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Comparison of analog and digital preoperative planning in total hip and knee arthroplasties

A prospective study of 173 hips and 65 total knees

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Introduction Digital correction of the magnification factor is expected to yield more accurate and reliable preoperative plans. We hypothesized that digital templating would be more accurate than manual templating for total hip and knee arthroplasties.

Patients and methods Firstly, we established the interobserver and intraobserver reliability of the templating procedure. The accuracy and reliability of digital and analog plans were measured in a series of 238 interventions, which were all planned using both techniques.

Results Interobserver reliability was good for the planning of knee arthroplasties (κ-values 0.63–0.75), but not more than moderate for the planning of hip arthroplasties (κ-values 0.22–0.54). Analog plans of knee arthroplasties systematically underestimated the component sizes (1.1 size on average), while the digital procedure proved to be accurate (0.1–0.4 size too small on average). The following figures show percentage of cases receiving a correct implant, allowing an error of one size. Digital templating of the hip arthroplasty was less frequently correct (cemented cup and stem: 72% and 79%; uncemented cup and stem: 52% and 66%) than analog planning (cemented cup and stem: 73% and 89%; uncemented cup and stem: 64% and 52%).

Interpretation Planning of component sizes for total knee arthroplasties is an accurate procedure when performed digitally. Our digital preoperative plans which were performed by someone other than the surgeon were less accurate than the analog plans prepared by the surgeon.

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Preoperative planning is an important part of the surgical procedure. The technical goals of preoperative planning of the total knee arthroplasty are to achieve accurate prosthetic seating with proper axial alignment (Krackow 1986). When planning a total hip arthroplasty, the surgeon searches for optimal fit, the method of reconstructing leg length and the position of the centre of rotation, all of which are dependent on the implant size. This procedure forces the surgeon to think three-dimensionally, improves the precision of surgery, shortens the length of the procedure and reduces the incidence of complications (Capello 1986, Muller 1992, Dore and Rubash 1994, Eggli et al.1998, Blackley et al. 2000, Haddad et al. 2000). Preoperative planning also provides the surgeon with a tool in order to ascertain that the correct prosthetic component sizes are available.

The inability to accurately determine the magnification factor of the radiograph is one of the major problems in analog preoperative planning of total hip and knee arthroplasties. In addition, the use of templates with standard magnifications does not permit accurate correction of the magnification factor (Knight and Atwater 1992, Linclau et al. 1993, Heal and Blewitt 2002). One way of overcoming this problem might be the use of CT images (Barmeir et al. 1982, O'Toole III et al. 1995, Sugano et al. 1998, Kerschbaumer 2000, Schiffers et al. 2000, Starker et al. 2000). Routine use of CT scans results in more radiation exposure and puts a greater demand on the radiology department, with increased costs. Digital planning using

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plain radiographs would be worth considering for these reasons alone, quite apart from the fact that digital radiographs are gradually replacing conventional radiographs. The problems to be overcome are (1) the correction of magnification, and (2) working with a two-dimensional projection of a three-dimensional structure.

We determined the accuracy of digital preoperative plans for primary total hip and knee arthroplasties and compared this with analog planning.

Patients and methods

Patients

182 primary total hip arthroplasties were performed in the period between January 2002 and March 2003. 117 patients underwent an arthroplasty with a cemented total hip prosthesis and 65 patients received an uncemented primary total hip prosthesis. 70 patients had a total knee prosthesis operation. This yielded 252 interventions available for inclusion. All interventions were primary arthroplasties for osteoarthrosis. Patients with a history of previous surgery on the region of interest were excluded, when the operation had disturbed the normal bony anatomy. A substantial number of patients did not have radiographs with calibration objects on the day of admission. In most cases it was possible to prepare new radiographs to correct this. Otherwise, the patient was excluded from the study. 112 cemented hip arthroplasties (with 5 patients excluded) and 61 uncemented hip arthroplasties (4 patients excluded) were available for planning, yielding a total of 173 preoperative plans. After exclusion of 5 interventions, 65 knee arthroplasties were planned.

For the knee arthroplasty, a full-leg length standing radiograph with knees in full extension and non-weight bearing anteroposterior and lateral knee images were obtained. The calibration object, a 28-mm femoral head, was positioned at the estimated height of the centre of the joint.

For the planning of total hip arthroplasties, a plain pelvic radiograph in supine position and with both legs in maximum internal rotation was made. The calibration object was positioned between the legs of the patient at the level of the greater trochanter. This bony structure is best palpable when the femoral anteversion is neutralized with the legs in 20º endorotation (Reikeras and Hoiseth 1982, Blackley et al. 2000). If the patient was unable to endorotate this much, the calibration object was placed 1–2 cm higher than the greater trochanter.

Prostheses

The Mallory Head (MH) prosthesis with a metal backed cup was used for uncemented total hip arthroplasties, the Scientific Hip Prosthesis (SHP) with a non-metal backed cup was used for all cemented total hip arthroplasties, and the Anatomic Graduated Components Knee Prosthesis (AGC) was used for all primary total knee arthroplasties.

The Mallory Head cups were available in 10 sizes, and the stems were available in 8 sizes. Both the SHP cups and the stems were available in 7 sizes. The AGC femoral component was available in 6 sizes and the tibial component was available in 7 sizes.

Preoperative planning

The day before surgery, the orthopedic surgeon planned the arthroplasty with analog templates on conventional radiographs. Templates of the hip prosthesis had a 115% magnification factor, and those of the knee, 110%. The implant sizes chosen were noted in the patient's medical record, to make it easy to retrieve in the operating room.

The digital preoperative plan was performed by the first author without knowledge of the analog plan. The digitally chosen implant sizes were stored in a database. We used the preoperative planning software HyperORTHO (Rogan-Delft B.V., Veenendaal, the Netherlands).

Interobserver and intraobserver reliability

Preoperative planning on radiographs of 5 patients of each group (cemented total hip arthroplasty, uncemented total hip arthroplasty and total knee arthroplasty) was performed by five different surgeons to determine interobserver reliability. The same radiographs were evaluated a second time by the same surgeons after approximately three weeks, to measure the intraobserver reliability of preoperative planning. None of these surgeons were involved in the actual surgery of

Table 1. Mean differences between the planned and the implanted component sizes

Planning method	SHP C	SHP S	MH C	MH S	AGC F	AGC T
Digital [a]	0.0	–0.5	0.3	–0.7	–0.1	–0.4
Analog [b]	0.4	0.0	–0.3	–1.0	–1.1	–1.1
Independent analog [c]	1.0	1.2	0.8	0.7	–1.0	–0.2

Negative values indicate that the planned size was smaller than the implanted size.
C cup, S stem, F femoral, and T tibial component.
[a] digital planning, but not by actual surgeon.
[b] analog planning by actual surgeon.
[c] analog planning, but not by actual surgeon.

these patients. Although all plans were made on analog images, these measurements of reliability apply to both digital and analog methods since they differ only in correction of magnification, which only affects the accuracy and not the reliability of the plans. Accuracy of these analog plans was determined by assessing the differences with the actual implant sizes used. Methodologically, this is comparable to the digital plans which were also performed by someone other than the actual surgeon, and which were not incorporated into the rest of the surgical procedure.

Statistics

To be able to detect systematic errors, the mean differences between either type of plan and the implant sizes used were measured. The success rates of the digital and analog preoperative plans were measured using two different cut-off points to define a correct plan: (1) exact matching, and (2) matching allowing for a difference of one size. The t-test for paired observations was used for analysis of the differences between the analog and the digital plans regarding the mean absolute differences between planned and implanted component sizes.

Weighted kappa was used to measure the chance corrected interobserver and intraobserver reliability. While no absolute definitions were possible, we rated the strength of agreement with scores of 0.20 or less as ‘poor’, 0.21–0.40 as ‘fair’, 0.41–0.60 as ‘moderate’, 0.61–0.80 as ‘good’ and 0.81–1.00 as ‘very good’ (Altmann 1991).

Table 2. Cumulative percentage of correct plans allowing for different margins of error

Margin of error	Prosthesis and component		Analog plan (%)	Digital plan (%)
None [a]	SHP	C	23	36
		S	37	35
	MH	C	34	16
		S	30	34
	AGC	F	8	55
		T	14	52
One size [b]	SHP	C	73	72
		S	89	79
	MH	C	64	52
		S	52	66
	AGC	F	64	92
		T	69	94

C cup, S stem, F femoral, and T tibial component.
[a] Perfect match between the planned component size and the implanted component size.
[b] One size difference was allowed between the component size planned and that used.

Results

Mean differences

For most components, the mean difference between planned sizes and sizes actually used was no more than half a size. Only the analog and digital plans for the uncemented stem, and also the analog plans for the femoral and tibial knee components, tended to be approximately one size too small (Table 1).

Absolute differences for the hip

Both the digital and the analog preoperative plans for the total hip arthroplasties were in exact agreement with the implanted component sizes in less than 40% of the times tested (Table 2). When considering a deviation of one size as still being a correct plan, the success rates rose to approximately 60% for both uncemented components, 70% for the cemented cups and 80% or more for the cemented stems.

For the preoperative plans for total hip arthroplasty, analog planning of the SHP stem was more accurate than digital (mean difference 0.2; $p < 0.02$), as was analog planning of the Mallory Head cup (mean difference 0.6; $p < 0.001$) (Table 3). The analog series measured by independent surgeons was too small for us to draw solid conclusions, but there was a tendency to be less accurate

Table 3. Mean absolute differences between component sizes planned and implanted

Absolute error	SHP C	SHP S	MH C	MH S	AGC F	AGC T
Digital [a]	1.1	0.9	1.8	1.3	0.6	0.3
Analog [b]	1.2	0.7	1.2	1.5	1.2	1.4
p-value [c]	0.6	0.02	0.001	0.2	< 0.001	< 0.001
Independ. analog [d]	1.4	1.4	1.8	1.5	1.0	0.5

C cup, S stem, F = femoral, and T tibial component.
[a] digital planning, but not by actual surgeon.
[b] analog planning by actual surgeon.
[c] p-values of the difference between Digital [a] and Analog [b]
[d] analog planning, but not by actual surgeon.

Table 4. Interobserver and intraobserver reliability of preoperative planning

Measurements	SHP C	SHP S	MH C	MH S	AGC F	AGC T
Interobserver						
SD [a]	0.9	0.8	1.4	0.9	0.3	0.4
κ(w) [b]	0.22	0.26	0.53	0.54	0.75	0.63
Intraobserver						
SD [a]	0.5	0.5	0.5	0.6	0.1	0.1
κ(w) [b]	0.49	0.48	0.79	0.64	0.82	0.88

C cup, S stem, F femoral, and T tibial component.
[a] Standard deviation, is expressed in component size and is an indication of the differences between or within observer measurements.
[b] weighted kappa-score is a measure of the chance-corrected proportional agreement between or within observer measurements.

than both the analog and digital plans of the main series.

Absolute differences for the knee

For the total knee arthroplasties, the analog plans scored poorly concerning exact agreement (Table 2). Even when allowing for one size difference, the results were disappointing. The digital plans for both components scored better, with more than 50% exact agreements and more than 90% agreements when allowing an error of one component size.

The absolute differences between the sizes planned preoperatively for the total knee arthroplasty and implanted component sizes were significantly less for digital planning than for analog planning, regarding both the femoral component (mean difference 0.6; $p < 0.001$) and the tibial component (mean difference 1.1; $p < 0.001$) (Table 3).

Interobserver and intraobserver reliability

The standard deviations for interobserver and intraobserver reliability measurements for the planning procedure were consistently smaller than one size, except for the Mallory Head cup (Table 4). This was a result of having more component sizes to choose from, and is corrected for in the weighted κ-score. These scores indicate that planning of the Mallory Head was actually done with a higher degree of reliability than planning the SHP. Mallory head planning had a ‘moderate’ strength of agreement, as opposed to a ‘fair’ agreement for planning the SHP components. The variability in planning of the sizes of AGC components was even lower. This could not be explained by having fewer sizes to choose from, as can be derived from the κ-scores, which are substantially higher than for the hip measurements and indicate a good strength of agreement. Intraobserver reliability was higher than interobserver reliability for planning each of the components. The strengths of agreement were moderate for planning of the SHP, good for planning of the Mallory Head, and very good for the AGC.

Discussion

Currently, there is a growing number of hospitals with digital radiographic facilities (PACS – Picture Archiving and Communication System). The precise implications for costs and changed routines are unclear (Lee et al. 1991, Reiner et al. 2000, Maass et al. 2001, Scholl et al. 2001). Even without being able to foresee all the consequences, this seems to offer great advantages in terms of making, storing, retrieving and analyzing images (Dooley et al. 1992, Foord 1999, Gross-Fengels et al. 2002, Pilling 2002, Reiner and Siegel 2002). Such a system also allows the orthopedic surgeon to carry out digital preoperative planning for total hip and knee arthroplasties. This study is the first to investigate and compare the results of digital and analog preoperative plans.

With the use of calibration objects, the digital images can be corrected for the magnification factor. This is generally assumed to be an advantage, but if the position of the calibration object differs too much from the region of interest, it will lead to a structural error in digital correction of magnification. The position of the knee joint can be estimated accurately through physical examination, but the hip joint is difficult to assess. Its position can only be estimated indirectly, which could in theory be a source of errors. The calibration protocol used in this investigation has been validated in a recent as yet unpublished study by The et al. In 95% of cases, variability in positioning of the calibration object can be expected to result in an error of correction of the magnification ranging from –3% to +3%.

Both kinds of plan for the uncemented stem, and also the analog plans for the knee components, were one size too small on average. This can be explained by the variability of the data, considering the plans for the uncemented stems. [unclear] Regarding analog plans for knee prostheses, an actual systematic error in planning seems plausible. The best explanation is that the 110% magnification of the templates, although it is the smallest available, is still too large in general. This type of error is an implicit pitfall of analog planning in general, but it is not always recognized as such. In theory, it could also arise in digital planning when the calibration protocol is not accurate or not followed accurately.

The reliability of the knee plans was good, but the plans for the uncemented hip were only moderately reliable, and the cemented hip plans were even less reliable. The uncemented stem uses clearer bone references for planning, which may explain the lower variability. For the cups, however, this explanation is not valid. Taking into account the possibility of using cement as a buffer may have caused the observers to do less strict planning.

The fact that planning of the knee prosthesis uses clear bony landmarks as well as the fact that the sizes differ by 4 mm for the tibial component and even by 5 mm for the femoral component can probably account for the small variability. Intraobserver reliability had consistently higher scores than interobserver reliability. This means that it is generally more reliable to leave the choice of component sizes to the surgeon himself, which is consistent with the philosophy that the preoperative planning is part of the entire surgical procedure.

Planning of the component sizes of knee prostheses was far more accurate than planning the components of hip prostheses. This information is most useful from an economic point of view, since the high success rates regarding prediction of component sizes provide us with a tool for stock control. However, the clinical value of such a tool for total knee arthroplasties is limited. Determining the correct size for the components of the knee prosthesis can be done under direct visualization of the bony landmarks intraoperatively. The more essential planning of correction of axial alignment could not be performed in this developmental phase of HyperORTHO, and was left out of the present study.

One must bear in mind that the value of preoperative planning decreases when it is not integrated into the complete process of surgery. The analog plans were made by the same surgeon who would perform the arthroplasty the next day, and the data of these plans were available in the operating room. The digital plans were not made by the operating surgeon; nor were the data available to him. The results of the small series in which independent surgeons performed analog planning for the total hip arthroplasties suggest that this may have influenced the results in the main series in favor of the analog procedure.

On the other hand, the analog preoperative plans were made using templates with a standard magnification factor. We chose this approach because it is common practice in most hospitals, but the calibration object does provide the surgeon with the possibility of getting an estimate of the magnification merely by measuring the diameter of its projection. Choosing between the templates with a 110%, 115% or 120% magnification factor could be done using this information. This would have been of little help when planning the knee arthroplasties, however. The smallest available magnification for knee templates was used and it was in general still too large, giving rise to the systematic underestimation of component sizes mentioned above.

It was also noted that the radiographic result of the arthroplasties sometimes gave rise to criticism concerning the choice of component sizes, or otherwise. In this respect, it can be argued that the reference for correct planning should not be the components that have been used. If the surgeon who performed the arthroplasty recognises that a different component size could and should have been used, the reference should be adjusted likewise.

Another interesting question is how much benefit can be obtained in clinical outcome when digital preoperative planning becomes better developed, with added digital applications to enable biomechanical planning. Possibly leg-length correction, reconstruction of the centre of rotation and offset, and reduction in operation time – along with potential benefits such as lower infection rates, and reduction of complications like perioperative fractures – may all be influenced for the better. Investigations will be required in the near future to determine these potential benefits.

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