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Computertomographically Determined Design Parameters for Optimized Fit of an Acetabular Reconstruction Cage

Parametry konstrukce optimálního usazení rekonstrukčního prstence acetabula stanovené pomocí CT

G. MATZIOLIS, M. LUCKE, C. PERKA

Center for Musculoskeletal Surgery Charité University Medicine, Berlin

ABSTRACT

PURPOSE OF THE STUDY

Reinforcement rings are widely used for treatment of large acetabular defects but significant migration due to a lack of implant integration into the bone is a common problem. Although insufficient congruence between implant and acetabular bone has been identified main factor in early implant loosening, there are no reconstruction ring design parameters based upon anatomical data of the pelvis available.

MATERIAL

In this study such parameters were calculated on the basis of standardized computer tomograms of the hip region of 10 male and 10 female patients (40 data sets).

METHODS

The center of rotation, the acetabular entrance plane and the geometry of a simulated cranial and caudal flange of a reconstruction ring were determined. The flanges geometry was defined by the angles between the flanges and the entrance plane, the angle between the flange projections onto the entrance plane, the torsion and the width of each flange depending on the distance to the center of rotation, and the flanges torsion and width at their origin at the acetabular circumference.

RESULTS

An optimal alignment between reconstruction ring and the periacetabular bone could be achieved with a medial angulation of 19.9° ± 19.4° of the cranial and 14.7° ± 7.1° of the caudal flange against the entrance plane. The angle between the flanges projections onto the entrance plane was calculated to be 162.2° ± 6.4°. At its origin from the acetabular circumference the cranial flange is twisted 28.5°, the caudal flange –0.8° against the entrance plane. The maximal flanges widths were calculated to 21–54 mm for the cranial and 22–25 mm for the caudal flange depending on the distance from the acetabular circumference.

DISCUSSION & CONCLUSION

The given design parameters may result in optimized implants respecting the pelvic anatomy and possibly providing improved fixation.

Key words: revision hip arthroplasty, bone defect, reinforcement ring.

INTRODUCTION

A main problem during revision hip arthroplasty is the loss of acetabular bone. Defect management includes reconstruction with jumbo cups, bipolar prostheses, structured allografts or impaction bone grafting, oval acetabular implants, reinforcement rings, and costum made prostheses (2, 3, 9–13, 18, 19, 21). Despite the wide choice of different implants, early loosening, component fracture, and hip instability remain commonly observed problems.

Reinforcement rings are widely used for treatment of large acetabular defects (1, 4, 5, 8, 15, 20). The implant principle is the minimization of forces acting on the pelvic bone stock by maximization the contact area between the implant and bone. It is recommended to position the cranial flange onto the outer corticalis of the iliac bone and, in order to achieve a high primary stability, to slot the caudal flange into the ischium (6). For that purpose most of these implants must be deformed intraoperatively thereby increasing the risk for fatigue failure. Reinforcement rings do not integrate into the bone resulting in a decreasing stability over time (7, 16). Significant migration has been observed in dorsocranial acetabular wall defects, where only limited fixation stability can be achieved (14). The fixation stability of reinforcement rings is crucial to prevent migration, that is a commonly reported problem (15, 17, 22).

Although insufficient congruence between implant and acetabular bone seems to be the main cause of migration and early loosening (22), no publication could be found recommending specific reinforcement ring design parameters based upon anatomical data of the pelvis (Medline Query 06/2005).

In almost all cases in the senior authors series since 1990 the flanges have to be bent against each other, mostly they have to be bended versus the cup entrance plain. As a result of the complex 3dimensional acetabular geometry multiple attempts are necessary to achieve a satisfying congruence between implant and bone.

In this study design parameters for a reinforcement ring with flanges is calculated based upon the pelvic anatomy with the intention to maximize the contact area between the implant and bone for the first time.

MATERIALS AND METHODS

Patients

20 patients were included in the study after obtaining their consent. The solely inclusion criterium was the presence of a computertomography of the pelvis for tumor staging (bronchial, mamma, and prostata carcinoma). Exclusion criteria were deformities of the muskulosceletal system, metabolic disorders, operations and fractures of the pelvis or the proximal femur. The 10 males and 10 females were 64 ± 12 years old. In each patient both hips were scanned resulting in 40 data sets, that were evaluated by two independent physicians (G. M. and M. L.).

All examinations were performed without contrast agent on a 32 row toshiba CT with a gantry tilt of 0°. Transversal 1mm scans were obtained from the first sacral vertebra to the distal margin of the ischium with a resolution of 3 pixel per mm.

Data analysis

Image analysis was performed on a PC using Corel Draw Ver. 12, calculations of angles and best fit straight lines and planes using Excel.

Simplified a reconstruction ring can be defined as a hemispherical shell, whose aequatorial plane corresponds the acetabular entrance plane. Two flanges originate from the circumference of the shell, the cranial to be fixated onto the iliac bone, the caudal being slotted into the ischium.

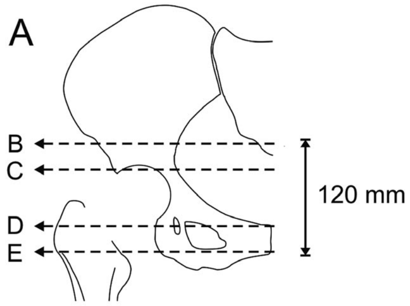
The center of rotation was determined for each hip by fitting graphically a sphere into the acetabulum. All horizontal scans 70 mm cranial and caudal this spheres center were evaluated (Fig. 1a). The acetabular entrance plane was calculated as best fit plane of 20 points on the acetabular circumference using a least square quadrat algorithm.

In each transversal CT scan lines were fitted tangentially for best coverage to the outer corticalis of the ilium thereby simulating the cranial flange of the reconstruction ring (Fig. 1b & c). The caudal flange geometry was similarly determined by fitting lines into the maximal diameter of the oval ischiac cavity thus maximizing the contact area between the implant and bone (Fig. 1d & e). The central points of the graphically fitted lines were acquired, and best fit straight lines calculated for the ilium flange (g_1) and the ischiac flange (g_2) using a least square quadrat algorithm. The aim of this procedure was to determine the angle between the ilium and ischium toward each other and toward the acetabulum entrance plane in regard to a simulated implantation of a reconstruction ring (Fig. 2).

The lines g_1 and g_2 were projected onto the acetabulum entrance plane E giving g_1‘ and g_2‘ and the angle between g_1‘ and g_2‘ was determined. Also the angles g_1 / E and g_2 / E between the ilium as well as the ischium flange line g_1 and g_2 respectively and the acetabulum entrance plane E were calculated (Fig. 2).

Additionally the angles between the lines representing transversal scans of the cranial and caudal flange (Fig. 1b & c) and the cup entrance plane E were determined for each CT scan. Figure 3 illustrates these flange twist angles and best fit graphs in regard to the flange distance from the center of rotation. φ_{1E} is thereby defined as twist angle of the ilium versus the acetabulum entrance plane E at the origin of the ilium flange. Similarly φ_{2E} is defined as twist angle of the ischium versus E at the origin of the ischium flange.

The length of the lines representing transversal scans of the cranial and caudal flange (Fig. 1b & c) was determined for each CT scan and illustrated in Figure 4 as function of the distance to the center of rotation. This graph gives the maximal possible width of the cranial and caudal flange.



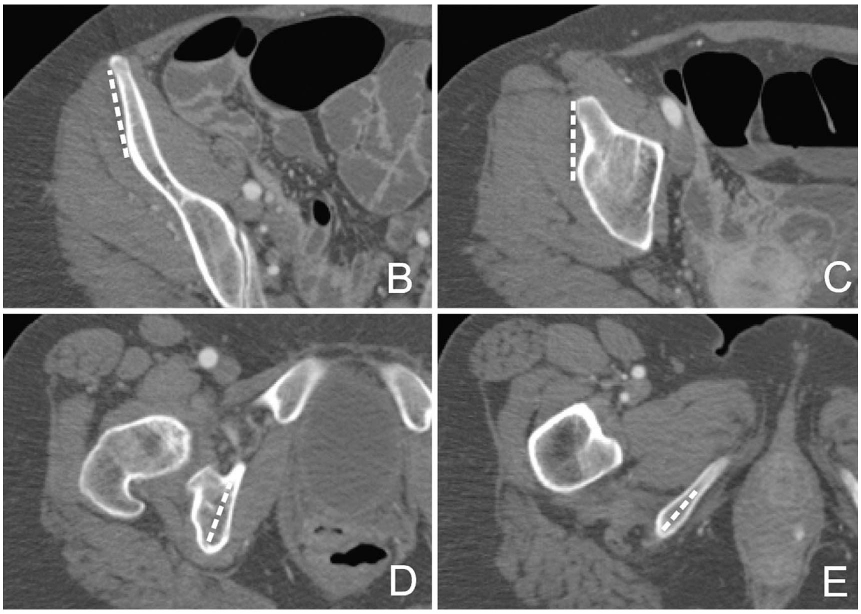


*Fig. 1. **A:** Drawing of a human pelvis in a frontal plane. **B – E** depict horizontal CT scans located as marked in **A**. The dotted lines represent the principle of best fitting for determination of the geometry of the outer surface of the ilium (**B, C**) and the medullary cavity of the ischium (**D, E**).*

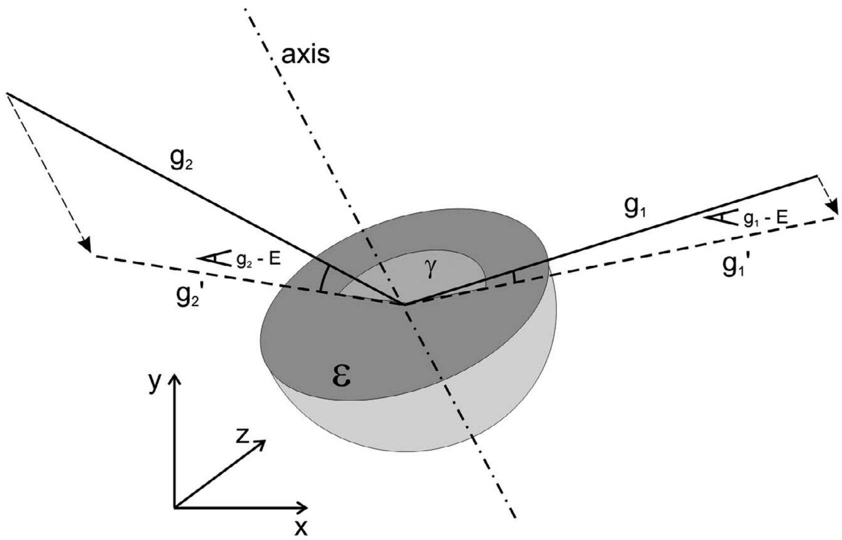


*Fig. 2. The acetabulum is depicted as a hemisphere. The equatorial plane **E** represents the plane of entrance to the acetabulum. g_1 and g_2 represent the lines through the middle of the fitting lines of ilium and ischium after correction by the least square principle. g_1' und g_2' are the projections of g_1 and g_2 onto the equatorial plane **E** of entrance to the acetabulum.*

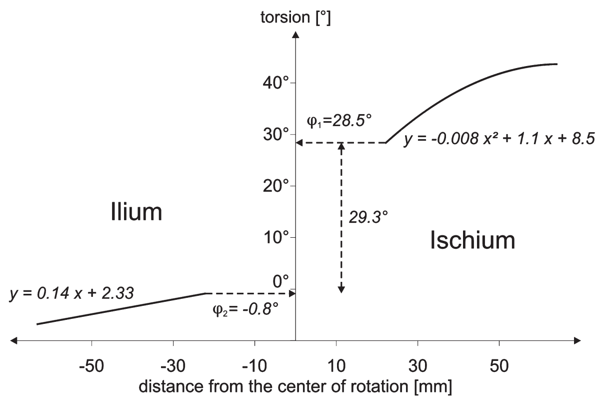


Fig. 3. Angle of torsion of the outer surface of the ilium and the plane defined by the maximum diameter of the ischium in relation to the distance from the center of rotation. Torsion of the outer surface of the ilium takes place according to an exponential function as presented. The torsional angle of the ischium takes place according to linear function.

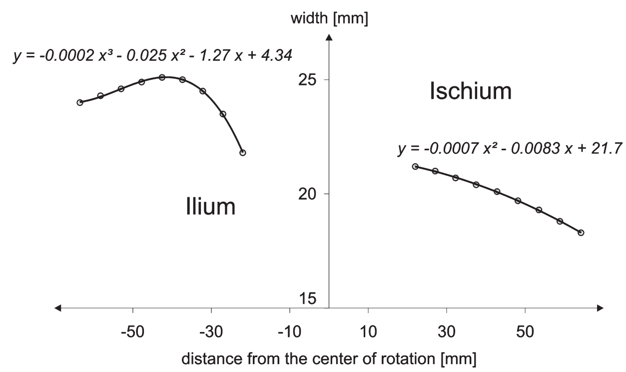


Fig. 4. Maximum width of the flanges of ilium and ischium in relation to the distance from the center of rotation.

Statistical analysis

Each physician evaluated all 40 data sets, mean value and standard deviation were calculated for every parameter with SPPS Ver. 12. Observer bias was excluded by comparing both physicians results using the non-parametric Wilcoxon Test for paired groups. The same was done for each parameter to exclude differences between male and female patients. The level of significance was set to 0.05.

RESULTS

Tab. 1. Summary of the determined anatomic parameters presented as mean ± standard deviation out of n=40 measurements.

angle g_1 / E	19.9° ± 19.4°
angle g_2 / E	14.7° ± 7.1°
angle g_1' / g_2'	162.2° ± 6.4°
torsion ilium flange	28.5° to 58.9°
torsion ischium flange	–0.8° to –6.8°
φ_1	28.5°
φ_2	–0.8°
width ilium flange	21mm to 54mm
width ischium flange	22mm to 25mm

The results of all measurements are summarized in table 1, they did not differ more than 9.8 % between both observers (n. s.), no significance was found between male and female patients in regard to any of the examined parameters.

An optimal alignment between reconstruction ring and the periacetabular bone could be achieved with a medial angulation of 19.9° ± 19.4° of the ilium flange (g_1 / E) and a medial angulation of the ischium flange of 14.7° ± 7.1° (g_2 / E). The angle between g_1‘ and g_2‘ representing the flange projection onto the cup entrance plane E was calculated to be 162.2° ± 6.4° (Fig. 2).

The outer surface of the ilium as well as the plane defined by the maximal diameter of the ischium cavity were complex 3dimensionally twisted planes (Fig. 3). At its origin from the acetabular circumference the ilium flange is twisted 28.5° against the cup entrance plane (φ_{1E}). In contrast the ischium flange was calculated having a twist angle φ_{2E} of only –0.8° at its origin. This corresponds with a twist angle between the cranial and the caudal flange at their origin of $\varphi_{1E} - \varphi_{2E} = 29.3°$ to achieve an optimal congruency between the implant and bone. This angle varies depending on the distance d from the center of rotation as shown in Figure 3. Figure 4 illustrates the maximal width of the flanges as a function of the distance to the center of rotation. They were calculated to 21–54 mm for the ilium, and 22–25 mm for the ischium.

DISCUSSION

Revision surgery of the acetabular component in hip arthroplasty should aim at primary as well as long term stability, while the physiological center of rotation needs to be restored and the damage to the soft tissues kept to a minimum. Depending on defect size and quality of the acetabular bone stock a variety of different implants is applicable, including modular and non modular implants as well as custom made prosthesis.

In large defects the use of antiprotrusion shells and reinforcement rings has become a standard procedure (1, 4, 5, 8, 15, 20). As these implants do not integrate biologically it is crucial that biomechanical forces become transmitted homogenously at the interface of bone and implant (7, 16). Stress maxima and peak forces at the interface can be reduced, the better the implant aligns with the periacetabular bone. The present study demonstrates the relevant design parameters to achieve an optimum congruency of bone and implant for fixation of a two flange reinforcement ring.

Between the two planes of external surface of the ilium and the plane defined by the greatest diameter of the ischium a mean angle of 29.3° exists. The most common technique of fixation, which provides the highest stability, includes the fixation of the distal flange within the medullary cavity of the os ischium. According to our results the distal flange should therefore feature an angle of torsion of –0.8° to the equatorial plane of the shell and the proximal flange should feature an angle of torsion 28.5°. This fits our personal experience with reinforcement rings. There is always a torsional bending of the flanges necessary in order to adjust the implant to anatomic situation. Only by torsional bending we achieve an optimum alignment of the proximal flange to the external surface of the ilium while placing the distal flange firmly within the cavity of the os ischium.

The design parameters given in this study are mean values, the necessity for intraoperative bending can be decreased but not excluded.

Custom made acetabular components fit the individual anatomy best but they require preoperative computer tomography for planning, are expensive, technically difficult to implant, and inflexible in regard to intraoperatively arising bone defects (3, 10). Modular implants can be adjusted to the individual anatomy of the pelvis during surgery (12). The possibility of fretting and the development of third body wear is thereby of disadvantage. In addition modular implants are expensive and their long term stability is uncertain as it has not yet been investigated extensively.

Non modular implants are far less expensive and easy to handle. To a certain extend they can also be adjusted to the individual anatomy by bending and molding. However the mechanical stability of the implant becomes impaired by the process of bending which may cause the flanges to brake. Repetitive trials in situ during the process of implant adjustment to the pelvic anatomy mean an increase of soft tissue damage, especially to the gluteal muscles. The superior gluteal nerve is also at risk as it crosses the anatomical site where the proximal flange becomes fixed.

Therefore an optimized design of non modular implants should be mandatory to minimize the necessity of implant adjustment intraoperatively.

Respecting the anatomical parameters of this study the design of implants and thus the alignment of implant and periacetabular bone could be optimized. This might lead to an improved implant fixation and possibly result in a shortening of operation time, in reduced soft tissue damage and a decrease of perioperative complications.

ZÁVĚR

Podpůrné prstence se široce využívají při ošetření rozsáhlých defektů acetabula. Velmi častým problémem je však jejich migrace v důsledku nedostatečné integrace implantátu v kosti. Ačkoli byla jako hlavní faktor časného uvolnění implantátu zjištěna nedostatečná kongruence mezi implantátem a kostním lůžkem acetabula, nebyla při konstrukci těchto prstenců zohledněna patřičná anatomická data.

V této studii byly odpovídající anatomické parametry vypočítány na základě standardizovaných CT řezů v oblasti kyčle u 10 mužů a 10 žen (40 datových souborů).

Byl stanoven střed rotace, rovina vchodu acetabula a tvar simulované kraniální a distální příruby rekonstrukčního prstence. Tvar jednotlivých částí příruby byl vymezen úhly mezi přírubou a rovinou vchodu acetabula, torzí a šířkou každé části příruby v závislosti na vzdálenosti od středu rotace.

Optimálního prostorového souladu mezi podpůrným prstencem a periacetabulární oblastí lze dosáhnout při mediální angulaci 19,9° (±), 19,4° kraniální a 14,7° (±) 7,1° kaudální části příruby vzhledem k rovině vchodu acetabula. Úhel mezi jednotlivými částmi příruby projektovanými do roviny acetabula činil 162,2° (±) 6,4°. Odstup proximální části příruby je ohnut vzhledem k rovině vchodu acetabula v úhlu 28,5° a odstup kaudální části v úhlu 0,8°. Maximální šířka jednotlivých částí příruby byla vypočítána pro kraniální část na 21–54 mm a pro kaudální část na 22–25 mm v závislosti na vzdálenosti od obvodu acetabula.

Zjištěné konstrukční parametry mohou přispět k optimalizaci implantátů z hlediska anatomie pánve a tím i k zajištění jejich lepší fixace

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Dr. med. Georg Matziolis,
Center for Musculoskeletal Surgery,
Orthopaedic Department
Charité University Medicine Berlin,
Charitéplatz 1,
101 15 Berlin
Germany
Phone: +49-30-450 615 093
Fax: -49-30-450 515 911
E-mail: Georg.Matziolis@Charite.de

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