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Threedimensional, CT-assisted preoperative planning for primary total hip arthroplasty

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Abstract

Purpose: In hip arthroplasty, exact positioning of the implants is imperative. Preoperative planning is essential to achieve this and is generally conducted using conventional radiographs. The objective of our study was to examine the clinical feasibility of a 3D planning system. **Methods:** In 500 patients (average age 72.8 (31-87) years), a CT was performed preoperatively for 3D planning. The data were further processed in DICOM format on an external workstation for 3D planning, with the aid of special software (SYMBIOS® 3D-Hip Plan), whereby an exact presentation of the acetabulum and femur was possible in all three planes. The clinical outcome was documented by using the Harris Hip Score. **Results:** In 470/500 patients (94%), the acetabular cup was successfully implanted as planned. In the area of the stem, in 10/500 patients (2%) a custom made stem was implanted, as adequate treatment due to anatomical reasons could not have been achieved here. Overall, the stem planning could be implemented exactly in 475/500 patients (95%). The neck length of the head was implemented as planned in 465/500 patients (93%). The Harris Hip Score improved from a preoperative average of 47.6 to 70.6. **Conclusion:** 3D hip planning enables a preoperative simulation of implant positioning, which makes it possible to optimally determine and reconstruct the centre of hip rotation. Potential difficulties that might arise intraoperatively can already be identified preoperatively. Patients who require a custom made stem can be reliably identified.

Keywords: Computed Tomography, Minimally invasive hip arthroplasty, Three dimensional planning, Total hip arthroplasty.

INTRODUCTION

The implantation of a total hip replacement to treat the pain and functional impairment caused by osteoarthritis of the hip has developed since the 1960s into a successful and established method [1]. Despite all of the advances made, perioperative complications continue to be experienced, such as periprosthetic fractures, dislocations, bleeding, vascular and nerve damage, deep leg thrombosis and infections, with a rate of around 3 - 10 % [2, 3].

Around 240,000 primary total hip replacements are implanted in Germany every year [4], whereby a total of 150,284 datasets for primary implantations on the hip joint were sent to the German Arthroplasty Registry for the calendar year 2018 [5]. Prerequisite for optimal joint replacement surgery is appropriate preoperative planning [6]. Planning is currently performed on the basis of two-dimensional, conventional radiographs with the aid of digital planning programs [6, 7]. However, in particular the planning of cementless stems frequently leads to problems with in part considerable differences between preoperative planning and the actually implanted stem size and position [8]. The reasons for this are above all anteversion, which is difficult to determine on radiographs, torsion abnormalities, as well as a frequently underestimated femoral offset, with impaired rotation capacity of the hip joint [9]. A possible improvement of planning can be achieved using a three-dimensional image generated from computed tomography data, the main advantage of this method being the fact that imaging is free of superimposition and is independent of magnification factors and patient positioning [10, 11, 12, 13].

We present data on the clinical feasibility of a computed-tomography-based, three-dimensional planning system for primary implantation of total hip replacements.

MATERIALS AND METHODS

In a prospective study, a total hip replacement was implanted in 500 consecutive patients (295 women, 205 men, average age 72.8 (32-87) years) over the period from January 2015 to June 2020. Most of the patients were suffering from osteoarthritis of the hip corresponding to grade 3 / 4 according to Kellgren & Lawrence [14], while the smaller proportion was made up of patients with post-traumatic hip osteoarthritis and hip osteoarthritis secondary to rheumatoid arthritis. The average BMI was 28.3 (17-43).

Computer-assisted preoperative planning

Preoperatively, a CT scan (Siemens Sensation 64) was performed for 3D planning.[15,16] A continuous spiral was performed from the iliac crest to 20 cm distal to the acetabulum with a slice thickness of 2 mm and a reconstruction interval of 2.5 mm. In addition, 6 single slices with a slice thickness of 2 mm were performed in the area of the knee joint to determine the bicondylar plane. The average effective radiation dose was 2.9 (2.3 - 6.1) mSv.

The data were further processed in DICOM format on an external workstation for 3D planning with the aid of special software (SYMBIOS® 3D-Hip Plan), whereby an exact representation of the acetabulum and femur was possible in all three planes. Different cups and stems are stored in the system for planning, whereby the Pressfit cup type April® and the cementless stem types SPS-Evolution® and Arcad® (all from Symbios, Yverdon, CH) were chosen for our patients, with a ceramic articular pairing being used in all cases.

The workflow of the planning is systematised and predefined in its individual steps, with 5 main steps being processed here in succession. First, the leg lengths are determined and it is decided whether it will be necessary to correct the leg length, followed by automated determination of the pelvic inclination, then the size and position of the cup and the stem are determined, and finally the neck length of the head is determined (Fig. 1a - d). All planning was carried out by a single primary surgeon (SR).

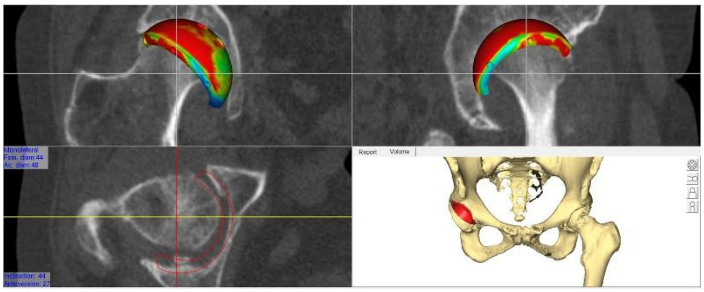

Figure 1a: Illustration of the planned cup position in the planning program in 3 planes. In the color display, the contact between the cup and the bone is visualized (red: contact with a good bone substance, green: contact with a less dense bone substance, blue: poor bone contact).

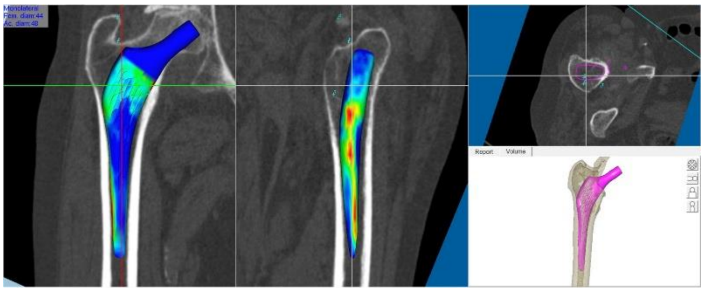

Figure 1b: Illustration of the planned stem position in the planning program in 3 planes. Similar to the cup, the bone contact is shown in color. In the metaphyseal area there is good contact between the prosthesis and the bone, and there is good lateral support for the stem in particular. In the axial image, in the calcar area, there is a small cortical spur that extends into the medullary canal, which can lead to malrotation during implantation of the stem prosthesis if not observed.

Figure 1c: Illustration of the planned stem position in the planning program in 3 planes as in Fig. 1b, rotated horizontally by 180°. There is good bone contact of the stem in the calcar area and metaphyseal dorsally.

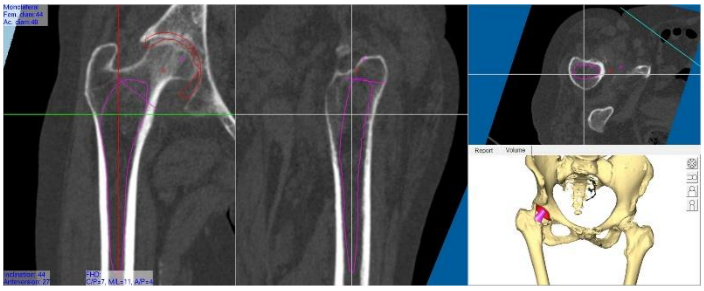

Figure 1d: Representation of the cup and the stem with the associated center of rotation (cup: red, stem with center of rotation: magenta). The centers of rotation differs by 7 mm because there is a leg length discrepancy preoperatively.

Surgical approach and conduct of the operation

The operation was performed in the supine position on a standard operating table without traction assistance. Surgical access was via a slightly modified Smith-Petersen approach [17, 18, 19]. The skin incision starts approx. 2 cm below and lateral to the anterior superior iliac spine and follows the anteromedial portion of the tensor fasciae latae muscle, the length varying according to the individual patient situation. After typical osteotomy of the femoral neck and removal of the femoral head, the acetabulum is exposed using specially angled retractor hooks and prepared to the appropriate size using reamers mounted on either straight or angled handles. This is followed by implantation of the original cup.

To prepare the femur, the legs are lowered by about 20° and the leg to be operated on is adducted and externally rotated, then the femur is mobilised and positioned ventrally with the aid of a two-pronged retractor, which comes to rest at the level of the innominate tubercle, so that the femoral canal can be prepared to the desired size for implantation of the stem prosthesis using medullary reamers. The original prosthesis is then implanted and the position of the stem is checked using the bony landmarks (lesser trochanter and trochanteric fossa). A trial position and a leg length check are performed, using the medial malleoli as landmarks. In addition, stability is checked by moving the hip joint through the range of motion, where both dislocation tendencies and impingement can be detected. After all original parts have been inserted and the final reduction has taken place, an intra-articular redon drain is inserted and the wound is closed layer by layer.

Postoperative control

A radiographic control was carried out in the operating theatre for all patients. Before the start of the rehabilitation measure, a pelvic survey image was taken and the implant was displayed in the second plane to detect periprosthetic fissures and / or fractures. On these images, a possible leg length difference (determination by means of the trans-teardrop line as the pelvic reference line and the connecting line between the centre of the two lesser trochanters as the femoral reference, a perpendicular line is drawn between these lines, the difference between the two lines being the difference in leg length), the offset, the acetabular inclination angle, the positioning of the femoral stem as well as the centre of rotation were determined.

Clinical outcomes were documented using the Harris Hip Score [20] preoperatively and 6 weeks postoperatively.

Statistics

Statistical analysis was performed using Prism 5 software (Graph Pad). The Wilcoxon rank sum test for paired samples was used to analyse the development of the Harris Hip Score. Statistical significance was marked as *$p < 0.05$, **$p < 0.005$ and ***$p < 0.0005$.

This study is in accordance with the legal provisions as well as the Declaration of Helsinki of 1975 (in the revised, current version).

RESULTS

The acetabular cup was implanted as planned in 470/500 (94%) cases, the remaining 6% were one size smaller or larger. A custom prosthesis was produced and implanted in 10/500 (2%) of patients based on CT planning. The stem was implanted exactly as planned in 475/500 (95%) cases, 3% received one size smaller or larger. The neck length of the head was selected as planned in 465/500 (93%) cases, the remaining 7% were one neck length more or less. Taking all 3 components into account, the accuracy of the preoperative planning was 81% (**Fig. 2**). A typical example of a patient's pre- and postoperative radiographs is shown in Fig. 3a, b and Fig. 4a, b.

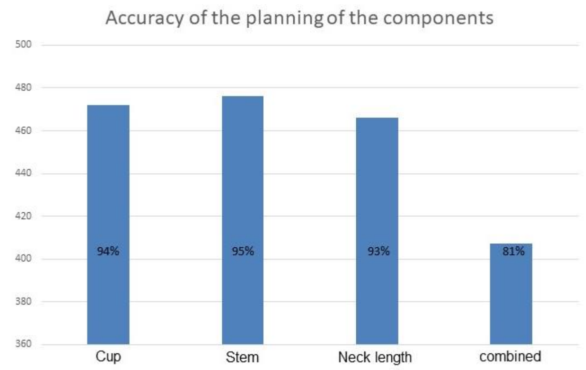

Figure 2: Accuracy of the 3D planning for the individual components and their combination.

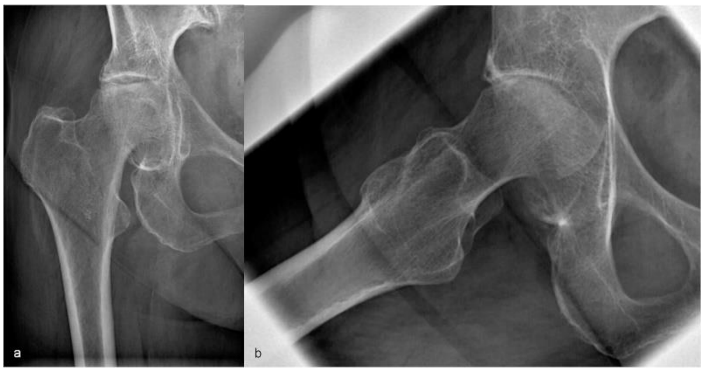

Figure 3a, b: Preoperative x-rays a.p. and axial: illustration of the hip joint with a subchondral fracture of the femoral head and additional arthritic changes.

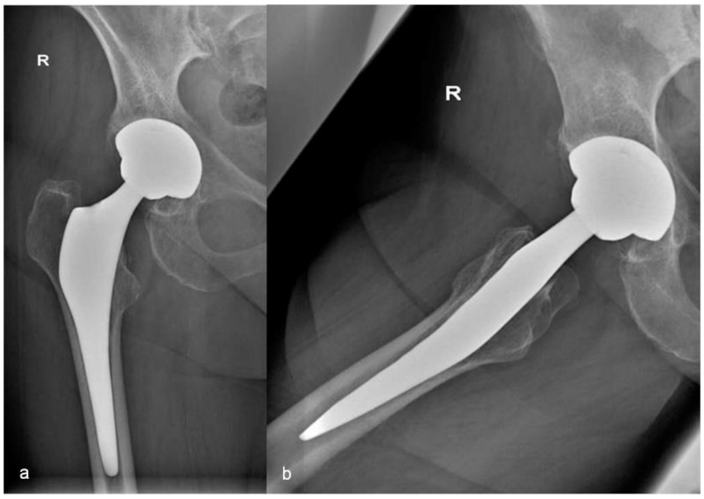

Figure 4a, b: Postoperative x-rays a.p. and axial: correct position of the implanted, cementless total hip endoprosthesis.

The preoperatively planned position of the implants matched the positions checked in the postoperative radiographic controls in more than 90% of cases. The average difference in length compared with the planned leg length was 4.4 mm (-5 to + 7mm).

The Harris Hip Score averaged 47.6 (± 9.4) preoperatively, with a significant increase of 70.6% to an average of 81.2 (± 8.3) 6 weeks postoperatively ($p < 0.005$).

Perioperative complications documented were a periprosthetic femoral fracture and a superficial wound healing disorder.

DISCUSSION

Preoperative planning is an essential element in the implantation of total hip replacements. It allows potential anatomical problems to be identified, thus minimising intraoperative complications and reducing operating times [21, 22, 23]. The established standard is 2D digital planning, where a wide range of accuracies of 40-75% is stated for the implant sizes used [7, 8, 12, 24, 25, 26]. A marked improvement in accuracy by using 2D digital systems compared to conventional planning on foils has yet to be achieved [8, 26]. Mainard *et al.* [27] report an improvement in the predictability of implant sizes by using 3D planning based on 2D digital radiographs, with the accuracy of ± 1 size for the cup improving from 87% to 92% and the accuracy of ± 1 size for the prosthetic stem from 68% to 84%.

A promising further development is 3D planning with the aid of raw data acquired in spiral computed tomography [28]. The advantages lie in an image free of superimposition in a calibrated space, elimination of projection-related magnifications and the possibility to determine defined distances and angles independently of the patient's position [11, 13, 15, 29]. In addition, intramedullary features such as cortical spurs can be visualised and the contact surfaces of the implant to the bone can be shown [16]. With the aid of appropriate planning software, which is now widely available from various manufacturers [12, 30], the prediction accuracy of implant sizes and alignment can be markedly improved. Schiffner *et al.* [31] achieved a prediction accuracy of 56.9% for the cup and 58.6% for the stem with the help of their planning software. Inoue *et al.* [32] report an accuracy of 92% for the cup and of 65% for the stem in their study. The research groups of Sariali *et al.* [12] and Hassani *et al.* [30] achieved markedly better results, with accuracies of 96/94% for the cup and 100% for the stem in each case. Hassani *et al.* [30] additionally report a prediction accuracy of 88% for the neck length. The results of the latter two authors are in line with our results, which showed a prediction accuracy of 92% for the cup, of 97% for the socket and of 93% for the neck length. It is possible that the planning software used has an influence on the prediction accuracy, with Saliari *et al*. [11, 12] and Hassani *et al*. [30] using the same software as our research group.

An additional advantage of 3D planning is the recognition of anatomical features and severe deformities, which opens up the possibility of producing a custom prosthesis in individual cases [33]. As in the case of our 10 patients who received a custom prosthesis, the data generated in the CT scan can be used for production of the prosthesis.

The effective dose of approx. 2.9 mSv applied in the low-dose CT scan is only slightly higher than the dose applied in conventional 2D planning [16], so that the radiation exposure does not represent a limitation for the method.

Limitations

To improve the strength of our results, the following optimisations would be conceivable:

- Postoperative CT scan of the total hip replacement.
- Inclusion of a comparative group with 2D planning.
- Determination of interobserver variability. This was not done in the present study, as the planning was performed exclusively by a single primary surgeon.

CONCLUSIONS

With 3D hip planning, an exact prediction of the implant sizes and their positioning is possible. At an acceptable level of radiation exposure, the accuracy is markedly increased compared to 2D planning. In certain anatomical situations, the data obtained can be used for the production of a custom prosthesis.

Diosclosure

The authors declare that they have no conflict of interest.

Authors' Contribution

Sebastian Radmer created the study design, did data acquisition and analysed and interpreted the data. Julian Ramin Andresen did data acquisition and analysed and interpreted the data. Both authors drafted the article and finally approved it.

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