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Accuracy and Precision of Computer-Assisted Surgery Compared with Conventional Instrumentation for Total Ankle Arthroplasty

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Abstract

Computer-Assisted Surgical (CAS) systems have demonstrated successful application in joint arthroplasty, enhancing the precision of resections across multiple joint surgeries, including hip, knee, and shoulder procedures. A CAS system for Total Ankle Arthroplasty (TAA) was developed with the objective of streamlining the surgical process and improving the accuracy of bone resections within the foot and ankle. The system's accuracy was subsequently compared to a conventional technique using artificial ankle joint specimens. The results of these evaluations showed lower levels of resection error for tibial slope and talar slope and talar cut height for the navigated instrumentation when compared to conventional surgery.

1 Introduction

Computer-Assisted Surgical (CAS) systems have demonstrated their efficacy in enhancing the accuracy of joint arthroplasty resections. The utilization of CAS has resulted in a reduction of outliers and improvement in the targeted alignment of orthopedic implants across many orthopedic applications [1]. Total ankle arthroplasty (TAA) constitutes a suitable surgical intervention for end-stage ankle osteoarthritis, and contemporary TAA techniques have yielded favorable clinical outcomes, establishing them as a viable alternative to ankle arthrodesis [2,3]. The alignment of implants during TAA remains a complex challenge due to limited surgical exposure and reliance on fluoroscopic guidance. To address these limitations, a TAA application for a CAS system was developed by incorporating CT-based alignment to facilitate the procedure for enhancing the accuracy of bone resections while ostensibly reducing dependence on fluoroscopy. The accuracy and precision of the newly developed TAA CAS system was previously assessed relative to anatomic landmarks [4] (Figure 1A). The primary objective of this study was to compare the accuracy of a conventional technique alongside the CAS system using the same method.

2 Methods

TAA was performed by a board-certified, fellowship-trained orthopedic surgeon on twelve artificial ankle joint specimens (PN1132-3, Pacific Research) using conventional instrumentation (Vantage, Exactech). Video tracking was performed to confirm surgical technique was standardized for all specimens. Scans of each of the twelve specimens were performed before TAA using a structured light industrial scanner (Metrascan, Black Elite) used for assessing surface profiles with an accuracy better than 25μm. Bone resections were performed using conventional cutting guides and positioning jigs in conjunction with fluoroscopy (Figure 1B). Resections on the talus included a flat cut with three degrees of freedom (e.g. varus, slope, and cut height), whereas tibial resections included distal and medial cuts with five degrees of freedom (e.g. varus, slope, axial rotation, medial offset and cut height). Consistent with established protocols employed in prior peer-reviewed knee arthroplasty studies [5-7], the resected bones were scanned and subsequently overlaid with the initial model using an open source cloud fitting software (CloudCompare) to evaluate the discrepancy between the actual and planned resections. Finally the conventional results were compared to the CAS results from the previously executed study.

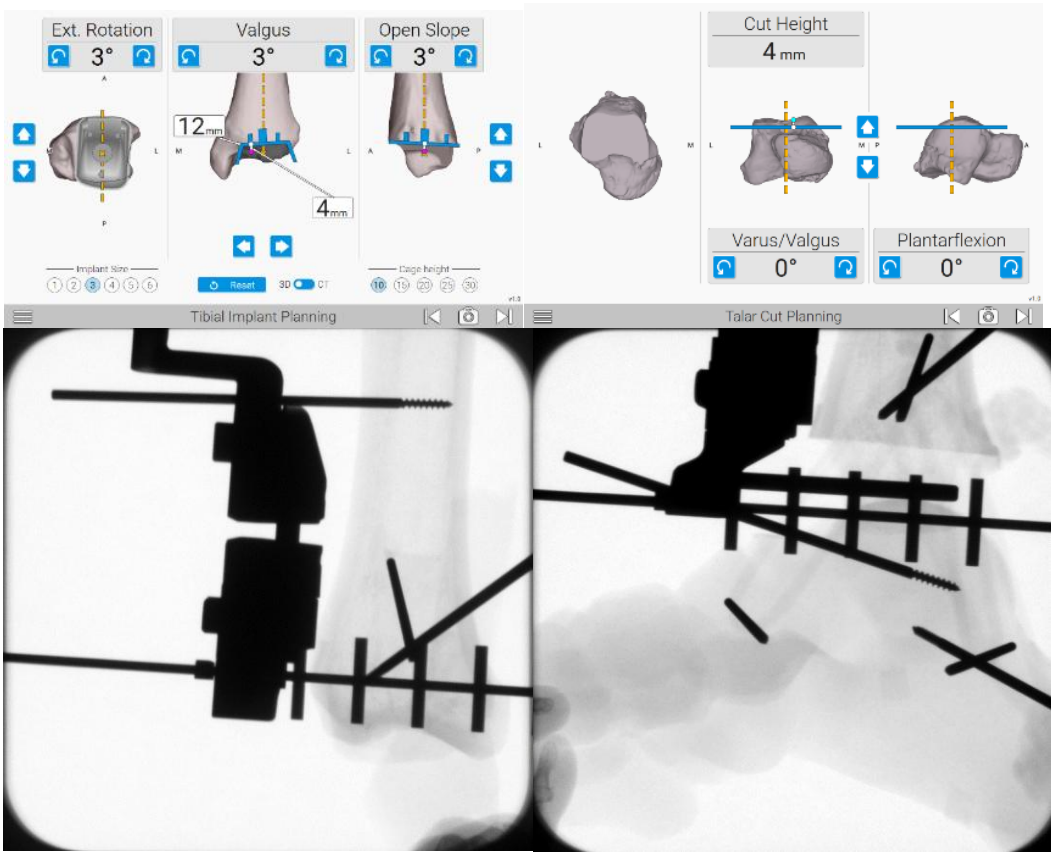

Figure 1A: CAS planning of the tibial and talar resections (top)
Figure 1B: Conventional alignment of the tibia and talus using fluoroscopy (bottom).

3 Results

Tibial deviations from plan and 95% confidence intervals were compared: varus error was 1.18°±0.50° for conventional and 0.22°±0.56° for CAS, closed slope error was -2.38°±0.78° for conventional and -0.50°±0.53° for CAS, internal rotation error was -0.31°±2.45° for conventional and -0.10°±0.69° for CAS, cut height error was 0.58mm±0.49mm for conventional and 0.14mm±0.48mm for CAS, and mediolateral position error was 0.32mm±1.45mm for conventional and 0.15mm±0.59mm for CAS. For the talus: varus error was 0.15°±1.05° for conventional and -0.24°±0.79° for CAS, slope error was -4.12°±1.27° for conventional and -1.32°±0.55° for CAS, and cut height error was 0.58mm±0.49mm for conventional and 0.14mm±0.48mm for CAS. The mean and 95% confidence intervals of all parameters were within 2mm and 2° with the exception of tibial closed slope, tibial internal rotation and talar slope (Figure 2).

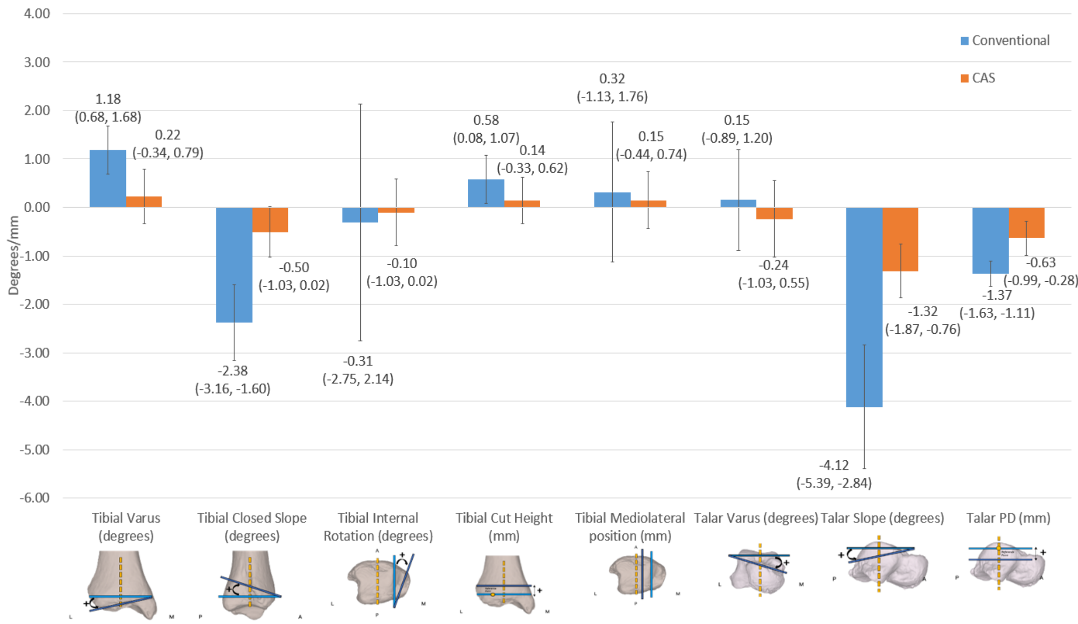

Figure 2: Comparison of conventional and CAS TAA resection parameter average positions and 95% confidence intervals

4 Discussion

The results of the study show that the bone resections using artificial ankle joint specimens using this conventional instrumentation and fluoroscopy are consistent with absolute deviation reported in literature [8,9]. The coronal plane was associated with a greater accuracy than the sagittal plane. The accuracy and precision of the conventional instrumentation was lower than the same resections performed with CAS when combining all parameters with an average absolute accuracy of 1.63°±1.21° and 0.76mm±0.73mm for the conventional instrumentation and 0.48°±0.62° and 0.31mm±0.47mm with CAS. The CAS system helped to reduce outliers of the tibial slope/rotation and talar slope parameters. Regarding limitations, the surrounding soft tissues were not present, and variability across multiple users was not considered. Future work should consider additional surgeon users, cadaver specimens with ankle arthritis and/or deformity, and comparison to patient-specific instrumentation (PSI) techniques. In conclusion, the conventional instrumentation provided acceptable levels of accuracy and precision while the CAS system was able to improve accuracy and precision while reducing outliers without the need of fluoroscopy for positioning of the instrumentation.

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