Orthopaedics & Traumatology: Surgery & Research xxx (xxxx) 103925

Contents lists available at ScienceDirect

Orthopaedics & Traumatology: Surgery & Research

journal homepage: www.elsevier.com

Original article

Osteotomies for genu varum: Should we always correct at the tibia? A multicenter analysis of practices in France

Grégoire Micicoi[a], Matthieu Ollivier[b,*], Nicolas Bouguennec[c], Cécile Batailler[d], Nicolas Tardy[e], Goulven Rochcongar[f], Jean-Marie Fayard[g]

[a] *Unité de recherche clinique Côte d'Azur (UR2CA), institut universitaire locomoteur et du sport (IULS), CHU de Nice, hôpital Pasteur 2, 30, voie Romaine, 06000 Nice, France*
[b] *CNRS, ISM, Aix-Marseille University, Institute for Locomotion, Sainte-Marguerite Hospital, APHM, Marseille, France*
[c] *Clinique du sport de Bordeaux-Mérignac, Mérignac, France*
[d] *Service de chirurgie orthopédique, hôpital de la Croix-Rousse, Lyon, France*
[e] *Centre ostéo-articulaire des cèdres, clinique des cèdres, 5, rue des Tropiques, 38130 Échirolles, France*
[f] *Département de chirurgie orthopédique et traumatologique, CHU de Caen, université de Caen, UNICAEN, Basse-Normandie, Caen, France*
[g] *Ramsay-générale de Santé, hôpital privé Jean-Mermoz, Lyon, France*

ARTICLE INFO

Article history:
Received 9 December 2023
Accepted 26 March 2024
Available online xxx

Keywords:
Knee
High tibial osteotomy
Varus deformity
Joint line obliquity
Anatomical correction

ABSTRACT

Introduction: Tibial correction is often performed during a valgus-producing osteotomy for genu varum. However, overcorrection and the creation of a joint line obliquity (JLO) have been associated with unfavorable functional outcomes after high tibial osteotomy (HTO). The aims of this study were to analyze: 1) the corrections obtained after HTO; 2) the rationale behind the indication per the European Society for Sports Traumatology Surgery and Arthroscopy (ESSKA) recommendations; and 3) the correlation between the postoperative corrections obtained and functional outcomes.
Hypothesis: A significant number of patients who underwent an isolated HTO did not present an "ideal" theoretical indication based on the preoperative angles and correction targets to be performed.
Materials and methods: This multicenter study included 289 isolated HTOs. Demographic and morphometric data were anonymized and compiled in a database. Preoperative radiographic parameters were compared with the ESSKA consensus recommendations on osteotomies for genu varum. The consensus defined the "ideal" indication for performing an HTO as medial tibiofemoral compartment pain with significant tibial varus deformity (medial proximal tibial angle [MPTA] < 85°), no significant femoral varus deformity (lateral distal femoral angle [LDFA] < 90°), an expected postoperative obliquity of less than 5°, and a correction resulting in moderate tibial valgus (postoperative MPTA < 94°). The incidence of patients with an "ideal" theoretical indication for isolated HTO and those with a theoretical indication not perfectly justified by the radiographic data and preoperative planning were recorded.
Results: Under the ESSKA consensus criteria, 25.3% ($n = 73$) of isolated HTOs, 15.6% ($n = 45$) of isolated femoral osteotomies, 9.3% ($n = 27$) of double-level osteotomies, and 49.9% ($n = 144$) of cases where no osteotomy was performed due to the lack of significant extra-articular tibial and/or femoral deformity were deemed justified. The presence of a preoperative femoral deformity and the absence of an "ideal" indication for HTO did not affect the postoperative Tegner Activity Scale or the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores ($p > 0.05$). A high preoperative hip-knee-ankle (HKA) angle and MPTA, which indicated less varus, were associated with a greater risk of there being no "ideal" theoretical indication for an HTO (coefficient of determination [R^2] = 0.19 and $R^2 = 1$, respectively; $p < 0.001$).

* Corresponding author.
E-mail address: ollivier.mt@gmail.com (M. Ollivier).

https://doi.org/10.1016/j.otsr.2024.103925

Conclusion: This study showed that isolated HTOs in current practice were not justified in a significant number of patients, even though they could lead to tibial overcorrection and excessive JLO. This did not impact the functional results of this series, but it might complicate the performance of a secondary knee arthroplasty. Nevertheless, some young patients in this series underwent a salvage osteotomy outside the "ideal" indications of the European recommendations.
Level of evidence: IV; case series.

1. Introduction

High tibial osteotomy (HTO) significantly improves clinical outcomes in young patients with medial compartment osteoarthritis [1]. However, excessive joint line obliquity (JLO) can complicate arthroplasty revision and reduce functional outcomes after HTO [2,3].

The European consensus on osteotomies for genu varum recently recommended that to prevent tibial overcorrection and excessive JLO, surgeons should plan a double-level osteotomy when the JLO is greater than 5° or the medial proximal tibial angle [MPTA] is greater than 94° and a femoral osteotomy when the varus deformity only involves the femur [4,5].

A previous study that considered all osteotomies and preoperative deformities demonstrated that postoperative non-anatomical corrections were planned in almost half of the cases [6]. Although the aim of HTO is to unload the medial compartment by pushing back the limits of the physiological angles, excessive tibial overcorrection could potentially lead to significant changes to the JLO, resulting in early deterioration of outcomes [7–9]. However, JLO's impact on functional outcomes remains the subject of debate [10].

No study has yet evaluated the true corrections obtained after HTO in a multicenter series by analyzing preoperative segmental deformities to determine whether the indication and site of isolated tibial HTO were justified.

The aims of this study were to analyze: 1) the corrections obtained after HTO; 2) the rationale behind the indication per the European Society for Sports Traumatology Surgery and Arthroscopy (ESSKA) recommendations; and 3) the correlation between the postoperative corrections obtained and functional outcomes.

Our hypothesis was that a significant number of patients who underwent isolated HTO did not present an "ideal" theoretical indication based on the preoperative angles and desired correction targets.

2. Materials and methods

2.1. Patients

This retrospective multicenter study analyzed patients who underwent an HTO from the 2019 Francophone Arthroscopy Society Symposium database [11]. Patients with symptomatic isolated medial compartment osteoarthritis were included in the study. The exclusion criteria were a torn anterior cruciate ligament and those under 18 years old. Distal femoral and double-level osteotomies were not assessed in this study as they were not included in the symposium. Of the 330 patients in the registry, only 289 were selected based on the inclusion criteria, with a mean age of 55 ± 8 years and a mean follow-up of 7 ± 4 years (Fig. 1). The demographic characteristics are shown in Table 1. All procedures were performed in accordance with the ethical standards of the institutional and national research committees and with the 1964 Declaration of Helsinki.

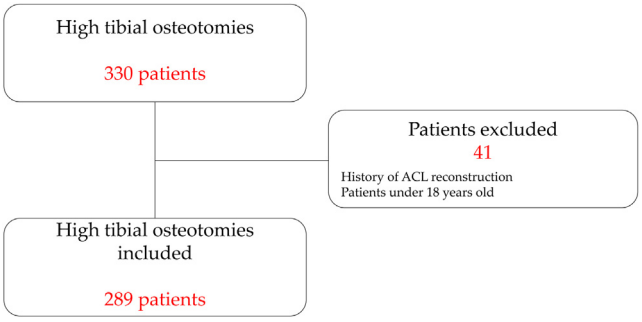

Fig. 1. Study flowchart.

Table 1
Demographic characteristics of the analyzed population.

	289 HTOs
Mean age, years ± SD	54.4 ± 7.4
BMI, kg/m², mean ± SD	28.4 ± 4.3
Sex, female/male, *n* (%)	89 (30.7)/200 (69.4)
Side, right/left, *n* (%)	151 (52.2)/138 (47.8)
Osteoarthritis severity (Ahlbäck	
classification)	45 (15.6)
Grade 1, *n* (%)	160 (55.3)
Grade 2, *n* (%)	84 (29.1)
Grade 3, *n* (%)	0 (0)
Grade 4, *n* (%)	
Osteoarthritis severity	
(Kellgren-Lawrence	52 (18)
classification)	64 (22.1)
Grade 1, *n* (%)	140 (48.4)
Grade 2, *n* (%)	33 (11.4)
Grade 3, *n* (%)	
Grade 4, *n* (%)	

BMI: body mass index; SD: standard deviation.

2.2. Clinical and radiographic assessment

The Tegner Activity Scale scores and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) stiffness, physical function, and overall scores were analyzed postoperatively [12]. The postoperative clinical scores are presented in Table 2.

All patients underwent preoperative radiographs to assess the extent of osteoarthritis using the Ahlbäck and Kellgren-Lawrence classification systems [13]. Angles were measured on weight-bearing anteroposterior long-leg radiographs, with the patella centered on the femoral condyles in full knee extension. The following parameters were assessed before and after surgery: hip-knee-ankle (HKA) angle representing the overall deformity, lateral distal femoral angle (LDFA) representing the femoral deformity, medial proximal tibial angle (MPTA) representing the tibial deformity, joint line convergence angle (JLCA) representing the intra-articular deformity, and JLO representing the horizontal joint line with the ground. An HKA < 180° indicates an overall lower limb varus deformity, MPTA < 90° a tibial varus, and LDFA < 90° a

Table 2
Postoperative functional results.

Functional scores	289 HTOs
WOMAC	
Stiffness, % ± SD	71.2 ± 26.3
Physical function, % ± SD	84.3 ± 16.3
Overall, % ± SD	79.6 ± 19.5
Tegner Activity Scale	
0, *n* (%)	1 (0.4)
1, *n* (%)	17 (6)
2, *n* (%)	50 (17.5)
3, *n* (%)	86 (29.8)
4, *n* (%)	76 (26.3)
5, *n* (%)	38 (13.1)
6, *n* (%)	10 (3.6)
7, *n* (%)	8 (2.8)
8, *n* (%)	3 (0.4)

HTO: high tibial osteotomy; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; SD: standard deviation.

femoral valgus. The physiological values found in an asymptomatic population are a mean MPTA of 86–87° (varus) and a mean LDFA of 86–87° (valgus) [14].

2.3. Deformity analysis and indications for high tibial osteotomy

The preoperative radiographic parameters were compared with the ESSKA consensus recommendations for performing an HTO [4,5]. The "ideal" theoretical indication for isolated HTO is a young, active patient with medial tibiofemoral compartment pain, minimal to moderate osteoarthritis (Ahlbäck grades 1 or 2), an overall varus deformity, and:

- significant tibial varus deformity (MPTA < 85°);
- no significant femoral varus deformity (LDFA < 90°);
- an expected postoperative joint line obliquity < 5°;
- a correction producing a moderate tibial valgus (postoperative MPTA < 94°).

The incidence of patients with an "ideal" theoretical indication for isolated HTO and those with a theoretical indication not perfectly justified by the preoperative radiographic data was recorded.

Postoperative data were also analyzed to confirm cases where the desired correction produced a tibial valgus of more than 94° MPTA.

Therefore, based on this series, which only included isolated HTOs, the incidences of "ideal" indications per ESSKA recommendations for double-level osteotomies or isolated distal femoral osteotomies were analyzed.

2.4. Surgical technique and postoperative care

A medial opening wedge HTO was performed in 226 (78%) cases and a lateral closing wedge HTO in 63 (22%) cases. A traditional free-hand technique was performed in 227 (79%), computer-assisted navigation in 33 (11%), and custom cutting guides in 29 (10%) of patients.

The choice of weight-bearing protocol was left to the surgeon's discretion: immediate early resumption of weight-bearing or partial resumption of weight-bearing 3 or 6 weeks later. Early mobilization of the knee was undertaken in all cases.

2.5. Statistical analysis

Mean values and standard deviations (SDs) were determined for the pre- and postoperative functional scores and angles. Normal (Gaussian) distributions were checked to determine what statistical method should be run (parametric or nonparametric). Each model variable yielding a *p*-value of less than 0.1 was retained in the final model. The statistical analyses were performed using IBM SPSS software (IBM Corp., Armonk, New York, USA).

Table 3
Pre- and postoperative angle measurements.

Angle measurements	289 HTOs
Preoperative HKA, in° ± SD	173.7 ± 3.1
Preoperative MPTA, in° ± SD	85.2 ± 2.9
Preoperative LDFA, in° ± SD	89.1 ± 1.7
Preoperative JLCA, in° ± SD	2.8 ± 2.2
Preoperative JLO, in° ± SD	2.8 ± 2.1
Postoperative HKA, in° ± SD	181 ± 3.8
Postoperative MPTA, in° ± SD	91.8 ± 5.9
Postoperative JLCA, in° ± SD	3.1 ± 5.3
Postoperative JLO, in° ± SD	1.8 ± 4.8

HKA: hip-knee-ankle; MPTA: medial proximal tibial angle; LDFA: lateral distal femoral angle; JLO: joint line obliquity; JLCA: joint line convergence angle; SD: standard deviation.

3. Results

The pre- and postoperative mean radiographic angles are shown in Table 3. The MPTA increased on average by 7.5 ± 4.2° and the HKA angle by 5.8 ± 6° ($p < 0.01$). A femoral deformity was found in 18.3% ($n = 53$) of cases and a JLCA > 6° in 9.7% ($n = 28$) of cases.

Under the ESSKA consensus criteria, 25.3% ($n = 73$) of isolated HTOs, 15.6% ($n = 45$) of isolated femoral osteotomies, 9.3% ($n = 27$) of double-level osteotomies, and 49.9% ($n = 144$) of cases where no osteotomy was performed due to the lack of significant extra-articular tibial and/or femoral deformity were deemed justified. Indeed, 32.9% ($n = 95$) of patients had a postoperative MPTA > 94°.

The presence of a preoperative femoral deformity, a JLCA > 6°, and the lack of an indication for HTO did not affect the postoperative Tegner Activity Scale and WOMAC scores ($p > 0.05$).

4. Discussion

This study demonstrated that in a large multicenter series, the "ideal" theoretical indication for an isolated HTO was only justified in about a quarter of cases (25.3%) based on the recommendations to prevent postoperative tibial overcorrection and/or a JLO > 5°.

Previous studies have shown that a postoperative MPTA ≥ 95° was associated with poorer clinical scores at the 2-year follow-up and subjective International Knee Documentation Committee (IKDC) scores at the 10-year follow-up after an osteotomy [7,15].

Besides a significant intra-articular deformity, the femur should also be regarded as a potential varus source that may necessitate correction. A recent study reported that double-level osteotomies had to be performed in 17.8% of cases and distal femoral osteotomies in 27.9% to avoid crossing the MPTA > 94° and JLO > 5° thresholds [16]. These results were comparable to our series, which involved more centers. However, the percentage of recommended double-level osteotomies was lower (9.3%), which could be explained by the fact that these patients were not included in the series because they had previously undergone a double-level osteotomy for a large varus deformity. The contribution of the femur in overall varus is actually more prevalent and was found in 18.3% of cases in this series. Razak et al. showed a greater femoral varus in patients with medial tibiofemoral osteoarthritis after HTO compared to a non-arthritic group with the same tibial deformity [17].

No correlation was found between the justification of the surgical indication and the functional results (WOMAC and Tegner Activity Scale). This series' results grouped several centers with different levels of expertise and heterogeneous indications, which

could explain the lack of correlation with the clinical outcomes. Nonetheless, by homogenizing indications and corrections, the ESSKA consensus recommendations appear to act as a safeguard that clarifies site-specific surgical indications and the degrees of correction required during knee osteotomy.

An exception to the rule that was not evaluated in this series was the inclusion of young patients with significant osteoarthritis who, without obvious bone deformity, underwent salvage tibial osteotomies to avoid early recourse to knee arthroplasty. This could explain why 49.9% of patients in the series had no indication for an osteotomy.

A preoperative analysis must take into account the presence of a tibial and/or femoral deformity, as well as the correction target (50–55% in this series), which, depending on the bone defect, will need to be corrected in the tibia, femur or both, and in cases of pure intra-articular wear without bone deformity will either require an arthroplasty or medial compartment unloading without an osteotomy [18].

Finally, the creation of an excessive JLO after HTO might cause difficulties in performing a secondary knee arthroplasty related to ligament balancing, respecting the height of the joint space, and femorotibial and patellofemoral kinematics, which might require implant constraint induced by the malunion caused by a tibial overcorrection [10]. While there is no study on medial unicompartmental arthroplasty after HTO with excessive JLO, it can be assumed that this could place excessive stresses on the tibial implant, leading to early prosthetic failure.

This study had several limitations. First, it was a retrospective study comprising different practices depending on the centers, and the analysis of deformities that lead to the decision of whether to perform or not an isolated HTO may differ from one center to another. However, the multicenter nature of this study made it possible to report general practices among surgeons with a certain level of experience in performing osteotomies, which did not limit the external validity of the study. Second, the impact of the indication for isolated HTO on survivorship could not be analyzed, given the lack of long-term follow-up. This type of analysis would require patient homogenization, particularly preoperative deformity and degree of osteoarthritis. Third, the fact that the angles were measured on weight-bearing radiographs without a 3-dimensional computed tomography scan analysis could have induced a measurement bias due to a lack of precision. However, an analysis of intra-articular deformations was permitted in the radiographic analysis. Finally, the fact that no interobserver assessment was performed may have limited the external validity of this study due to measurement biases inherent to long-leg radiographic techniques influenced by poor patella positioning, a rotational disorder, or associated flexion deformity.

The clinical significance of this study resides in the importance of the detailed analysis of preoperative deformities and planning that will determine whether the “ideal” indication for an isolated HTO is justified or not. A prospective study based on ESSKA recommendations, separating patients with bone deformities and mild-to-moderate osteoarthritis (Ahlbäck grades 1 and 2) from those with advanced osteoarthritis, would enable us to determine the impact of the corrections (tibial, femoral, or both) on changes to the joint line, functional outcomes, and long-term survivorship.

5. Conclusion

This study showed that isolated HTOs in current practice were not justified in a significant number of patients, even though they could lead to tibial overcorrection and excessive JLO. This did not impact the functional results of this series, but it might complicate the performance of a secondary knee arthroplasty. Nevertheless, some young patients in this series underwent a salvage osteotomy outside the “ideal” indications of the European recommendations.

Declaration of Generative AI and AI-assisted technologies in the writing process

Artificial intelligence technology was not used in this study.

Disclosure of interest

JMF and MO are consultants for Newclip®.

The authors GM, NB, NT, CB, and GR declare that they have no competing interest.

Funding

This study results from data collection that the Francophone Society of Arthroscopy partially funded.

Contributions

Nicolas Bouguennec, Cécile Batailler, Nicolas Tardy, Goulven Rochcongar, Jean-Marie Fayard, and members of the 2019 Francophone Arthroplasty Society Symposium created the initial database. M. Ollivier and G. Micicoi extracted data, designed the study, wrote the manuscript, and revised the various versions. All authors approved the final manuscript.

References

[1] Bouguennec N, Mergenthaler G, Gicquel T, Briand C, Nadau E, Pailhé R, et al. Medium-term survival and clinical and radiological results in high tibial osteotomy: factors for failure and comparison with unicompartmental arthroplasty. Orthop Traumatol Surg Res 2020, http://dx.doi.org/10.1016/j.otsr.2020.08.002. S1877056820302267.
[2] Chen X, Yang Z, Li H, Zhu S, Wang Y, Qian W. Higher risk of revision in total knee arthroplasty after high tibial osteotomy: a systematic review and updated meta-analysis. BMC Musculoskelet Disord 2020;21:153, http://dx.doi.org/10.1186/s12891-020-3177-9.
[3] Song J-H, Bin S-I, Kim J-M, Lee B-S. What is an acceptable limit of joint-line obliquity after medial open wedge high tibial osteotomy? Analysis based on midterm results. Am J Sports Med 2020;48:3028–35, http://dx.doi.org/10.1177/0363546520949552.
[4] Dawson M, Ollivier M. Osteotomy around the painful degenerative varus knee: a 2022 ESSKA formal consensus. Knee Surg Sports Traumatol Arthrosc 2023;31:3041–3, http://dx.doi.org/10.1007/s00167-022-07024-0. Epub 2022 Jun 13. PMID: 35697873.
[5] Dawson MJ, Ollivier M, Menetrey J, Beaufils P. Osteotomy around the painful degenerative varus knee: a 2022 ESSKA formal consensus. Knee Surg Sports Traumatol Arthrosc 2022, http://dx.doi.org/10.1007/s00167-022-07024-0, s00167-022-07024-0.
[6] Micicoi G, Grasso F, Kley K, Favreau H, Khakha R, Elhinger M, et al. Osteotomy around the knee is planned toward an anatomical bone correction in less than half of patients. Orthop Traumatol Surg Res 2021:102897, http://dx.doi.org/10.1016/j.otsr.2021.102897.
[7] Akamatsu Y, Kumagai K, Kobayashi H, Tsuji M, Saito T. Effect of increased coronal inclination of the tibial plateau after opening-wedge high tibial osteotomy. Arthroscopy 2018;34:2158–69, http://dx.doi.org/10.1016/j.arthro.2018.01.055, e2.
[8] Babis GC, An K-N, Chao EYS, Rand JA, Sim FH. Double level osteotomy of the knee: a method to retain joint-line obliquity. Clinical results. J Bone Joint Surg Am 2002;84:1380–8, http://dx.doi.org/10.2106/00004623-200208000-00013.
[9] Nakayama H, Schröter S, Yamamoto C, Iseki T, Kanto R, Kurosaka K, et al. Large correction in opening wedge high tibial osteotomy with resultant joint-line obliquity induces excessive shear stress on the articular cartilage. Knee Surg Sports Traumatol Arthrosc 2018;26:1873–8, http://dx.doi.org/10.1007/s00167-017-4680-x.
[10] Xie T, Brouwer RW, Van Den Akker-Scheek I, Van Der Veen HC. Clinical relevance of joint line obliquity after high tibial osteotomy for medial knee osteoarthritis remains controversial: a systematic review. Knee Surg Sports Traumatol Arthrosc 2023;31:4355–67, http://dx.doi.org/10.1007/s00167-023-07486-w.
[11] Mabrouk A, Ollivier M, Fayard J, Batailler C, Bougennec N, Tardy N, et al. Les résultats des OTV sont similaires avec ou sans antécédent de méniscectomie totale/partielle : analyse secondaire matchée selon l'âge, le sexe et le

score WOMAC du symposium de la SFA. Orthop Traumatol Surg Res 2023, http://dx.doi.org/10.1016/j.rcot.2023.06.012. S187705172300182X.
[12] Mabrouk A, Ollivier M, Fayard J, Batailler C, Bougennec N, Tardy N, et al. High tibial osteotomy is equally effective for varus malaligned knees with either virgin or wrecked medial meniscus: an age and gender matched secondary analysis of a francophone arthroscopy society symposium. Orthop Traumatol Surg Res 2023:103650, http://dx.doi.org/10.1016/j.otsr.2023.103650.
[13] Wing N, Van Zyl N, Wing M, Corrigan R, Loch A, Wall C. Reliability of three radiographic classification systems for knee osteoarthritis among observers of different experience levels. Skeletal Radiol 2021;50:399–405, http://dx.doi.org/10.1007/s00256-020-03551-4.
[14] Micicoi G, Jacquet C, Sharma A, LiArno S, Faizan A, Kley K, et al. Neutral alignment resulting from tibial vara and opposite femoral valgus is the main morphologic pattern in healthy middle-aged patients: an exploration of a 3D-CT database. Knee Surg Sports Traumatol Arthrosc 2020, http://dx.doi.org/10.1007/s00167-020-06030-4.
[15] Schuster P, Geßlein M, Schlumberger M, Mayer P, Mayr R, Oremek D, et al. Ten-year results of medial open-wedge high tibial osteotomy and chondral resurfacing in severe medial osteoarthritis and varus malalignment. Am J Sports Med 2018;46:1362–70, http://dx.doi.org/10.1177/0363546518758016.
[16] Ollivier M, An J-S, Kley K, Khakha R, Fernandes LR, Micicoi G. A significant rate of tibial overcorrection with an increased JLO occurred after isolated high tibial osteotomy without considering international consensus. Knee Surg Sports Traumatol Arthrosc 2023, http://dx.doi.org/10.1007/s00167-023-07518-5.
[17] Razak HRBA, Micicoi G, Khakha RS, Ehlinger M, Faizan A, LiArno S, et al. Patients with varus knee osteoarthritis undergoing high tibial osteotomy exhibit more femoral varus but similar tibial morphology compared to non-arthritic varus knees. Knee Surg Sports Traumatol Arthrosc 2021, http://dx.doi.org/10.1007/s00167-020-06426-2.
[18] Slynarski K, Walawski J, Smigielski R, Van Der Merwe W. Feasibility of the atlas unicompartmental knee system load absorber in improving pain relief and function in patients needing unloading of the medial compartment of the knee: 1-year follow-up of a prospective, multicenter, single-arm pilot study (PHANTOM High Flex Trial). Clin Med Insights Arthritis Musculoskelet Disord 2017;10, http://dx.doi.org/10.1177/1179544117733446, 117954411773344.