International Orthopaedics (SICOT) (2000) 24:23–27

ORIGINAL PAPER

Juliane Rösler · Carsten Perka

The effect of anatomical positional relationships on kinetic parameters after total hip replacement

Accepted: 4 November 1999

Abstract The purpose of this study was to evaluate the significance of positional relationships of the components on gait after total hip replacement (THR). Gait was analysed using multicomponent force platforms integrated into a treadmill, in conjunction with an optoelectric measuring system. 26 patients, after undergoing total hip replacement, were classified according to the vertical and horizontal positions of the centre of rotation, the vertical position of the femur and the functional leg length, and compared with a control group. Deterioration in parameters of gait was observed following cranialisation of the centre of rotation or of the femur, whereas neither medial movement of the centre of rotation nor leg lengthening by up to 1 cm had any effect. This study emphasises the importance of considering, at the time of preoperative planning, the effect of the position of the prosthesis on the functional parameters of gait.

Résumé L'objectif de la présente étude était de juger de l'importance des relations anatomiques de la position des composants articulaires sur la représentation de la marche postopératoire après l'implantation d'une endoprothèse de la hanche. On a employé le procédé de l'analyse de la marche en utilisant des plates-formes de mesures à plusieurs constituants intégrées dans un tapis roulant, ainsi qu'un système de mesure opto-électrique. 26 patients ayant subit une implantation primaire d'endoprothèse totale de la hanche ont été divisés en groupes, suivant la position verticale et horizontale du centre de rotation, la position verticale du fémur et les longueurs fonctionnelles des jambes, et comparés à un groupe de référence comprenant des sujets d'expérience en bonne santé. On a ainsi observé une détérioration des paramètres de l'analyse de la marche en cas de mouvement ascendant du centre de rotation et en cas de mouvement ascendant du fémur. En revanche, une médialisation du centre de rotation n'a aucune influence sur les paramètres enregistrables dans l'analyse de la marche, ni le rallongement de la jambe jusqu'à 1 cm. La présente étude montre que, outre l'adaptation géométriquement exacte de l'implant lors de la phase de planification préopératoire, il faut impérativement prendre en compte la répercussion de la position de l'implant sur les paramètres fonctionnels.

C. Perka (✉) · J. Rösler
Orthopädische Klinik und Poliklinik der Charité,
Schumannstrasse 20/21, D-10098 Berlin, Germany
e-mail: carsten.perka@charite.de
Tel.: +49-30-2802-5912, Fax: +49-30-2802-1142

Introduction

The introduction of computer-assisted planning when implanting hip prostheses makes preoperative three-dimensional virtual movement of the prosthesis possible and may ensure optimal positioning [2]. Previously the position of the prosthesis was chosen according to the geometric characteristics of the joint [3,10]. However, the ideal geometric position need not be the best for function, and in particular for gait. Gait analysis is necessary for accurate assessment of prosthesis function [16]. We studied, by gait analysis, the effect of different operative position of parameters on hip function after prosthetic replacement.

Material and methods

A prospective study was conducted between December 1995 and March 1997 with 26 patients in whom THR was performed for osteoarthritis of the hip. All patients had unilateral disease, and the prosthesis used was a Zweymüller TEP (Endoplus, Marl, Germany). There were 15 female and 11 male patients with a mean age of 64.6 years (sd=7.73), a mean weight of 72.5 kgs (sd=9.64), and a mean height of 1.68 m (sd=0.07). 22 patients had primary osteoarthritis and 4 had avascular necrosis of the femoral head. A direct lateral approach was used. All patients received the same postoperative physiotherapy and rehabilitation programmes. The patients were examined preoperatively and twice after surgery. The first postoperative examination was carried out when the patient could walk on a flat surface without support (mean 14.4 weeks. Range 12–16). The second examination was carried out after twice this interval (mean 27. 8 weeks, range 26–30). The control group consisted of 10 female and 10 male volunteers without any locomotor

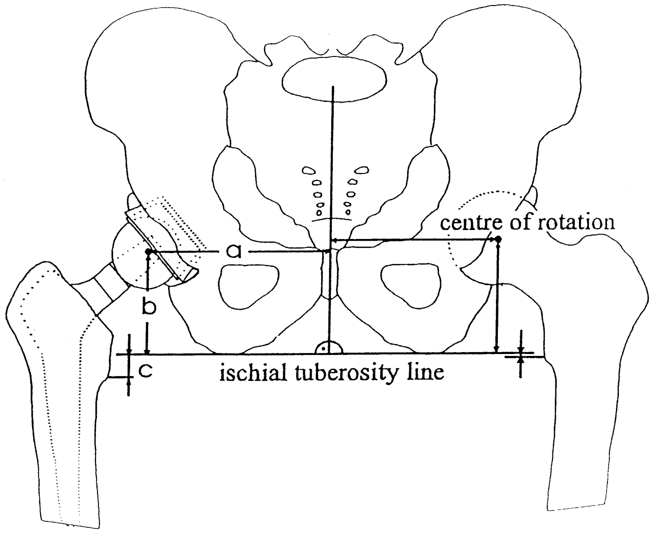

Fig. 1 Positional relationships measured at the hip. *a* Horizontal position of the centre of rotation: distance between centre of rotation and vertical line connecting the ischial tuberosities, running through the pubic symphysis. *b* Vertical position of the centre of rotation: distance between centre of rotation and the line connecting the ischial tuberosities. *c* Vertical position of the proximal femur relative to the pelvis: distance between the lesser trochanter and the line joining the ischial tuberosities

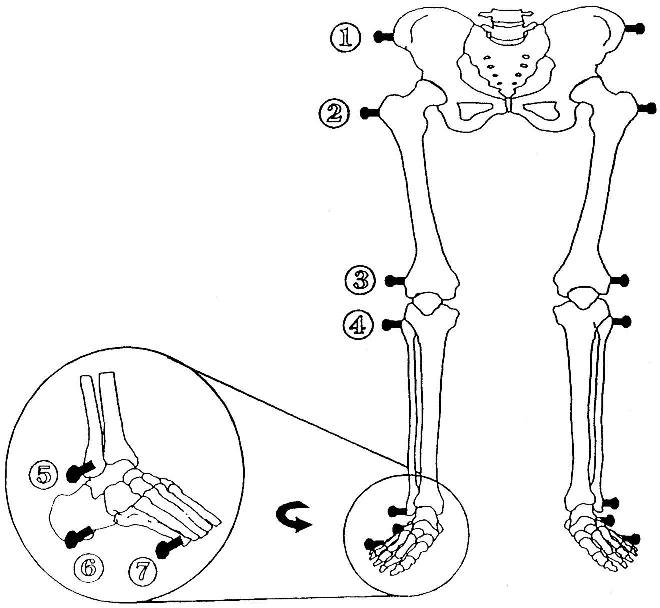

Fig. 2 Positioning the markers. *1*, anterior superior illiac spine; *2*, greater trochanter; *3*, lateral femoral condyle; *4*, fibular head; *5*, lateral malleolus; *6*, calcaneus, vertical below *5*; *7*, fifth metatarsal head

symptoms. The mean age of this group was 42.1 years (sd=13.53), their weight was 71.3 kgs (sd=8.75), and height was 1.74 m (sd=0.08).

AP postoperative radiographs were taken and the following parameters recorded (Fig. 1) : the vertical position of the centre of rotation, the horizontal position of the centre of rotation, the vertical position of the femur and the functional leg length. The values for the vertical and horizontal positions of the centre of rotation in the replaced hips were obtained by comparison with the contralateral hip [10,17], and the patients were assigned to the following 3 groups. In Group I the horizontal position at the centre of rotation was moved by±4 mm (7 patients), and in Group II it was moved by >4 mm medially (19 patients). Similarly for the vertical position of the centre of rotation. In Group I the position was moved by±4 mm (9 patients), in Group II there was a caudal shift of >4 mm (4 patients) and in Group III a cranial movement of >4 mm (13 patients). With regard to leg length there were no difference in Group 1 (17 patients), a lengthening of 0.5–1 cm in Group II (7 patients) and a shortening by 0.5–1 cm in Group III (2 patients). With regard to the vertical position of the femur this was normal in Group I (11 patients) with a deviation of±4 mm; in Group II a caudal shift of >4 mm (7 patients); and in Group III a cranial shift of >4 mm (8 patients).

The gait analysis apparatus consisted of a treadmill, two force plates, a video system and a PC workstation. Multicomponent measuring platforms from the Kistier company (Type 928 1 B/985 1) were integrated into the treadmill. Four infra-red video cameras of the optoelectric ELITE system recorded the motion pattern data simultaneously using foil markers on reproducible anatomical sites (Fig. 2). The patient walked exclusively on the force plates in the field of vision of the cameras at an acceptable speed. The patients, after a period of familiarisation, were recorded for 16 seconds. The software generated three-dimensional coordinates from the two-dimensional camera images. An integrated interface recorded the bilateral ground reaction forces simultaneously.

The following parameters were measured:

(a) *Time and distance parameters*: walking velocity (km/h), transition from the stance phase to the swing phase (% double step [DS]), transition ftom the swing to the stance phase (% DS), single stance duration/%DS, relative step length = quotient of double step length (m)/leg length
(b) *Force parameters*: vertical force = integral of the vertical ground pressure force over time (%BW · %DS), strike force F 1 = 1. Peak vertical load in the early stance phase (%BW), push-off force (F2=2). Peak load in the late stance phase (%BW).
(c) *Angular parameters*: Maximum extension and flexion of the hip and knee joints (degrees).

All the parameters, except walking velocity, were calculated from the mean double step. The overall duration of one double step was defined as 100%. In order to calculate gait asymmetry the following formula was used. “Symmetry parameters = Parameters (pathological) - parameters (healthy)”. Symmetry parameters only were included as they are independent of velocity. The results were analysed using the Mann Whitney U test ($P<0.05$).

Results

The positions on plain radiographs are summarised in Table 1.

Horizontal position of the centre of rotation

The patients without leg length inequality showed no significant difference for any of the parameters; whereas both groups showed a decrease in vertical loading compared with the control group. The symmetry of the individual stance pictures and the transition from the stance to the swing phase showed a difference at the time of the first postoperative examination only (Table 2).

Table 1 The position of the centre of rotation as measured on AP radiographs in hipjoints with and without THR (in mm)

	Horizontal position	Vertical position	Vertical position of the proximal Femur
Joint without THR	113±0.53	74±0.79	11±0.95
Joint with THR	103±0.52	79±0.81	12±1.06
Difference: THR-Healthy	–9±0.69	5±0.79	–2±0.81

Table 2 Symmetry parameters of the patients without different horizontal positions (Group 1) and patients with medially shifted centre of rotation (Group 2) compared with normals. *italics*=value significantly different from normal

Parameter	Group 1		Group 2		Normal
Symmetry of:	Postop1	Postop2	Postop1	Postop2	
Single stand (% DS)	*–2.5*±1.07	–0.5±1.32	*–2.6*±2.87	–1.0±2.99	–0.3±1.03
Transition stand – swing (% DS)	*–1.1*±2.13	–0.4±1.13	*–1.9*±2.69	–0.1±2.67	–0.2±1.77
Transition swing – stand (% DS)	0.6±2.47	0.8±1.23	0.8±2.55	0.7±2.16	0.3±0.89
Vertical force (%BW · % DS)	*–2.7*±4.64	*–1.0*±2.04	*–2.8*±2.99	*–1.8*±3.12	0.3±1.28
Strike force F1 (%BW)	–0.9±4.17	–0.4±2.41	–0.7±5.28	–0.7±3.06	0.5±2.92
Push-off force F2 (%BW)	1.5±2.90	–0.1±1.39	0.0±2.57	0.3±4.20	0.1±3.68
Hip joint:					
Peak extension (degree)	*–3.5*±1.58	*–2.5*±1.24	*–2.3*±2.99	*–1.6*±1.99	–0.3±0.74
Peak flexion (degree)	*–2.4*±1.59	*–2.4*±1.38	*–2.5*±2.64	*–1.6*±1.99	0.2±1.07
Knee joint:					
Peak extension (degree)	*0.3*±2.47	*0.9*±3.58	*1.1*±2.80	*0.4*±3.26	0.0±2.58
Peak flexion (degree)	*–6.5*±4.17	*–4.3*±3.61	*–5.7*±5.28	*–2.7*±4.67	1.0±4.32

Table 3 Correlation between the gait parameters and the vertical position of the centre of rotation. As cranial shift increases the symmetry of flexion and extension decreases at the hip and knee joints: *italics*=value significantly different from normal

Parameter Symmetry of:	Postop 1 Coefficient of correlation	Postop 2 Coefficient of correlation
Single stand (% DS)	0.095	0.077
Transition stand – swing (% DS)	0.093	0.073
Transition swing – stand (% DS)	–0.054	0.082
Vertical force (%BW · % DS)	0.142	0.140
Strike force F1 (%BW)	–0.106	0.201
Push-off force F2 (%BW)	0.093	0.102
Hip joint:		
Peak extension (degree)	*–0.406*	*–0.429*
Peak flexion (degree)	*–0.467*	*–0.470*
Knee joint:		
Peak extension (degree)	*–0.359*	–0.267
Peak flexion (degree)	*–0.488*	*–0.434*

Vertical position of the centre of rotation

A decrease in flexion and extension of the hip and ipsilateral knee was seen with cranialisation of the centre of rotation (Table 3).

Vertical position of the femur

There was a reduction in maximum flexion and extension of the hip in patients with no difference in the vertical position of the femur (Group 1) and those with cranialisation of the femur (Group 2) which was not seen in patients with caudal movement of the femur (Group 3). The patients in Group 2 showed a reduction in maximum flexion and extension of the knee during the walking cycle when compared to those in Groups 3 and 4 (Table 4).

Functional leg length

There was no difference in kinetic data between patients with no leg length discrepancy and those with lengthening of the leg (Group 2). At the first postoperative examination, these patients showed a deficit in vertical force, individual stance duration, transition from stance to swing phase, and range of movement of the hip and knee on the contralateral side. At the second examination neither the vertical force nor the maximum extension of the knee differed from that of the contralateral side (Table 5).

Discussion

This study confirms that the functional results after THR may be influenced by various anatomical parameters which can be assessed by gait analysis. The results are

Table 4 Symmetry parameters of the patients with normally positioned femur (Group 1) and those with femurs shifted cranially (Group 2) and caudally (Group 3). *italics*=value significantly different from normal

Parameter	Group 1		Group 2		Group 3	
Symmetry of:	Postop 1	Postop 2	Postop 1	Postop 2	Postop 1	Postop 2
Single stand (% DS)	*–2.3*±2.10	–0.6±1.82	*–2.5*±3.73	*–1.4*±3.13	*–3.0*±2.46	0.1±2.19
Transition stand – swing (% DS)	*–1.9*±1.43	–0.2±1.54	–0.1±4.40	–0.4±3.63	*–1.8*±1.55	0.1±2.02
Transition swing – stand (% DS)	0.8±2.49	1.0±1.33	0.6±3.09	0.8±2.02	1.3±2.19	0.4±2.79
Vertical force (%BW · % DS)	*–3.4*±3.18	*–1.3*±2.82	*–2.8*±3.26	*–1.4*±2.95	*–2.8*±1.70	*–0.8*±3.11
Strike force F1 (%BW)	–0.1±1.80	–0.1±2.67	–0.9±6.84	–0.4±4.17	–1.3±1.52	–0.8±1.87
Push-off force F2 (%BW)	0.8±2.10	–0.3±2.91	–2.1±3.40	0.3±3.38	1.6±3.07	1.2±5.10
Hip joint:						
Peak extension (degree)	*–2.3*±1.47	*–1.6*±1.27	*–4.7*±2.26	*–3.3*±1.16	–0.9±2.56	–0.6±2.25
Peak flexion (degree)	*–2.5*±1.58	*–1.3*±1.23	*–4.4*±1.46	*–3.6*±1.00	–0.8±2.87	0.7±2.16
Knee joint:						
Peak extension (degree)	–0.3±2.58	0.0±3.59	*–4.4*±1.77	*–3.0*±1.69	0.0±2.23	–0.1±2.91
Peak flexion (degree)	*–2.4*±4.38	–1.7±3.47	*–7.5*±2.13	*–5.3*±2.76	*–5.7*±6.34	–1.6±4.73

Table 5 Symmetry parameters of the patients without leg length differences (Group 1) and those with lenghtended on the operated side (Group 2). *italics*=value significantly different from normal

Parameter	Group 1		Group 2		Normal
Symmetry of:	Postop1	Postop2	Postop1	Postop2	
Single stand (% DS)	*–2.0*±2.40	–0.6±2.19	*–3.6*±1.73	–2.3±2.36	–0.3±1.03
Transition stand – swing (% DS)	*–0.5*±1.67	–0.1±1.46	*–2.7*±0.71	–0.4±1.85	–0.2±1.77
Transition swing – stand (% DS)	0.8±2.31	1.0±1.91	1.4±3.10	0.4±2.38	0.3±0.89
Vertical force (%BW · % DS)	*–2.3*±3.82	*–1.0*±2.41	*–4.5*±1.56	*–2.3*±2.78	0.3±1.28
Strike force F1 (%BW)	–0.5±4.49	–0.4±2.66	–0.1±1.76	–0.9±2.58	0.5±2.92
Push-off force F2 (%BW)	1.5±2.35	1.1±2.71	0.0±2.72	–0.5±3.39	0.1±3.68
Hip joint:					
Peak extension (degree)	*–2.5*±2.24	*–2.9*±1.45	*–1.7*±3.48	*–1.2*±1.82	–0.3±0.74
Peak flexion (degree)	*–2.6*±2.33	*–3.0*±1.60	*–1.9*±2.31	*–1.5*±1.80	0.2±1.07
Knee joint:					
Peak extension (degree)	0.8±2.45	0.9±3.33	0.4±3.57	0.0±3.45	0.0±2.58
Peak flexion (degree)	*–5.8*±4.48	*–4.3*±4.26	*–5.1*±5.47	*–2.1*±3.97	1.0±4.32

worse after cranialisation of the centre of rotation of the femur; whereas neither medial movement of the centre of rotation nor leg lengthening by up to 1 cm have any effect. Cranialisation of the femur, as occurs when the femoral component is implanted deeply into the femur, leads in the mid term to reduction in movement of the hip and of the knee. By contrast, caudal shift of the femur results in symmetrical movement of the hip and knee 14 weeks after surgery; and the range of flexion and extension of the hip improves. These changes are primarily attributable to changes in muscle power, as the power of ab- and adductors decreases with cranialisation of the femur [6,14] and increase with caudal shift [7]. Cranialisation of the centre of rotation of the prosthesis is associated with a similar reduction in range of movement, due, probably, to a decrease in muscle power [5]. Medial shift of the centre of rotation (by a mean of 10 mm) does not influence gait. Several studies recommended moving the centre of rotation medially in order to decrease the forces acting across the joint [1,8,9,12,17]. The theory that moving the centre medially shortens the lever arm and thus reduces muscle power is not confirmed by gait analysis. Leg length differences of up to 1 cm also had no effect. Brand and Yack [4] did not observe changes in the power exerted on the hip joint with experimentally induced leg length differences of up to 2.3 cm; whereas other authors have shown gait asymmetry with leg length differences of 2 cms [13,14]. Computer-aided preoperative planning allows the implant to be fitted with high anatomical accuracy. The exact placement of the components may be varied by preparation of the adjacent bony surfaces and choosing an appropriate size of implant. We have shown that both cranialisation of the centre of rotation and cranial shift of the femur should be avoided whereas gait analysis shows no effects of a medial shift or of a leg length discrepancy of up to 1 cm.

References

1. Antolic V, Iglic A, Herman S, Srakar F, Macek AL, Krajl VI, Brajnik D, Stanic U (1994) Resultant hip joint force after total hip replacement. Acta Chir Orthop Traumatol Cech 61:42–44
2. Bargar WL, Bauer A, Börner M (1998) Primary and Revision total hip replacement using the Robodoc System. Clin Orthop 354:82–91

3. Börner M, Bauer A, Lahmer A (1997) Computerunterstützter Robotereinsatz in der Hüftendoprothetik. Unfallchirurg 100: 640–645
4. Brand RA, Yack HJ (1996) Effects of leg length discrepancies on the forces at the hip joint. Clin Orthop 333:172–180
5. Delp SL, Komattu AV, Wixson RL (1994) Superior displacement of the hip in total joint replacement: effects of prosthetic neck length, neck-stem angle and anteversion angle on the moment-generating capacity of the muscles. J Orthop Res 12: 860–870
6. Gore DR, Murray MP, Gardner GM, Sepic SB (1977) Roentgenographic measurements after Müller total hip replacement. J Bone Joint Surg [Am] 59.948–953
7. Gore DR, Murray MP, Sepic SB, Gardner GM (1982) Anterolateral compared to posterior approach in total hip arthroplasty. Clin Orthop 165:180–187
8. Greenwald AS, Nelson CL (1973) Biomechanics of the reconstructed hip. Orthop Clin North Am 4:435–447
9. Hamilton HW (1986) Prosthetic position in total hip replacement. Orthop Rev 15:294–300
10. Jerosch J, Hasselbach C, Filler T, Peuker E, Rahgozar M, Lahmer A (1998) Qualitätssteigerung in der präoperativen Planung und intraoperativen Umsetzung durch die Verwendung von computerassistierten Systemen und Operationsrobotern – eine experimentelle Untersuchung. Chirurg 69:973–976
11. Johnston RC, Brand RA, Crowinshield RD (1979) Reconstruction of the hip. J Bone Joint Surg [Am] 61:639–652
12. Lui XC, Fabry G, Molenaers G, Lammens J, Moens P (1998) Kinematic and kinetic asymmetry in patients with leg-length discrepancy. J Pediatr Orthop 18:187–189
13. Murray MP, Brewer BJ, Zuege RC (1972) Kinesiologic measurements of funcional performance before and after McKee-Farrar total hip replacement. J Bone Joint Surg [Am] 54:237–256
14. Saleh M, Murdoch G (1985) In defence of gait analysis. J Bone Joint Surg [Br]67:237–241
15. Schmalzried TP, Szuszczewicz ES, Akizuki KH, Petersen TD, Amstutz HC (1996) Factors correlating with long term survival of McKee-Farrar total hip prosthesis. Clin Orthop 329 [Suppl]: S48–S59