REVISTA
ESPAÑOLA DE PODOLOGÍA

Publicación Oficial del Consejo General de Colegios Oficiales de Podólogos

ORIGINAL
Bilingual article English/Spanish

Rev Esp Podol. 2024;35(2):99-104
DOI: http://dx.doi.org/10.20986/revesppod.2024.1708/2024

Improving the accuracy of metatarsal osteotomies in minimally invasive surgery using digital technology: comparison in vitro and cadaveric models

Mejora de la precisión de las osteotomías metatarsales en cirugías mínimamente invasivas con tecnología digital en modelos óseos y modelos cadavéricos

Carlos Fernández-Vizcaíno, Eduardo Nieto-García, Leonor Ramírez-Andrés, Elena Nieto-González, Nadia Fernández-Erling, and Javier Ferrer-Torregrosa

Departamento de Podología. Universidad Católica de Valencia, Spain

Keywords:

Metatarsal osteotomy, digital inclinometer, minimally invasive surgery, surgical accuracy, in vitro study, cadavers, metatarsal, metatarsalgia.

Abstract

Introduction: The precision in the angulation of metatarsal osteotomies is crucial in minimally invasive foot surgical procedures (MIS). Surgical techniques can impact postoperative outcomes. This study evaluates the effectiveness of a digital inclinometer integrated into the cutting motor, comparing the angular accuracy of metatarsal osteotomies with and without the inclinometer in cadaveric specimens and resin skeletons.

Materials and methods: A total of 87 metatarsal osteotomies were performed on cadaveric specimens and resin skeletons, divided into two groups: without inclinometer and with inclinometer. Angular accuracy was measured using X-rays and analyzed with software. Differences were assessed using Student's t-tests.

Results: In the study using resin skeletal models, cuts performed with the inclinometer showed significantly greater accuracy than those performed without it ($p = 0.04$), with less angular variability. However, in the cadaveric study, the differences between the groups did not reach statistical significance ($p = 0.42$), which could be attributed to greater variability and the small sample size in this group.

Conclusions: The use of a digital inclinometer improves accuracy in metatarsal osteotomies, especially in skeletal models. In cadaveric specimens, soft tissues may have affected the results. Inclinometers in MIS can reduce variability between operators and improve postoperative outcomes. The digital inclinometer shows promise for increasing precision in metatarsal osteotomies, although further research in cadaveric specimens is needed to confirm its clinical effectiveness.

Palabras clave:

Osteotomía metatarsal, inclinómetro digital, cirugía mínimamente invasiva, precisión quirúrgica, estudio *in vitro*, cadáveres, metatarsiano, metatarsalgia.

Resumen

Introducción: La precisión en la inclinación de las osteotomías metatarsales es clave en cirugías mínimamente invasivas (CMI) del pie. Las técnicas quirúrgicas pueden afectar los resultados postoperatorios. Este estudio evalúa la efectividad de un inclinómetro digital integrado en el motor de corte, comparando la precisión angular de osteotomías metatarsales, con y sin inclinómetro en especímenes cadavéricos y esqueletos de resina.

Material y métodos: Se realizaron 87 osteotomías metatarsales en especímenes cadavéricos y esqueletos de resina, divididos en dos grupos: sin inclinómetro y con inclinómetro. La precisión angular fue medida con radiografías y analizada mediante software. Las diferencias se evaluaron con pruebas t de Student.

Resultados: En el estudio con modelos esqueléticos de resina, los cortes realizados con inclinómetro mostraron una precisión significativamente mayor que los realizados sin él ($p = 0{,}04$), con una menor variabilidad angular. Sin embargo, en el estudio cadavérico, las diferencias entre los grupos no alcanzaron significación estadística ($p = 0.42$), lo que podría atribuirse a la mayor variabilidad y el pequeño tamaño de la muestra en este grupo.

Conclusiones: El uso del inclinómetro digital mejora la precisión en osteotomías metatarsales, especialmente en modelos esqueléticos. En especímenes cadavéricos, los tejidos blandos podrían haber afectado los resultados. Los inclinómetros en cirugías CMI pueden reducir la variabilidad entre operadores y mejorar los resultados postoperatorios. El inclinómetro digital es prometedor para aumentar la precisión en osteotomías metatarsales, aunque se requiere más investigación en especímenes cadavéricos para confirmar su eficacia clínica.

Received: 09-21-2024
Aceptado: 10-28-2024

Corresponding author:
javier Ferrer-Torregrosa
E-mail address: javyferrer@gmail.com

Introduction

The precision in the angle of metatarsal osteotomy cuts is crucial for the success of minimally invasive foot surgical procedures (MIS)[1,2]. Specifically, metatarsal osteotomies, which are common procedures for treating various forefoot conditions, must be performed accurately to ensure optimal recovery and minimize postoperative complications[3,4]. Performing these osteotomies at the metatarsal head level is currently a widely used minimally invasive procedure for treating forefoot conditions[5].

Surgical techniques for treating metatarsalgia can be performed through either open or minimally invasive approaches. In open surgery, the Weil osteotomy is the most widely used technique, as it produces a shortening and elevation effect. For minimally invasive surgery, two options are considered: distal metaphyseal metatarsal osteotomy (DMMO)[6-10], which involves an extracapsular cut, and distal intracapsular metatarsal osteotomy (DICMO)[11], performed intracapsularly. However, the success of the technique largely depends on the surgeon's skill and experience[12-14], as well as the osteotomy being performed at approximately 45°[8,14-17]. Conducting these surgical procedures by multiple operators leads to variations in the cut angles, negatively impacting postoperative outcomes[3,18].

In this context, technology could begin to play a key role in optimizing these surgical procedures[19]. The use of digital inclinometers, devices that allow for precise measurement[1,20] of angles during osteotomies, has proven to be a valuable tool for improving accuracy in these procedures[18,20]. Unlike manual techniques that rely on visual observation and the surgeon's experience, the inclinometer provides an objective measurement that can significantly reduce the margin of error.

This study focuses on evaluating the effectiveness of a digital inclinometer integrated into the cutting motor during metatarsal osteotomies. The research aims to determine whether the use of this technology can improve the precision of the cutting angle and, consequently, optimize plantar pressure distribution in patients after surgery. The underlying hypothesis is that using a digital inclinometer can achieve greater consistency in surgical outcomes, reducing the variability associated with freehand techniques.

This approach could make a significant difference in surgical practice, not only by improving clinical outcomes but also by shortening the learning curve[21] for surgeons performing MIS on the forefoot. Ultimately, the incorporation of technologies like the digital inclinometer could make and advance in surgical techniques, offering benefits for both patients and healthcare professionals.

Materials and methods

Study Design

We conducted an initial study on resin skeletal pieces, with a total of 20 samples.

Subsequently, cadaver specimens were selected, and 36 metatarsal osteotomies were performed following the inclusion criteria: complete metatarsal bones, adult age, and absence of bone deformities or signs of osteoporosis. Specimens with prior fractures, visible injuries, dislocations, and/or degenerative metatarsophalangeal processes were excluded.

The experimental study was conducted in September 2023 in the dissection room of the School of Medicine and Health Sciences at the Universidad Católica de Valencia (Valencia, Spain).

Sample

The osteotomies were divided into two groups for both the skeletal and cadaver studies, with the experimental group using an inclinometer and the other group without an inclinometer (Figure 1). Four surgeons performed the procedures in a controlled environment, with appropriate standardization of technique for all groups created. The surgeons had over 15 years of experience.

Radiographic and Manual Measurements

After the surgical techniques were completed on the anatomical pieces, a thorough evaluation was conducted through oblique projection radiographs, maintaining a constant focal distance of 50 cm. DICOM files from the radiographs were analyzed with the Osirix software (Pixmeno, Switzerland), with 3 independent measurements made by the same observer for each osteotomy. The mean of these measurements was used for comparative analysis. Subsequently, anatomical dissection of the samples was performed to confirm the osteotomy angle. This rigorous approach allowed for precise study of the differences between osteotomies performed with and without the aid of an inclinometer.

Additionally, all osteotomies on the skeletal models were measured with a goniometer.

MIS Osteotomy Technique

The DICMO technique for treating primary metatarsalgia involves performing a distal intracapsular osteotomy on the metatarsal at 45° relative to the bone longitudinal axis with a distal-dorsal and plantar-proximal inclination. This outpatient procedure follows a series of steps to ensure precision and standardization, regardless of the surgeon.

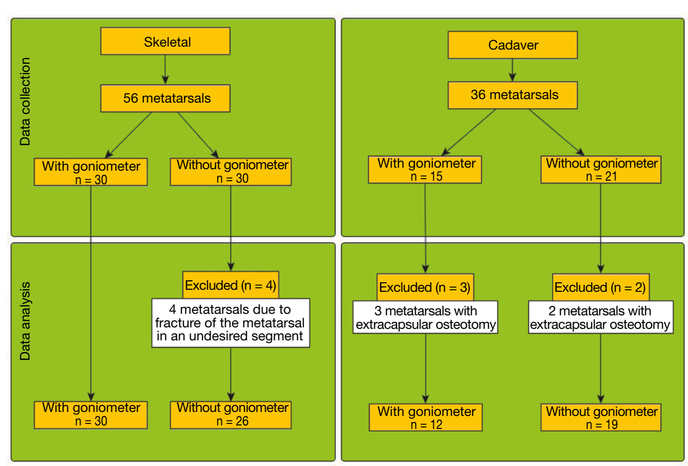

Figure 1. Diagram of the study in resin and in cadaver.

First, the metatarsal head is located using the passive hand's fingers, and position is confirmed with fluoroscopic control. A small incision is, then, performed dorsally on the metatarsal at 45°, lateral to the extensor tendons, until reaching the surgical neck of the metatarsal, with slight marking of the periosteum to prevent displacement during the cut.

Next, the long Shannon Isham surgical burr is inserted into the notch made, maintaining a 45° angle. Controlled oscillating movements are used to cut until approximately one-third of the metatarsal is reached. Then, without removing the burr, the position is adjusted for a final cut from plantar to dorsal.

The procedure concludes when the lack of bone resistance is detected, indicating the cut is complete. The osteotomy is verified by fluoroscopy, checking for bone fragment displacement when applying distal traction on the operated toe.

In the goniometer-assisted technique, the same steps are followed, but with the addition of the goniometer to measure and ensure the angular precision of the cut (Figure 2).

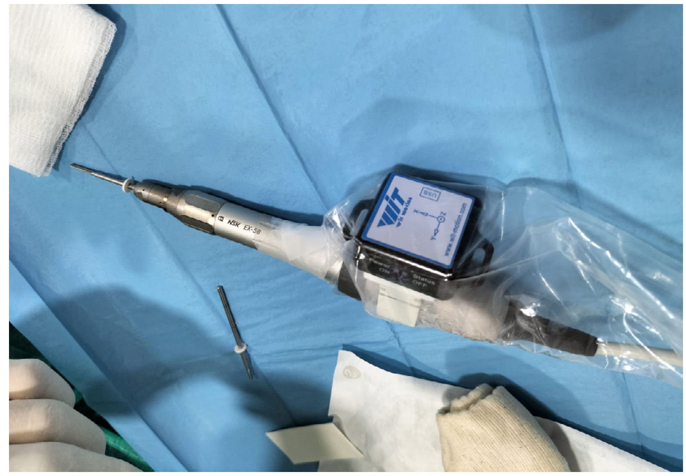

Figure 2. Inclinometer integrated into the surgical motor.

The correct placement of the motor with the goniometer was achieved via the use of intraoperative fluoroscopy. First, the incision point was located, and the goniometer was set to 0° when a 90° angle was observed with respect to the diaphyseal axis of the metatarsal where the osteotomy would be performed (Figure 3A, 3B, and 3C). The device was then tilted to 45°, at which point the osteotomy was performed (Figure 3D, 3E, and 3F).

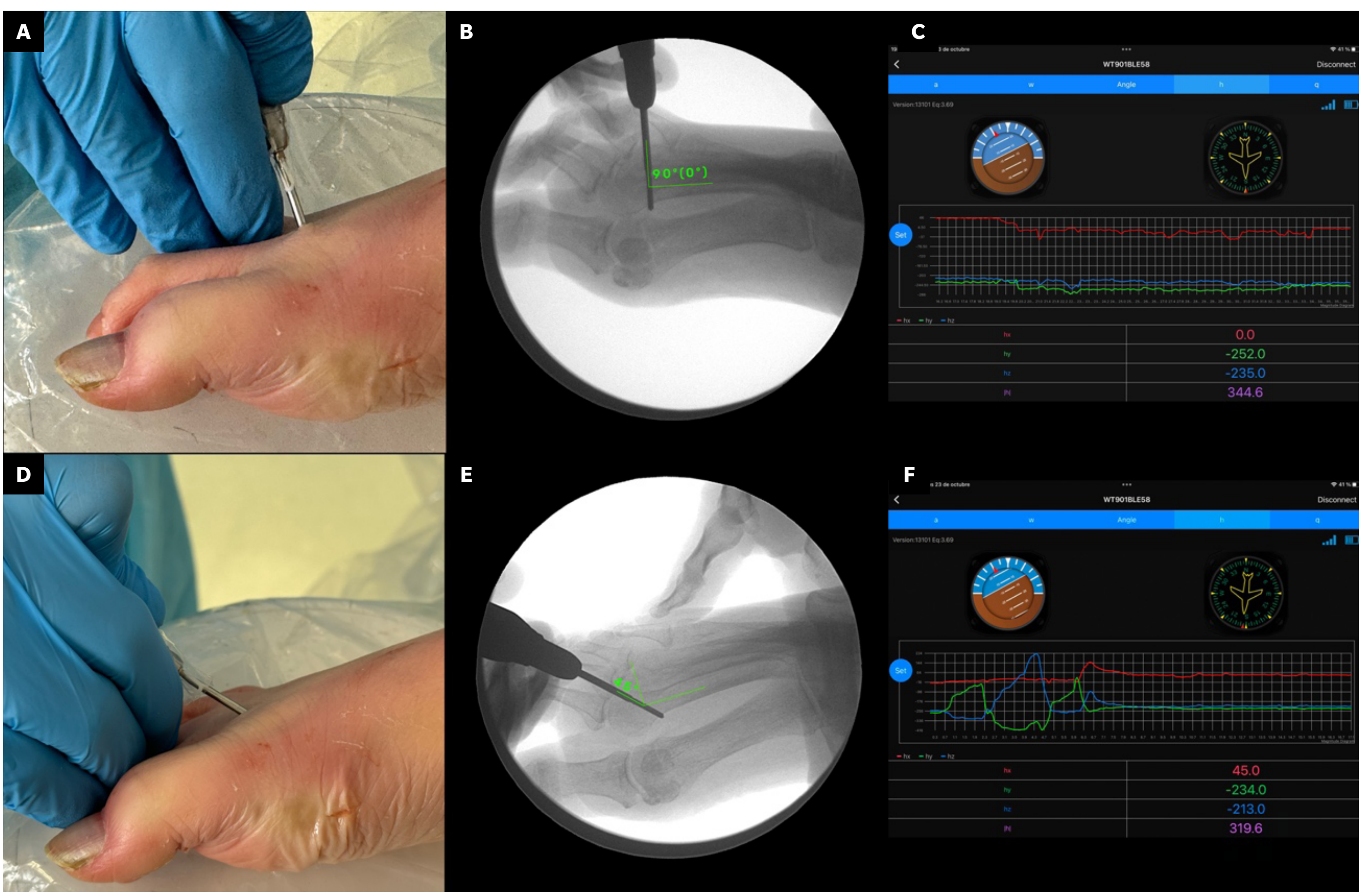

Figure 3. A and D show the correct placement of the surgical burr. B and E present the intraoperative fluoroscopic image. C and F reflect the software of the goniometer with the recorded angle.

Statistical methods

An analyst uninvolved in the experimental design conducted all evaluations. Data were expressed as mean and standard deviation (SD). To test data normality, the Shapiro-Wilk test was applied. In the resin skeletal study, both the goniometer and non-goniometer groups showed deviations from normality, with a W value of 0.93 and $p = 0.05$ for the surgery group, and a W value of 0.92 and $p = 0.05$ for the non-surgical group. Similarly, in the cadaver study, both groups also showed a W value of 0.91, although with $p = 0.21$ for the surgery group and $p = 0.07$ for the non-surgical group.

A significance level of $p < 0.05$ was set. Statistical analysis was conducted using SPSS 24 (SPSS Inc., Chicago, IL, USA), and graphical data representation was performed using Jeffreys's Amazing Statistical Package (JASP V0.16.4, Amsterdam, The Netherlands). Inter-groups differences with and without an inclinometer were analyzed using the Mann-Whitney U test. The groups, with and without inclinometer, were considered independent variables in this analysis. The effect size (ES)[22,23] was calculated using Biserial Rank Correlation.

Sample size calculation was performed to detect a minimum detectable difference of 0.5° in the osteotomy angulation. With 14 observations per group (a total of 28), to detect a difference of 0.5° in angulation at a significance level of 5%, the study power would be 90%, assuming normality. The anticipated confidence interval half-width was 0.31077°, ensuring adequate precision for the study.

Results

Figure 1 shows a diagram of data collection and analysis in skeletal models and cadavers. The descriptive analysis in the skeletal study showed that the group with the inclinometer had a mean angulation of 49.33°, with a standard deviation (SD) of 7.67, while the group without the inclinometer showed a mean of 55.50°, with a standard deviation of 13.93 (Table I). This indicates greater variability in the group without the inclinometer. In contrast, the descriptive results in the cadavers indicated means of 53.25° (SD, 9.48) for the group with the goniometer and 56.95° (SD, 13.81) for the group without the goniometer, reinforcing the idea of a smaller difference in cadavers.

The difference in mean values between both studies suggests that while changes in inclination are observed in both cases, the effect appears more pronounced in skeletal samples than in cadavers. This behavior could be explained by differences in soft tissue resistance present in cadavers but not in skeletal samples.

Table I. Descriptive data of angulation in resin skeletal models and cadavers.

	Group	N	Mean	SD	SE	Coefficient of variation
Resins	WITH	30	49.33	7.67	1.40	0.16
	WITHOUT	26	55.50	13.93	2.73	0.25
Cadaver	WITH	12	53.25	9.48	2.74	0.18
	WITHOUT	19	56.95	13.81	3.17	0.24

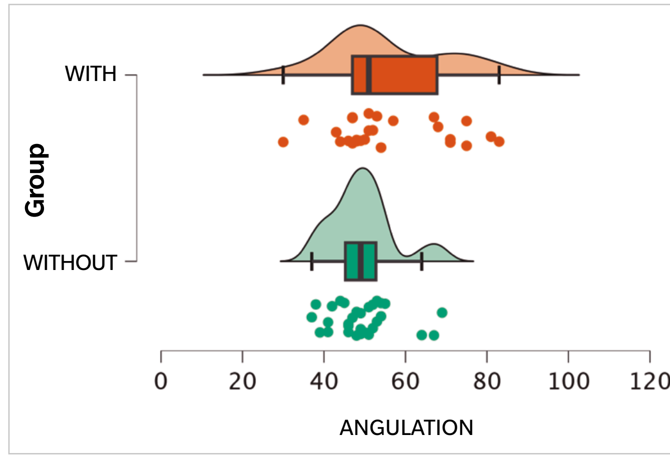

Figure 4. Cloud-type graph showing the angulation performed in skeletal models.

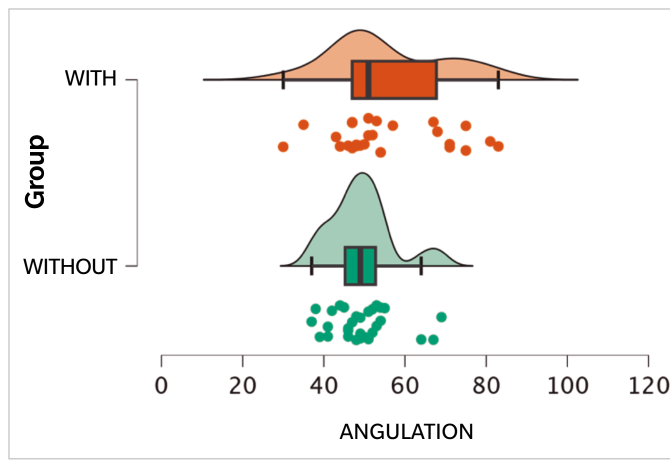

Figure 5. Cloud-type graph showing the angulation performed in cadavers.

In the results of the comparison for independent samples, we first observe, for the studies in skeletons, the value of W = 293.00, with a $p = 0.11$, indicating that statistical significance was not reached. Additionally, the biserial rank correlation is -0.25 with a standard error of 0.15, suggesting a moderate negative relationship between the variables assessed in the skeletons. This interpretation can be clearly visualized in the graph of the skeletal data, where the distribution of points shows greater dispersion (Figure 4).

On the other hand, in the studies with cadavers, we obtained the following results with a value of W = 102.50 and a $p = 0.66$, indicating that there is no significant difference between the groups. The biserial rank correlation is -0.10, with a standard error of 0.21, suggesting a very weak negative relationship (Figure 5).

Discussion

The findings of this study regarding the use of the goniometer align with the recommendations of Olivier Laffenêtre[11,24,25], where the importance of performing the osteotomy on the metatarsal at a 45° angle is emphasized[25]. Furthermore, we present and support the improvement in the precision of osteotomies via the use of a digital goniometer within the minimally invasive foot surgery context, compared to conventional freehand techniques[8], which could be optimal for improving metatarsal surgery.

The integration of the goniometer into the handpiece of the surgical motor facilitates the acquisition of angulation during the surgical act, allowing real-time monitoring of the osteotomy angle. The use of this type of technology, as well as the integration of surgical guides, has already been employed in various fields, both in podiatry[26,27] and in other medical specialties[1,28,29], achieving very satisfactory results. An important aspect of this technological advancement lies in its ability to reduce reliance on subjective visual perception and the experience of the surgeon[12,21], introducing a standardized technique facilitated by the goniometer, thereby mitigating variability among operators[3].

The study involved the examination of 31 complete metatarsals in a controlled cadaveric environment that allowed for direct comparisons between osteotomies performed with and without a goniometer. These rigorous cadaveric tests allowed for accurate measurements and evaluations of angular outcomes, providing critical foundations and evidence regarding the possible improvements in accuracy and precision with the goniometer.

By using this technology, the angles cluster, and variability and standard deviation decrease. Conversely, if this technology is not used and we opt for conventional manual surgical techniques, inclination results tend to be higher, and greater dispersion is observed.

While former studies have investigated foot and ankle surgery in cadavers to compare techniques[26-30], this study uniquely leveraged cadaveric metatarsal osteotomies to isolate the impact of the goniometer itself. By standardizing other surgical variables through the cadaver model, we could directly quantify the differences in angular precision between conventional freehand osteotomies and those performed with the goniometer. These controlled comparative tests in cadavers paralleled similar research modalities in orthopedic surgical examination techniques[31-34]. The protocol in cadaver tests reinforced the validity and potential generalization of the findings.

Accurate angulation is fundamentally important in the context of this surgical procedure, as osteotomies with incorrect angles can profoundly affect the biomechanics of the foot, potentially leading to unfavorable postoperative outcomes[16]. The use of digital goniometric techniques to ensure the obtained angle offers a promising perspective for mitigating complications associated with imperfect angular correction[21].

The main limitations of this study include the small sample size, particularly in the study with cadaver specimens, which could have affected the ability to achieve statistical significance in the results. Additionally, variability in the soft tissues present in the cadaver specimens may have influenced the accuracy of the measurements, generating greater variability compared to the skeletal models. It is also important to note that the study was conducted under controlled conditions, which may not fully reflect the complexity of surgical interventions in a real clinical environment. Lastly, although improvements in angle precision were observed with the use of the digital inclinometer, further research is required to validate these results in a broader clinical context and with a larger sample.

In conclusion, the use of a digital inclinometer in metatarsal osteotomies improves the precision of the cutting angle vs conventional freehand techniques. In particular, the tests conducted with resin and cadaver skeletons did not show any significant differences in angulation between the groups that used the inclinometer and those that did not, but there was lower variability in the group, indicating a substantial improvement in the precision of the procedure. Nevertheless, the research demonstrates that the incorporation of technology such as the digital inclinometer can reduce variability in surgical outcomes and facilitate a more standardized technique.

Funding

None declared.

Ethical statement

The study was conducted in full compliance with the Declaration of Helsinki and was approved by (UCV/2022-2023/094). This research also complies with the guidelines and general principles included in the code of ethics of the General Council of Official Colleges of Podiatrists of Spain, amended in 2018 (Code of Ethics | General Council of Official Colleges of Podiatrists (CGCOP)). Furthermore, it complies with the Spanish Data Protection Legislation (L.O3/2018 of December 5).

Data availability statement

The data presented in this study are available upon request from the corresponding author.

Conflicts of interest

None declared.

Authors' contributions

Study conception and design: CFV, JFT.
Data collection: CFV, JFT.
Analysis and interpretation of results: CFV, ENG, LRA, JFT.
Creation, writing, and preparation of the draft: CFV, ENG, LRA, ENG, NFE, JFT.
Final review: CFV, ENG, LRA, ENG, NFE, JFT.

References

1. Darrith B, Bell JA, Culvern C, Della Valle CJ. Can the use of an inclinometer improve the positioning of the acetabular component in total hip arthroplasty? Bone Joint J. 2018;100-B(7):862-6. DOI: 10.1302/0301-620X.100B7.BJJ-2017-1607.R1.
2. del Bello Cobos P, Nieto García E, Naranjo Ruiz C, Ramírez Andrés L, Nieto González E. Cirugía metatarsal mínimamente invasiva en la metatarsalgia iatrogénica. Serie de casos retrospectiva. Rev Esp Podol. 2020;31(2):93-101. DOI: 10.20986/revesppod.2020.1574/2020.
3. Swarup I, Goodbody C, Gausden E, Mintz D, Scher D, Widmann R. Evaluating the use of an electronic inclinometer in correcting rotational disorders of the hip in children. J Clin Orthop Trauma. 2019;10(3):609-14. DOI: 10.1016/j.jcot.2018.06.002.
4. Van Enoo RE, Cane EM. Minimal incision surgery. A plastic technique or a cover-up? Clin Podiatr Med Surg. 1986;3(2):321-35.
5. McMurrich W, Peters A, Ellis M, Shalaby H, Baer G, MacDonald D, McKinley JC. MIS Distal Metatarsal Metaphyseal Osteotomy in the treatment of metatarsalgia: MOXFQ patient reported outcomes. Foot (Edinb). 2020;43:101661. DOI: 10.1016/j.foot.2019.101661.
6. Vandeputte G, Dereymaeker G, Steenwerckx A, Peeraer L. The Weil osteotomy of the lesser metatarsals: a clinical and pedobarographic follow-up study. Foot Ankle Int. 2000;21(5):370-4. DOI: 10.1177/107110070002100502.
7. Sharma DK, Roy N, Shenolikar A. Weil Osteotomy of lesser metatarsals for metatarsalgia: A clinical and radiological follow-up. The Foot. 2005;15(4):202-5. DOI: 10.1016/j.foot.2005.07.006.

8. Redfern DJ, Vernois J. Percutaneous Surgery for Metatarsalgia and the Lesser Toes. Foot Ankle Clin. 2016;21(3):527-50. DOI: 10.1016/j.fcl.2016.04.003.
9. Thomas M, Jordan M. Minimal-invasive Korrektur von Deformitäten der Kleinzehen und Behandlung der Metatarsalgie [Minimally invasive correction of lesser toe deformities and treatment of metatarsalgia]. Oper Orthop Traumatol. 2018;30(3):171-183. DOI: 10.1007/s00064-018-0548-6.
10. Bauer T. Percutaneous forefoot surgery. Orthop Traumatol Surg Research. 2014;100(1):S191-204. DOI: 10.1016/j.otsr.2013.06.017.
11. Laffenêtre O, Perera A. Distal Minimally Invasive Metatarsal Osteotomy ("DMMO" Procedure). Foot Ankle Clin. 2019;24(4):615-25. DOI: 10.1016/j.fcl.2019.08.011.
12. Krenn S, Albers S, Bock P, Mansfield C, Chraim M, Trnka HJ. Minimally Invasive Distal Metatarsal Metaphyseal Osteotomy of the Lesser Toes: Learning Curve. Foot Ankle Spec. 2018;11(3):263-8. DOI: 10.1177/1938640017750251.
13. Jowett CRJ, Bedi HS. Preliminary Results and Learning Curve of the Minimally Invasive Chevron Akin Operation for Hallux Valgus. J Foot Ankle Surg. 2017;56(3):445-52. DOI: 10.1053/j.jfas.2017.01.002.
14. Merc M, Fokter SK, I IS. Learning curve in relation to radiation exposure, procedure duration and complications rate for Minimally Invasive Chevron Akin (MICA) osteotomy. BMC Musculoskelet Disord. 2023;24(1):575. DOI: 10.1186/s12891-023-06706-1.
15. Naranjo-Ruiz C, Martínez-Nova A, Canel-Pérez MLÁ, López-Vigil M, Ferrer-Torregrosa J, Barrios C. Influence of Foot Type on the Clinical Outcome of Minimally Invasive Surgery for Metatarsalgia. A Prospective Pilot Study. Front Surg. 2021;8:748330. DOI: 10.3389/fsurg.2021.748330.
16. De Prado M, Cuervas-Mons M, Golanó P, Vaquero J. Distal Metatarsal Minimal Invasive Osteotomy (DMMO) for the Treatment of Metatarsalgia. Tech Foot Ankle Surg. 2016;15(1):12-8. DOI: 10.1097/BTF.0000000000000093.
17. Henry J, Besse JL, Fessy MH. Distal osteotomy of the lateral metatarsals: a series of 72 cases comparing the Weil osteotomy and the DMMO percutaneous osteotomy. Orthop Traumatol Surg Res. 2011;97(6 Suppl):S57-65. DOI: 10.1016/j.otsr.2011.07.003.
18. Vendittoli PA, Duval N, Stitson DJ, Mâsse B. Vertical acetabular positioning with an inclinometer in total hip arthroplasty. J Arthroplasty. 2002;17(7):936-41. DOI: 10.1054/arth.2002.34820.
19. Pongkunakorn A, Chatmaitri S, Diewwattanawiwat K. Use of smartphone to improve acetabular component positioning in total hip athroplasty: A comparative clinical study. J Orthop Surg (Hong Kong). 2019;27(1):2309499019825578. DOI: 10.1177/2309499019825578.
20. van Duren BH, Al Ashqar M, Lamb JN, Pandit HG, Brew C. A novel mechanical inclinometer device to measure acetabular cup inclination in total hip arthroplasty. J Med Eng Technol. 2020;44(8):481-8. DOI: 10.1080/03091902.2020.1825846.
21. Palmanovich E, Ohana N, Atzmon R, Slevin O, Brin Y, Feldman V, et al. MICA: A Learning Curve. J Foot Ankle Surg. 2020;59(4):781-3. DOI: 10.1053/j.jfas.2019.07.027.
22. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41(1):3-13. DOI: 10.1249/MSS.0b013e31818cb278.
23. Hopkins W. A scale of magnitudes for effect statistics [Internet]. Sports Science; 2002 [citado el 9 de septiembre de 2021]. Disponible en: http://www.sportsci.org/resource/stats/effectmag.html
24. Olivier Laffenêtre. Distal Minimally Invasive Metatarsal Osteotomy. In: Ettore Vulcano A, Holly Johnson, Oliver N. Schipper, editors. Minimally Invasive Foot and Ankle Surgery: A Percutaneous Approach. 1ª ed. USA: Wolters Kluwer; 2023. p. 77-86.
25. Laffenêtre O, Dalmau-Pastor M, Bauer T. Osteotomías de los metatarsianos laterales. EMC - Técnicas Quirúrgicas - Ortopedia y Traumatología. 2019;11(1):1-10. DOI: 10.1016/S2211-033X(19)41780-5.
26. Ferrer-Torregrosa J, García Vicente S. Guiding and holding device for minimum incision foot surgery [Internet]. European patent EP2997926 (A1); 2014. Disponible en: https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2014091054
27. Ferrer-Torregrosa J, Garcia-Vicente S, Fernández-Ehrling N, Torralba-Estellés J, Barrios C. Design of a Three-Dimensional-Printed Surgical Glove for Minimal-Incision Podiatric Surgery. J Am Podiatr Med Assoc. 2019;109(3):207-14. DOI: 10.7547/17-014.
28. Flügge TV, Nelson K, Schmelzeisen R, Metzger MC. Three-dimensional plotting and printing of an implant drilling guide: simplifying guided implant surgery. J Oral Maxillofac Surg. 2013;71(8):1340-6. DOI: 10.1016/j.joms.2013.04.010.
29. Alhumaidan A, Al-Qarni F, AlSharief M, AlShammasi B, Albasry Z. Surgical guides for esthetic crown lengthening procedures: Periodontal and prosthetic aspects. J Am Dent Assoc. 2022;153(1):31-8. DOI: 10.1016/j.adaj.2021.07.005.
30. Lopez-Vigil M, Suarez-Garnacho S, Martín V, Naranjo-Ruiz C, Rodriguez C. Evaluation of results after distal metatarsal osteotomy by minimal invasive surgery for the treatment of metatarsalgia: patient and anatomical pieces study. J Orthop Surg Res. 2019;14(1):121. DOI: 10.1186/s13018-019-1159-0.
31. Park JH, Choi YJ, Lee M, Kim D, Kwon HW, Park KR, et al. Anatomical Characteristics of Extensor Hallucis Longus Tendon Variations and Its Clinical Implications: A Korean Cadaveric Study. Int J Environ Res Public Health. 2022;19(16):9833. DOI: 10.3390/ijerph19169833.
32. Chan JY, Leung I, Navarro-Alarcon D, Lin W, Li P, Lee DL, et al. Foot-controlled robotic-enabled endoscope holder for endoscopic sinus surgery: A cadaveric feasibility study. Laryngoscope. 2016;126(3):566-9. DOI: 10.1002/lary.25634.
33. Moroni S, Márquez J, Fernández-Gibello A, Nieves GC, Montes R, Vázquez T, et al. The hallucal interphalangeal ossicle: anatomy and basis for ultrasound-guided surgical shaving. Sci Rep. 2022;12(1):4789. DOI: 10.1038/s41598-022-08805-w.
34. Moroni S, Fernández-Gibello A, Nieves GC, Montes R, Zwierzina M, Vazquez T, et al. Anatomical basis of a safe mini-invasive technique for lengthening of the anterior gastrocnemius aponeurosis. Surg Radiol Anat. 2021;43(1):53-61. DOI: 10.1007/s00276-020-02536-1.