean distance of 6.44 mm from the medial branch, with one pin 9 mm from the lateral branch. One incident of direct injury to the neurovascular bundle was observed.

*Conclusion:* Preparing the joint from the medial side using a percutaneous approach is less invasive, but presents a relative risk for neuritis. Care should be taken during insertion of the percutaneous screw after TMT joint preparation for fusion.

**Level of Evidence:** Level V, cadaver study.

## 1. Introduction

The modified Lapidus technique for the first tarsometatarsal joint (first TMT) fusion has become a routinely performed procedure for conditions such as hallux valgus, metatarsus primus varus, and traumatic or end stage arthritis. It is particularly common for treatment of hallux valgus with first ray hypermobility [1]. The standard dorsal approach has proven successful, and some surgeons use a medial approach. Despite the efficacy of these approaches, minimally-invasive approaches have become increasingly common, as they provide adequate fixation while minimizing soft tissue damage, reducing morbidity rates, and decreasing operative time and recovery time [2]. In the medial approach as well as the minimally-invasive approach for the modified Lapidus procedure, screws are placed percutaneously through the dorsum of the foot. As this approach becomes more widely-implemented, establishing its safety is paramount.

Working incisions in the minimally-invasive approach are 1–3 cm such that exposure is minimized. However, structures cannot be directly visualized as with the traditional open approach [3]. The joint is then prepared, and fixation is executed first temporarily with K-wires. Lag screws are then inserted for permanent stabilization, typically using a cross-screw construct [4,5]. Although this approach minimizes trauma to nearby soft tissues, limited visualization does inherently place anatomical structures within close proximity of pin insertion at risk. Damage may result in loss of sensation, chronic pain, and neuroma formation [6].

The superficial peroneal nerve (SPN) branches distally into an intermediate and medial cutaneous branch. The medial branch again bifurcates, and the most medial branch – the dorsomedial cutaneous nerve (DCN) – supplies cutaneous innervation to the medial border of

* Corresponding author at: Division of Orthopaedic Surgery, Department of Surgery, University of Alabama, Birmingham, School of Medicine, 1313 13th Street South, Suite 226, Birmingham, AL, 35205, USA.

*E-mail addresses:* ejl29@med.miami.edu (E. Lehtonen), harshadkumar.patel@duke.edu (H. Patel), sunglee@uab.edu (S. Lee), johnlacorda@yahoo.com (J. LaCorda), Hmcki003@fiu.edu (H.M. McKissack), sameernaranje@uabmc.edu (S. Naranje), ashishshah@uabmc.edu (A. Shah).

https://doi.org/10.1016/j.foot.2019.05.006
Received 19 February 2019; Received in revised form 11 May 2019; Accepted 16 May 2019

the hallux [7]. Theoretically, branches of the SPN are susceptible to iatrogenic injury during percutaneous screw placement due to its superficial course across the dorsum of the foot in close proximity to the first TMT joint. However, there is a paucity of literature which objectively addresses this risk. A prospective study by Jastifer et al. reported nine of 11 patients who sustained a sensory nerve deficit after undergoing hallux valgus correction, but without specification of the insulted nerve [8]. Other studies have also assessed postoperative neurological dysfunction following hallux valgus surgery, including damage to the dorsal cutaneous nerve following mini-invasive Mitchell–Kramer and chevron procedures [9]. However, no studies specifically report risk of damage to the superficial peroneal nerve with the percutaneous Lapidus approach.

To date, no study exists describing the risk of direct injury or approximate distances to the SPN using percutaneous screw insertion for the modified Lapidus procedure. Superiority of percutaneous versus open techniques has not been clearly established, and characterization of risk of injury may provide valuable information regarding safety of percutaneous screw insertion for TMT fusion and aid in the risk-benefit comparisons of each for surgical decision making. The purpose of this cadaveric study was to investigate the rate of injury and the proximity of screws to the medial branch of the superficial peroneal nerve in percutaneous screw insertion for TMT fusion.

## 2. Materials and methods

### 2.1. Specimen preparation

Eleven fresh-frozen below-knee human cadaveric specimens were obtained. Specimens were stored at −20 °C and were thawed to room temperature prior to use in the study. Visual and radiographic inspection was performed to evaluate for gross musculoskeletal deformities. Two specimens were excluded due to gross deformity of the first TMT joint. The remaining nine specimens (five female and four male) had a mean age of 79 ± 11 years (Range 60–96). The mean height and weight were 71 in. (S.D. = 12.8, range 61–105) and 177 pounds (S.D. = 74.6, range 81–300). All specimens were left-sided.

### 2.2. Surgical technique

All surgeries were performed by one fellowship-trained foot and ankle surgeon. After marking anatomical landmarks, a medial incision was made under fluoroscopic guidance along the first ray from the medial aspect of the medial cuneiform to the base of the first metatarsal. The joint capsule was released, and the first TMT joint was exposed. The articular surface of both sides of the joint was denuded with a combination of osteotomes and curettes in the routine surgical manner [5]. The TMT joint was provisionally fixed with 1.6 mm K-wire.

A cross-screw construct was created through two small 0.5 cm incisions as described by Cohen et al. [10]. Two 1.4 mm guide wires were inserted using a 1.4 mm drill guide: one directed from the dorsolateral metatarsal base to the plantar-lateral cuneiform (“distal pin”) and the other from the dorsomedial cuneiform to the plantar-medial first metatarsal base (“proximal pin”). Guidewire entry points were determined under fluoroscopic guidance approximately 10–15 mm away from the joint line. Two partially threaded self drilling 4.0 mm stainless steel screws (Stryker Corp., Kalamazoo, Michigan, USA) were inserted over the guidewire with the use of a soft tissue protector until adequate joint compression was confirmed with direct visualization and radiologically (Fig. 1).

### 2.3. Assessment of outcomes

Careful dissection was performed to determine the proximity of each screw from adjacent neurovascular structures, particularly the medial branch of the superficial peroneal nerve (Fig. 2). The shortest distances between each screw and the medial and lateral branch of the superficial peroneal nerve were measured to the nearest 1 mm using a precision digital caliper. All measurements were taken by a single independent observer and verified by a second observer. In cases where distance was 0 mm (i.e., when contact occurred between a screw and a neurovascular structure) further distinctions were made. If the screw was abutting the structure without evidence of gross injury to the structure, the event was termed “Contact” (Table 1). In contrast, if the screw was found to be pinching, crushing, or piercing the structure, or if the structure was transected or otherwise visibly damaged, this event was termed “Injury” (Table 1). The type of injury was recorded, and the event was photographed.

Descriptive statistics were calculated for the sample of cadaver specimens.

## 3. Results

Results are shown in Table 1. The mean distance of the proximal pin to the medial branch of the superficial peroneal nerve was 4.33 mm (S.D. = 3.84 mm). The mean distance of the distal pin to the same nerve was 6.44 mm (S.D. = 3.00 mm). There was one case of injury to the medial branch of the superficial peroneal nerve (11%), in which the neurovascular bundle was pierced by the distal pin (Figs. 3, 4, and 5 ). No injury to any other structures by either proximal or distal pins was observed. One case of anatomic anomaly in which the peroneal nerve split proximal to the distal pin was present in this study. In this specimen, the distal pin was 5 mm from the medial branch and 9 mm from the lateral branch.

## 4. Discussion

No consensus exists regarding superiority of fusion methods between cross-screws, H-plate, locking plate, or hybrid techniques. The technique utilizing the cross-screw construct involves fusing the first TMT joint by placing two percutaneous screws from the dorsum of the foot to cross the prepared joint to achieve fixation [11]. On the other hand, numerous techniques with several different types of plates – including a simple locking plate with a single interfragmentary screw, locking plate with an integrated compression screw, H-plate, etc. – placed in various positions around the TMT joint in varying numbers have been described in the literature [5,10–12]. Regardless of technique, most techniques use percutaneous screw with medial approach as adjuvant fixation to control the intermetatarsal angle and have found relative success with high union rates and eventual return to weight-bearing [13].

Biomechanically, some authors have suggested that cross-screw fixation is superior to locking plate fixation in stiffness and strength, while others have found that a medial locking plate with a compression screw is superior to a cross-screw construct [5,10,14]. Still, others report no difference between a plate construct with compression screw and a cross-screw construct [15]. In the modern era of mixed consensus, the cross-screw technique remains widely used. Of note, this study demonstrated that it is important for surgeons to consider the possibility of anatomical variants when using the percutaneous cross-screw technique, as they may increase the risk of neurovascular injury. While there is a growing body of literature describing the strength and stiffness of the cross-screw construct, very few studies have been published regarding the neurovascular complications and safety of this technique.

In this cadaveric study, the first TMT fusion utilizing the cross-screw technique on nine thawed fresh-frozen feet to investigate the anatomic structures at risk during the percutaneous placements of the pins and screws was performed. As with all percutaneous techniques, there exists a potential for injury to soft tissues and nearby neurovasculature. Our nine first TMT dissections show that injury to the medial branch of the superficial peroneal nerve is possible during First TMT fusion using a percutaneous crossed-screw technique. Of the nine fusions, there was

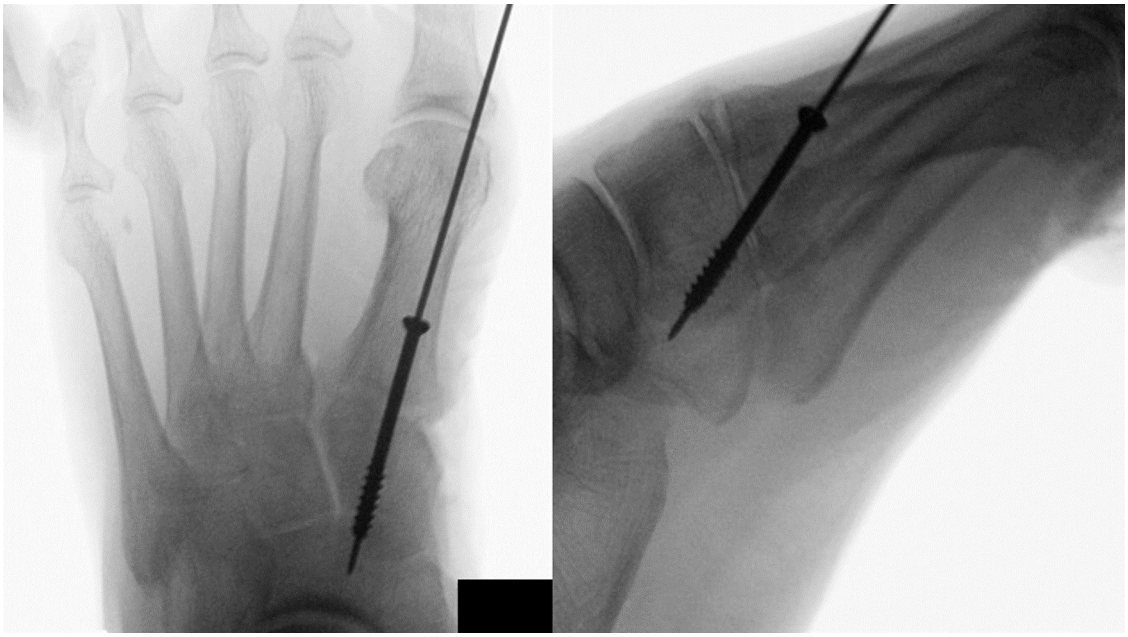

**Fig. 1.** X-ray imaging of first TMT fusion using cross-screw technique. AP (left) and lateral (right) views of the "distal pin" placed from the dorsolateral metatarsal base to the plantar-medial cuneiform.

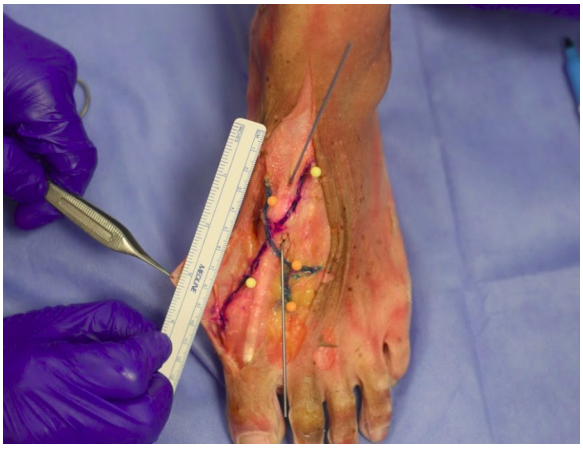

**Fig. 2.** Superior view demonstrating proximity of proximal and distal pin to medial branch of superficial peroneal nerve (purple) and cutaneous vessel (blue) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

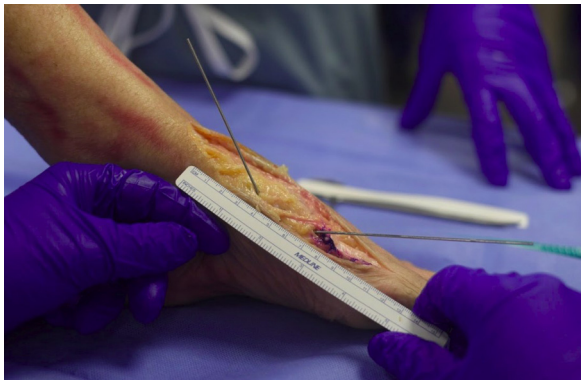

**Fig. 3.** Medial view of distal pin piercing medial branch of superficial peroneal nerve.

one case (11%) of direct injury to the neurovascular bundle, in which the medial branch of the superficial peroneal nerve was pierced by the distal pin. Clinical literature reports that acute TMT fusion in trauma cases carries a risk of nerve inflammation (9%) and neuroma formation (7%) [16]. Neuroma formation following elective TMT fusion has also been described, though the risk is much lower (2%) [17]. While no

**Table 1**
Cadaver characteristics and respective distances from SPN to proximal and distal pins.

| Cadaver number | Age | Sex | Height (in.) | Weight (lbs) | Proximal pin distance to nerve (mm) | Distal pin distance to nerve (mm) | |
|---|---|---|---|---|---|---|---|
| 1 | 80 | F | 65 | 139 | 4 | 7 | |
| 2 | 60 | M | 75 | 250 | 4 | 6 | |
| 3 | 81 | M | 65 | 160 | 7 | 0 | Injury: pierced nerve bundle |
| 4 | 81 | F | 64 | 105 | 5 | 9 | |
| 5 | 74 | M | 72 | 300 | 0 | 7 | Contact |
| 6 | 95 | F | 61 | 105 | 10 | 5 | Distal pin 5 mm to medial branch, 9 mm to lateral branch |
| 7 | 67 | M | 67 | 280 | 9 | 5 | |
| 8 | 96 | F | 62 | 130 | 0 | 9 | Contact |
| 9 | 79 | F | 66 | 150 | 0 | 10 | Contact |
| Average ( ± S.D.) | | | | | 4.33 ( ± 3.84) | 6.44 ( ± 3.00) | |

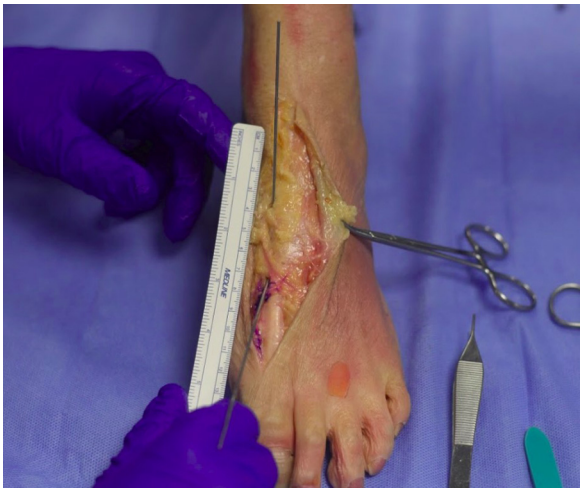

**Fig. 4.** Superior view of distal pin piercing medial branch of superficial peroneal nerve.

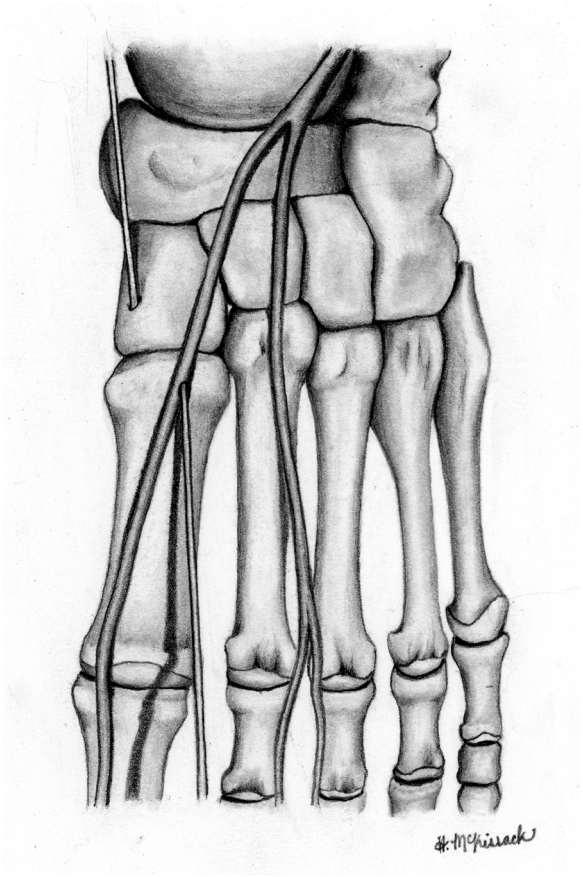

**Fig. 5.** Illustration of distal pin piercing medial branch of superficial peroneal nerve.

clinical studies have yet been published specifically looking at the rate of nerve injury following elective, non-traumatic TMT fusion, authors have experienced similar rates of superficial peroneal neuritis following elective non-traumatic crossed-screw TMT fusion in practice.

It is important to consider the potential anatomical variations of the superficial peroneal nerve when interpreting the results of this study, as demonstrated by the instance of anatomic anomaly found in one specimen. Anatomically, the SPN typically bifurcates into the intermediate dorsal cutaneous nerve (IDCN) and the medial dorsal cutaneous nerve (MDCN). However, the SPN itself, as well as the IDCN and MDCN, may have a variety of branching patterns and give rise to accessory branches. A meta-analysis by Tomaszewski et al. reported three different patterns of SPN bifurcation location and fascial piercing, of which the normal anatomical pattern was most common (82.7% prevalence among 665 lower limbs). Other variants included more proximal bifurcation, as well as lack of an IDCN [18]. In a study of 50 cadaveric specimens, Darland et al. found that 84% of specimens had two SPN branches at the ankle joint, 22% had 3 branches, and 10% had four [6]. Nagabhooshana et al. reported on a cadaveric specimen in which the MDCN divided into two dorsal digital nerves; one supplied the medial hallux, while the other supplied the second and third toes. Anomalous accessory branches also arose from the medial branch [19]. The MDCN specifically was studied by Solan et al.; among 15 cadavers, 12 had a single medial branch of the MDCN, while three had two smaller branches [7]. If not identified, as is likely in the setting of percutanous fixation in which visualization is limited, anomalous accessory branches are at increased risk of iatrogenic injury. Patients with anatomical variation of the distal branches of the SPN may therefore be more likely to experience neurological damage and associated symptoms postoperatively.

This study has several limitations that should be considered before application of the results into clinical practice. First, unlike living patients undergoing First TMT fusion, the specimens used in this study were without any known evidence of underlying disease. This lack of pathology, in addition to the freezing and thawing of the specimens may have affected the soft tissues and relationships of interest in this study. Additionally, the average age at death of the specimens used in this study was 79 years, and only one specimen had an age at death less than 65 years. The usual patient population undergoing this procedure is younger. Next, this study reports anatomic proximity to neurovascular structures in lieu of clinical outcomes. While it seems likely that injury would have occurred in the single case of direct microscopic damage to the nerve, proximity or direct contact may not lead to clinically relevant symptoms. It is also important to note that large variability in standard deviation may be due to anatomical variations in the course of the SPN. Finally, due to the relatively limited number of specimens, this study was unable to compare the risk of nerve injury between different techniques. More research is needed to determine the effect of open visualization or other fusion techniques on the risk of nerve injury during First TMT fusion.

## 5. Conclusion

Although percutaneous techniques are preferable for many patients, surgeons should consider the risk of injury to the superficial peroneal nerve when percutaneously placing the cross screws in First TMT fusions. Care should be taken during insertion of the percutaneous screws and a small incision with adequate dissection should be considered for better visualization of neurovascular structures at risk.

## Conflicts of interest

The authors have no conflicts of interest or funding information to disclose.

## References

[1] Lapidus PW. A quarter of a century of experience with the operative correction of the metatarsus varus primus in hallux valgus. Bull Hosp Jt Dis 1956;17:404–21.
[2] Malagelada F, Sahirad C, Dalmau-Pastor M, Vega J, Bhumbra R, Manzanares-Céspedes MC, et al. Minimally invasive surgery for hallux valgus: a systematic review of current surgical techniques. Int Orthop 2018;43:625–37. https://doi.org/10.1007/s00264-018-4138-x.
[3] Maffulli N, Marinozzi A, Longo UG, Denaro V. Hallux valgus: effectiveness and safety of minimally invasive surgery. A systematic review. Br Med Bull 2010;97:149–67. https://doi.org/10.1093/bmb/ldq027.
[4] Schuberth JM, Babu N. Minimally invasive Lapidus procedure. Pod. Inst. Updat. 2018 Proc. Annu. Meet. Pod. Inst. 2010:203–7.

[5] Baxter JR, Mani SB, Chan JY, Vulcano E, Ellis SJ. Crossed-screws provide greater tarsometatarsal fusion stability compared to compression plates. Foot Ankle Spec 2014;8:95–100. https://doi.org/10.1177/1938640014543358.
[6] Darland AM, Kadakia AR, Zeller JL. Branching patterns of the superficial peroneal nerve: implications for ankle arthroscopy and for anterolateral surgical approaches to the ankle. J Foot Ankle Surg 2015;54:332–7. https://doi.org/10.1053/j.jfas.2014.07.002.
[7] Solan MC, Lemon M, Bendall P. The surgical anatomy of the dorsomedial cutanous nerve of the hallux. J Bone Jt Surg Br 2001;83:250–2.
[8] Jastifer JR, Coughlin MJ, Doty JF, Stevens FR, Hirose C, Kemp TJ. Sensory nerve dysfunction and hallux valgus correction: a prospective study. Foot Ankle Int 2014;35:757–63. https://doi.org/10.1177/1071100714534216.
[9] Gądek A, Liszka H, Wordliczek J. Postoperative pain and preemptive local anesthetic infiltration in hallux valgus surgery. Foot Ankle Int 2014;36:277–81. https://doi.org/10.1177/1071100714553790.
[10] Cohen DA, Parks BG, Schon LC. Screw fixation compared to H-locking plate fixation for first metatarsocuneiform arthrodesis: a biomechanical study. Foot Ankle Int 2005;26:984–9. https://doi.org/10.1177/107110070502601114.
[11] Galli MM, McAlister JE, Berlet GC, Hyer CF. Enhanced Lapidus arthrodesis: crossed screw technique with middle cuneiform fixation further reduces sagittal mobility. J Foot Ankle Surg 2015;54:437–40. https://doi.org/10.1053/j.jfas.2014.10.008.
[12] Bednarz PA, Manoli A. Modified Lapidus procedure for the treatment of hypermobile hallux valgus. Foot Ankle Int 2000;21:816–21. https://doi.org/10.1177/107110070002101004.
[13] DeVries JG, Granata JD, Hyer CF. Fixation of first tarsometatarsal arthrodesis: a retrospective comparative cohort of two techniques. Foot Ankle Int 2011;32:158–62. https://doi.org/10.3113/FAI.2011.0158.
[14] Klos K, Gueorguiev B, Mückley T, Fröber R, Hofmann GO, Schwieger K, et al. Stability of medial locking plate and compression screw versus two crossed screws for Lapidus arthrodesis. Foot Ankle Int 2010;31:158–63. https://doi.org/10.3113/FAI.2010.0158.
[15] Gruber F, Sinkov VS, Bae S-Y, Parks BG, Schon LC. Crossed screws versus dorsomedial locking plate with compression screw for first metatarsocuneiform arthrodesis: a cadaver study. Foot Ankle Int 2008;29:927–30. https://doi.org/10.3113/FAI.2008.0927.
[16] Rao S, Nawoczenski DA, Baumhauer JF. Midfoot arthritis: nonoperative options and decision making for fusion. Tech Foot Ankle Surg 2008;7:188–95.
[17] Coetzee JC, Wickum D. The Lapidus procedure: a prospective cohort outcome study. Foot Ankle Int 2004;25:526–31. https://doi.org/10.1177/107110070402500803.
[18] Tomaszewski KA, Graves MJ, Vikse J, Pekala PA, Sanna B, Henry BM, et al. Superficial fibular nerve variations of fascial piercing: a meta-analysis and clinical consideration. Clin Anat 2017;30:120–5.
[19] Nagabhooshana S, Vollala VR, Rodrigues V, Rao M. Anomalous superficial peroneal nerve and variant cutaneous innervation of the sural nerve on the dorsum of the foot: a case report. Cases J 2009;2:197. https://doi.org/10.1186/1757-1626-2-197.