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Intraoperative digital radiography: An opportunity to assure

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ABSTRACT

Over the last few years, low-dose digital radiography (DR) has all but replaced traditional chemical image processing. The purpose of this article was to assess the reliability of DR in achieving the desired radiographic parameters of a successful THA. Intraoperative digital radiographs in 139 consecutive THAs were compared to the standard postoperative radiographs to verify the accuracy of intraoperative DR. In 98% of all hips, the intraoperative measurements were within 5° of the postoperative ones. Intraoperative digital imaging is an efficient, affordable, and reliable tool for achieving the desired radiographic results and should contribute to a paradigm shift in the THA workflow.

There is general agreement that total hip arthroplasty (THA) is one of the safest and most successful surgical procedures performed today [1–3]. In spite of the clinical success, there is current data indicating that radiographic outcomes are not as good as they could be [4,5]. An excellent early clinical result can belie the accelerated failure potential of malpositioned implants (Fig. 1) [6–13]. Dislocation and implant instability have been the major factors in revision total hip arthroplasty [14]. Properly positioned acetabular cups can prevent complications such as decreased range-of-motion, impingement, and gait disturbances [15–22]. Limb length inequality is still the number one reason for malpractice suits in orthopedics [23,24]. The recent availability of digital radiography appears to have the potential to be a game-changing concept in the effort to bring unprecedented precision and reproducibility to total hip arthroplasty.

1. Current techniques

Current options for component placement include conventional instrumentation and positioning guides. As noted, they appear to be 60–70% accurate for acetabular component positioning (Fig. 2) [4,5,25–27]. Conventional instrumentation and conventional radiographs have been limited by time constraints and the need to control for patient positioning and image quality. The need for adjusting exposure and patient position while waiting for chemical processing from film to film has made the concept of radiographic guidance, using traditional techniques, impractical (Fig. 3). Current instrumentation and the use of the C-arm have added accuracy for many surgeons [28–31]. The fact that most C-arms will provide a view limited to one hip at a time, however, appears to have added great complexity for others. If this technique is to be accurate, the orientation of each hip must be identical and a wide enough view has to be obtained to simulate a full anteroposterior (AP) pelvic view. An example of the unacceptable margin for error is seen in Figure 4. There is also the concern of extended radiographic exposure for the patient and the surgeon as multiple images are obtained with the C-arm. At the authors' institution, an average radiation exposure of 24 s per case is reported when using the C-arm.

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Figure 1 – Influence of cup orientation on polyethylene wear. A 68-year-old female presented for a recent follow-up at 13 years after bilateral total hip arthroplasty. Of note is the presence of significantly measurable wear on the left hip where the abduction angle measures 32°. There is no measurable wear on the right with an abduction angle of 54°.

Computer guidance systems utilizing preoperative CT imaging were introduced over a decade ago. Cost, time constraints, radiation exposure, the technical variability of secure reference pin placement, and the registration process appear to have made these systems undesirable for most surgeons [32–41].

This same computer guidance technique, but with the addition of a haptically guided robotic cutting tool, has been available for the last few years. Attempts are currently being made to confirm its accuracy, practicality, and safety as well as to show advantages over alternative techniques [42,43]. In addition, perhaps the major barrier to widespread adoption of robotically assisted THA thus far has been the extraordinary entry level price of over $1,300,000 for unproven technology that at the present time admittedly adds an average of 30 min to each procedure [43].

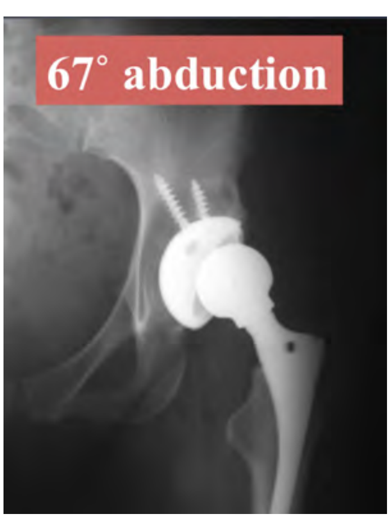

Figure 2 – High acetabular cup angle. Traditional alignment guides alone can be imprecise and result in acetabular cup inclination outside the recommended range.

2. Digital radiography

Advances in computer technology have revolutionized photography and the processing of light. For most of us, film has given way to a dedicated digital camera and/or a smart phone camera. A similar revolution has occurred with the processing of a radiographic beam as it courses through the human body. Rather than requiring chemical processing to reveal an image, a specially constructed flat panel detector (identical in size to a standard radiographic cassette) receives the transmitted radiographic beam. The computer then electronically processes the transmitted signal. It then creates and displays an image. Today's digital radiographic image requires 70% of the radiation

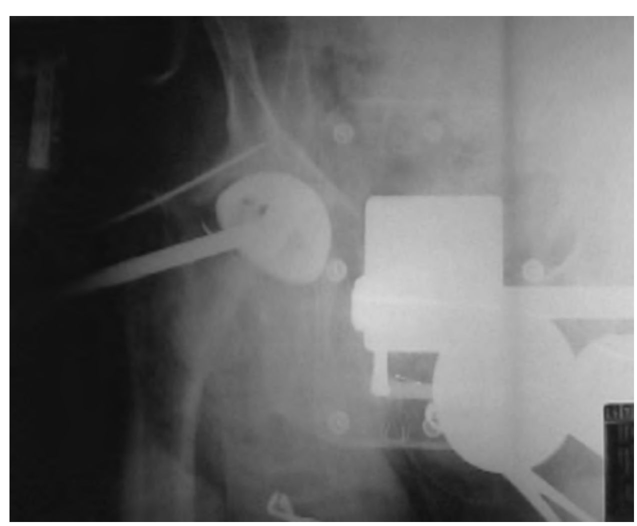

Figure 3 – Conventional pelvic radiograph. Chemical image processing has not been practical because of unreliable image quality and the long period of time from exposure to image viewing.

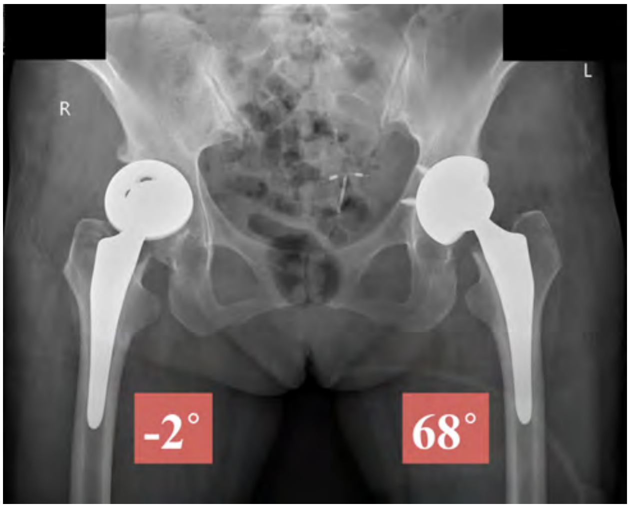

Figure 4 – Acetabular cup malpositioning. This postoperative anteroposterior pelvic radiograph shows malpositioned acetabular components in a 44-year-old woman who underwent bilateral THA via the direct anterior approach. The limited view using the C-arm intraoperatively for cup positioning is more likely to result in inaccurate measurements.

of a conventional anteroposterior pelvic radiograph and 1/15th of the exposure of a pelvic CT. As with digital photography, there is significantly more access to, and control of, this "processed" data. The ability to further process or adjust the image eliminates the problem of technician error. Perhaps the greatest advantage, in addition to consistent image quality, is the fact that a digital image is generated in 4–6 s. The modern systems are cordless and utilize Bluetooth functionality. This latter feature, for example, not having to move the cassette to a processor, permits efficient positional corrections when necessary. Typically, if the patient is in the lateral decubitus position, the operating table is rotated slightly forward or backward to obtain a true anteroposterior pelvis film. The goal is an image showing the symphysis centered over the sacrum. A full size, standard AP pelvis film is obtained in this manner. The cost for the detector and processor is approximately $75,000. A standard portable radiographic machine, found in all hospitals and many surgery centers, is utilized.

3. Preferred technique

We have used this type of digital technology in more than 1000 hips over the past 4 years. The preferred workflow for a primary total hip arthroplasty is as follows:

(1) Obtain a preoperative AP pelvis radiograph (typically in the office, unless case done emergently). This provides the reference orientation for the intraoperative film.
(2) Perform usual preoperative templating. Confirm desired limb length and offset adjustment. Estimate component sizing. Estimate desired depth of femoral broach insertion in reference to the tip of the greater trochanter.
(3) Proceed with femoral preparation and leave the "best-estimate" broach in place. This is the best estimate regarding the size required to achieve fit and fill. It is also the best estimate regarding depth of insertion relative to the palpable tip of the greater trochanter suggested by preoperative templating.
(4) Acetabular preparation and implantation using conventional alignment guides. Place fixation screw(s) if desired. Place trial liner (preferably held in place with a central screw).
(5) Proceed with standard trial range-of-motion (ROM) testing. Assess joint stability through extremes of motion. Assess soft tissue tension and gross estimate of limb length (or surgeon's usual technique of limb length estimate). Make obvious corrections if necessary.

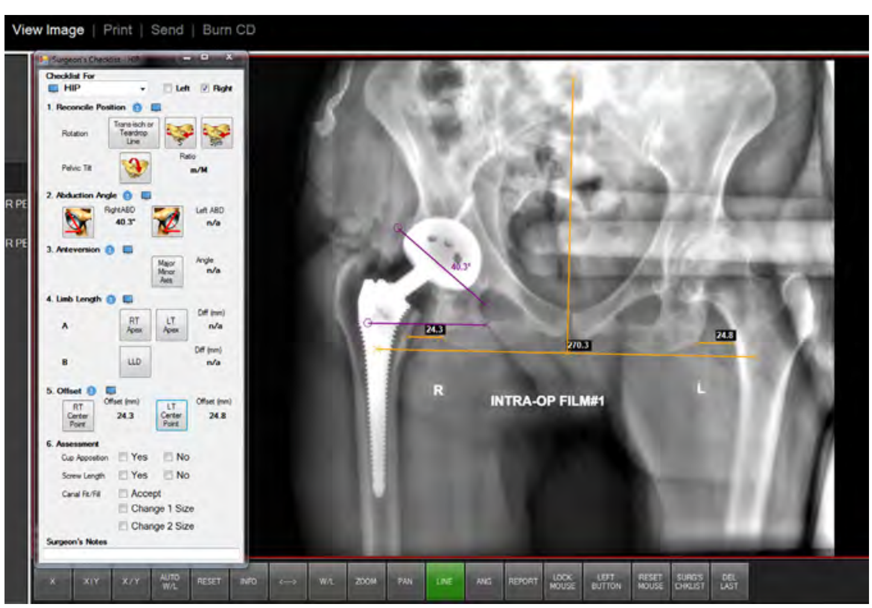

Figure 5 – Intraoperative digital radiograph. This is an example of an intraoperative digital radiograph obtained after femoral trail placement during THA. The surgical checklist, seen on the left of the image, provides a guideline for assessment of all relevant radiographic parameters.

(6) Obtain AP pelvis radiograph. The arthroplasty starts here. Ideally, your system will come with assistive software to facilitate assessment of all relevant parameters. These parameters are determined, and the arthroplasty is fine tuned as required. Current technology should enable accurate assessment of the following parameters (Fig. 5):
   (a) cup apposition
   (b) acetabular abduction
   (c) acetabular anteversion
   (d) femoral alignment
   (e) femoral sizing
   (f) screw position/length
   (g) limb length
   (h) offset

4. Validation of the new technique

A consecutive prospective evaluation of 139 primary THAs employing intraoperative digital radiography was performed. An anteroposterior (AP) radiograph with the patient in the lateral decubitus position was taken after acetabular component placement and femoral trial insertion. Intraoperative film was deemed adequate when it closely matched the orientation of the preoperative film with regard to rotation and tilt. A precise AP film was obtained within 4–6 s by simply adjusting the operating table. Implant position and sizing were adjusted according to this radiograph. The final intraoperative film was compared to a postoperative standard radiograph in supine position at 2 weeks postoperatively to verify the accuracy of intraoperative digital imaging.

5. Clinical results

In 98% of all hips, the intraoperative measurements were within 5° of the postoperative ones. In 90% of cases, these measurements were within 3° of the postoperative ones. In 2% of cases, the cup inclination on the intraoperative and the postoperative images was measured with more than 6° difference, which was attributed to the great difference in pelvic tilt in the compared images. The mean intraoperative cup abduction angle was 40° (range 23–52°), and the mean postoperative cup abduction angle was 41° (range 25–55°). In 97% of all cases, the postoperative cup inclination was between 28° and 50°. However, in the remaining 4 hips, the postoperative cup inclination was within 3° of the intraoperative one. In 99.3% of all cases, the postoperative cup inclination was less than 50°. Cup orientation was adjusted in 10%, apposition was within 2 mm in all hips, and cup reseating was necessary in one hip. Femoral component was upsized in 55%. Intraoperatively measured limb length discrepancy and offset were within 3 mm of the postoperative measurement in all hips.

6. Conclusions

1. Digital radiography provides a reliable, cost-effective guidance tool for THA.
2. DR can be seamlessly integrated into the standard workflow with minimal increase in operative time.
3. A significant reduction in technical errors that could occur during THA can be achieved by the use of digital radiography.
4. All significant parameters related to implant placement can be addressed.

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