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Comparative impact of high tibial osteotomy and supramalleolar osteotomy on limb alignment and ankle function: a retrospective study

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Abstract

Objective This retrospective study aimed to conduct a comparative analysis of the impact of high tibial osteotomy (HTO) and supramalleolar osteotomy (SMOT) on lower limb alignment and ankle function after surgery.

Methods A cohort of patients who underwent either HTO ($n = 63$) or SMOT ($n = 51$) for lower limb alignment issues was included in the study. Inclusion criteria comprised individuals who underwent the surgical procedures between June 2018 and June 2021; exclusion criteria encompassed incomplete medical records and inadequate follow-up data. Baseline characteristics, weight-bearing line ratios, ankle joint function, and lower limb lines of force were evaluated before surgery, postoperatively, and at the 6-month follow-up. Statistical analyses were performed to compare the outcomes between the HTO and SMOT groups, as well as between non-deviated and deviated subgroups. Spearman rank correlation analysis was used to reveal correlations between variables.

Results The preoperative and immediate postoperative weight-bearing line ratios were similar between the HTO and SMOT groups. However, a notable difference emerged at the 6-month follow-up, suggesting distinct impacts of the two procedures on lower limb alignment. Additionally, the HTO group exhibited superior postoperative outcomes in ankle joint function, specifically in pain alleviation and functional improvement, compared to the SMOT group. The analysis of lower limb lines of force demonstrated a significant association between the surgical procedure and alterations in lower limb biomechanics, emphasizing the differential impact of HTO and SMOT. Furthermore, the comparison between non-deviated and deviated subgroups highlighted the potential impact of lower limb alignment on postoperative ankle function.

Conclusion The findings contribute valuable insights into the comparative effectiveness of HTO and SMOT in addressing lower limb alignment and ankle function. This study's results have significant implications for orthopedic treatment and may guide treatment strategies for patients undergoing lower limb realignment surgery, ultimately enhancing the quality of life for affected individuals.

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Keywords High tibial osteotomy, Supramalleolar osteotomy, Lower limb alignment, Lower limb alignment ratio, Ankle function, Surgical intervention, Retrospective study

Introduction

Lower limb deformity or malalignment can significantly impact an individual's overall stability and mobility by altering normal biomechanical forces that affect joint health and function [1–3]. Specifically, abnormalities in lower limb alignment can lead to a range of musculoskeletal issues, such as osteoarthritis, ligament injuries, and cartilage damage [4, 5]. (Fig. 1) High tibial osteotomy (HTO) and supramalleolar osteotomy (SMOT) are two surgical procedures that are frequently employed to address lower limb malalignment and associated conditions [6–8]. Both procedures aim to correct the lower limb alignment and ultimately improve ankle function; however, there is a gap in the literature regarding the comparative effectiveness of these two approaches on postoperative outcomes [9–11].

Tibial osteotomy at a high level involves surgical modification of the proximal tibia to alter the weight-bearing axis of the lower limb, thereby reducing pressure on the site of knee joint injury, improving weight distribution, and also enhancing ankle joint function [12, 13]. On the other hand, SMOT aims to correct the alignment of the ankle joint by altering the load distribution through the tibia, thereby addressing issues related to ankle instability and deformity [14]. While some SMOT procedures may contribute to correcting ankle deformities, not all are designed to improve ankle instability [15].

Despite documented evidence on the efficacy of these procedures individually, a direct comparison of their impact on lower limb alignment and ankle function remains essential for guiding clinical decision-making and optimizing patient outcomes [16, 17]. Furthermore, recent studies have explored the association between lower limb alignment and hindfoot deformity in the coronal plane using weightbearing CT analysis, providing valuable insights into how these factors interrelate [18].

The current retrospective study aims to address this gap by conducting a comparative analysis of the impact of HTO and SMOT on lower limb alignment and ankle function after surgery. By examining two cohort of patients who have undergone either procedure, we intend to assess and compare the postoperative outcomes, including changes in lower limb alignment, ankle function, and patient-reported outcomes. We hypothesize that HTO will demonstrate superior improvements in lower limb alignment and ankle function compared to SMOT over the follow-up period.

Understanding the relative benefits and limitations of these two surgical interventions is imperative for orthopedic surgeons and healthcare providers to make informed decisions regarding the most suitable approach for individual patients. Given the increasing prevalence of lower limb malalignment and ankle-related issues, this study aims to elucidate the comparative effectiveness of HTO and SMOT. Its findings have the potential to significantly advance orthopedic treatment and surgical interventions, providing valuable insights that can inform clinical practice, optimize treatment strategies, and ultimately enhance the quality of life for patients undergoing lower limb realignment surgery.

Materials and methods

Participant selection

The retrospective study included patients who underwent either HTO group ($n = 63$) and SMOT group ($n = 51$) for lower limb alignment issues. Electronic medical records and databases from the orthopedic surgery department were utilized for participant selection. Inclusion criteria comprised individuals who underwent the surgical procedures during a from June 2018 to June 2021, while exclusion criteria encompassed incomplete medical records and inadequate follow-up data. The study design flow chart is shown in Fig. 2.

Data collection

Baseline characteristics, including age, body mass index, affected limb, operative time, blood loss, and hospital stay, were collected for both the HTO and SMOT groups. Weight-bearing line ratios, ankle joint function (pain, function, and mobility), and lower limb lines of force were measured before surgery, after surgery, and at the 6-month postoperative mark. These parameters were chosen to evaluate the impact of the surgical interventions on lower limb alignment and ankle function.

Treatment

HTO: The surgeries were performed by a team of fellowship-trained orthopedic surgeons with over 10 years of experience in lower limb realignment procedures, all of whom are board-certified in orthopedic surgery. The patient was placed in a supine position, and after anesthesia, a HTO at the distal end of the tibial tuberosity was performed. The osteotomy plane was first determined, with the osteotomy plane positioned 1/3 below the tibial tuberosity and 0.5 cm below the tibiofibular joint, intersecting the joint line at a 30° angle. Using C-arm fluoroscopy, the osteotomy plane was confirmed, and a marking pen was used to mark the osteotomy line on the skin surface. The surgical approach was then determined, with a 4–6 cm incision made 0.5 cm anterior and superior to the

Fig. 1 Lower limb deformity

posterior edge of the tibia, intersecting with the osteotomy plane. The skin, fascia, and deep fascia were incised, and the superficial and deep fascia, as well as part of the periosteum of the proximal tibia, were dissected. Along the predetermined osteotomy line, a Steinmann pin was inserted obliquely from the proximal tibia to the tibiofibular joint, and after confirming the satisfactory position under C-arm fluoroscopy, the osteotomy procedure began. A large blunt hook reduction lever was used to protect the surrounding soft tissues and neurovascular structures, and an oscillating saw was used to perform the osteotomy along the osteotomy line, leaving approximately 1 cm of the lateral cortical bone intact. Subsequently, weakening of the lateral cortex of the bone was performed by drilling 5 holes using a Steinmann pin. One assistant supported the osteotomy end by hand, while the other rotated the foot externally to 15° off center, with the surgeon applying external force to elevate the osteotomy site. Under C-arm fluoroscopy, it was confirmed that the line connecting the two femoral condyles formed a 93° angle with the longitudinal axis of the tibial. Then, the osteotomy is fixed with 8-hole dynamic compression plate, in order to place four proximal and four holes distal to the osteotomy site. The gap is filled with autologous or allogenic bone graft. Upon satisfactory fluoroscopy, a drain tube was placed, followed by layered closure and sterile dressing (Fig. 3).

SMOT: The patient was placed in the supine position and under general anesthesia. A 7 cm longitudinal incision is made along the anteromedial aspect of the distal tibia. Two Kirschner wires are inserted about 5 cm above the ankle mortise, just proximal to the tibiofibular syndesmosis, under fluoroscopic image intensifier in order to guide the osteotomy. Then, a periosteal incision of less than 1 cm is made along the site to perform the osteotomy, in an effort to maintain as many soft tissue attached to the distal bone fragment as possible. The osteotomy is performed parallel to the ankle mortise, and the lateral cortex at the apex of the distal part of the tibia must be preserved so that it can be used as a hinge. After completing the osteotomy, the distal osteotomized fragment is shifted inferiorly by introducing an osteotome through the medial aspect of the osteotomized site. Intraoperative visualization and fluoroscopy are used to evaluate the adequacy of the correction angle and lower limb alignment. Then, the osteotomy is fixed with dynamic compression plate, in order to place five holes proximal and three holes distal to the osteotomy site. The gap is filled with autologous or allogenic bone graft (Fig. 4).

Inspection method

The Baird-Jackson ankle joint function scoring system was used to evaluate pre- and post-treatment ankle function, which consists of three dimensions: pain (0–50 points), function (0–30 points), and mobility (0–20 points), with a total score of 100 points. A higher score indicates better recovery of ankle joint function.

The lower limb alignment ratio was used to assess changes in limb alignment preoperatively, intraoperatively after correction, and at 24 months postoperatively. The lower limb alignment ratio is the relative position of the lower limb axis on the tibial plateau in full-length weight-bearing X-rays of the lower limbs, expressed as a percentage, where the most medial edge of the tibial plateau is 0% and the most lateral edge is 100%.

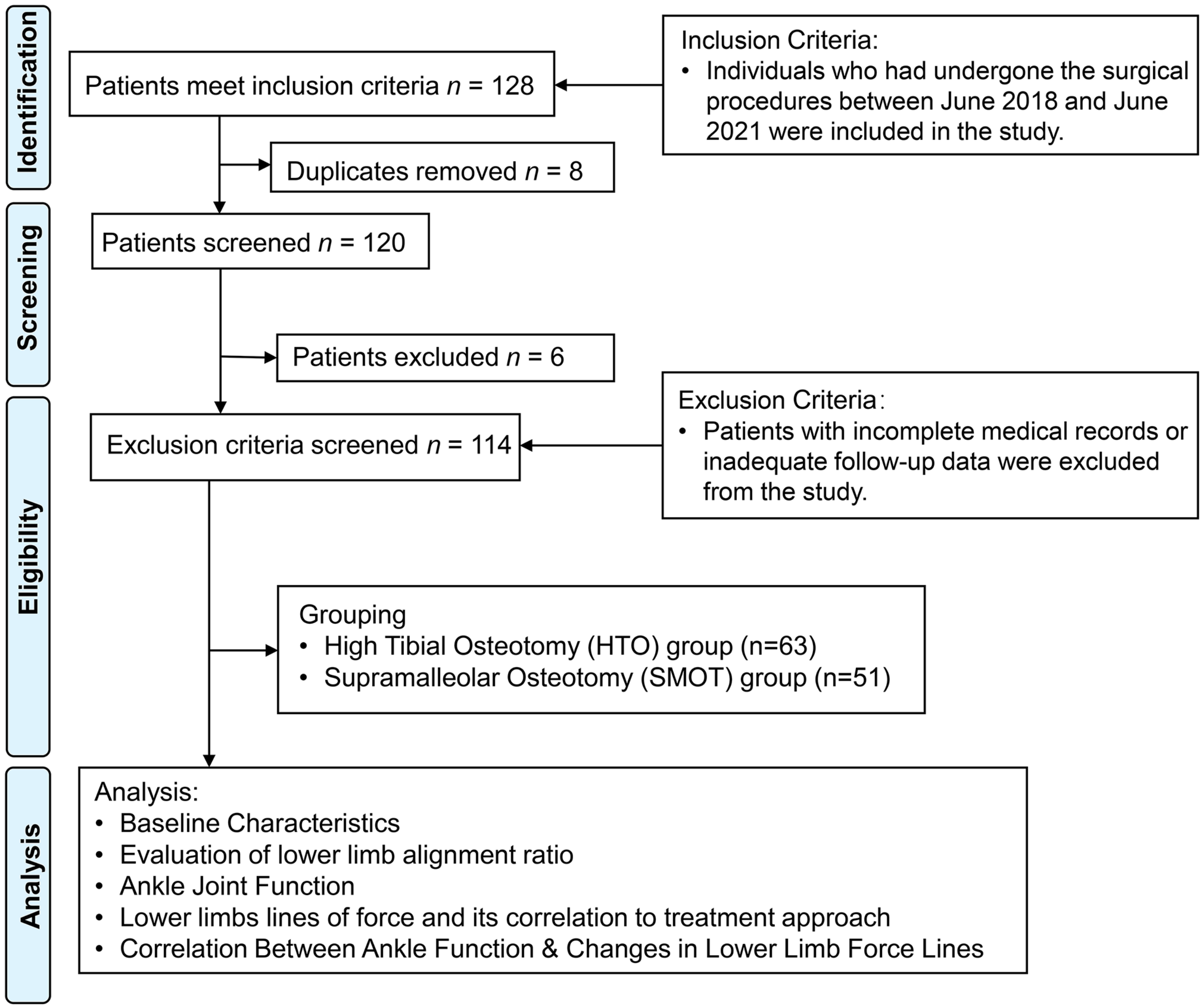

Fig. 2 Study design flow chart

Full-length weight-bearing X-rays of both lower limbs were taken from patients preoperatively and at 3 months postoperatively. The line connecting the center of the femoral head to the midpoint of the ankle was used as the lower limb axis. The angle formed between the axis and the tibial mechanical axis is the lower limb varus (valgus) angle, where if the axis is located on the outside of the tibial mechanical axis, it is considered varus and an angle $\leq 1°$ is considered normal (Deviated Group), while an angle $> 1°$ is considered abnormal (Non-Deviated Group).

Power analysis

A power analysis was conducted using G*Power 3.1.9.7 to ensure adequate statistical power for detecting significant differences between HTO and SMOT. This analysis, designed for a two-tailed test comparing the means of two independent groups, utilized an effect size dd of 0.6, an alpha error probability (α) of 0.05, and aimed for a power (1 -β error probability) of 0.8, assuming an allocation ratio of 1. The results indicated that a minimum total sample size of 90 participants (45 per group) would be necessary to achieve 80% power at an α level of 0.05. With actual sample sizes of 63 and 51 for the HTO and SMOT groups respectively, the achieved power surpasses the initial requirement, providing enhanced capability to detect significant differences between the two surgical interventions. This robust statistical power strengthens the validity and reliability of the comparative analysis in this study.

Statistical analysis

Descriptive statistics were used to summarize the baseline characteristics of the HTO and SMOT groups. Continuous variables were presented as mean ± standard deviation, while categorical variables were presented as

Fig. 3 Postoperative X-ray examination of HTO

frequencies and percentages. To compare continuous variables between the two groups, independent t-tests were performed, and for categorical variables, chi-square tests were conducted. Spearman rank correlation analysis were used to reveal the correlation between HTO/SMOT group. Besides, Spearman rank correlation analyses were carried out to assess the associations between lower limb lines of force alterations and ankle joint function. Statistical significance was set at $P<0.05$.

Results

Baseline characteristics

The baseline characteristics of the patients in the HTO and SMOT groups were comparable (Table 1), with no statistically significant differences observed in age (45.24 ± 5.67 years for HTO vs. 46.11 ± 6.32 years for SMOT, $P=0.45$), body mass index (28.56 ± 3.41 kg/m^2 for HTO vs. 29.02 ± 3.89 kg/m^2 for SMOT, $P=0.513$), distribution of affected limb (left/right), operative time (92.45 ± 12.36 min for HTO vs. 95.32 ± 13.47 min for SMOT, $p=0.244$), blood loss (180.25 ± 30.15 ml for HTO vs. 185.32 ± 28.74 ml for SMOT, $P=0.361$), and hospital stay (3.27 ± 0.95 days for HTO vs. 3.41 ± 1.05 days for SMOT, t = 0.764, $P=0.447$). Additionally, the postoperative alignment was similar between the two groups, with mean angles of 176.32 ± 3.56 degrees for HTO and 177.48 ± 3.27 degrees for SMOT ($P=0.075$). These findings suggest that the baseline characteristics and

Fig. 4 Postoperative X-ray examination of SMOT

Table 1 Baseline characteristics of HTO and SMOT groups

Parameter	HTO Group ($n=63$)	SMOT Group ($n=51$)	t/χ2	*P* value
Age (years)	45.24 ± 5.67	46.11 ± 6.32	0.758	0.45
Body Mass Index (kg/m^2)	28.56 ± 3.41	29.02 ± 3.89	0.656	0.513
Affected limb (left/right)	27 (42.86%) / 36 (57.14%)	25 (49.02%) / 26 (50.98%)	0.219	0.64
Operative time (minutes)	92.45 ± 12.36	95.32 ± 13.47	1.172	0.244
Blood loss (ml)	180.25 ± 30.15	185.32 ± 28.74	0.917	0.361
Hospital stay (days)	3.27 ± 0.95	3.41 ± 1.05	0.764	0.447
Postoperative alignment (degrees)	176.32 ± 3.56	177.48 ± 3.27	1.799	0.075

postoperative alignment were comparable between the HTO and SMOT groups, providing a strong basis for the subsequent comparative analysis of the impact of these surgical procedures on lower limb alignment and ankle function.

Evaluation of lower limb alignment ratio

The evaluation of lower limb alignment ratio revealed no significant differences between the HTO and SMOT groups before operation (17.42 ± 1.85 for HTO vs. 17.09 ± 1.45 for SMOT $p=0.283$) and after operation (62.21 ± 1.47 for HTO vs. 62.51 ± 2.13 for SMOT, $P=0.392$). However, at the 6-month follow-up, the lower limb alignment ratio in the HTO group (61.26 ± 1.66) was significantly different from that in the SMOT group (62.51 ± 1.38), with a *p* value of less than 0.001 (t = 4.384) (Fig. 5). These results indicate that while the preoperative and immediate postoperative lower limb alignment ratio were similar between the two groups, a notable difference emerged at the 6-month follow-up, suggesting a potential distinct impact of the two surgical procedures on lower limb alignment ratio.

Comparison of Ankle Joint function between two groups

The comparison of ankle joint function between the HTO and SMOT groups demonstrated significantly different outcomes in pain and function. Specifically, the HTO group exhibited higher mean scores for pain (39.54 ± 4.11 for HTO vs. 33.68 ± 3.76 for SMOT, $P < 0.001$) and function (23.51 ± 2.77 for HTO vs. 18.17 ± 2.18 for SMOT, $P < 0.001$) compared to the SMOT group, indicative of superior postoperative ankle joint function in the HTO group. However, no statistically significant difference was observed in mobility between the two groups (15.51 ± 3.47 for HTO vs. 12.45 ± 7.89 for SMOT, $P = 0.012$) (Fig. 6). These findings suggest that while both surgical procedures positively impacted ankle joint function, HTO may result in better pain alleviation and functional improvement compared to SMOT, highlighting the potential differential effectiveness of these interventions in addressing ankle function after surgery.

The comparison of lower limbs lines of force and its correlation to treatment approach

The comparison of lower limb lines of force between the HTO and SMOT groups revealed a significant association between the surgical procedure and the alteration of lower limb lines of force, with a *p* value of less than 0.001 ($\chi 2 = 30.675$). Specifically, in the HTO group, 82.54% of patients exhibited non-deviated lower limb lines of force, whereas in the SMOT group, only 29.41% of patients had non-deviated lower limb lines of force. Additionally, the

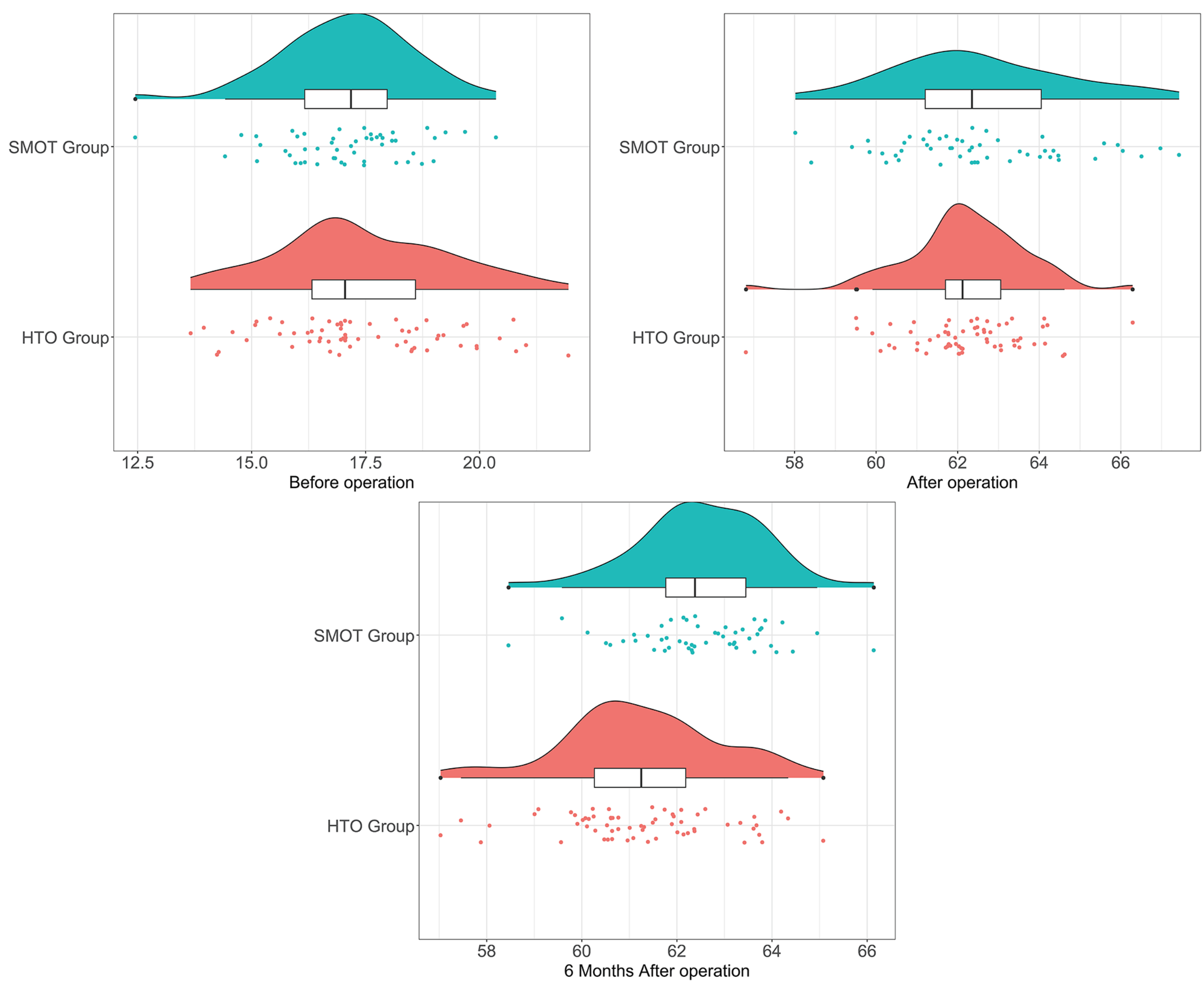

Fig. 5 Evaluation of lower limb alignment ratio

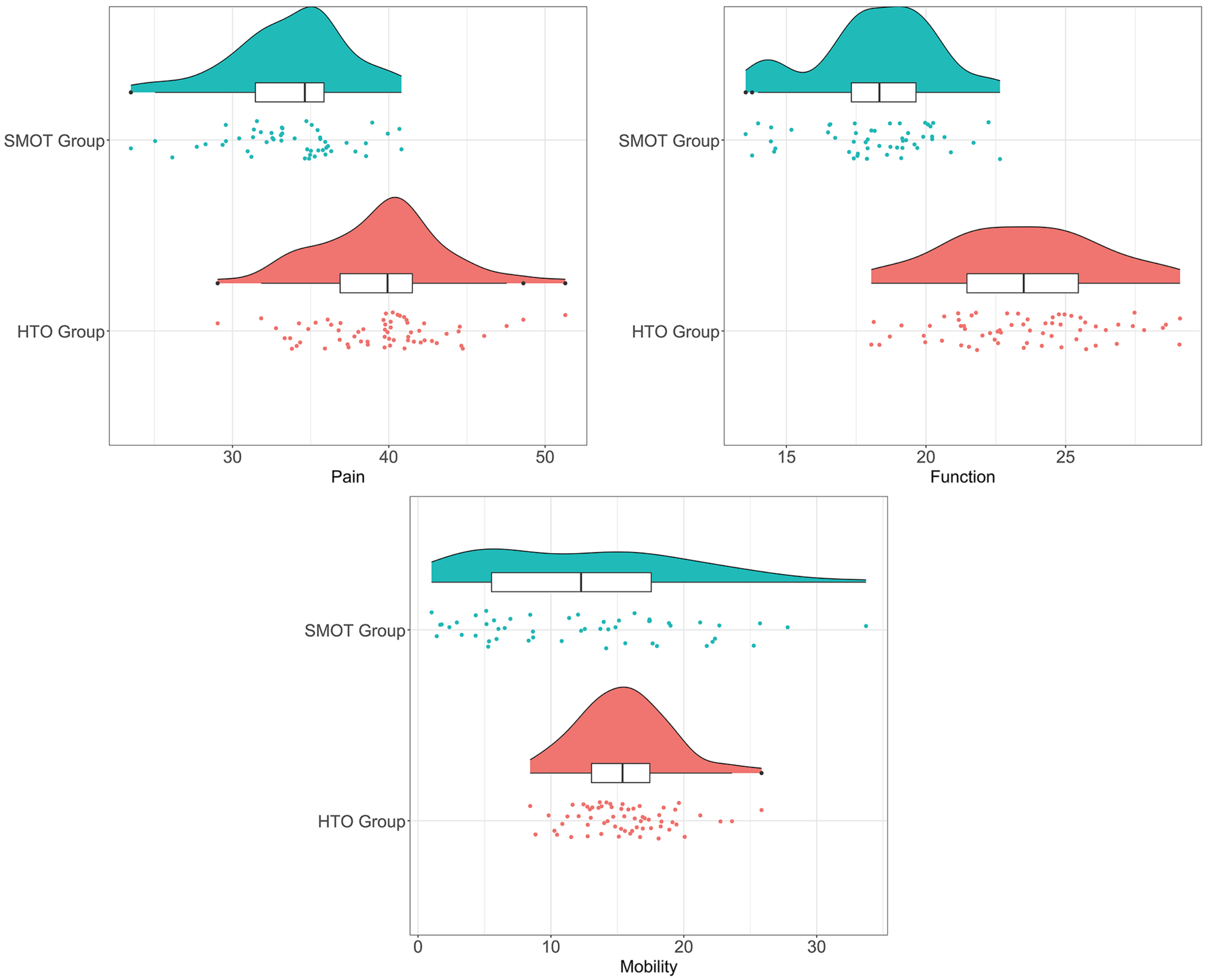

Fig. 6 Comparison of Ankle Joint Function between Two Groups

analysis demonstrated a significant correlation (Fig. 7, $P < 0.001$) between the alteration of lower limb lines of force and the surgical procedure, with an r value of 0.537 and an R2 value of 0.288, indicating that the choice of surgical approach (HTO or SMOT) significantly impacts the changes in lower limb lines of force. These results underscore the distinct impact of HTO and SMOT on lower limb biomechanics and highlight the importance of considering this factor in the selection of surgical interventions for addressing lower limb alignment issues.

The correlation analysis between ankle joint function and changes in lower limb lines of force revealed significant associations

Pain exhibited a positive correlation with changes in lower limb lines of force (Table 2), with an r value of 0.227 and a significant *p* value of 0.015, indicating a modest relationship between these variables. Function demonstrated a stronger positive correlation with changes in lower limb lines of force, as evidenced by an r value of 0.45 and a highly significant *p* value of less than 0.001, implying a more substantial association. Additionally, mobility displayed a modest positive correlation with changes in lower limb lines of force, with an r value of 0.191 and a *p* value of 0.042. These results underscore the influence of lower limb biomechanics on ankle joint function, particularly in relation to pain, function, and mobility, highlighting the interconnectedness of these aspects in the context of lower limb realignment surgery.

Discussion

The management of lower limb malalignment and associated deformities is critical for preserving overall stability, mobility, and quality of life in affected individuals [19–21]. HTO primarily aims at correcting the alignment of the lower limb by modifying the load-bearing axis, which indirectly can influence ankle function, SMOT specifically targets deformities around the ankle joint

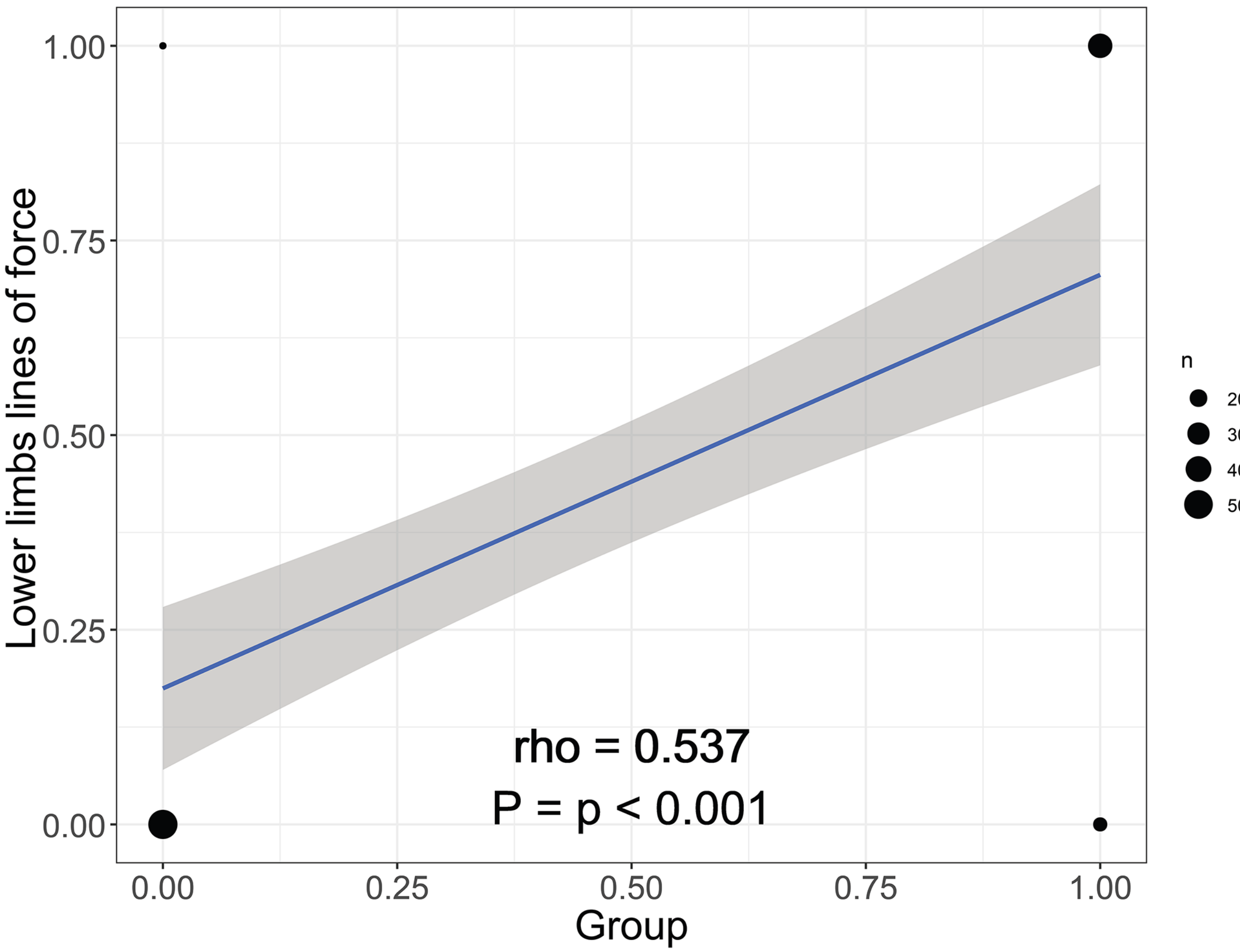

Fig. 7 The correlation of Lower limbs lines of force and to treatment approach

Table 2 Correlation analysis between ankle joint function and changes in lower limb lines of force

Parameter	*r*	R2	*P* value
Pain	0.227	0.052	0.015
Function	0.45	0.202	*P* < 0.001
Mobility	0.191	0.036	0.042

[22–27]. While both interventions have been individually studied, a comprehensive comparison of their postoperative impact on lower limb alignment and ankle function is essential for informing clinical decision-making and optimizing patient outcomes [28–35]. Our retrospective study aimed to address this gap by conducting a comparative analysis of the impact of HTO and SMOT on lower limb alignment and ankle function, shedding light on the relative effectiveness of these surgical approaches. The findings of our study have significant implications for orthopedic treatment and may guide treatment strategies for patients undergoing lower limb realignment surgery.

Our study revealed several important insights into the comparative effectiveness of HTO and SMOT in addressing lower limb alignment and ankle function. The evaluation of weight-bearing line ratio showed that while the preoperative and immediate postoperative ratios were similar between the two groups, a notable difference emerged at the 6-month follow-up. This suggests a potential distinct impact of the two surgical procedures on lower limb alignment, with implications for the long-term outcomes and stability of the lower limb. Furthermore, the comparison of ankle joint function between the HTO and SMOT groups demonstrated differences in pain and function, with the HTO group exhibiting superior postoperative outcomes in these aspects. However, there was no statistically significant difference in mobility between the two groups.

The analysis of lower limb lines of force also provided valuable insights into the impact of HTO and SMOT on biomechanics. The results revealed a significant association between the surgical procedure and the alteration of lower limb lines of force, with a notable correlation between the choice of surgical approach (HTO or SMOT) and changes in lower limb lines of force. This underscores the distinct impact of HTO and SMOT on lower limb biomechanics, highlighting the importance of considering this factor in the selection of surgical interventions for addressing lower limb alignment deformity. Additionally, the comparison of baseline characteristics and ankle joint function between non-deviated and deviated groups further emphasized the potential impact of lower limb alignment on postoperative ankle function.

Our study's findings align with existing literature [10, 36–39] on the individual efficacy of HTO and SMOT in addressing lower limb malalignment. HTO has been shown to effectively modify the load-bearing axis of the lower limb, thereby reducing pressure on the damaged part of the knee joint and improving weight-bearing distribution [40–42]. This aligns with our findings of superior postoperative outcomes in ankle joint function, specifically in pain alleviation and functional improvement, in the HTO group. On the other hand, SMOT aims to correct the alignment of the ankle joint by altering the load distribution through the tibia, addressing deformity related to ankle instability and deformity. HTO, due to its proximity to the proximal tibia, allows for easier alteration of the alignment of the lower limb with minimal angle changes. Additionally, the surgical site's distance from the ankle joint facilitates better preservation of local blood circulation, thereby promoting the recovery of ankle joint function [43].

The implications of our study's findings extend to clinical practice and treatment decision-making. The findings also have the potential to contribute significantly to the advancement of orthopedic treatment and surgical interventions, offering valuable insights that may inform clinical practice and ultimately enhance the quality of life for patients undergoing lower limb realignment surgery. The insights gained from this study could be instrumental in designing patient-specific guides to plan deformity corrections more accurately. Utilizing advanced imaging techniques such as weight-bearing CT scans, personalized surgical guides can facilitate precise osteotomy planning and execution, potentially leading to better long-term outcomes for patients [44]. Furthermore, the use of patient-specific instrumentation (PSI) in SMOT has demonstrated advantages in achieving optimal correction of cavovarus foot deformities [45]. By integrating these innovative approaches into clinical practice, we can enhance the precision and effectiveness of surgical interventions aimed at correcting lower limb alignment and improving ankle function.

It is important to acknowledge certain limitations of our study. As a retrospective analysis, our study is inherently limited by its reliance on existing medical records and databases, which may have introduced inherent biases and limitations related to data availability and completeness. Additionally, the retrospective nature of the study may have limited the ability to control for potential confounding factors and variables that could influence the outcomes. Future prospective studies with larger sample sizes and longer follow-up periods are warranted to further validate and expand upon the findings of our study, providing more robust evidence for the comparative effectiveness of HTO and SMOT in addressing lower limb alignment and ankle function.

Conclusion

In conclusion, our retrospective study provides valuable insights into the comparative impact of HTO and SMOT on lower limb alignment and ankle function after surgery. The findings contribute to the body of knowledge on lower limb realignment surgery, offering valuable insights for clinicians and healthcare providers involved in the management of lower limb malalignment and associated conditions. Future research should aim to validate these findings through prospective studies with larger sample sizes and longer follow-up periods, explore patient-specific factors influencing surgical outcomes, investigate biomechanical effects using advanced imaging techniques, and evaluate patient-reported outcomes and quality-of-life measures to provide a more comprehensive understanding of the long-term benefits and implications of these procedures.

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None.

Author contributions
Jun Li: Conceptualization, Formal analysis, Funding acquisition. Ruiqi Li: Conceptualization, Methodology, Investigation. Yijiong Li: Methodology, Formal analysis, Data Curation. Zhenshuan Zhao: Data Curation, Methodology, Writing-Original Draft.

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Data availability
The datasets used during the present study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study received approval from the Institutional Review Board and Ethics Committee of the First Hospital of Hebei Medical University.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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