Evaluation Of Knee Deformity On Alignment Discrepancies During Total Knee Arthroplasty Using A Computer-assisted Guidance System

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Introduction: Clinical outcomes of total knee arthroplasty (TKA) are especially sensitive to lower extremity alignment and implant positioning, with research associating tibial bone cuts in more than 3° of residual varus with higher risk of implant failure. From pre-operative planning to final implant cementation, TKA preparation is a succession of many individual steps, each presenting potential sources of error that can result in devices being implanted out of the desired range of alignment. The objective of our study was to evaluate alignment discrepancy occurring during different TKA steps using an image-free computer-assisted orthopedic surgery (CAOS) guidance system (Exactech GPS, Blue-Ortho, Grenoble, FR). This evaluation was performed by comparing steps for a leg model with a normal mechanical axis with a steps used for a leg model with an abnormal (i.e., in excessive varus or valgus) mechanical axis.

Methods: We used a commercially available artificial leg (MITA trainer leg M-00058, Medical Models, Bristol, UK) that simulates the proximal tibia and distal femur using modular knee models. We randomly and sequentially used simulated knees from a pool of varus-deformed (n=12), neutral (n=12), and valgus-deformed (n=4) models (MITA knee insert M-00566, M-00598, M-00567; respectively, Medical Models, Bristol, UK). A pre-surgical profile was established to define resection parameters for the proximal tibial and distal femoral cuts (Figure 1A). The proximal tibial cut was defined by the resection level off a medial plateau reference point, the varus/valgus alignment, and the slope angle. The lateral resection was therefore an output and not reported. A similar rationale applies to the medial resection of the distal femoral cut.

First, the CAOS system was used to acquire the pre-identified landmarks. Next, the cutting block was adjusted to match the resection targets and fixed to the bone using locking pins. Bone cuts were performed and the actual cuts checked. Data from the guidance system were collected at three separate steps: (1) cutting block adjusted but not pinned to the bone (Figure 1B), (2) cutting block adjusted and pinned to the bone (Figure 1C), and (3) after the cuts were checked (Figure 1D). These data were then compared to the resection target parameters to track potential dispersions occurring during the process.

Due to the amount of data (i.e., four studied resection parameters per bone, three operative steps, and three knee model types), the authors introduced an “error index”, which was a unitless indication of overall error magnitude obtained by averaging the absolute values of all linear and angular measurement errors. Due to knee model dimensions (~55 mm), the authors equally considered linear and angular measurement values (i.e., 1 mm equivalent to 1°).
Results: Regardless of resection parameter or bone deformity type, all linear or angular error distributions were symmetrical around the neutral value (i.e., the mean difference between the checked and the targeted value was always inferior to 0.5 mm or 0.5°), which tends to imply there was no obvious skew in terms of error direction. The observed errors were largely random in nature, instead of having a systematic bias. The type of knee model deformity had almost no effect on overall error magnitudes across different surgical steps. This was illustrated by similar overall error index trends for both the femur and the tibia of the three different of knee inserts.

Discussion: Few studies present possible causes for errors when using CAOS for TKA. Notably, Bathis et al. evaluated cutting errors as the difference between the primary cutting block position and the resulting resection plane. As a result, errors due to a malpositioning of the guide jig itself were not described. In other words, they weren’t able to directly differentiate the degree to which deviation of the resection plane is due to inadequate fixation of the cutting block or a result of the sawing procedure. Based on 50 patients, they reported mean errors of $1.4^\circ \pm 1.3^\circ$ and $1.0^\circ \pm 1.0^\circ$ for femoral and tibial flexion/extension, respectively.
In general, the authors found the dispersions at each step to seemingly be random. For both the tibia and the femur, a significant increase in the error index from the adjusted to the attached step (p<0.001 and p=0.005; respectively) was observed, meaning the pinning of the cutting block to the bone is a key step. Also, observing the relationship between linear and angular parameters was relevant. For example, for the femur, a cut in extension was highly correlated with lower than expected distal femoral resection (Pearson correlation factor of 0.783 and 0.913 at the checked step for the medial and lateral distal femoral resections; respectively, p<0.001).

Regardless of the presence and type of deformity, the evaluated image-free computer-assisted guidance system did not exhibit substantial alignment dispersions during any step of the procedure. Even at the final step (“checked”), the mean error indexes for all three deformity groups were less than 0.7, reflecting the robustness of the system and the surgical technique.

Significance: Knee prosthesis implantation involves successive discrete steps, each representing a potential source of misalignment due to error. The authors found the dispersions at each step to seemingly be random. For both the tibia and the femur, a significant increase in the error index was observed during the pinning of the cutting block to the bone.

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