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Computer assisted implantation of the femoral stem in THA – an experimental study

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Abstract Fourteen femoral stems were implanted either manually by an experienced surgeon or by a robot in fresh human cadaveric femora. The neck-shaft angle, the anteversion, the length of the femoral neck and the gap between stem and bone was measured in each specimen. Implantation by robot showed higher precision in reconstructing the true anatomic situation as well as providing a better press fit.

Résumé 14 prothèses de la hanche ont été introduites soit manuellement soit par un robot dans des os de fémurs humains frais. Pour remplacer l'articulation de la hanche, un procédé opératoire orthopédique assisté par ordinateur permet une plus grande précision dans la reconstruction des données anatomiques individuelles du patient ainsi qu'un meilleur maintien de l'implant. De plus, il rend possible un contrôle de la qualité par la comparaison des données obtenues dans les phases préet postopératoires.

Introduction

In order to improve surgical precision, computer aided techniques have been recently introduced in some specialities. Intraoperative surgical guidance can be provided with the help of preoperative planning and by semiautomatic devices (robots), which can perform operative steps under supervision by the surgeon. In order to optimize implantation techniques in hip replacement ISS (Integrated Surgical Systems, Sacramento, USA) developed a computer based system to work with a surgical robot [1, 7]. The purpose of this study was to evaluate the quality of computer assisted orthopaedic surgery (CAOS) in arthroplasty of the hip.

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Material and methods

Fourteen fresh human cadaveric femora with moderate degenerative disease of the femoral head were CT scanned, digitised and reconstructed 3-dimensionally so that for every femur a 3D-data set was available. Virtual preoperative planning for implantation of a cementless total hip arthroplasty using a special software package was undertaken (ORTHODOC™, ISS, Sacramento). The specimen were randomised into two groups, of which one had manual implantation (MI) and the other a robot implantation (RI) (ROBODOC™, ISS, Sacramento) of the appropriate stem (Precision Osteolock™; Howmedica). All femora underwent standardised manual neck osteotomy. In the MI-group, preparation of the femoral cavity and implantation of the stem was performed by an experienced hip surgeon. In the RI-group preparation of the femoral cavity was performed by the robot. After implantation all specimens were re-evaluated by CT scan and digitised. The slice thickness was 1 mm in order to optimise the visualisation of the interface. Three-dimensional reconstruction was performed with an algorithm which diminished metal artefacts. CCD- (caput-collum-diaphysis), AV- (anteversion) angle and neck length were recorded. In addition the implant – bone interface was calculated for each Gruen-zone [4] by measuring the distance between the implant and bone, starting at the tip of the greater trochanter, in 1 cm intervals and 4 quadrants (anterior, posterior, medial, lateral). In selected cases the bone-implant interface was morphologically evaluated after maceration, embedding and cutting in the transverse plane corresponding to the CT-studies. Statistical evaluation was performed using the Wilcoxon-test.

Results

The average time for the implantation was 18.5 minutes in both groups. The preoperative CCD-angle was compa-

Table 1 Pre- and postoperative values for neck-shaft (CCD) – and AV-angle as well as neck length in the manual implanted (MI) and robot implanted (RI) group

	Preoperative	Postoperative
CCD – MI	126.7°±4.0°	131.9°±0.8°
CCD – RI	127.8°±4.3°	133.2°±1.9°
AV – MI	31.3°±8.8°	20.5°±9.5°
AV – RI	30.9°±8.0°	31.3°±8.7°
neck length – MI	57.7 mm	63.3 mm
neck length – RI	58.6 mm	63.3 mm

rable in the two groups (Table 1). Postoperatively this angle averaged in the MI-group 131.9° (S=0.8) and 133.2° (S=1.9) in the RI-group. Significant differences were present when comparing the AV-angle. The preoperative AV-angle in the MI-group decreased considerably after implantation. The range of postoperative AV-angle in this group varied from 9.5° to 36.5°. In the RI-group this angle was comparable before and after implantation (Table 1). The differences between pre- and postoperative AV-angle averaged 10.8° (S=6.4) in the MI-group compared with 0.4° (S=0.9) in the RI-group, which was statistically significant (P<0.01). The neck length was also significantly different when comparing pre- and postoperative findings (Table 1). The difference in neck length averaged 7.9 mm in the manual and 5.4 mm in the RI-group.

The measurements of the implant-bone interface in Gruen zone 7 (medial calcar) was significantly less in the robot group compared the manual group (RI: 1.6 mm. MI: 5.1 mm. P<0,01). The interface between implant and adjacent bone showed intact trabecular architecture in the RI-group, whereas in the MI-group the trabeculae were grossly destroyed, resulting in microfractures (Fig. 1). In one MI-specimen a bone fissure could be detected.

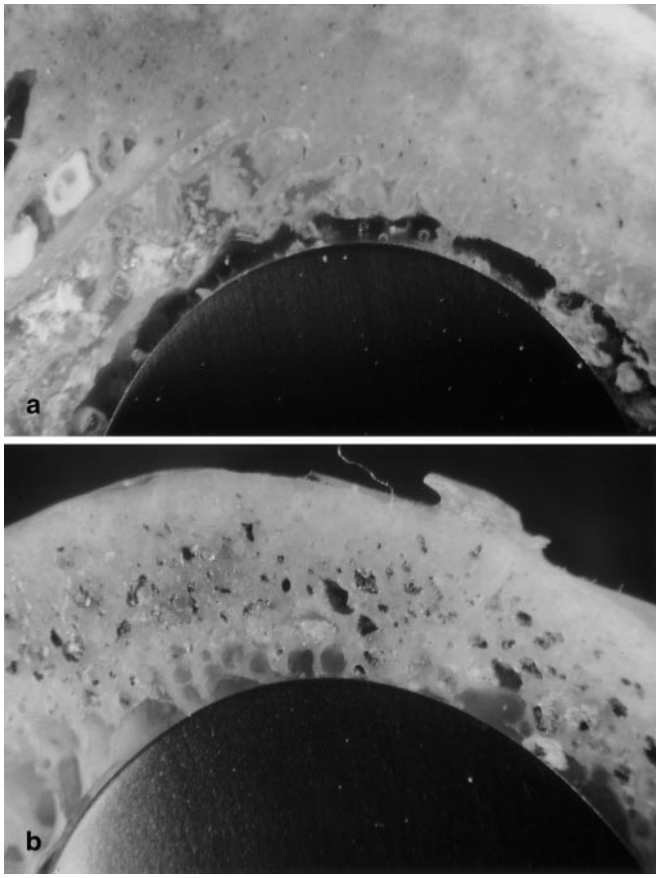

Fig. 1 Bone-implant interface in MI-group (**a**) and RI-group (**b**)

Discussion

The quality of stability in cementless hip replacement correlates with implant-bone-contact in specific zones of the proximal femur, of which the medial calcar area is of particular significance. Our results demonstrate that with the CAOS-technique implanted endoprostheses have an excellent bone-implant contact especially in this area. The bone-implant interface shows intact trabeculae in the robot implanted situation, whereas the trabeculae are considerably destroyed when the bed of the implant was prepared by manual rasping. The clinical significance of this finding is not clear.

The long-term success of a hip prosthesis may depend not only on the implant-bone interface, but also on correct restoration of CCD- and AV-angle. Malpositioning of the femoral shaft may lead to delayed osteointegration with the risk of early aseptic loosening. Different authors have documented a postoperative varus malpositioning as high as 20% and a valgus malpositioning in 1–2% of cases [9].

Although the complications with varus- and valgus malpositioning have been extensively published, the complications associated with altered femoral anteversion have not been reported in detail except as an occasional suggested cause of loosening[2]. However, even without loosening, changes in anteversion will have significant influence on joint mechanics. This may have more importance for the short rotator muscles which have a more horizontal orientation when compared to the gluteal musculature [6].

We have shown that by using CAOS the correct AV-angle may be reconstructed thus avoiding these surgical errors. This requires careful preoperative planning. Effenberger et al. [3] showed that in Germany only in 47% of cases was preoperative planning performed using a drawing and only in 53% by templating. We also believe that CAOS will have an important place in total knee replacement, revision knee surgery, periacetabular osteotomy and for estimating the correct resection planes in tumor surgery.

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