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A Pilot Study of Augmented Reality Technology Applied to the Acetabular Cup Placement During Total Hip Arthroplasty

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A B S T R A C T

Background: We developed an acetabular cup placement device, the AR-HIP system, using augmented reality (AR). The AR-HIP system allows the surgeon to view an acetabular cup image superimposed in the surgical field through a smartphone. The smartphone also shows the placement angle of the acetabular cup. This preliminary study was performed to assess the accuracy of the AR-HIP system for acetabular cup placement during total hip arthroplasty (THA).
Methods: We prospectively measured the placement angles using both a goniometer and AR-HIP system in 56 hips of 54 patients undergoing primary THA. We randomly determined the order of intraoperative measurement using the 2 devices. At 3 months after THA, the placement angle of the acetabular cup was measured on computed tomography images. The primary outcome was the absolute value of the difference between intraoperative and postoperative computed tomography measurements.
Results: The measurement angle using AR-HIP was significantly more accurate in terms of radiographic anteversion than that using a goniometer (2.7° vs 6.8°, respectively; mean difference 4.1°; 95% confidence interval, 3.0-5.2; $P < .0001$). There was no statistically significant difference in terms of radiographic inclination (2.1° vs 2.6°; mean difference 0.5°; 95% confidence interval, −1.1 to 0.1; $P = .13$).
Conclusion: In this pilot study, the AR-HIP system provided more accurate information regarding acetabular cup placement angle than the conventional method. Further studies are required to confirm the utility of the AR-HIP system as a navigation tool.

Optimal anteversion and inclination angles of the acetabular cup are crucial for hip function after total hip arthroplasty (THA) [1–9]. The interaction between acetabular cup position and femoral stem anteversion contributes to the functional range of hip motion, while preventing intra-articular and extra-articular impingements, instability, and polyethylene wear [1–10].

A mechanical guide has been the most common technique to place the acetabular cup in THA. The accuracy of the mechanical guide is not sufficiently accurate to obtain satisfactory placement angle of the acetabular cup [11–13]. Although computed tomography (CT)–based navigation may be one of the most accurate methods for THA, it has not been widely adopted because of its high cost, invasiveness, and prolonged operation duration [14–16]. To resolve these issues, we have developed an acetabular cup measurement device, the AR-HIP system, using a novel image technology, which is called augmented reality (AR), a variant of virtual reality [17,18]. The AR-HIP system is easy to use and requires no expensive equipment or software.

AR is defined as "a live, copied view of a physical, real-world environment whose elements are augmented by computer-generated sensory input, such as sound, video, graphics, or global positioning system data" [17,19]. Although there are various kinds of AR, the most common is based on systems that displays a 3-dimensional (3-D) model on a monitor by recognizing markers, which are sometimes called targets, that contain the information. Regardless of the camera angle, these relationships in positioning are consistent, because both the marker and 3-D model data determine the respective 3-D positioning. This allows the operative team to see 3-D models on a monitor as if they existed in reality.

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This pilot study was performed to investigate the accuracy of the acetabular placement angle measured using the AR-HIP system compared with that using the conventional mechanical guide. The hypothesis was that the AR-HIP system would provide more accurate placement angle than the mechanical guide.

Materials and Methods

Patients

In this pilot study, all participants provided a signed informed consent form after receiving an explanation of the procedures, radiological studies, follow-up schedules, and possible risks of the study. This study was performed in compliance with the Declaration of Helsinki and was approved by the local ethics committee.

We prospectively studied acetabular cup orientation angles during THA using the AR-HIP system. We enrolled 54 patients (56 hips; 48 women and 6 men) who underwent primary THA from January to June 2014. Primary diagnoses were secondary osteoarthritis with dysplasia in 49 hips, osteonecrosis in 5 hips, and rapidly destructive coxarthrosis in 2 hips. The mean ± standard deviation age at the time of surgery was 67.5 ± 10.2 years (range 41-86 years) and the mean body mass index was 23.9 ± 3.7 kg/m^2 (range 16.4-33.3 kg/m^2). We used two pairs of cementless femoral stem and acetabular cup (Ranawat acetabular cup and Taperloc femoral stem [Biomet, Warsaw, IN] and Trident acetabular cup and Accolade TMZF femoral stem [Stryker, Kalamazoo, MI]) during the study period. All patients underwent primary THA by 2 surgeons (HO and SH) using the direct anterior approach with the patient in the supine position.

AR-HIP System

The AR-HIP system allows the surgeon to view an acetabular cup image superimposed on the real surgical field through the display of a smartphone with registration of the bilateral anterior superior iliac spine and pubic symphysis (Figs. 1 and 2). The display of the smartphone shows inclination and anteversion angles of the acetabular cup (Fig. 2).

The AR-HIP system does not require expensive software, such as 3-D digital templating systems, or expensive equipment, such as navigation devices. The necessary equipment is a standard CT, a smartphone, a dedicated software application that we developed, and a dedicated intraoperative guide (Fig. 2).

For preoperative planning, CT images were taken and transferred to multiplanar reconstruction. To reduce the radiation dose exposure, we minimized the scan range of CT images as much as possible. Using multiplanar reconstruction images, four 3-D coordinate points including the bilateral anterior superior iliac spine, pubic symphysis, and cup center position (planning position) were set manually (Fig. 3). Only 3 of these 4 points are needed to use AR-HIP system during surgery. Three reference points as described previously determined the 3-D coordinate points of the pelvis and cup center position (planning position). Once this was registered, the AR-HIP software displayed the image of the acetabular cup and cup introducer corresponding to the actual location of the cup center.

In this study, we developed a software application for a smartphone using software *Unity 3D* and *Vuforia SDK*, which can automatically create both an AR marker and 3-D model data of the acetabular cup, cup introducer, and guide once the user has entered the 4 coordinate points. As the coordinate points of the bilateral anterior superior iliac spine were defined as “R” and “L,” pubic symphysis as “P,” cup center position (planning position) as “C,” the point “H” was defined at the intersection on the line “R-L” and the line perpendicular to the line “R-L” at the point “P.” This program created the marker and a guide image at a position 90 mm ventral and 30 mm caudal to point “H.” It also created the cup and cup introducer images at position “C.” On running this program, a guide image with legs 50 mm in length at positions “R,” “L,” and “P” was made automatically, and an 80-mm cube marker was also created on the guide image. We made a stainless steel guide with position adjustable 50-mm legs and a cube-type AR marker. The legs of the stainless steel guide were placed on the skin. We did not perform any invasive procedures for placement of the stainless steel guide, such as drilling into the bone. Although any marker size is available in this program, we used a marker size of 80 mm on each side to obtain good recognition rate based on the results of preliminary experiments. By changing the distances “R-H,” “L-H,” and “P-H,” we could match the actual guide to the guide on the image and could sterilize the other THA instruments in an autoclave.

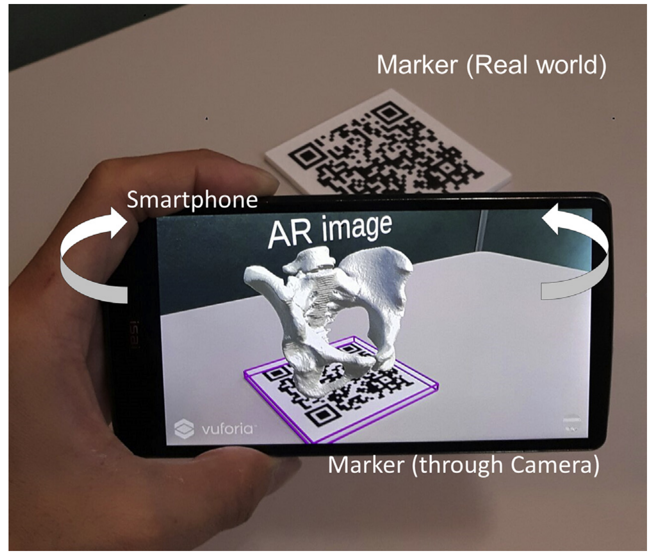

Fig. 1. Three-dimensional (3-D) models constructed by AR technology. Viewing marker containing 3-D model information through the camera, the AR program allows us to see a 360° image as if they existed in reality in the monitor. AR, augmented reality.

We programmed the software for additional functionality, which allows for moving the image according to the values of radiographic inclination and anteversion when they are changed on a touch panel intraoperatively. This function allows the surgeon to measure radiographic inclination and anteversion by superimposing the image on the surgical site.

Finally, 3-D models created by the computer program were matched to an AR “marker” in the real world and transferred to a smartphone. Preoperative planning only required inputting 4 coordinate points taken preoperatively into the software running on the smartphone. Then, we confirmed whether the 3-D model image was properly presented on the monitor based on the information of the AR marker received through the camera.

After adjusting the sterilized guide attached to the AR marker, we placed the guide on the skin of bilateral anterior superior iliac spine and pubic symphysis. The unsterilized smartphone was placed in a sterilized waterproof sealable bag (iKappa; Rasta Banana Co, Ltd, Nagoya, Japan). The plastic bag was sterilized using hydrogen peroxide gas plasma. While receiving the information from the AR marker, the cup image was shown in the planned position of the cup center. Regardless of camera angle, this coordinate was consistent. These angles in the functional pelvic plane were used as the reference plane.