Orthopaedics & Traumatology: Surgery & Research 105 (2019) 1131–1136

Contents lists available at ScienceDirect

Orthopaedics & Traumatology: Surgery & Research

journal homepage: www.elsevier.com

Original article

Reliability of a new dynamic ultrasound test for quantifying first-ray mobility

Yves Stiglitz[a,*], Cyrille Cazeau[a], Shahnaz Klouche[b], Thomas Bauer[b]

[a] Clinique Victor-Hugo, 5, rue du Dôme, 75116 Paris, France
[b] Department of Orthopaedic Surgery, hôpital Ambroise-Paré, hôpitaux universitaires Paris-Ile-de-France-Ouest, 9, avenue Charles-de-Gaulle, 92100 Boulogne-Billancourt, France

ARTICLE INFO

Article history:
Received 23 April 2018
Accepted 7 February 2019

Keywords:
First ray hypermobility
Ultrasound test
First tarso-metatarsal joint
Hallux valgus

ABSTRACT

Background: First-ray hypermobility (FRHM) is a documented abnormality whose pathogenic role is controversial. FRHM has been suggested to participate in many common disorders such as paediatric hallux valgus and recurrence after hallux valgus surgery. The controversy is due to lack of functional data on the first tarso-metatarsal joint (TMT1) in real-life situations, to its major anatomical variability, and to the absence of simple investigation methods. The objective of this study was to assess the feasibility and the inter- and intra-observer reproducibility of a new dynamic ultrasound test that quantifies TMT1 mobility and is simple to use provided a good-quality ultrasound machine is available.
Hypothesis: The new ultrasound TMT1 mobility test is reproducible.
Material and methods: The 32 feet of 16 consecutive patients whose first ray was considered normal were included. Ultrasonography was performed at rest and during a stress test consisting in causing TMT1 gaping by applying a distal dorsal drawer movement to the first metatarsal. The two plantar bony prominences on either side of the TMT1 were identified, and the distance between them was measured at rest and during the stress test. The stress/rest ratio was computed. Each foot was tested twice by two different examiners, for a total of 128 tests.
Results: Mean TMT1 gaping distance was 1.38mm (range, 1.01–2.02mm) at rest and 1.67mm (range, 1.12–2.95mm). The mean stress/rest ratio was 1.21 (range, 1.02–1.62). Both inter- and intra-observer reliability was strong for all measured parameters.
Discussion: A simple and reproducible ultrasound test for measuring TMT1 mobility is described for the first time. The good reproducibility confirms the working hypothesis. This preliminary study was designed to validate the new test. The measured values need to be assessed in various disorders including FRHM, for which the test was designed. Should the results prove conclusive, the TMT1 gaping test may become a pivotal diagnostic tool.
Level of evidence: IV, diagnostic study.

1. Introduction

First-ray hypermobility (FRHM), also known as metatarso-cuneiform joint or first tarso-metatarsal joint (TMT1) laxity, is controversial [1–4]. However, associations have been reported linking FRHM to several pathological events such as hallux valgus recurrence after surgery [5–10]. Thus, Lapidus or modified Lapidus TMT1 fusion, the reference standard treatment for FRHM, has been suggested for patients with failed hallux valgus surgery [5,11,12].

This controversy is partly attributable to the absence of reliable quantitative data on the normal TMT1 motion range. The most accurate studies were done on cadavers [13,14]. In vivo, studies are less reliable because they were based on less accurate measurements obtained from skin markers [15,16].

To our knowledge, a single study has assessed in vivo TMT1 motion range in healthy individuals, using temporarily inserted intra-cortical pins [14]. This method allowed an evaluation of TMT1 mobility during normal walking. Mean TMT1 motion range was 5.3° in the sagittal plane (plantar/dorsal flexion), 5.4° in the coronal plane (pronation/supination), and 6.1° in the transverse plane (adduction/abduction). However, although the experimental set-up replicated real-life conditions, the inter-subject coefficient of

* Corresponding author.
E-mail address: yves.stiglitz@free.fr (Y. Stiglitz).

https://doi.org/10.1016/j.otsr.2019.02.016
1877-0568/

multiple correlations was less than 0.3, indicating considerable variability in TMT1 mobility.

This functional variability is associated with marked anatomical variability affecting both the distal articular facet of the medial cuneiform (C1) [17–19] and the base of the first metatarsal (M1) [20]. Hyer et al. also suggested an age-related increase in obliquity of the first metatarsal base and a role for this anatomical region in the development of acquired hallux valgus [20].

Nonetheless, considerable progress has been made in clinical and imaging-study assessments of the TMT1 aimed at detecting FRHM. A complex angle-measurement device was described by Klaue et al. [21] and a device for measuring drawer mobility by Glasoe et al. [22]. Kim et al. developed a simpler device [23]. Fritz et al. reported a radiographic test [24]. Thus, several methods are available for measuring TMT1 mobility in the sagittal plane. However, they are cumbersome and therefore ill-suited to everyday clinical practice.

Ultrasonography is being increasingly used, not only by experienced musculo-skeletal radiologists, but also by non-radiologists who have limited experience with ultrasonography, as an adjunct to the physical examination.

The objective of this study was to assess the feasibility and the inter- and intra-observer reproducibility of a new dynamic ultrasound test that objectively quantifies TMT1 mobility and is simple to use provided a good-quality ultrasound machine is available. The working hypothesis was that this new test is reproducible.

2. Patients and methods

This non-interventional single-centre study was carried out between September 2016 and January 2018 after receiving approval from our institutional review board (#CERC-VS-2018-02-1). Patients were informed about the study and signed a consent form to the use of their anonymised data at the same time as the consent form for the surgical procedure.

2.1. Inclusion and exclusion criteria

We included consecutive patients who were admitted to our centre for surgery on the second to fifth rays, but not the first ray, or on a Morton's neuroma; had no history of surgery on either foot; and had no symptoms from the first ray of either foot.

Exclusion criteria were conditions that might modify the proximal and/or distal motion ranges of the first ray, i.e., of the TMT1 and/or first metatarso-phalangeal joint (MTP1), such as acquired or constitutional laxity, neurological disorders, radiographic evidence of TMT1 osteoarthritis, pes planus valgus, pes cavus, and hallux valgus with metatarsus varus greater than 12°.

During the study period, 16 patients met these selection criteria, 14 females and 2 males with a mean age of 50.1 years (range, (21.4–72.6), a mean height of 161.7cm (range, 152.3–170.2), a mean body weight of 60.2kg (range, 47.0–74.2), and a mean body mass index of 23.8kg/m^2 (range, 20.2–32.4). The study was performed on the 32 feet of these 16 patients.

2.2. Description of the ultrasound test

All patients underwent surgery under ankle nerve block anaesthesia administered with ultrasound guidance. The ultrasound test took place during this anaesthetic procedure before the first anaesthetic agent injection, using a portable ultrasound machine (LOGIQ E, GE Healthcare, Chicago, IL, USA) with a flat 12-MHz probe.

When loading the forefoot during the stance phase of walking, the mechanical forces are applied vertically from the ground up under the metatarsal heads. The resulting movement of the M1 head can be replicated clinically by a dorsal drawer manoeuvre, which induces dorsal flexion with plantar gaping of the TMT1.

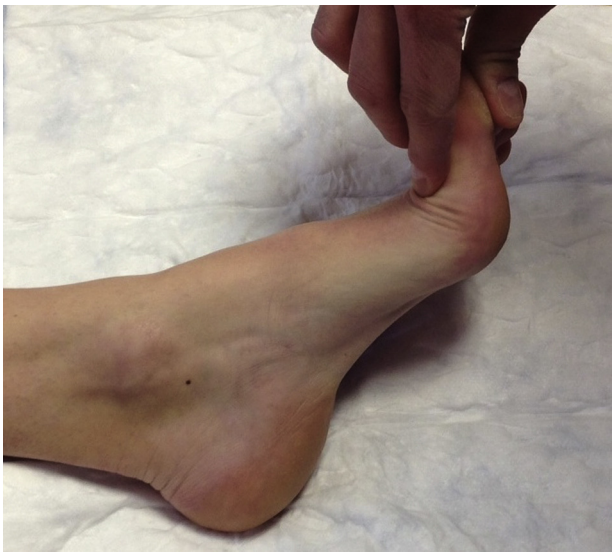

Fig. 1. Positioning of the foot before the ultrasound scan. The patient is supine with the ankle in moderate plantar flexion. Strong passive dorsal flexion of the first metatarso-phalangeal joint causes the planar aponeurosis to bulge under the skin.

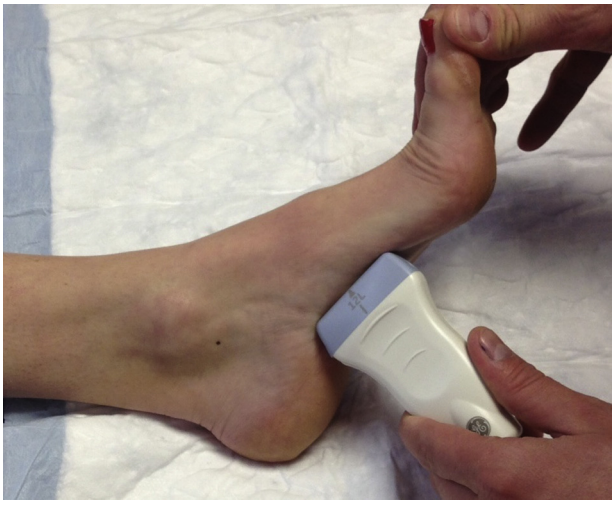

Fig. 2. Positioning of the ultrasound probe for the measurement at rest. The probe is placed longitudinally along the medial edge of the plantar aponeurosis and centred on the plantar aspect of the first metatarso-cuneiform joint.

The new test described here consists in using ultrasonography to measure the amount of plantar TMT1 gaping induced by a distal dorsal drawer manoeuvre applied to the head of M1. The patient is supine with the ankle in the neutral position (slight plantar flexion). The medial edge of the plantar aponeurosis is identified by inducing forced passive dorsal flexion of the MTP1 joint (Fig. 1). The ultrasound probe is then positioned parallel to the aponeurosis edge, over the TMT1 (Fig. 2). Three structures then become visible (Fig. 3): the anechoic joint space at the centre, the plantar prominence of the M1 base distally, and the plantar prominence of the distal end of the C1 proximally. A static image is obtained to measure the distance between the two bony prominences on either side of the joint space, designated plantar TMT1 gap herein, in millimetres. A stress test is then performed by applying a dorsal drawer manoeuvre to the M1 head to induce plantar gaping of the TMT1 joint. A static ultrasound image in this position serves to identify the same structures and to measure the plantar TMT1 gap

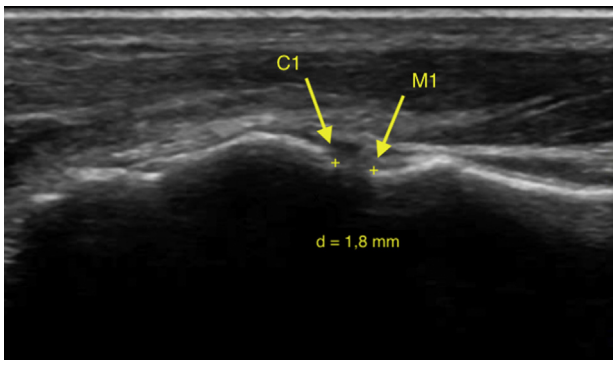

Fig. 3. Ultrasound measurements at rest. C1: edge of the joint surface of the medial cuneiform; M1: edge of the joint surface of the first metatarsal; d: distance between C1 and M1 in the resting position (resting plantar TMT1 gap).

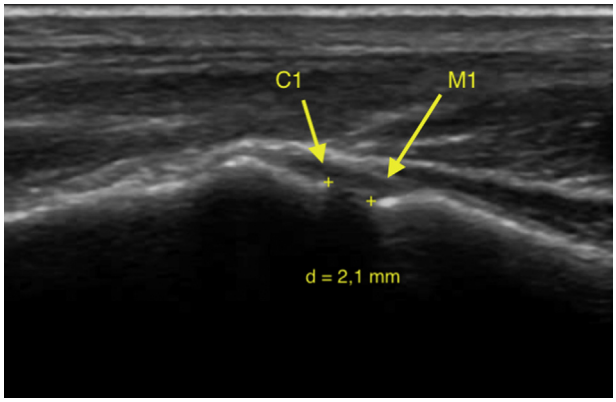

Fig. 4. Ultrasound measurements during the stress manoeuvre. C1: edge of the joint surface of the medial cuneiform; M1: edge of the joint surface of the first metatarsal; d: distance between C1 and M1 in the stress position (stress plantar TMT1 gap).

(Fig. 4). Finally, the ratio of the values obtained during the stress test and at rest is computed.

2.3. Inter- and intra-observer reproducibility and statistical methods

For the assessment of inter- and intra-observer reproducibility, measurements were performed by two observers (YS and TB). Both were orthopaedic surgeons specialised in foot and ankle surgery and having only limited experience with osteo-articular ultrasonography. The measurements were performed during the same session, twice by observer 1 then twice by observer 2. The measured values were recorded, then immediately masked to blind each observer to the other observer's values and to his previous values. Thus, each TMT1 was tested four times, yielding a total of 128 tests for the 32 feet.

Stata IC software version 10.0 (StataCorp, College Station, TX, USA) was used for the statistical analyses. We estimated the sample size needed to obtain a Pearson correlation coefficient (ρ) of 0.8 with a confidence interval width (ω) of 0.2 and a risk of Type I error (α) of 0.05. The confidence interval was then [0.74; 0.94], with a width of 0.225. The required sample size was 20.7, i.e., 21 feet. To allow for ultrasonography being inconclusive in some cases, we planned to include 30 feet, i.e., 15 patients. Data distribution normality was checked using the Shapiro–Wilk test and the homogeneity of variance assumption using Bartlett's test. Statistical correlations between values obtained by the same observer and by the two different observers were assessed using Pearson's correlation coefficient (r), which was interpreted as follows: >0.5, strong correlation; 0.3–0.5, moderate correlation; 0.1–0.3, weak correlation; and <0.1, no correlation. Intra- and inter-observer reproducibility of the measurements was evaluated by computing the intra-class coefficient (ICC), which was interpreted as follows: >0.75, excellent; 0.40–0.75, good; and <0.40, poor. For all correlations, values of p lower than 0.05 were taken to indicate statistical significance.

3. Results

Mean plantar TMT1 gap for the 128 measurements was 1.38 ± 0.21mm (range, 1.01–2.02mm) at rest and 1.67 ± 0.35mm (range, 1.12–2.95mm) during the stress test. The rest and stress values differed significantly in each patient ($p < 10^5$), with a mean difference of 0.29mm. The mean stress/rest ratio was 1.21 ± 0.13 (range, 1.02–1.62).

3.1. Intra-observer reproducibility

The test-retest correlation was strong. For each observer, the values were 0.65 and 0.74 ($p < 10^5$) for the measurements at rest, 0.70 and 0.77 ($p < 10^5$) for the measurements during the stress test, and 0.66 and 0.67 ($p < 10^5$) for the stress/rest ratio (Table 1).

For each observer, agreement between the two measurements of the same joint was good or excellent, with ICCs of 0.67 and 0.76 ($p < 10^5$) at rest, 0.68 and 0.88 ($p < 10^5$) during the stress test, and 0.67 and 0.83 ($p < 10^5$) for the stress/rest ratio.

3.2. Inter-observer reproducibility

The correlations ranged from moderate to strong, with values of 0.40 ($p = 0.01$) and 0.69 ($p < 10^5$) at rest, 0.59 ($p = 0.0002$) and 0.77 ($p < 10^5$) during the stress test, and 0.39 ($p = 0.02$) and 0.51 ($p = 0.002$) for the stress/rest ratio (Table 2).

Inter-observer agreement was consistently significant and usually good, with ICC values of 0.39 ($p = 0.009$) to 0.69 ($p < 10^5$) at rest, 0.65 to 0.70 ($p < 10^5$) during the stress test, and 0.31 ($p = 0.03$) to 0.56 ($p = 0.0002$) for the stress/rest ratio.

4. Discussion

Our findings confirm our working hypothesis that the new ultrasound test TMT1 mobility test described here is reproducible. Our study is innovative since, to our knowledge, it is the first published description of a dynamic ultrasound test for directly evaluating the mobility of the TMT1. Several methods that quantify FRHM have

Table 1
Intra-observer reproducibility: Pearson's correlation coefficient (r) and intra-class correlation coefficient (ICC).

	Rest		Stress		Stress/rest ratio	
	r	ICC	r	ICC	r	ICC
Observer 1	$r = 0.65$ (strong) $p < 0.00001$	$\rho = 0.67$ (good) $p < 0.00001$	$r = 0.77$ (strong) $p < 0.00001$	$\rho = 0.88$ (excellent) $p < 0.00001$	$r = 0.66$ (strong) $p < 0.00001$	$\rho = 88$ (excellent) $p < 0.00001$
Observer 2	$r = 0.74$ (strong) $p < 0.00001$	$\rho = 0.76$ (excellent) $p < 0.00001$	$r = 0.70$ (strong) $p < 0.00001$	$\rho = 0.68$ (good) $p < 0.00001$	$r = 0.67$ (strong) $p < 0.00001$	$\rho = 0.68$ (good) $p < 0.00001$

Table 2
Inter-observer reproducibility.

		Observer 1 Plantar TMT1 gap at rest				Plantar TMT1 gap during the stress manoeuvre				Stress/rest ratio			
		Evaluation 1		Evaluation 2		Evaluation 1		Evaluation 2		Evaluation 1		Evaluation 2	
Observer 2	Evaluation 1	$r = 0.40$ (moderate)	$p = 0.01$	$r = 0.69$ (strong)	$p < 10^5$	$r = 0.71$ (strong)	$p < 10^5$	$r = 0.77$ (strong)	$p < 10^5$	$r = 0.39$ (moderate)	$p = 0.02$	$r = 0.47$ (moderate)	$p = 0.004$
		$\rho = 0.39$ (weak)	$p = 0.009$	$\rho = 0.67$ (good)	$p < 10^5$	$\rho = 0.66$ (good)	$p < 10^5$	$\rho = 0.70$ (good)	$p < 10^5$	$\rho = 0.31$ (poor)	$p = 0.03$	$\rho = 0.56$ (good)	$p = 0.0002$
	Evaluation 2	$r = 0.41$ (moderate)	$p = 0.01$	$r = 0.64$ (strong)	$p < 10^5$	$r = 0.68$ (strong)	$p < 10^5$	$r = 0.59$ (strong)	$p < 10^5$	$r = 0.51$ (strong)	$p = 0.002$	$r = 0.48$ (moderate)	$p = 0.004$
		$\rho = 0.41$ (good)	$p = 0.006$	ρ=0.69 (good)	$p < 10^5$	$\rho = 0.68$ (good)	$p < 10^5$	$\rho = 0.65$ (good)	$p < 10^5$	$\rho = 0.38$ (poor)	$p = 0.01$	$\rho = 0.50$ (good)	$p = 0.0009$

r: Pearson's correlation coefficient; ρ: intra-class correlation coefficient (ICC).

been validated and shown to correlate with one another [21–23]. However, they are not suitable for everyday practice either because they are cumbersome to implement or because the measurement devices they rely on are not commercially available and must therefore be made in-house. The test we describe here is simple and available, even to surgeons who have little experience with ultrasonography.

When designing the test, we elected not to use the cartilaginous edges of the joint, as their low echogenicity makes them difficult to identify accurately. Instead, we used bony prominences, which are highly echogenic and consequently easy to identify. The wide variability in their anatomical features was not an obstacle, since the objective of this study was not to describe the TMT1 using a new modality but to measure the joint mobility based on the identified bony landmarks. The anatomical variability translated in our study into a fairly broad range of plantar TMT1 gap values, both at rest and during the stress test. These differences in values do not provide any information per se. They had no adverse effect on the validity of the test, which was found to be reproducible over a wide spectrum of values.

The plantar TMT1 gap differed significantly at rest and during the stress test, confirming the ability of the ultrasound measurement to detect the effects of the drawer manoeuvre performed by the surgeon. The mean stress/rest ratio was 1.21 (range, 1.02–1.62). This ratio quantifies the movement of the joint when it transitions from the resting position to the extreme dorsal drawer position. Since the ratio has no physical dimension, it is independent from the anatomical features of the individual patient and can be used to compare individuals of different height and habitus. We decided to use this ratio based on previous work by others at other joints. At the knee, for instance, the Caton–Deschamps index for measuring patellar height [25] is a well-validated tool that has been extensively disseminated and is widely used. As a dimensionless ratio of two distances, the Caton–Deschamps index is independent from patient's height and from the scale used to print or display the radiographic images. Similarly, the stress/rest ratio used in our study holds promise as a diagnostic tool that is only minimally affected by anatomical variability.

The dynamic test described here evaluates TMT1 mobility in the sagittal plane. It measures plantar gaping, i.e., the relative displacement away from each other of the plantar edges of the joint surfaces of M1 and C1, during a passive movement, which is only limited by the TMT1 capsule and ligaments. Consequently, our test may prove particularly useful for evaluating FRHM.

Our test does not evaluate TMT1 mediolateral movements, those due to axial rotation of M1 [26], or those occurring in the dorsomedial direction. Emphasis has been put on the multidirectionality of FRHM, notably in the pathogenesis of hallux valgus. However, the difficulty in measuring mobility in planes other than the sagittal plane is well recognised. Our test does not provide information on these other directions of motion but considerably simplifies the assessment of mobility in the sagittal plane.

After this first technical validation step, we must now assess the diagnostic usefulness of our test by comparing its results to those of accepted diagnostic tools. The preliminary work reported here was necessary before embarking on a more ambitious phase II study of diagnostic performance versus a reference standard.

The choice between conservative surgery by metatarsal osteotomy and Lapidus-type fusion for the treatment of hallux valgus remains a matter of debate. Conservative hallux valgus surgery was followed by the resolution of FRHM in several studies [27,28]. No correlations were found linking FRHM to anatomical or radiographic features of the TMT1 [29]. However, FRHM has been blamed for making a major contribution to postoperative recurrence, and studies have suggested that it may be underdiagnosed [5–9]. Given the absence of a simple and widely available test, identifying and quantifying FRHM has indeed been challenging. We hope that our test will eventually fill this gap as a simple diagnostic tool, particularly as portable ultrasound machines are becoming increasingly available.

A potential limitation of our study is the fast pace of improvements made in the field of ultrasonography. The flat thick 12-MHz probes used in our study are probably less effective and less well suited to the region of the sole overlying the TMT1 compared to higher frequency golf club probes. The availability of increasingly sophisticated equipment and the accumulation of ultrasonography experience by surgeons will no doubt further improve the accuracy and reproducibility of our plantar TMT1 gaping test. However, given our limited experience with ultrasonography, a simple probe was sufficient for statistical validation of our test and confirmation of our working hypothesis. Another potential limitation is that our patients were scheduled for foot surgery. Although no patient had clinical abnormalities related to the first ray, we cannot be sure that the first ray was entirely normal. Associations exist between disorders of the lateral rays and mild or subclinical abnormalities of the first ray. We applied stringent inclusion and exclusion criteria to minimise this potential source of bias. However, evaluating the reproducibility of a test is not the same as assessing its diagnostic performance. Our objective was to assess reproducibility, without taking the specific values into account. Given this point, we also believe that including both feet of each study patient does not limit the validity of our results.

5. Conclusion

We describe the first ultrasound test for evaluating plantar TMT1 mobility. Its main advantages are good reproducibility, simplicity, and independence from inter-individual anatomical variability. It opens up new prospects for elucidating controversial conditions such as FRHM.

Disclosure of interest

The authors declare that they have no competing interest.

Y.S. receives consultancy fees from Novastep. C.C. receives consultancy fees from Novastep and Stryker. S.K. receives consultancy fees from Ceraver. T.B. receives consultancy fees from Arthrex and Zimmer.

Funding

None.

Contributions

YS contributed to the theoretical design of the test, to implement the study, and to perform the ultrasound examinations; collected and entered the data; contributed to draft the manuscript; and submitted the manuscript.

CC contributed to the theoretical design of the test and contributed to draft the manuscript.

SK performed the statistical tests and wrote the statistical section of the manuscript.

TB contributed to implement the study and to perform the ultrasound examinations.

All authors read and approved the final version of the manuscript.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.otsr.2019.02.016.

References

[1] Doty JF, Coughlin MJ. Hallux valgus and hypermobility of the first ray: facts and fiction. Int Orthop 2013;37:1655–60.
[2] Myerson MS, Badekas A. Hypermobility of the first ray. Foot Ankle Clin 2000;5:469–84.
[3] Wukich DK, Donley BG, Sferra JJ. Hypermobility of the first tarsometatarsal joint. Foot Ankle Clin 2005;10:157–66.
[4] Bauer T. Percutaneous forefoot surgery. Orthop Traumatol Surg Res OTSR 2014;100 [S191-204].
[5] Espinosa N, Wirth SH. Tarsometatarsal arthrodesis for management of unstable first ray and failed bunion surgery. Foot Ankle Clin 2011;16:21–34.
[6] Glasoe WM, Allen MK, Saltzman CL. First ray dorsal mobility in relation to hallux valgus deformity and first intermetatarsal angle. Foot Ankle Int 2001;22:98–101.
[7] Raikin SM, Miller AG, Daniel J. Recurrence of hallux valgus: a review. Foot Ankle Clin 2014;19:259–74.
[8] Sammarco GJ, Idusuyi OB. Complications after surgery of the hallux. Clin Orthop Relat Res 2001:59–71.
[9] Scranton Jr PE, McDermott JE. Prognostic factors in bunion surgery. Foot Ankle Int 1995;16:698–704.
[10] Besse J-L. Metatarsalgia. Orthop Traumatol Surg Res OTSR 2017;103 [S29-39].
[11] Coetzee JC, Resig SG, Kuskowski M, Saleh KJ. The Lapidus procedure as salvage after failed surgical treatment of hallux valgus. Surgical technique. J Bone Jt Surg Am 2004;86–A:30–6.
[12] Cazeau C, Stiglitz Y. Minimally invasive and percutaneous surgery of the forefoot current techniques in 2018. Eur J Orthop Surg Traumatol 2018.
[13] Whittaker EC, Aubin PM, Ledoux WR. Foot bone kinematics as measured in a cadaveric robotic gait simulator. Gait Posture 2011;33:645–50.
[14] Lundgren P, Nester C, Liu A, Arndt A, Jones R, Stacoff A, et al. Invasive in vivo measurement of rear-, mid- and forefoot motion during walking. Gait Posture 2008;28:93–100.
[15] Leardini A, Benedetti MG, Berti L, Bettinelli D, Nativo R, Giannini S. Rear-foot, mid-foot and fore-foot motion during the stance phase of gait. Gait Posture 2007;25:453–62.
[16] Reinschmidt C, van Den Bogert AJ, Murphy N, Lundberg A, Nigg BM. Tibiocalcaneal motion during running, measured with external and bone markers. Clin Biomech 1997;12:8–16.
[17] Ajmani ML, Ajmani K, Jain SP. Variations in the articular facets of the adult cuneiform bones. Anthr Anz 1984;42:121–6.
[18] Kelikian AS, Sarrafian SK. Sarrafian's Anatomy of the Foot and Ankle: Descriptive, Topographic, Functional. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2011.
[19] Singh I. Variations in the metatarsal bones. J Anat 1960;94:345–50.
[20] Hyer CF, Philbin TM, Berlet GC, Lee TH. The obliquity of the first metatarsal base. Foot Ankle Int 2004;25:728–32.
[21] Klaue K, Hansen ST, Masquelet AC. Clinical, quantitative assessment of first tarsometatarsal mobility in the sagittal plane and its relation to hallux valgus deformity. Foot Ankle Int 1994;15:9–13.
[22] Glasoe WM, Yack HJ, Saltzman CL. The reliability and validity of a first ray measurement device. Foot Ankle Int 2000;21:240–6.
[23] Kim JY, Keun Hwang S, Tai Lee K, Won Young K, Seon Jung J. A simpler device for measuring the mobility of the first ray of the foot. Foot Ankle Int 2008;29:213–8.
[24] Fritz GR, Prieskorn D. First metatarsocuneiform motion: a radiographic and statistical analysis. Foot Ankle Int 1995;16:117–23.
[25] Caton J, Deschamps G, Chambat P, Lerat JL, Dejour H. Patella infera. A propos of 128 cases. Rev Chir Orthop Reparatrice Appar Mot 1982;68:317–25.
[26] Mortier J-P, Bernard J-L, Maestro M. Axial rotation of the first metatarsal head in a normal population and hallux valgus patients. Orthop Traumatol Surg Res OTSR 2012;98:677–83.
[27] Kim JY, Park JS, Hwang SK, Young KW, Sung IH. Mobility changes of the first ray after hallux valgus surgery: clinical results after proximal metatarsal chevron osteotomy and distal soft tissue procedure. Foot Ankle Int 2008;29:468–72.
[28] Coughlin MJ, Smith BW. Hallux valgus and first ray mobility. Surgical technique. J Bone Joint Surg Am 2008;90:153–70.
[29] Doty JF, Coughlin MJ, Hirose C, Stevens F, Schutt S, Kennedy M, et al. First metatarsocuneiform joint mobility: radiographic, anatomic, and clinical characteristics of the articular surface. Foot Ankle Int 2014;35:504–11.