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Precision of Robotic Guided Instrumentation for Acetabular Component Positioning

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ABSTRACT

Robotic computerized instrumentation that guides bone preparation and cup implantation in total hip arthroplasty was studied. In 38 patients (43 hips) intraoperative cup inclination and anteversion were validated by postoperative CT scans. Planned inclination was 39.9° ± 0.8° and with robotic instrumentation was 38. 0° ± 1.6° with no outliers of 5°; on the postoperative CT scan there were 5 outliers (12%). Planned anteversion was 21.2° ± 2.4° and intraoperatively was 20.7° ± 2.4° with no outlier of 5°; on the CT there were 7 outliers (16%). The center of rotation (COR) was superior by a mean 0.9 ± 4.2 mm and medial by 2.7 ± 2.9 mm. This robotic instrumentation achieved precision of inclination in 88%, anteversion in 84% and COR in 81.5%.

The most common indications for revision of total hip arthroplasty are dislocation and aseptic loosening [1,2]. Multiple studies have correlated these complications to poor implant position [3–8]. Likewise, poorly positioned acetabular cups have been correlated with additional complications of impingement, edge loading, increased wear and pelvic osteolysis [6–13]. An analysis of large cohorts at both a tertiary and a community hospital found at least 50% of cups to be outside the safe zone of Lewinnek et al [12] for both inclination and anteversion [13]. There are similar data for cups placed to a target number for anteversion with outliers beyond 10° of 10–50% [14,15].

Instrumentation using computer navigation has improved the accuracy of component positioning by providing the surgeon quantitative knowledge to give greater precision for intraoperative decisions [14,6–20]. However, computerized instruments are still manually controlled, and manual reaming, even with computerized instruments, can have a difference between the planned and reamed center of rotation for the cup of 6.39 ± 2.44 mm [21]. Robotic computer guided instrumentation was designed to prevent the errors of manual reaming and cup implantation by providing a physical constraint to surgical tools by stereotactic boundaries, i.e., virtual walls, and thereby enabling accurate performance. During reaming, robotic instrumentation allows the surgeon to work within a virtual haptic tunnel, and a fail-safe mechanism stops the reamer if it exceeds the planned bone preparation in any plane by more than 2 mm. Cup impaction likewise is done through this haptic constrained tunnel so accuracy of inclination, anteversion and center of rotation can be achieved as planned.

New technology introduced into clinical practice necessitates validation of its theoretical improvement. Our study was conducted to confirm that the software of this robotic system (MAKO-Stryker, Ft. Lauderdale, FL) performed as accurately and precisely as expected. Two questions were asked: (1) How accurate and precise was acetabular cup inclination and anteversion intraoperatively as compared to the preoperatively planned positions, and as validated by postoperative CT scans? (2) How often was the cup center of rotation (hip center of rotation) within 3 mm superior and 5 mm medial as measured on postoperative anteroposterior (AP) pelvic radiographs?

Material and Methods

This was an imaging study to validate a surgical technique. It was a prospective study of acetabular component position in primary total hip arthroplasty with the cup implanted using robotic guided instrumentation (MAKO Rio Robot, Ft. Lauderdale, FL). Forty-four patients (48 hips) agreed to participate in this prospective study approved by the institutional review board (IRB) and all patients gave informed consent. One hundred forty-six patients (162 hips) were operated by the surgeon (LDD) during the ten months of this study but only 75 of these patients were operated with the robot. Forty-four of these 75 patients agreed to the study with those who declined doing so because of the necessity of a postoperative CT scan. In three of the 44 patients (5 hips) the robotic arm could not function because it impinged on the tissues within the wound. Therefore, the study population is 40 patients with 43 hips (Table 1). In the 5 cups implanted manually we could still obtain quantitative measurement of their inclination and anteversion by a method named the Fitplane in which the pointer guide touched the metal edge of the cup at five different points, and

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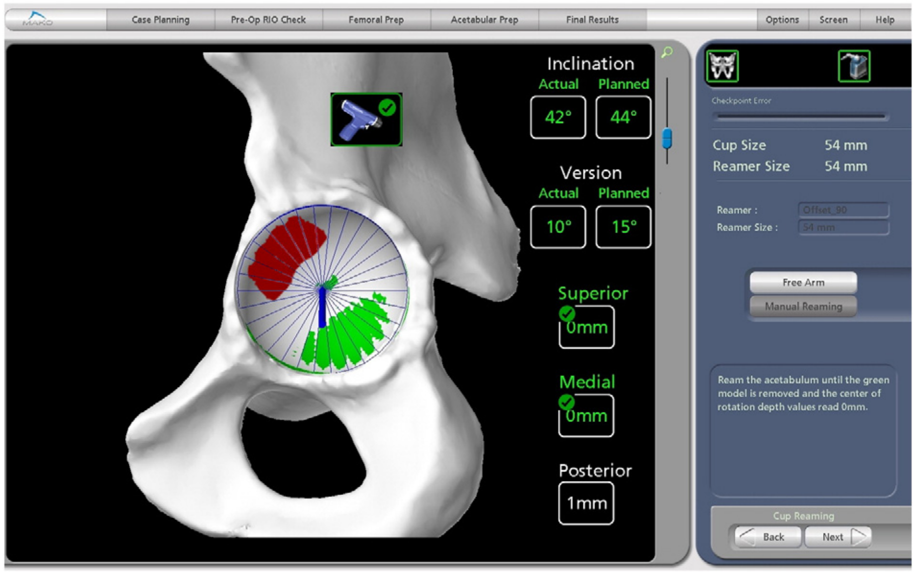

Fig. 1. Computer screen during reaming. Green represents the area to be reamed; white is the area reamed to correct depth; red is the area reamed beyond planned depth. Irregularity of reaming by 1–2 mm is the reason the fail-safe mechanism does not activate until any area is overreamed by 2 mm. Vertical boxes show the remaining depth to be reamed to reconstruct the COR, and when the box turns green the depth is reached. The remaining posterior reaming matches the green area on the screen. The inclination and anteversion numbers can be within 10° of plan during reaming.

the robotic software could then calculate the inclination and anteversion which was displayed on the computer screen. With manual implantation the cup COR could not be determined.

All surgeries were performed using the posterior mini-incision [22] by a single surgeon (LDD) with operative time from incision through closure of mean 85 ± 17 minutes. The patient was in the lateral position, and the pelvic array with reflective markers was attached to the pelvic rim with a baseplate secured with 1/8″ threaded pins. Inside the wound, a 4.5 mm screw was inserted in the posterior–superior pelvic bone 1 cm proximal to the acetabular rim, and it was touched with the array guide to confirm the authenticity of the robotic numbers. Surface registration of 32 points of the acetabulum and its rim registered the bony acetabulum into the software which matched it to the virtual 3D pelvis constructed from the CT scan. A registration error of the bony acetabulum of less than 0.5 mm was accepted. Precise reaming is controlled by a stereotactic interface which restricts the reamers to a predefined volume of resection so that a line-to-line reaming was done for the planned cup size. A fail-safe mechanism stops the reamer if the COR in any direction is exceeded by 2 mm (Fig. 1). The cup was then impacted through the haptic tunnel until it was seated within 0–1 mm of the acetabular surface. The system error for cup inclination and anteversion was 5° and that is the reason that outliers were considered to be beyond 5°.

A preoperative CT scan was used to plan the size and coverage of the cup in the acetabular bone as well as the COR in the cephalocaudad, medial–lateral, and anterior–posterior directions (Fig. 2). The same imaging scanner in the radiology department was used for both the preoperative and postoperative CT scans of the pelvis (64 channel multidetector CT, Brilliance 64, Phillips Medical Systems, Best, The

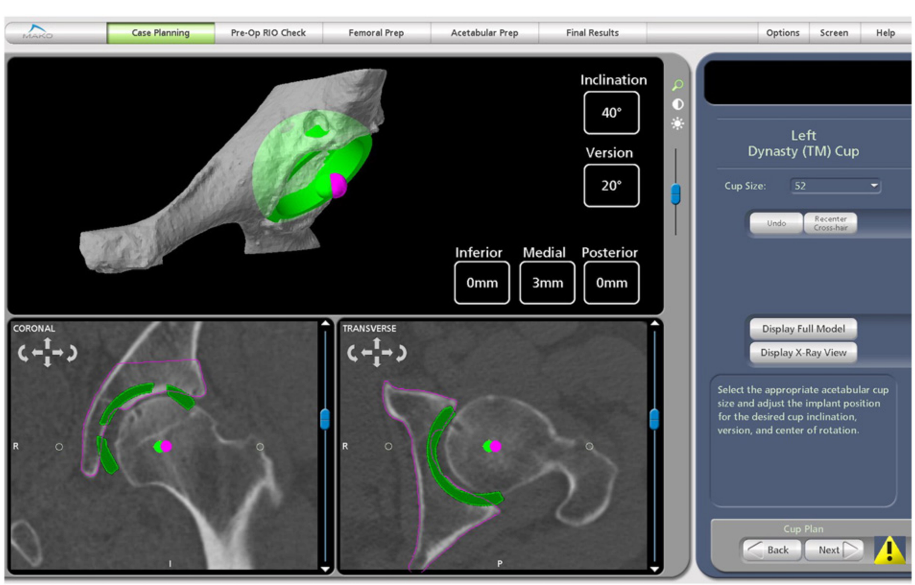

Fig. 2. Preoperative plan on CT scan. The inclination and anteversion, size and center of rotation (COR) of the planned acetabular cup are determined with the relationship of the cup COR (green) to the arthritic hip COR (magenta) displayed. The horizontal numbers show the planned COR in all planes with the horizontal COR 3 mm medial to the hip COR.