Cup placement accuracy with robot-assisted total hip arthroplasty

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Introduction: Acetabular cup positioning and alignment are critical factors affecting the impingement-free range of motion, leg-length, and dislocation potential with total hip arthroplasty. Methods to improve cup placement accuracy have included intraoperative imaging, image-based and non-image-based navigation systems, and now haptic or hands-on robotic surgical assistants. The purpose of this study was to quantify acetabular cup placement errors in total hip arthroplasty using standard instrumented techniques and using haptic robotic guidance.

Methods: Twelve total hip arthroplasties were performed bilaterally on six cadavers. The surgeries were planned based upon preoperative CT scans. One side of each specimen was operated with standard instrumented techniques while the other was carried out using haptic robotic guidance for reaming and cup impaction. Postoperative CT scans were acquired and segmented to identify the implants and bone. Three-dimensional cup placement errors were assessed by comparison of the preoperative plan and the postoperative scans (Figure 1). Leg reduction/lengthening and lateral offset were assessed by tracking the change in position of the native femoral head center, pre- and postoperatively (Figure 2). Leg-length and offset values reported by the robotic navigation system were recorded by the surgeon intraoperatively and were selected to avoid impingement and large changes in leg-length. The difference in reported leg-length and offset compared to an independent post-operative assessment was reported.

Results: Cup inclination errors (root mean squared) averaged 11.6 deg and 2.3 deg for manual and robotic surgeries, respectively ($p = 0.01$). Cup anteversion errors averaged 8.9 deg and 2.6 deg for manual and robotic surgeries ($p = 0.01$). Cup location errors averaged 4.1 mm and 2.8 mm for manual and robotic surgeries, respectively ($p=0.13$). Leg-length and offset of the robotic surgeries were restored to within 3.3 mm and 6.3 mm of the reported values, respectively.

Discussion: Accurate acetabular cup placement is associated with increased impingement-free range of motion, improved wear performance, and lower dislocation rates. The robotic guidance system provided accurate assessment of leg-length and offset intraoperatively. Our in vitro data suggest that robotic assistance in cup reaming and impaction can result in a significant improvement in cup placement accuracy. Additional patient trials will be required to determine if similar improvements are realized in clinical practice.

Significance: Current manual instrumentation techniques are not suitable for accurate cup reaming and impaction in total hip arthroplasty, resulting in increased dislocation rates, impingement and wear. Using a robotic-assisted surgical technique, acetabular cup placement was achieved within 1.9 mm and 2.6 deg of a preoperatively planned position and overall leg-length and offset were accurately provided intraoperatively, with the goal of improving implant performance and longevity.

Figure 1. Acetabular cup placement accuracy was determined by comparing the preoperative planned cup position (blue) with the actual cup position determined from postoperative CT scans. In the case shown, the left hip was performed with traditionally instrumented manual techniques and the right hip was performed with hapatic robotic guidance for broaching the acetabulum and impacting the cup.

Figure 2. Leg length (LL) and lateral offset (OS) was determined by comparing the position of the preoperative native femoral head center (FC – preop, red) to the postoperative virtual femoral head center (FC – postop, green).

Robotic Guidance Error (mm, deg)					
	ANT	SUP	RIGHT	INCL	ANTE
1	-1.4	-1.2	-0.3	-0.8	-0.9
2	-0.8	0.0	0.5	-0.4	3.5
3	-0.4	-2.1	0.9	0.6	3.2
4	-0.7	-3.1	-3.2	-0.3	-0.6
5	-2.0	1.3	0.6	4.5	0.8
6	1.3	-1.9	0.8	2.8	3.9
RMS	**1.2**	**1.9**	**1.5**	**2.3**	**2.6**

Standard Instrumentation Error (mm, deg)					
	ANT	SUP	RIGHT	INCL	ANTE
7	0.4	0.0	0.4	6.1	2.1
8	5.9	-4.6	-1.6	18.1	-11.9
9	-2.7	1.3	2.0	-13.8	16.5
10	0.7	1.1	2.9	12.6	3.0
11	3.3	-0.8	3.1	-6.4	-7.3
12	1.9	-3.2	-1.3	15.9	10.7
RMS	**2.8**	**2.2**	**2.0**	**11.6**	**8.9**

***Table 1**. Acetabular cup translation (anterior, superior, and right) and rotation (inclination and anteversion) errors relative to their planned/reported values are shown.*