International Orthopaedics (SICOT) (2008) 32:289–294
DOI 10.1007/s00264-006-0317-2

ORIGINAL PAPER

The utility and precision of analogue and digital preoperative planning for total hip arthroplasty

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Received: 15 November 2006 / Revised: 27 November 2006 / Accepted: 27 November 2006 / Published online: 3 April 2007

Abstract We prospectively compared the utility and precision of preoperative templating performed in printed films (analogue) with that performed on digital radiographs (digital) in 69 patients undergoing primary total hip replacement. Five patients were excluded when misplacement of the marker resulted in a magnification error greater that 10%; in the remaining patients (64 hips), the cup size was within ± one size in 62 (97%) of the analogue and 52 (81%) of the digital (p=0.01) plans. The stem size was within ± one size in 63 (98%) of the analogue and 60 (94%) of the digital (p=0.39) plans. The distance from the proximal corner of the lesser trochanter to the center of the prosthetic head (LTCD) in the analogue differed by 5 mm or more from the digital plan in nine cases (14%). Analogue preoperative planning yielded more predictable results than digital planning, particularly in terms of acetabular component size and LTCD that dictates limb lengthening-shortening. The sources of error were not clearly explained by variations in magnification. Inconsistent positioning of the magnification marker may jeopardise the safe implementation of digital templating.

This investigation was carried out at the Hospital for Special Surgery, New York City. This study was funded by a grant of the Orthopaedic Research and Education Foundation and by a grant of the Agfa Corporation. We are grateful to Mr. Joseph Barden from the Vidar Corporation for his generous provision of a radiograph scanner.

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Résumé Nous avons, de façon prospective, comparé l'utilité et la précision de la planification préopératoire réalisée sur des films radiologiques classiques ou sur des radiographies numérisées sur 69 patients devant bénéficier d'une prothèse totale de hanche. 5 patients ont été exclus car il existait une erreur de plus de 10% sur le coefficient d'agrandissement et sur les 64 hanches restantes, la taille prévue de la cupule correspondant dans 97% des cas (62 hanches) sur les films classiques et dans 81% des cas (52 hanches) sur les films numérisés. La taille de la pièce fémorale était celle prévue dans 98% des cas (63 hanches) sur les films classiques, dans 94% des cas (60 hanches) sur les films numérisés. La distance entre bord proximal du petit trochanter et la tête prothétique (LTCD) sur les films classiques, n'a pas montré de différence de plus de 5 millimètres. Cette distance était supérieure dans 9 cas (14%) sur les films numérisés. Une planification pré opératoire est beaucoup plus fiable sur les films classiques que sur les films numérisés, particulièrement en ce qui concerne la taille du composant acétabulaire et les problèmes d'inégalité de longueurs. Les sources d'erreur ne sont pas très clairement expliquées par les modifications du taux d'agrandissement, la planification sur des clichés numérisés peut être source d'erreur.

Introduction

Preoperative planning with overlying templates has become an indispensable part of modern total hip arthroplasty, and numerous methods have been proposed for its implementation [2, 3, 5, 7, 8, 15]. However, few studies have evaluated the utility of the different methods, and some of these have only focused on the predictability of the component's sizes [15]. A technique of preoperative planning and templating routinely used at the Hospital for Special Surgery (New York, USA), which has been refined by the senior investigator (E.A.S.) during the last two and a half decades, has recently been evaluated by our team in a retrospective, pilot study [8].

The standardised printed films required for templating are currently being replaced by digital images that can be displayed in a PACS (Picture Archiving and Communication System) monitor. Several software packages for preoperative templating on digital images have been developed [1, 19, 20]. Consequently, digital preoperative planning should be as useful and precise as the traditional method of acetate templates superimposed on standardised radiographs [8].

The purpose of this study was to prospectively compare the utility and precision of preoperative templating performed in printed films (analogue) with that performed on digital radiographs (digital). The study focused on predictability of the implant size, position and orientation of the components, centre of rotation of the arthroplasty, equalisation of limb length, anticipation and prevention of possible complications.

Materials and methods

After IRB approval and informed consent, 69 non-selected patients undergoing primary total hip replacement surgery in a single academic institution (HSS) by two hip arthroplasty surgeons (E.A.S., A.G.D.V.) were prospectively enrolled in the study.

Prior to surgery, the patients had a standardised preoperative radiograph, with the X-ray tube at a 1-m distance from the tabletop, to obtain a radiograph with a magnification that approximates 20±6% (2 SD) [4]. A magnification marker consisting of a plexiglass tube with two spheres embedded 100 mm apart was placed parallel to the femur at the level of the greater trochanter by trained radiology technicians. The radiographs were assessed for magnification and positioning of the magnification marker. Only those studies in which the magnification marker resulted in a magnification of 120±10% were considered to be accurate and included in the study. The printed film was used to perform the traditional analogue preoperative templating. In addition, the radiograph was scanned into a ".dicom" file using a radiographic scanner (Diagnostic Pro Plus; Vidar Corp., Herndon, Va.). The digital radiograph was calibrated for magnification and digital templating using the IMPAX ver. 5.0 software package (Agfa Corporation, Mortsel, Belgium). The preoperative templating followed a methodology that was conceived by the senior author (E.A.S.) and has been previously published and validated [7, 8] (see Appendix). To avoid recollection bias the analogue and digital templating were done at least 1 week apart.

The analogue and digital plans resulted in the following information: cup size and position, stem size, offset and position, height of the neck cut as measured from the proximal corner of the lesser trochanter, distance from the proximal corner of the lesser trochanter to the centre of rotation of the prosthetic head (LTCD), thickness of the calcar medial to the stem as a guide for proximal stem centralisation and diameter of the distal centraliser and plug. In addition, we measured the horizontal and vertical distances from an established point in the most distal aspect of the teardrop to the planned centre of rotation of the arthroplasty [5]. The teardrop was selected as a landmark to reference the horizontal and vertical position of the centre of rotation of the arthroplasty because it has proved to be the anatomical landmark least affected by pelvic tilt and rotation [13, 16].

Surgery was performed using a similar posterior approach, surgical and cementing technique [6, 10], and enhanced posterior soft tissue repair [17]. The analogue surgical plan was executed in a similar manner by both surgeons. The digital plan was not used during surgery. No fixed pelvic or femoral markers were used to determine limb length prior to dislocation. After hip dislocation, the lesser trochanter was routinely exposed. The altitude of the neck cut, as determined in the preoperative plan, was reproduced with a ruler. Exposure of the acetabulum included routine identification of the superolateral margin of the acetabulum and the cotiloid notch. The hemispherical reaming of the acetabulum was started by medial reaming up to the lateral wall of the teardrop, followed by reaming in the cephalad direction of the natural acetabular opening, to reproduce the medialisation and lateral coverage of the cup as predicted in the analogue plan.

In every case, a cementless Trilogy cup (Zimmer, Warsaw, Ind.) was implanted with a 2-mm press fit technique [9, 11]. No supplementary screw fixation was used unless the stability and/or anatomy dictated otherwise. In patients with acetabular protrusion, the thickness of the morsellised medial bone graft required to restore the anatomical centre of rotation of the cup was measured and reproduced during surgery. A cemented VerSys Heritage stem (Zimmer) was used with a modern cementing technique [6].

The preoperative values of the analogue and digital plans were compared with intraoperative data and measurements performed on standardised radiographs obtained 6 weeks after surgery. All measurements were corrected for magnification using the magnification marker in the preoperative radiograph and the known diameter of the prosthetic head in the postoperative radiograph. A single investigator (FC) performed all measurements to avoid inter-observer variability, using a magnification-calibrated digital caliper with a precision of 0.01 mm (X-Caliper Eisenlohr Technologies, Davis, Calif.).

Distances equal to or greater than 2 mm were considered to be relevant for this study. Differences were compared using the chi-square test for nominal variables or summarized data with or without continuity correction when appropriate. The *t*-test was used for a comparison of continuous variables at an alpha error of 0.05.

Results

Among the 68 patients enrolled in the study, the magnification marker indicated a magnification greater that 130% or smaller than 110% in five patients (five hips; 7%); these patients were subsequently excluded from the study. The remaining 63 patients (64 hips) comprised the study group. Diagnosis was primary osteoarthritis in all patients. The left hip was affected in 32 cases.

Prediction of cup size

The exact cup size was predicted by the analogue plan in 33 cases (51%). It was within ± one size of the plan in 62 cases (97%): one size smaller in seven, one size larger in 22 and two sizes larger in two. Digital templating predicted the exact cup size in 16 cases (25%) and was within ± one size in 52 (81%): three sizes smaller in three cases, two sizes smaller in three, one size smaller in ten, one size larger in 26, two sizes larger in five and four sizes larger in one. The difference in the ability of the analogue and digital plan to predict the cup size within ± one size was statistically significant ($p=0.01$).

Prediction of stem size and offset

The exact stem size was predicted by the analogue plan in 44 cases (69%). It was within ± one size of the plan in 63 cases (98%). The implanted stem was one size smaller in 12 cases, two sizes smaller in one and one size larger in seven. The stem offset was predicted by the analogue plan in 55 cases (86%), underestimated in five (8%) and overestimated in four (6%). Digital templating predicted the exact stem size in 37 cases (58%), within ± one size in 60 cases (94%), one size smaller in 11 (17%), two sizes smaller in three (5%), one size larger in 12 (19%) and two sizes larger in one (2%). The exact stem offset was predicted in 48 cases (75%), underestimated in 14 (22%) and overestimated in two (3%). The difference in the ability of the analogue and digital plan to predict the stem size within ± one size and the offset was not significant ($p=0.39$ and $p=0.18$, respectively).

Prediction of position of centre of rotation

In 58 of the 64 analogue plans (91%) and 56 of the digital plans (87%), the position of the centre of rotation of the arthroplasty was within 5 mm of the vertical and horizontal distance from the plan. The differences between the horizontal and vertical distances form the teardrop to the centre of rotation of the prosthetic head as determined with the analogue and digital plans, and those obtained in the final arthroplasty were not significant (horizontal difference: $p=0.35$; vertical difference: $p=0.64$).

Prediction of neck osteotomy level

The neck osteotomy level as measured from the proximal corner of the lesser trochanter in the analogue plan was within 2 mm of the digital plan in 44 cases (69%) and had a difference of 5 mm or more from the digital plan in eight cases (12%). Among these last eight cases, the neck osteotomy level was overestimated in the digital plan in six and underestimated in two. The difference between the analogue and digital plan was significant ($p=0.026$).

Prediction of LTCD

The LTCD in the analogue plan was within 2 mm of the digital plan in 42 cases (66%) and had a difference of 5 mm or more in nine cases (14%), including two cases in which the difference was 10 and 12 mm, respectively. Among these last nine cases, the LTCD was overestimated in the digital plan in six and underestimated in three. The difference between the analogue and digital plan was not significant ($p=0.54$).

Prediction of calcar thickness medial to stem

The measurement in the analogue plan was within 2 mm of the digital plan in 42 cases (66%) and had a difference of 6 mm or more from the digital plan in seven cases (11%). The difference was significant ($p<0.01$)

Prediction of diameter of distal centraliser

The diameter was predicted within ±2 mm by the analogue and the digital plan in 63 cases (98%).

Prediction of plug size

The plug size was within ± one size of the plan in all cases for the analogue plan (100%) and in 63 cases for the digital plan (98%).

Prediction of limb length

The surgeon equalised limb length within 3 mm in 51 cases (89%) and within 4 mm in 56 cases. One case had a 5-mm shortening; in the remaining seven cases, there was severe contralateral osteoarthritis and the operated hip was restored to the length of the pre-arthritic hip.

Discussion

Digital preoperative planning has recently been introduced in association with digital radiography and PACS [1]. Most publications in leading orthopaedic journals have focused on the description and methodology involved in using the software [1] and, to the best of our knowledge, only one report on an analysis of its accuracy and friendliness has been published in the English literature [19, 20]. This study was conducted to evaluate the utility and precision of digital preoperative templating for primary, conventional total hip arthroplasty for osteoarthritis. The question we posed was whether digital templating would be as useful and precise as analogue templating.

The analogue templating method used in this study has been refined by the senior author (E.A.S.) during the past two and a half decades. This preoperative planning and templating protocol has been recently evaluated and validated by our team in a pilot study [8]. The plan is designed and executed in a sequence that follows the steps of surgery, and it can be easily interpreted by all operating room personnel. It uses consistent anatomical landmarks that can be clearly visualised during surgery and corroborates the accuracy of the measured distances, thereby minimising errors based on single measurements [7, 8].

In our pilot study of analogue templating, the prediction of the acetabular and femoral component size within ± one size was achieved in 97.4% of the cases (271 of 278) [8], which is similar to the prediction values of analogue planning observed in this study.

In this study, analogue and digital planning yielded similar results in terms of predicting stem size and offset, positioning of the centre of rotation of the arthroplasty, distal centraliser and cement restrictor plug size. Substantial differences were observed in cup sizing, determination of neck cut, LTCD and the thickness of the calcar medial to the stem.

The analogue plan was more precise in predicting the acetabular component size than the digital plan. With the limited numbers available we were unable to establish a relationship between error in component size prediction and magnification. In the digital plans, the diameter of the acetabular component was overestimated by three to four sizes in three patients, with magnifications of 111, 117 and 125%, and overestimated by four sizes in one patient, with a magnification of 129%. We found no clear explanation for this difference. However, for analogue templating, the trained surgeon is used to the hip proportions observed on a standardised radiograph. On digital planning, the acetabulum can be magnified to occupy variable dimensions of the monitor screen, thus inducing errors in cup sizing.

The precision of the prediction of the femoral component size and offset was similar for the analogue and the digital plan. We [8] and others [15, 19] have found that the prediction of cemented components is more reliable during preoperative planning than the prediction of cementless components. In our pilot evaluation of the analogue plans of 139 cemented and hybrid total hip arthroplasties, the acetabular component size was predicted in 101 of 116 (87%) cemented cups and in 15 of 23 (65%) cementless cups [8]. Knight and Atwater studied the analogue preoperative plans of 110 cementless and hybrid total hip arthroplasties. Among the 110 cementless acetabular cups, 106 (96%) were within ± one size of the plan, while all 55 cemented stems (100%) and only 42 of 55 cementless stems (77%) were within ± one size of the plan [15]. The predictive value for the cemented stems was similar to the one observed in the analogue and digital plans of our study.

In a recent Scandinavian study, The et al. compared analogue and digital preoperative planning (HyperORTHO. Rogan-Delft, Veenendaal, the Netherlands) for cement and cementless fixation in 173 total hip arthroplasties performed with the Mallory-Head uncemented prosthesis and the Scientific Hip Prosthesis (SHP) [19]. For the Mallory-Head uncemented prosthesis, the cup was predicted within ± one size in 64 and 52% of the analogue and digital plans, respectively, and the stem in 52 and 66% of the plans. For the cemented SHP, the cup was predicted within ± one size in 73 and 72% of the plans, and the stem in 89 and 79% of the plans. Thus, the analogue and digital plans reported by The et al. had a lower predictive value than those observed in our study.

The difference in the neck osteotomy level between the analogue and digital plans does not necessarily mean that the digital plan is less precise. With the VerSys Heritage stem, changes in stem size may dictate changes in the osteotomy level. The selection of a smaller stem size will lead the surgeon to perform a longer neck cut than if a larger stem size were selected in order to maintain the planned LTCD.

We detected substantial variations in the LTCD between the analogue and digital plans, and in six cases the difference was greater than 5 mm. This difference could not be explained by differences in magnification: overestimation of the LTCD from 6 to 12 mm occurred in four digital plans performed on radiographs with magnifications of 123 and 125%. Underestimation of the LTCD from 6 to 10 mm was observed in two digital plans performed on radiographs with magnifications of 123 and 127%. In none of these six cases did the postoperative limb length discrepancy measured on the postoperative radiograph exceed 3 mm. We have recently determined that leg length discrepancies greater than 2.5 mm can be felt by 62% of the patients, particularly if they are young [12].

The discrepancy in the LTCD between the analogue and digital plans could be explained if there was a substantial difference in the cup size between the two plans. A larger diameter cup will lower the centre of rotation and will diminish the LTCD required to equalise limb length; the reverse is true for a smaller diameter cup. However, in four cases in which the LTCD was overestimated in the digital plan by 6, 7, 7 and 12 mm, respectively, the cup size was underestimated by three sizes in one case, by one size in a second case and overestimated by one size in the remaining two cases. In the two cases in which the LTCD was underestimated by 6 and 10 mm, respectively, the cup size was underestimated by two sizes in one case and overestimated by two sizes in the other. In summary, the substantial differences in the LTCD observed in 6 of 64 digital plans could not be explained by changes in cup sizes, suggesting limitations of the digital plan itself.

Finally, the differences in the measured thickness of the calcar medial to the stem may induce error in the orientation of the femoral component in the frontal plane. In six of the seven cases in which the calcar thickness was equal to or greater than 5 mm, the digital plan underestimated the measurement. This may mislead the surgeon in implanting the stem in varus.

Although not a limitation of digital planning "per se", 7% of the cases indicated a magnification error greater than 10%, suggesting misplacement of the marker. Consistency in the positioning of the magnification marker [14, 18] may be a limiting factor during implementation and validation of digital planning.

In conclusion, analogue templating yielded more predictable results than digital templating. The weaknesses in the system were observed in the prediction of the acetabular component size, the LTCD that dictates limb lengthening-shortening and the thickness of the calcar medial to the stem that dictates the orientation of the stem in the frontal plane. The sources of error we have mentioned here were not clearly explained by variations in magnification and may be due to limitations of the digital plan. Precise determination of radiographic magnification may improve the results of digital planning. Implementation and use of electronic preoperative planning should be preceded by studies that prove that the system has a precision that is at its minimum similar to that of analogue templating.

Appendix

Templating methodology

The templating process follows an established order. It begins by drawing a "horizontal reference" line through the base of the teardrops and determining three radiographic landmarks in the acetabulum: the base of the teardrop, the ilio-ischial line and the superolateral margin of the acetabulum. If the teardrops are not clearly visible, a horizontal reference line drawn at the most proximal aspect of the obturator foramen is used. The next step is to super-impose the cup templates on the radiograph, with the appropriate cup size placed at 40° to 45° of inclination; the infero-medial margin is levelled with the teardrop, the superior margin is covered by the superolateral acetabulum, the medial border approximates the lateral wall of the teardrop and the system allows for complete removal of medial ostheophytes and minimal removal of the native subchondral bone. With the cup template in place, the centre of rotation of the cup is marked on the radiograph using a soft pencil, and the lateral coverage of the cup is measured. The presence of intra-osseous cysts to be curetted and grafted before cup implantation and peripheral osteophytes to be removed after cup insertion are recorded.

The actual and functional limb length discrepancy is recorded in the office chart during the preoperative visit. The attending surgeon determines the amount of lengthening for that particular patient. In the postoperative radiograph, the limb length discrepancy is determined by subtracting the distance from the "reference line" to the junction between the proximal corner of the lesser trochanter and the femoral neck of both hips. In patients with fixed pelvic obliquity or other sources of limb length discrepancy (i.e. drop foot, previous fractures), equalisation of the functional limb length discrepancy is favoured.

For the femoral plan, the size of the stem template which matches the anatomy most closely is selected. It is aligned parallel to the longitudinal axis of the proximal femur and centred within the intramedullary canal. Once this is accomplished, the altitude and medialisation of the centre of the prosthetic head is compared with the centre of rotation of the previously templated cup. Adjustments are made to compensate for limb length and offset, as follows:

With the stem template in place, three distances are measured: (1) from the proximal corner of the lesser trochanter to the neck cut; (2) from the proximal corner of the lesser trochanter to the newly established centre of rotation of the prosthetic head; (3) the width of the calcar, medial to the stem at the level of the neck cut. The last measurement guides the stem alignment in the frontal plane: if a shorter distance is observed with the rasp in place, malalignment in varus is suspected, while valgus is suspected when the intraoperative distance is greater than templated.

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