J Orthopaed Traumatol (2001) 1:7–17

ORIGINAL

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Preoperative planning in revision hip surgery

Received: 16 August 2001
Accepted: 19 August 2001

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Abstract The usefulness of preoperative planning has been described by various studies. In revision hip surgery this method helps to analyze biomechanical changes due to bony defects and suggests a surgical tactic for restoration of hip function. When using this method the surgeon gains information of biomechanical changes which have to be addressed in order to achieve good postoperative results. Data of 100 revision hip cases, performed between 1993 and 1997, where preoperative planning was performed, show a correct prediction of stem size in 85% and of cup size in 78% of the cases. Preoperative limb shortening averaging 14.5 mm preoperatively was significantly reduced to 3 mm postoperatively. Centerpoint of rotation on the operated side was normalized from 12.1 mm preoperatively to 3.6 mm postoperatively. Postoperative dislocation rate was 2%. We conclude that the method described is comparatively easy and effective.

Key words Hip arthroplasty • Revision hip surgery • Preoperative planning • Biomechanics • Computer-assisted planning

Introduction

Several studies published over the past years have shown the usefulness of preoperative planning in primary hip arthroplasty [1–6]. This is normally achieved by templating radiographs preoperatively. From this activity, the surgeon gains an estimate of implant size and positioning as well as a picture of the final reconstruction.

In revision hip surgery, however, chances are high that this technique will not fulfill the surgeon's needs. Depending on the etiology of hip revision, various biomechanical considerations have to be taken into account. For example, in cases of aseptic loosening, major bone loss may have occurred with subsequent migration of the cup proximally. At the same time, loosening and subsidence of the stem may have affected the quality of the proximal femur. Biomechanical changes will almost always result, with diminished offset of the proximal femur, decrease in muscle lever arm, as well as proximalization of the centerpoint of rotation. Clinically, the patient notes significant limb shortening and weakness along with the pain of a loose implant.

We have developed an easy to use computer-assisted planning system [7] in order to properly assess management of revision surgery preoperatively in complex cases. This method validates previously mentioned biomechanical principles including predicted values of expected leg-length discrepancies and estimated inclination of the cup. It also offers the possibility of evaluating the need for allograft bone to be used and predicts the size of components to be utilized in revision hip surgery with a high degree of accuracy.

Materials and methods

Recommended hardware requirements include a desktop computer with an Intel-Pentium III processor of 600 MHz or faster, a hard drive, a 3.5-in. floppy disk drive, a graphic card, a controller and 2 serial and 2 parallel COM ports as well as keyboard and mouse devices. We suggest the use of a 17-in. Color monitor and a high resolution inkjet color plotter printing on paper of at least A3 size. Furthermore, a backlighted digitizing tablet is needed with the dimensions of 20x24 in^2.

Considering the software, either Windows NT 4.0 or a Windows 2000 operating system comply perfectly with the requirements of the basic CAD-Software Autosketch version 7.1 for Windows. This software offers the possibility of storing different levels of planning on various layers in a precalibrated system which meets the requirements of the magnification factor. Furthermore, PC-compatible templates of the implants to be used should be available.

Standard preoperative planning in hip revision surgery includes radiographs of the pelvis as well as lateral views of both hips (Lauenstein or cross-table lateral). The lateral views thereby offer good insight into femoral anteversion and the size of the acetabulum. In serious osseous destruction of the proximal femur, long anteroposterior (AP) and lateral radiographs of the hip (20x60 cm^2) should be taken preoperatively and a long-standing radiograph of the compromised side, if necessary. All preoperative radiograph for revision cases, except for the long AP and the long-standing AP, in our hospital take into account a magnification factor of 1:1.20, thereby correlating the usual size of templates commonly available for various prosthetic models.

The basic principle of our planning device consists of the manual transfer of the standardized radiograph into the computer via the process of digitizing. By doing this, a negative of the bony circumferences of the radiograph on the screen is created. Before continuing in gaining the desired biomechanical data, two lines of reference have to be established in order to achieve correct alignment between the radiograph and the sketch. This includes a horizontal line of reference, described as a line drawn between the lower edges of the obturator foramen and a vertical line of reference orthogonal to the horizontal line and running through the middle of the symphysis.

Standard biomechanical points of interest in our planning include: leg-length discrepancies, centerpoints of rotation for both hips and the muscle lever arms. The first one is achieved by measuring the differences in height using the tips of the lesser trochanters. In cases in which bone loss is extensive and the remnants of the lesser trochanter cannot be clearly visualized, another method can be used. By comparing the heights of the centerpoints of rotation of the femoral heads of each side, the leg-length discrepancy can be calculated once the centerpoints have been established. This is generally done with a precalibrated template consisting of concentric circles which are projected on both femoral heads. By symmetrically adapting its circumference to the outlines of the heads, the centerpoint can easily be localized. This will also help to gain information about migration of the cup. The correct offset of the muscle lever arm can be established using the resultant of Pauwels [8]. He described the effective muscle lever arm as being a tangent to the circumferences of the greater trochanter and a line perpendicular to this going through the center of rotation, whereby the tangent was established by using an intersection of the lines between the vertical line of reference and a direct line drawn between the center of rotation, this line intersecting the vertical line in a 16° angle.

Once this data has been recorded and assessed, the sketch is stored and printed since it will record the preoperative status. Thereafter, the biomechanical lines and the old prosthetic components are erased, leaving behind the rest of the sketch with the bony circumferences of the pelvis and the femur. The new prosthesis components can now be templated into the latter. We principally begin with the placement of the cup template using standard guidelines for correct inclination and rotation. Thereafter, the stem and the head templates are projected onto the drawing. Bony allografts can easily be applied in schematic patterns in order to fill up spaces where osseous defects show. Thereafter, the same biomechanical lines are redrawn in order to gain information about the postoperative status to be expected. If these results are unsatisfactory, it is easy to modify the implant type (e.g. implant with a different CCD-angle) or implant size (e.g. different cup size) to correct the deficiency. Time for preoperative planning for a primary hip averages approximately 25 min whereas for a complicated case of revision hip surgery it may well take up to 60 min.

Postoperatively patients receive standard radiographs of the pelvis, on which the biomechanical measurements can be directly conducted. By doing so, the surgeon can actually compare the biomechanical values achieved postoperatively to the ones planned preoperatively.

Case reports

Preliminary results of 100 revision total hip arthroplasties (THA) operated by the same orthopedic surgeon between June 1993 and March 1997 [9] show a significant reduction in leg-length discrepancy from, a preoperative value of -14.5 mm to -3 mm postoperatively. Additionally, there was normalization of the centerpoint of rotation from +12.1 mm preoperatively to +3.6 mm postoperatively. A precise prediction of stem size using this technique was possible in 85% of cases; cup size was correctly predicted in 78%. Postoperative rate of dislocation was 2%.

In order to demonstrate this technique, several cases are presented with their preoperative as well as postoperative radiographs and their planning.

The first case (Fig. 1a) is that of a 65-year-old woman, 17 years after cemented primary hip arthroplasty on the right side and 10 years after cementless hip arthroplasty on the left side. Both components on the right side showed evidence of loosening with cup migration and stem subsidence and varization. There were associated bony defects in the acetabulum and femur with thinning of the lateral cortex due to lateralization of the tip of the stem as well as

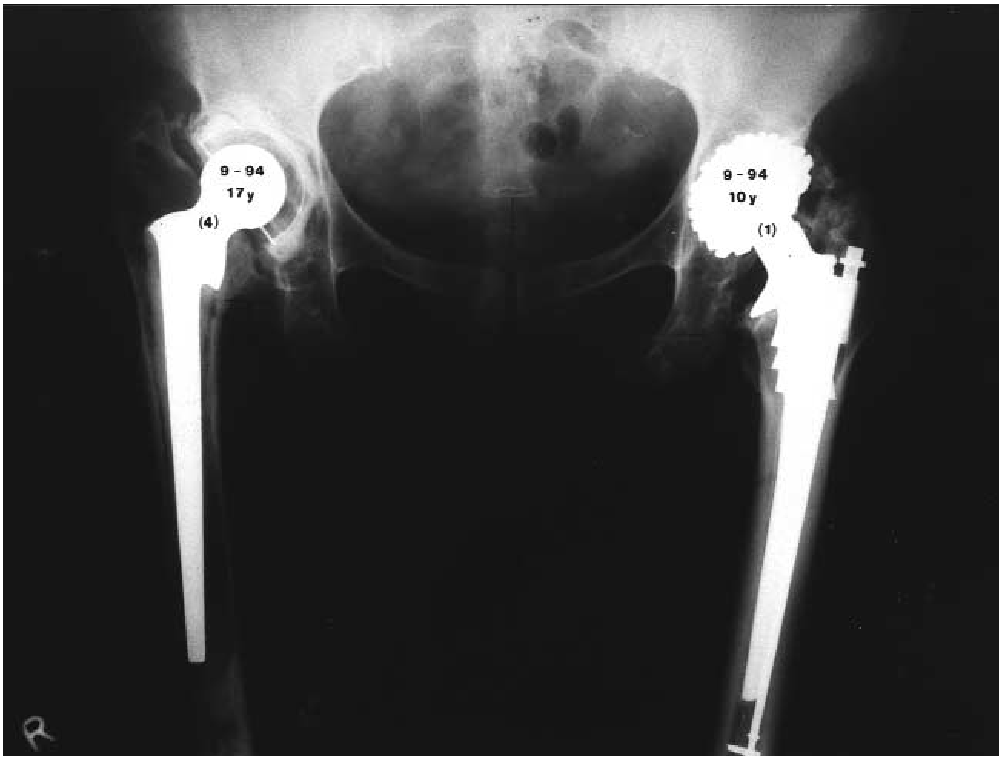

Fig. 1a Radiograph of a 65-year-old female patient with aseptic loosening of a cemented primary hip arthroplasty 17 years after implantation

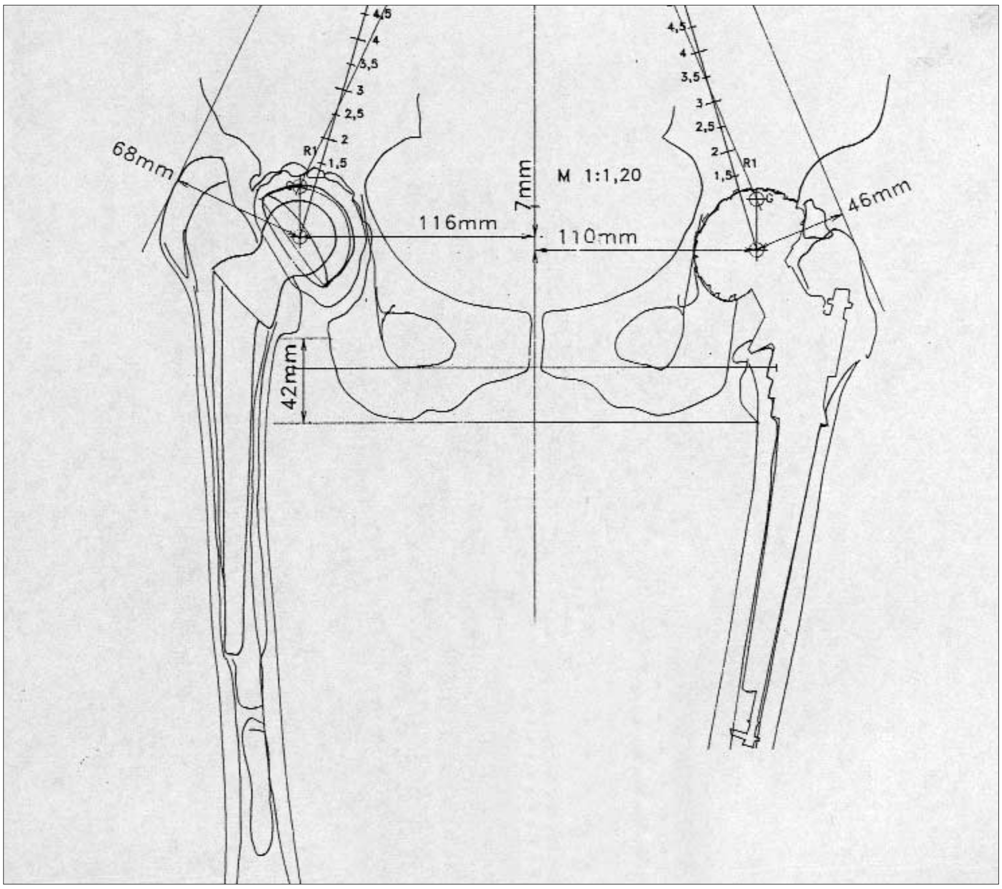

Fig. 1b Preoperative evaluation of the same patient as in Fig. 1a using the computer assisted planning program. *M*, magnification factor

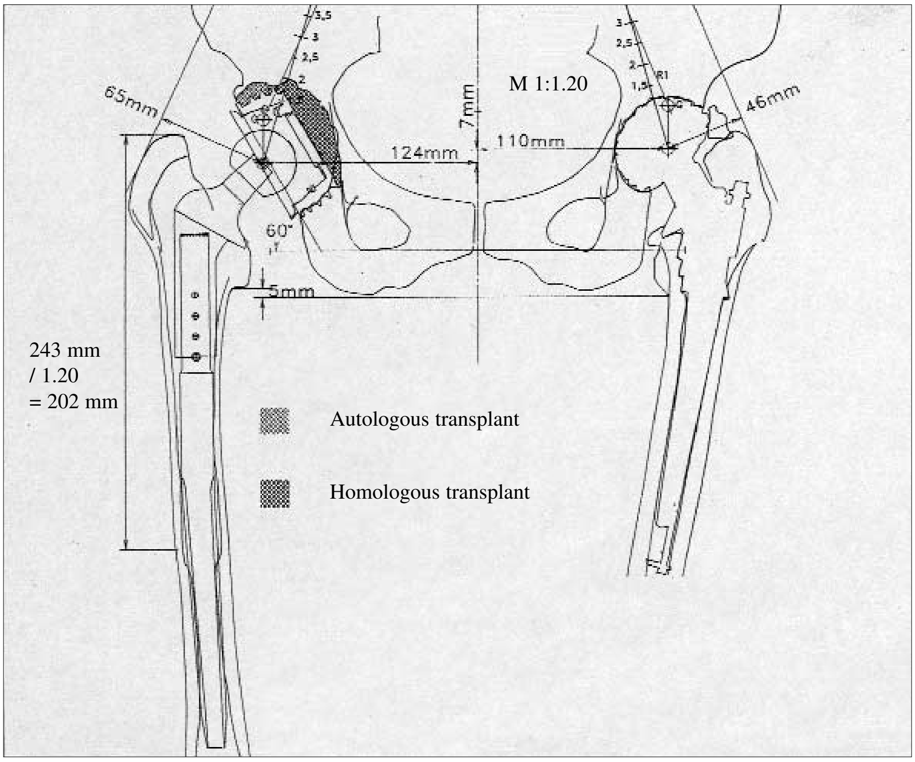

Fig. 1c Preoperative planning of the same patient as in Fig. 1a

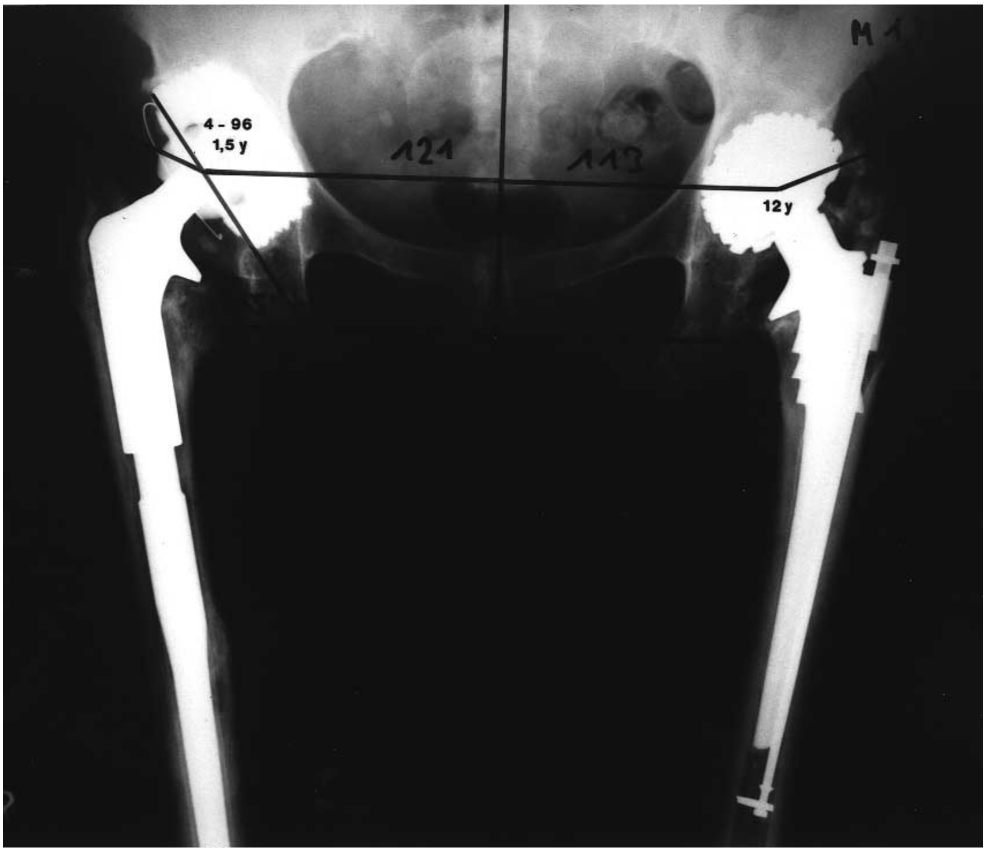

Fig. 1d Postoperative radiograph and evaluation of the same patient as in Fig. 1a after revision surgery

the build-up of a pedestal distally to the cement plug. Shortening of the right leg according to the radiograph was 42 mm.

Planning of the preoperative status (Fig. 1b) showed shortening of the right leg of 42 mm when using the lesser trochanters as reference points. Comparison of the height of centerpoints shows a proximalization of the cup of 7 mm as well as an offset of 116 mm. The muscle lever arm on the right side is 68 mm compared to 46 mm on the left side. Planning of the preoperative status with inserted revision components showed a leg-length discrepancy of still 5 mm by comparison of the lesser trochanters (Fig. 1c). The use of bone allograft was suggested in order to cover the osseous defects in the acetabulum, thereby bringing down the cup by about 12 mm and resulting in a cup offset of 124 mm. Muscle lever arm was 65 mm, inclination of the cup was 60° (Fig. 1c). On the postoperative radiograph taken 1.5 years after surgery, the actual offset of the cup was 121 mm, muscle lever arm was 60 mm and leg-length shortening was 6 mm on the operated side.

In the second case (Fig. 2a), a midshaft periprosthetic fracture occurred a 73-year-old woman 15 years after primary cementless hip arthroplasty (Judet prosthesis).

The preoperative evaluation (Fig. 2b) gave information about the length of the muscle lever arm (70 mm) and cup offset (100 mm). Estimated distance to cover in order to stabilize the fracture after removal of the prosthesis averaged 296 mm after calculation of the magnification factor. Difference in height of the cups was 10 mm (Fig. 2b). The preoperative template (Fig. 2c) suggested an implant with a length of 290 mm and a diameter of 18 mm, restoring a muscle lever arm of 51 mm compared to 61 mm on the opposite side. Inclination of the cup was 45 degrees. It also showed the use of extensive allograft in order to stabilize the floor of the acetabulum. On a radiograph taken 3 months postoperatively, the cup inclination was 47° and the muscle lever arm was 55 mm, leaving behind a shortening of approximately 8 mm according to the radiograph.

The third case is represented by an 87-year-old man with complete aseptic loosening of both prosthetic components 17 years after implantation of a cemented total hip arthroplasty (Fig. 3a). Major osseous defects were seen, especially in the acetabulum. Preoperative evaluation (Fig. 3b) showed a cup offset of 91 mm with a limb shortening of 12 mm judged by the height of the lesser trochanters. Muscle lever arm was 58 mm compared to 64 mm on the opposite side. Preoperative templating (Fig. 3c) suggested the use of a pelvic reconstruction ring, keeping the muscle lever arm more or less unchanged but restoring leg-length to nearly equal that on the opposite side. The postoperative radiograph 2.2 years after revision (Fig. 3d) showed an actual lengthening of the operated leg of 9 mm with a cup inclination of 56°. Different biomechanical values (muscle lever arm, 56 mm; offset of the cup, 103 mm) in this case derive from the fact that a reconstruction screw cup had been used by the operating surgeon instead of the suggested pelvic reconstruction cup.

Fig. 2a Radiograph of a 73-year-old female patient with a periprosthetic fracture and aseptic loosening of a cementless Judet prosthesis

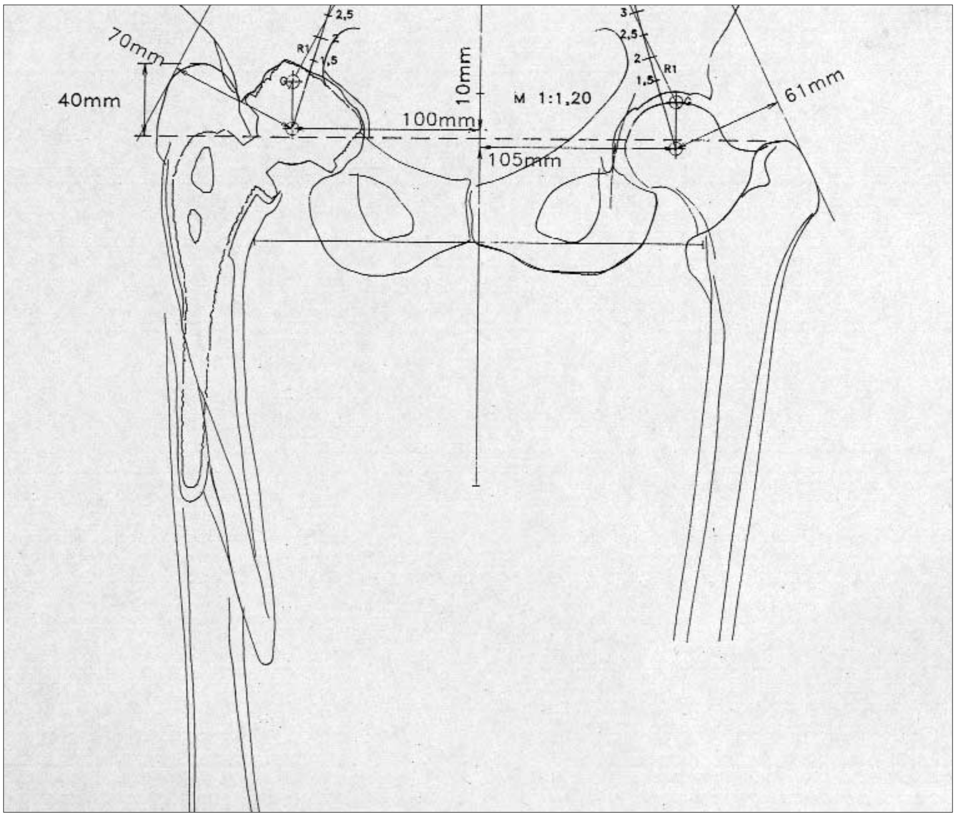

Fig. 2b Preoperative evaluation of the same patient as in Fig. 2a. *M*, magnification factor

Fig. 2c Preoperative planning of the same patient as in Fig. 2c suggesting the use of a cementless long revision stem

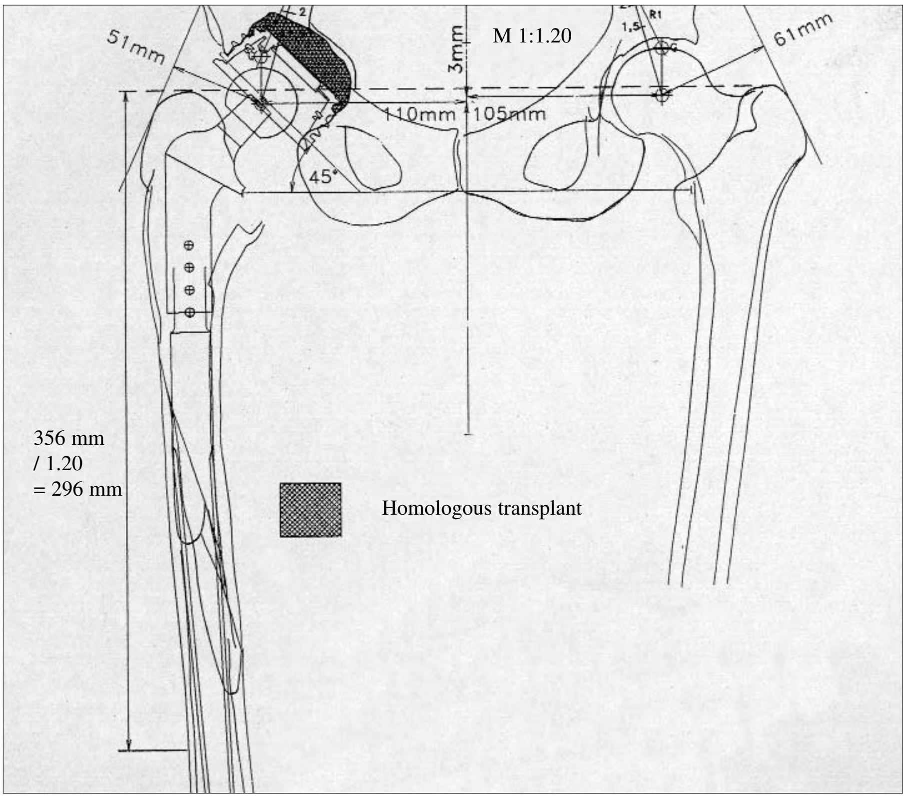

Fig. 2d Postoperative radiograph and evaluation of the same patient as in Fig. 2a

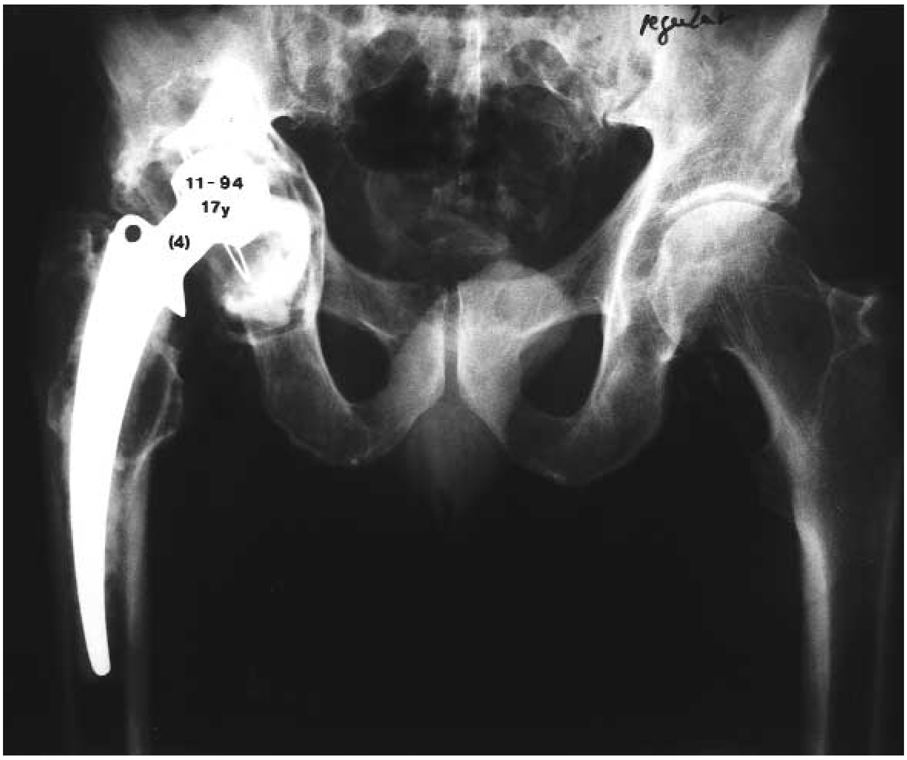

Fig. 3a 87-year-old male patient with aseptic loosening of a cemented total hip arthroplasty 17 years after implantation

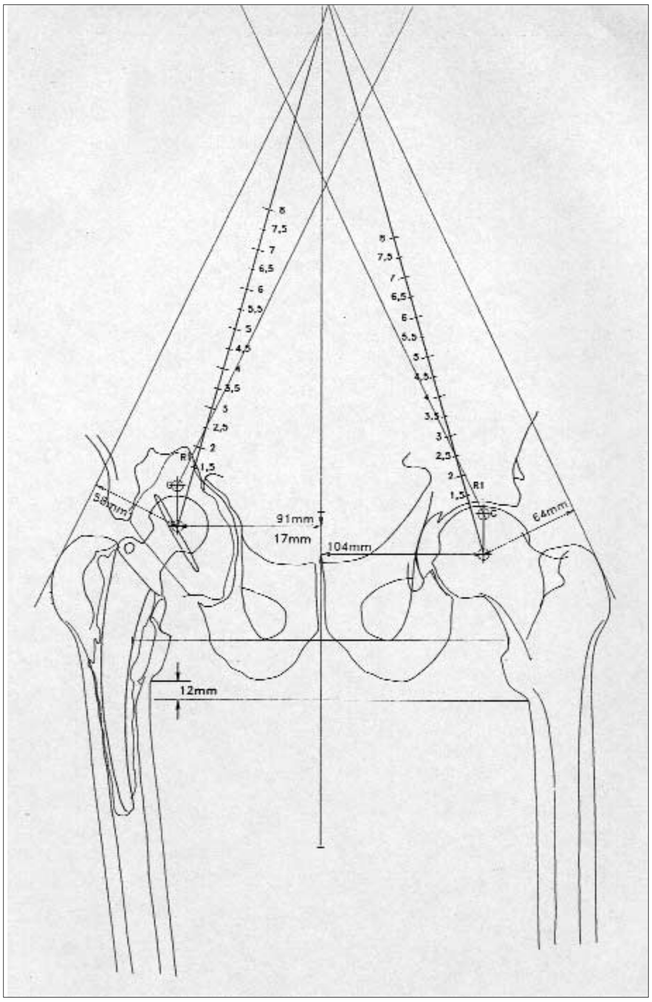

Fig. 3b Preoperative evaluation of the biomechanical situation of the same patient as in Fig. 3a. *M,* magnification factor

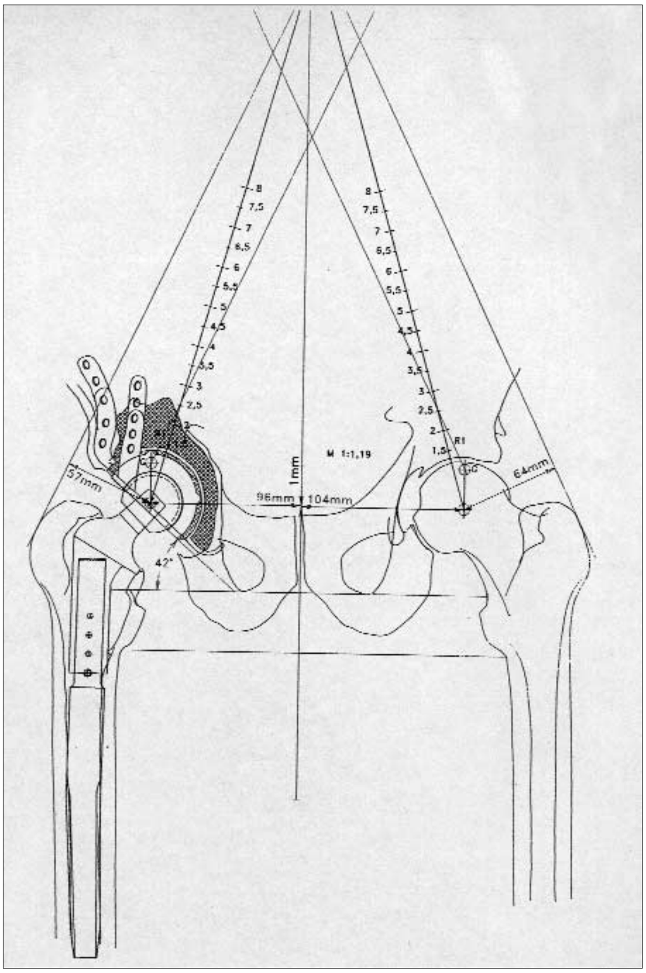

Fig. 3c Preoperative planning of the same patient as in Fig. 3a

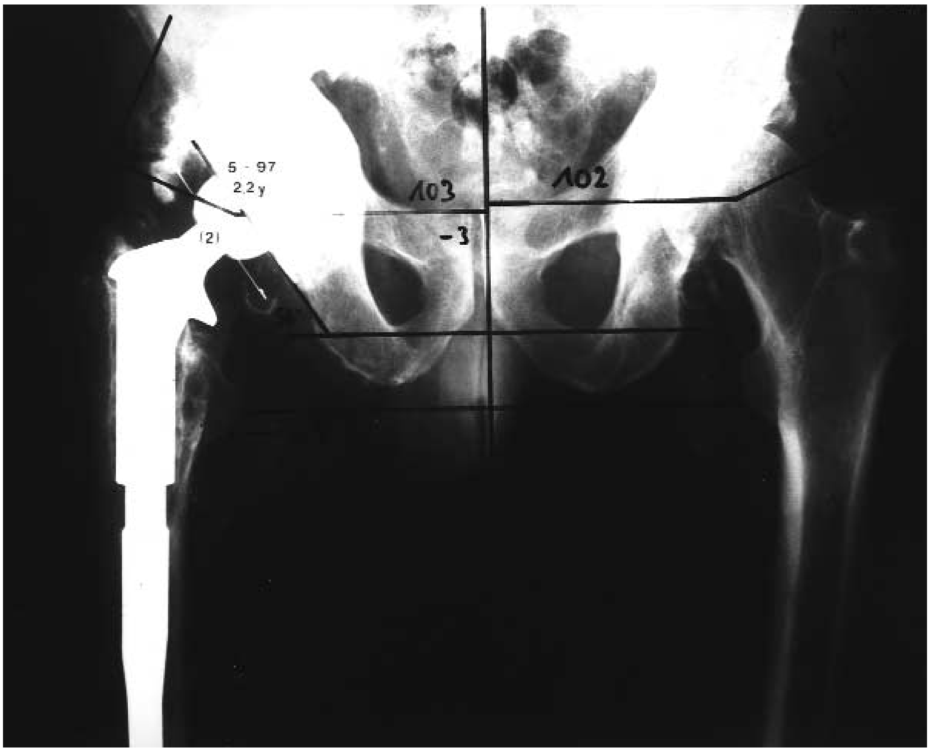

Fig. 3d Postoperative radiograph of the same patient as in Fig. 3a

Discussion

The usefulness of preoperative planning in hip surgery has been described by various authors [1–7]. The main goals of this procedure are to prepare for intraoperative problems as well as to establish good biomechanical conditions for a prolonged survival of the prosthetic components to be implanted. Jasty et al. [10] pointed out that although limb length discrepancies as much as 2 cm are common among the normal population and often are asymptomatic, they frequently lead to complaints in patients after primary total hip replacement [11, 12]. Woo and Morrey [12] found an average limb lengthening of 10 mm in a series of 333 cases after primary THA; Williamson and Reckling [13] even reported an average lengthening of 16 mm. Genzmer [14] in 1996 pointed out the consequences of limb lengthening as a major reason for litigation in orthopedic surgery in the United States. This emphasizes the importance of exact evaluation and preoperative planning even in primary hip surgery.

In revision cases, the situation is altered in such a way that it is quite often more difficult to establish the patient's original anatomy. In patients with progressive bone loss, the position of the cup is shifted from its original site to a more proximal and often medialized location. Due to stem subsidence and osseous destruction of the proximal femur, femoral offset may be altered and diminished, and shortening of the muscle lever arm may occur. Inadequate soft tissue tension can lead to instability, weakness and limp. Quite often a major difference in leg length will occur in these patients and a discrepancy of up to 4 cm or more is not unusual.

In our hospital, preoperative planning has proven to become an increasingly useful tool for identifying when intraoperative complications may be expected. It reduces surgical trial and error and operative time as the correct implant size is anticipated in a high percentage of cases. In unusual cases, the necessity of custom-made implants can be visualized if none of the regular implants fit the patient's anatomy. The use of allograft, if needed, is predicted with high probability.

In revision cases, it is useful to draw conclusions from the opposite hip joint of the patient in order to establish proper biomechanical relationships if this joint has not been operated on. However it also quite often happens that in this patient group both hips have been operated on previously (i.e. osteotomies or bilateral hip replacements), a situation which renders the task even more delicate. In this situation the primary goal should be to restore adequate soft tissue tension to ensure stability and function and only secondarily should leg length be addressed. Appropriate patient counseling is necessary with regard to anticipated leg length discrepancy. Pierchon et al. [15] have shown in their study of 38 patients with postoperative dislocations that the major reason for dislocation in these patients was rarely caused by malalignment of the components but more often by insufficient tension of the soft tissues. They also concluded that CT was of little value in preoperative assessment after dislocation of a total hip arthroplasty, presumably because of poor visualization of the soft tissues.

Pauwels [8] pointed out that, in a normal hip, an equilibrium exists between the weight bearing capacity of the upper end of the femur and the magnitude and type of load whereby the body weight is balanced by the force of the abductors which act laterally to the hip. The lever arm of the body weight is about three times that of the muscular force so that in order to maintain this equilibrium the muscular force (i.e. the abductor force) must be about three times that of the body weight. When this equilibrium is unilaterally disturbed by mechanical insufficiency of the tissues, whether congenital or acquired, the limit of tolerance to mechanical stress may be so reduced that even stressing of physiological magnitude induces pathological effects. This may lead to congenital coxa vara or ostheoarthritis (OA) due to a disturbance of balance.

In THA, where the same biomechanical rules apply, the consequences are even more clearly visible due to poor outcome and necessary early revision, as several studies have pointed out [16–19].

Restoring the equilibrium not only in primary THA but even more so in revision THA remains challenging. This makes preoperative planning even more necessary in order to find the best possible solutions for the restoration of biomechanical balance.

The importance of good radiograms is often underestimated. Eckrich et al. [20] described a change in radiographic projection of the proximal femur depending on the patient's position as a potential source of error when predicting the stem size in cementless THA. They pointed out that statistically significant changes in the measured dimensions of the proximal canal occurred on both the AP and lateral projections as a result of differing femoral rotation. Due to these results, the authors did not suggest a standard radiographic technique for preoperative planning, but recommended that intraoperative radiographs should be taken. Knight and Atwater [6] concluded that surgeons need better methods to estimate magnification and bone morphology from preoperative radiographs. Noble et al. [21] in a radiographic evaluation of 200 cadaveric specimens, suggested the existence of 17 different geometries with a wide variety of dimensions of the endosteal canal which further adds to the problems of optimal fill of the canal. Dossick et al. [5] suggested to use the CC ratio which defines the relationship between the isthmus of the femur and the endosteal canal in order to adress this problem and to achieve better predictability of the stem-bone ratio as well as a better proximal fill of the canal when using cementless prosthetic components.

On our preoperative standardized radiographs, patients internally rotate the femur 15°, thereby taking into account the anteversion of the head and neck, when an average antetorsion angle of 15° is assumed. In severely diseased hips, the pelvis is rotated in order to compensate for the loss of internal rotation. At the same time the magnification factor is accounted for: we only use radiographs taken in our department where we use a standard film focus distance of 1000 mm. In a series of 300 patients with primary THA with a known diameter of the head, this gave us an average magnification factor of 1:1.22. As mentioned previously in our revision radiographs, we refer to a magnification factor of 1:1.2 due to different formats of the radiographs taken for this procedure.

It is our opinion that a preoperative CT evaluation of the pelvis may improve the surgeon's understanding of the extent of osseous defects in cases of protruded cups. Contrast-enhanced CT may also help to uncover valuable information concerning the relationship of vessels to the prosthetic device and cement [22]. Its value concerning the preoperative planning, however, seems to be overestimated especially since the femoral problems are not addressed adequately. It therefore does not help the surgeon to resolve the problems that might arise when trying to insert the femoral component. Other methods frequently used include three-dimensional (3D) CT controlled manufactured 1:1 models as described by Mittelmeier et al. [23] and Kurth et al. [24]. These methods are still technically challenging, although John et al. [25] reported good results concerning prediction of implant size of 92% when using acetabular models. The question of price (up to US$ 2500 for one model), however, as well as the femoral issues remain. We therefore limit the use of this method only to certain indications.

"Total joint replacement should never be carried out without thorough preoperative planning" [26]. Nowhere is this more true than in revision hip surgery. We believe that the restoration of appropriate hip biomechanics optimizes the clinical result and improves the long-term outcome. A clear plan of how to accomplish this is paramount. Careful preoperative planning will also alert the surgeon to potential problems and complications, suggesting strategies, alternatives and solutions. Implant and graft requirements can be determined. We have found our CAD system indispensable in this undertaking, simplifying the analysis of the most complex reconstruction problems.

Acknowledgment. The authors thank Aaron A. Hofmann, MD for reviewing this article.

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