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ORIGINAL PAPER

Digital templating in total knee and hip replacement: an analysis of planning accuracy

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Abstract
Purpose The aim of this study was to determine how well pre-operative size selection for total knee and hip arthroplasties based on the digital imaging with and without additional referencing correlated with the size actually implanted.
Methods Size selection planning of total knee arthroplasty by digital templating was documented in 46 cases with reference ball (group A) and in 48 cases without ball (group B). In addition, prospective analysis of pre-operative planning was conducted for 52 acetabular components with reference ball (group C) and 69 without ball (group D) as well as stem planning in 38 cases with ball (group E) and 54 cases without ball (group F). The data were analysed and compared with the size of the final component selected during surgery.
Results The correlation between planned and implanted size for total knee arthroplasty in group A resulted in femoral anteroposterior (AP) $r=0.8622$ and lateral $r=0.8333$ and in group B AP $r=0.4552$ and lateral $r=0.6950$. Tibial in group A was AP $r=0.9030$ and lateral $r=0.9074$ and in group B AP $r=0.7000$ and lateral $r=0.6376$. For the acetabular components, the results in group C were $r=0.5998$ and group D $r=0.6923$. For stems, group E was $r=0.5306$ and group F $r=0.5786$. No correlation between BMI and the difference between planned and implanted size was found in any of the groups.
Conclusion In the case of total hip arthroplasty there was a relatively low correlation between planned and implanted sizes with or without reference ball. For total knee arthroplasties the already high precision of size planning was further improved by the additional referencing with a reference ball.

Keywords Templating · Digital · Hip arthroplasty · Knee arthroplasty · Pre-operative planning

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Introduction

The importance of size selection planning based on radiographs prior to implantation of hip or knee prostheses is undisputed [1–5]. Precise planning can minimize complications such as femoral shaft fractures, and anatomical variations leading to intra-operative problems can be identified prior to surgery and an optimal or even individualized implant can be selected [6]. Restoration of hip biomechanics can also be simulated and planned digitally. This applies especially to prevention of leg length differences, restoration of offset and balancing the force vectors to achieve best possible function and symmetrical loading to ensure the optimal longevity and function of the prosthesis [2, 7, 8].

Prior to the introduction of digital radiography, planning was performed using hard-copy radiographic films and traditional prosthetic overlays with fixed magnification factors of 115 % or 120 % [4, 9, 10]. The introduction of digital radiography included the development of software programs to enable direct size selection planning on the digital image [11]. The particular advantages lie in improved image quality due to image editing including modulation of brightness, grey scale, and contrast. Planning can also be safely stored digitally and is consequently easily accessible from any relevant workstation [12]. This improved image quality also leads to a reduction of radiation exposure per patient [13].

Due to different magnification factors of the digital image, the standard templates from the implant manufacturers have become redundant [14–16]. Different methods of scaling digital radiographs have been described and investigated to improve planning accuracy [17–21]. Accurate positioning of the reference ball at the level of the joint is crucial to achieving the greatest possible referencing reliability [17, 22, 23]. Another pre-requisite is precisely adjusted pelvic overviews and/or radiographs of the knee joint in two planes.

The aim of the present study was to determine how well size selection for total knee and hip arthroplasties based on the digital image and special planning software correlated with the size actually implanted. An additional aim was to investigate the extent to which selection match was improved by including a reference ball of pre-defined size within the X-ray field compared to a control group. In addition, the correlation between planned and implanted size differences and the patient's body mass index (BMI) was recorded.

Methods

All data recorded at our institution since the introduction of digital templating were included. Inclusion criteria were an accordance of the planned and actual implanted type of prosthesis and availability of standardized digital radiographs of the knee joint in two planes or respectively a pelvic overview.

The radiographs were obtained by digital luminescence radiography (DLR) (Polydoros Sx 50, Siemens, Erlangen, Optilix tube assemblies 150/30/50 C; imaging plates PCR [Philips computed radiography], Eleva workspot, Philips Electronics, Hamburg). The mean magnification factor without additional referencing was assumed as 110 %.

For referencing, a calibrated ball (30 mm) was placed between the legs of the patients as near to the joint as possible for hip overviews. In knee patients, the ball was placed at the level of the joint space and non weight bearing radiographs in two planes were obtained.

For pre-operative planning emphasis was given to the following criteria regarding image quality.

Hip overview:

- Symmetrical imaging of the pelvic overview (foramina obturatoria)
- Central adjustment of the coccyx over the symphysis (distance 1–2 cm)
- Correct placement of the reference ball between patient legs
- Rotation free imaging of the femoral neck (15° internal rotation of the leg)

Knee X-rays:

- Central positioning of the patella in the anteroposterior (AP) view
- Complete overlapping of the medial and lateral condyle in the lateral view

If the available X-rays did not meet those quality criteria they were considered not sufficient for pre-operative planning and repeated. All pre-operative planning and the following surgeries were performed by the same surgeon. Analysis was conducted by the first author, who did not participate in planning or surgery.

A total of 94 planned size selections were recorded and analysed prospectively for total knee arthroplasties and were compared with the actual size implanted at surgery (Figs. 1 and 2). Forty-six were analysed with reference ball of pre-defined size (group A) and 48 without reference ball (group B). Size planning was conducted using the Medi-Cad planning software (Hectec GmbH; Niederviehbach, Germany) in the form of two-dimensional digital planning for femur and tibia based on AP and lateral digital radiographs of the knee joint.

The knee implant used in all cases was the Aesculap Columbus knee (B-Braun Melsungen AG; Tuttlingen, Germany).

Concerning the BMI we did not find any significant differences between groups, i.e. in group A BMI was 30.41±0.93 and in group B 28.55±0.68.

In addition, the study included the prospective analysis of total hip arthroplasty planning based on digital pelvic overviews including 120 size selections of the acetabular component (52 with reference ball as group C and 68 without as group D) and 92 stem selections (38 with ball as group E; 54 without ball as group F) (Fig 3).

Bicontact stems and plasma pore-coated acetabular cups from the Aesculap company (B-Braun Melsungen AG; Tuttlingen, Germany) were used in all cases for total hip replacement. We also did not find any significant differences in BMI with 26.37±0.7775 in groups C/E with ball, and 26.15±0.5964 in groups D/F without ball.

Statistical analysis

Correlation of planned sizes with the final component sizes at surgery and the correlation with BMI was determined by the Spearman test. Percentage analysis of planning accuracy was also conducted. Statistical

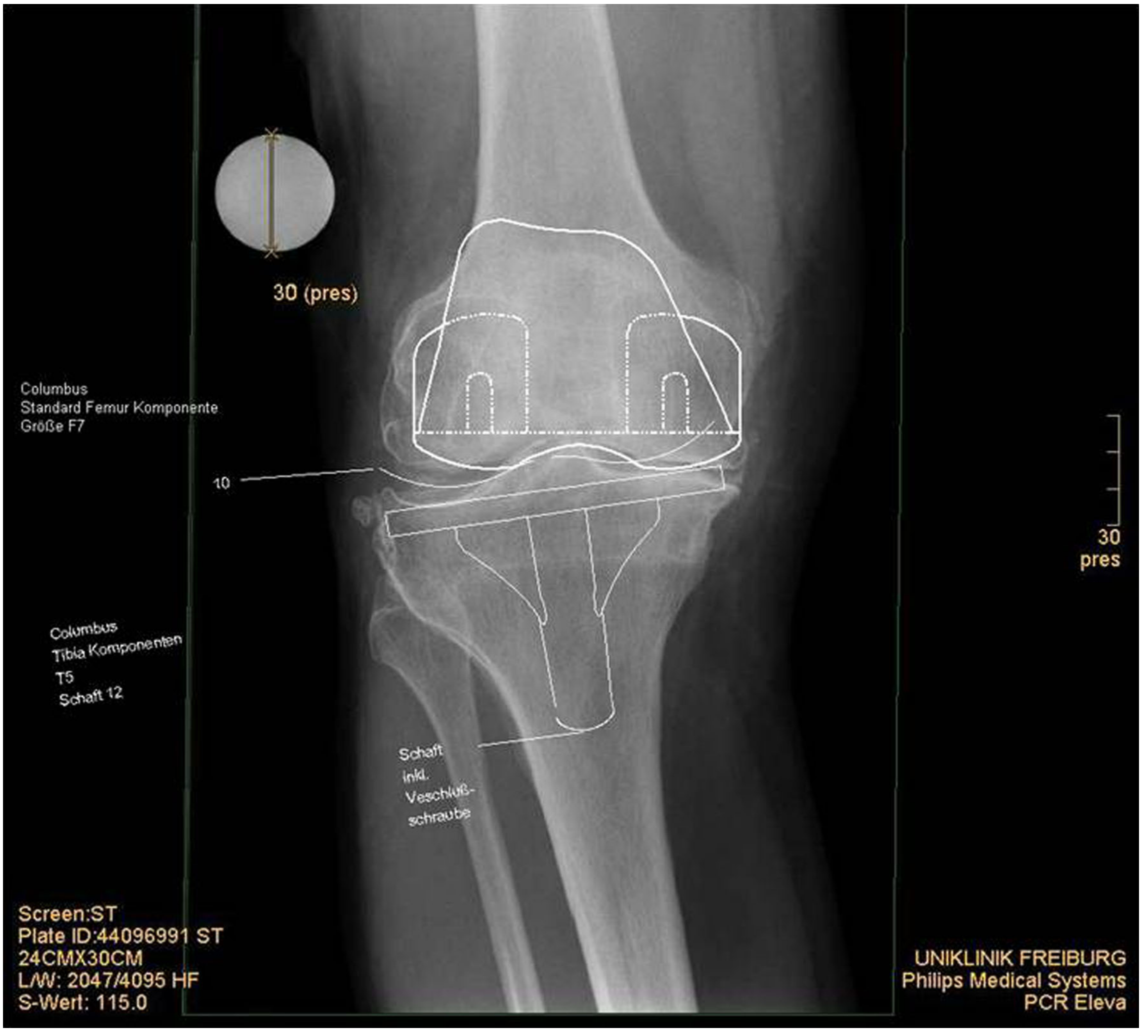

Fig. 1 Digital templating of knee arthroplasty; anteroposterior (AP) view with reference ball on joint line

analysis and creation of graphs was performed with GraphPad Prism software. The study was performed with the approval of the ethics commission of the Albert-Ludwig-University, Freiburg, Germany.

Results

Planning of total knee arthroplasty

Femoral component

Correlation of planned and implanted size selections for total knee arthroplasty for femoral AP view (r = 0.8622) and lateral view (r = 0.8333) were higher in group A with reference ball compared to AP (r = 0.4552) and lateral (r = 0.6950) in group B without reference ball. On the femoral side the planned and implanted sizes corresponded exactly in group A in the AP view in 52 % of cases and lateral in 33 % of cases. In group B without reference ball size selection was exact in 33 % of cases in the AP view and in 56 % in the lateral view. Size discrepancy was also calculated with tolerance of ± one size difference. These results are summarized in Table 1.

The percentage of femoral components that were too small or too large at the preoperative planning stage are shown in Table 2.

Tibial component

According to the results, femoral component planning of the tibial component was more exact with additional ball referencing (group A) in the AP view (r = 0.9030) and lateral view (r = 0.9074). In group B without reference ball the correlation was r = 0.7000 for the AP view and r = 0.6376 for the lateral view. Exact tibial match was achieved in group A AP in 72 % and lateral

Fig. 2 Digital templating of knee arthroplasty; lateral view with reference ball on joint line

in 70 %. In group B planned and implanted sizes were an exact AP match in 35 % and lateral in 46 % of cases. A summary of size differences ± 1 size difference is given in Table 1. The percentage of components that were planned too small or too large are shown in Table 2. There was no correlation between BMI and the difference between planned and implanted size in any of the groups.

Planning of total hip arthroplasty

Acetabular component

For the acetabular component correlation between planned and implanted size was $r = 0.5998$ in group C with ball and $r = 0.6923$ in group D without ball. Planned and implanted sizes were identical in 27 % of cases with reference ball and in 15 % without reference ball.

Stem

The correlations for stem planning were generally lower with hardly any differences between groups, i.e. $r = 0.5306$ in group E and $r = 0.5786$ in group F. Planned and implanted sizes were the same in 37 % of cases in group E and in 22 % of cases in group F. Size differences of ± one size are shown in Table 3.

The percentages of components that were planned too small or too big are given in Table 4.

There was no correlation between BMI and the difference between planned and implanted size in any of the groups.

Discussion

A study of the literature yields a great variety of data on the magnification factor in digital radiography. Bayne et al. report a magnification factor of 120 ±5%; in contrast, White and Shardlow found a factor of 97 %

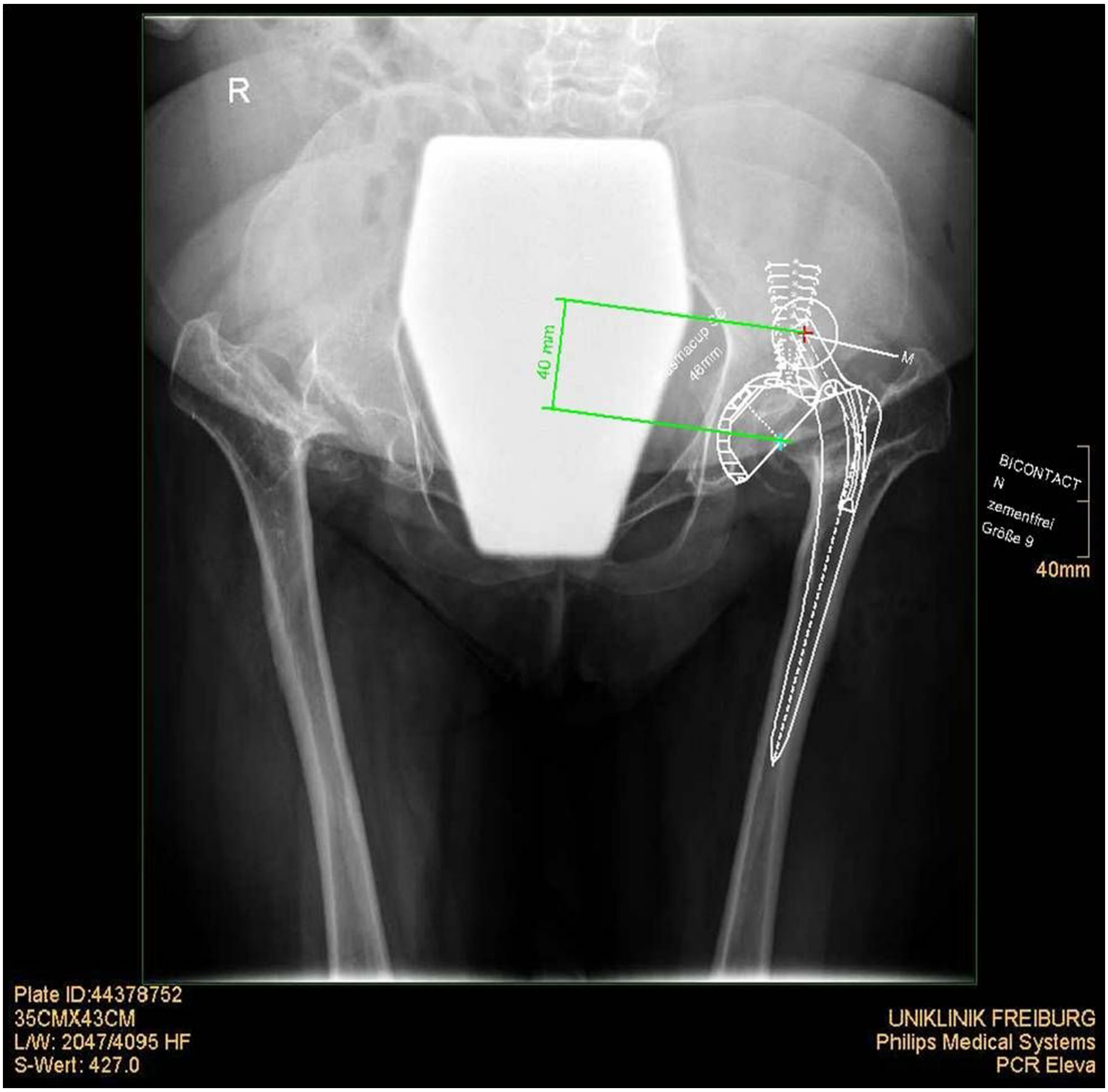

Fig. 3 Digital templating of a complex case of hip arthroplasty; hip overview without reference ball

for digital templating compared with 115–120 % for analogue templating [9, 17].

In our investigation there was a tendency for the planned size of prosthesis to be too big in the group without reference ball. This magnification factor was particularly clear in pelvic overviews for planning of total hip arthroplasty. Since the magnification increases proportionally to the distance between hip and film, greater magnification factor variance must be assumed for pelvic overviews due to the influence of corpulence [17, 21]. Nevertheless, we were unable to find any evidence of interdependence between planning accuracy and BMI in the planning of total knee or hip arthroplasties. As expected the use of a reference ball did, on the whole, lead to a better correlation between planned and implanted size. Planning accuracy was

Table 1 Planning accuracy ± 1 size difference

Measure	With reference ball	Without reference ball
Femur AP	98 %	88 %
Femur lateral	96 %	94 %
Tibia AP	96 %	88 %
Tibia lateral	100 %	85 %

Table 2 Percentage of too small or too large components

Measure	With reference ball		Without reference ball	
Planning	Too big	Too small	Too big	Too small
Femur AP	22 %	26 %	52 %	15 %
Femur lateral	20 %	48 %	31 %	13 %
Tibia AP	24 %	4 %	60 %	4 %
Tibia lateral	26 %	4 %	48 %	6 %

Table 3 Size difference ± 1 size difference

Component	With reference ball	Without reference ball
Acetabular component	67 %	29 %
Stem	53 %	44 %

better overall for total knee arthroplasty compared with total hip arthroplasty.

By accepting a size difference of ± 1 size a planning accuracy of 100 % was achieved for the tibial plateau. On the femoral side, tolerance of one size difference led to a planning accuracy of >90 %, whereby correlation was relatively poor without tolerance.

The greatest source of error in referencing using a reference object is incorrect placement of the ball or coin [20]. Compared to the hip joint the level of the joint line is easier to identify in the knee. Accordingly, accurate positioning of the reference ball is more easily obtained in knee X-rays. Furthermore, correct placement of the ball could be controlled, and if necessary corrected, in two planes regarding knee radiographs. As templating of the hip was conducted on one plane in the pelvic overview, correct placement of the reference ball could not be controlled in the second, lateral plane. As for the lateral plane a misplacement of the ball nearer to the film is more probable than vice versa.

A reduction in accuracy due to overlapping soft tissues as found by Bayne et al. for pelvic overviews is also irrelevant in most cases at the knee [17]. Directly compared to planning of the femoral component, templating of the tibial component was more accurate. Trickett et al. reported similar results [24] whereas Miller et al. reported a more accurate size planning for the femoral component [25].

The final decision for the actual implanted femoral component size of the Columbus knee system is based to an important extent on intra-operative measurement of ligament tension and not exclusively on anatomical bony landmarks. As pre-operative planning is based on those bony landmarks and ligament tension cannot be considered, this is a possible explanation for the greater variance we found between planned and implanted femoral component size compared to the more exact planning of the tibial plateau. This explanation is also supported by the fact that femoral size selection planning was achieved with a relatively high accuracy of 90 % given a tolerance of ± one size.

Table 4 Percentage of too small or too big components

Variable	With reference ball		Without reference ball	
Planning	Too big	Too small	Too big	Too small
Acetabular component	46 %	27 %	77 %	9 %
Stem	16 %	47 %	61 %	17 %

The difficulties described lead to the assumption that the corpulence of the patient has an influence on planning accuracy. However, contrary to expectations we were unable to find evidence of any correlation between BMI and the accuracy of size planning for total knee and hip prostheses.

When planning the size of the acetabular component additional challenges arise due to the difficulty of accurately assessing depth and width of milling, as important factors such as bone quality and amount of subchondral sclerosis cannot be taken into consideration preoperatively. An additional source to the above-mentioned errors is related to possible residual rotation and angulation errors in the pelvic overview.

Iorio et al. as well as Schmidutz et al. also reported greater planning reliability for the stem than for the acetabular component. In accordance with our results these researchers also found that planned size tended to be too large for the acetabular component and too small for the stem [26, 27].

With regard to planning of total hip prostheses our results showed, in accordance with the literature, that planning accuracy for the actual implanted size was relatively unreliable.

Conclusions

In principle, the introduction of digital radiography is advantageous to preoperative planning since it provides higher imaging quality through the possibility of image editing and individual referencing.

According to our findings, size planning accuracy for total knee prostheses is acceptable with only slight differences between planned and implanted sizes. Planning accuracy for hip prostheses was generally poorer. These results can be attributed partly to inconsistency and difficulty of the precise placement of the reference object, changes in the magnification factor or partial soft tissue coverage of the reference object.

Due to the difficulties involved in achieving exact and consistent referencing, no consistently significant improvement in planning accuracy has yet been proven for digital templating.

To further improve planning accuracy, attention must be directed not only toward precisely adjusted radiographic views but also toward exact and consistent positioning of the reference ball. Thorough training of the radiologist is indispensable if this is to be achieved.

Competing interests The authors declare that they have no financial nor non-financial competing interests.

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