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Dynamic parameters of three-point crutch gait in female patients after total hip arthroplasty

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Purpose: Patient recovery after a surgical procedure depends, among other factors, on the amount of the body weight with which patient loads lower limb. Research studies report different results of the degree of body weight with which lower limb is loaded during three-point crutch gait. The aim of this study was to evaluate the level of the ground reaction forces (GRF) during crutch gait used by patients after total hip arthroplasty (THA) in the first week after discharge from the orthopaedic units. *Methods*: Ten female patients diagnosed with primary unilateral coxarthrosis participated in a single measurement session. In order to record kinematic and dynamic variables of this gait pattern motion analysis system was used together with two force plates. The static test of body weight distribution between lower limbs was performed on a dual-top stabilometric plate. *Results*: The average peak values of loading on the operated (O) limb during mid stance and terminal stance of three-point crutch gait were 64.6% and 64.3% of body weight (BW), respectively, whereas in the case of the nonoperated (NO) limb 103.5%BW and 108.8%BW, respectively. The maximum loads on the crutches were significantly higher (by 9%BW) on the NO side as compared to the O side ($p < 0.05$). During the static test, average values of body weight distribution on the O and NO limb were 36%BW and 64%BW, respectively. *Conclusions*: The patients showed surprisingly similar level of loading on the O limb. The weight bearing on the O limb was lower during static trial than during three-point crutch gait.

Key words: *total hip arthroplasty, three-point crutch gait, partial weight bearing, biomechanics*

1. Introduction

Early rehabilitation is of utmost importance for patients after total hip arthroplasty (THA). Depending on the patients' condition, they can assume upright position on the first day after the surgery and during the next days they can start to learn crutch ambulation with partial loading of the operated (O) limb. The first and most often recommended pattern of locomotion is the "step to" gait pattern which consists in moving both crutches forward simultaneously, then moving the O limb forward and loading it as much as it is permitted by the physician, followed by moving forward the second lower limb [3], [18]. This is a safe gait pattern due to its stability that results from multiple points of support. After it has been mastered, patients are recommended to move to the three-point crutch gait pattern, which is characterized by simultaneous movement of both crutches and the O limb. It is relatively easy to learn faster and provides a wide range of control over the amount of the load on the O lower limb. It is also more natural because of alternating lower limbs movement similar to standard gait [10], [14], [20], [21]. A detailed biomechanical description of three-point crutch gait can be found in Dworak et al. [4]. Few authors analyzed the degree of weight bearing on one lower limb during a three-point crutch gait and their research focused mostly on healthy individuals [14], [27].

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It is very difficult to evaluate the degree to which a patient loads O lower limb within the environment of a typical hospital ward. Improper loading may lead to longer recovery and even deterioration of patient's condition. That is why the analysis of ground reaction forces (GRF) recorded with force plates is so useful for assessment of gait pathomechanics in patients undergoing convalescence [5], [7], [18], [25]. Biomechanical evaluation of the dynamic parameters of pathological gait enables control of the gradation of weight bearing on the O lower limb. It also allows the patients to be educated on how to reproduce the value of weight bearing assigned by the physician or physiotherapist [8], [9], [11]–[14], [16], [17], [23], [24], [26], [27].

Proper degree of weight bearing of the lower limb among subjects after unilateral THA is a very important element of the rehabilitation program and contributes to faster restoration of full physical capabilities [13], [15], [27]. Within hospital environment, it is difficult to teach patients how to apply the recommended weight to the O limb. Very often the only equipment which could be used there is a weighing scale, which due to the static nature of the exercise does not reflect the dynamics of walking. The idea of this research project derives from the fact that physicians recommend different degrees of weight bearing of the O lower limb from 30%BW up to full load attempts, even if they have no possibility to verify the real load applied during gait.

The purpose of this study was to evaluate the level of GRF during three-point crutch gait in female patients who underwent THA, as well as during static test. The study is based on the hypothesis that the weight bearing on the O lower limb during a three-point crutch gait is notably higher in comparison with the static test and that most patients do not really restrict physicians` indications concerning the level of load on the O limb.

2. Materials and methods

Ten female subjects aged (59 ± 8) years, who underwent the surgical procedure of THA resulting from primary unilateral coxarthrosis participated in the study. The patients with coexisting diseases, which may influence the gait pattern, were excluded from the study. The subjects were recruited from orthopedic units of the city of Poznań, Poland. Table 1 summarizes the group characteristics.

Table 1. The characteristics of participants (n = 10)
AV – arithmetic mean, SD – standard deviation,
CV – coefficient of variation

Parameter	Time from procedure to trial	Age	Height	Body weight	BMI	Average gait velocity
	[days]	[years]	[cm]	[kg]	[kg/m^2]	[m/s]
AV	25	59	162	71	27.4	0.61
SD	5	8	6	11	4.9	0.11
CV [%]	20	13	4	16	18.0	18.8

The inclusion criteria were as follows:
- type of surgical procedure (THA with the use of cementless Implantcast Ecofit),
- time from the procedure to the trial (it was set to the first week after discharge from the orthopaedic unit),
- type of crutch gait (three-point crutch gait).

The study was approved by the Bioethical Commission of the Poznań University of Medical Sciences. The measurements were carried out in the Biomechanical-Kinesiological Laboratory of the Department of Biomechanics at University School of Physical Education in Poznań. All tests were carried out in single measurement session. In order to record kinematic and kinetic variables of the gait, two integrated and synchronized measurement systems were used: 6-camera stereophotogrammetric motion capture system BTS SMART D and 2 AMTI force plates, integrated into a specially designed measurement walkway. The patients were asked to walk with the crutches naturally, with self selected speed. The starting point was always indicated individually, so the patients without focusing on any target, could hit the center of force plate independently with one foot or crutch. No additional instructions were given to the patients.

Separate signals of GRF were recorded for the O and non-operated (NO) lower limb as well as for the right and the left crutch. The best measurement samples were chosen for final analysis according to similarity in gait velocity and centeredness of limb or crutch position on the plate. The static test of body weight bearing of both participant's feet was performed on an AMTI dual-top stabilometric plate. The measurement lasted 15 seconds and the subjects were standing freely, without crutches with both feet positioned at a distance approximately equal to the pelvic width. For the calculation of the spatio-temporal data the Vaughan–Davis model was extended by 6 markers placed on the crutches. This measurement method has been described in detail in the works of Dworak et al. [4], [6].

Statistica 8.0 software was used for statistical analysis of the values of parameters used to describe the group of participants, as well as the results of kinetic and stabilometric variables. To verify the distributions of the variables the Shapiro–Wilk ($p < 0.05$) test was used. Analysis of the significance of differences in three-point crutch gait kinetic parameter values between the O and NO limbs was carried out using Student's *t*-test ($p < 0.05$) and Wilcoxon test ($p < 0.05$). Another part of the study consisted of statistical analysis of time characteristics when peak values of the vertical component of GRF (R_z) appeared.

3. Results

Vertical component of ground reaction forces (R_z)

For the lower limbs two peaks of R_z appeared in characteristic phases of gait cycle: first (R_{zMSt}) during mid stance phase ($t_{zMStmax}$) and the second (R_{zTSt}) in terminal stance phase ($t_{zTStmax}$). For the crutches only one maximum R_{zCR} in t_{zCRmax} occurred. Time was normalized to 100% of the gait cycle [%GC].

Both peaks R_{zMSt} and R_{zTSt} appeared significantly later on the O side, by 4.4%GC ($t_{zMStmax}$) (Student's *t*-test, $p < 0.05$) and 5.2%GC ($t_{zTStmax}$) (Wilcoxon test, $p < 0.05$) (Table 2). The degree of load on the O limb during three-point crutch gait was at the level of (64.6 ± 14.1)%BW during mid stance (R_{zMSt}) and (64.3 ± 17.1)%BW during terminal stance (R_{zTSt}), while on the NO limb these levels were (103.5 ± 4.1)%BW and (108.8 ± 3.8)%BW, respectively (Fig. 1).

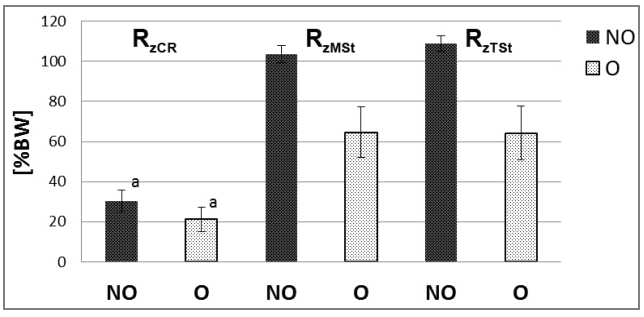

Fig. 1. Peak values of vertical component of GRF for crutches – RzCR and lower limbs during: mid stance – RzMSt, and terminal stance – RzTSt in three-point crutch gait, a – Student's *t*-test, $p < 0.05$

The average maximum load for crutches (R_{zCR}) on the NO side was at the level of (30.3 ± 5.5)%BW and on the O side (21.3±7.1)%BW respectively; the differences were statistically significant (Student's *t*-test, $p < 0.05$). As far as R_{zCR} it appeared also significantly later by 4.8%GC (t_{zCRmax}) for the crutch on O side (Wilcoxon test, $p < 0.05$) (Table 2).

Table 2. Time to peak vertical GRF to crutches and patients' feet: a – Student's *t*-test, $p < 0.05$, b – Wilcoxon test, $p < 0.05$, AV – arithmetic mean, SD – standard deviation, CV – coefficient of variation, tzCRmax – time to peak RzCR, tzMStmax – time to peak RzMSt, tzTStmax – time to peak RzTSt

Parameter	Crutches		Lower limbs			
	t_{zCRmax}		$t_{zMStmax}$		$t_{zTStmax}$	
	[%GC]		[%GC]		[%GC]	
	NO	O	NO	O	NO	O
AV	39.4[b]	44.2[b]	17.5[a]	21.9[a]	43.5[b]	48.7[b]
SD	6.7	11.9	3.2	3.8	5.9	3.5
CV [%]	17.0	26.9	18.3	17.4	13.6	7.2

During the static test, average values of body weight distribution on the O and NO limbs were 36%BW and 64%BW, respectively.

Anteroposterior component of ground reaction forces (R_y)

Figure 2 presents average peak values of the anteroposterior GRF during mid stance (R_{yMSt}) and terminal stance (R_{yTSt}) of crutch gait, for both NO and O limbs.

In deceleration phase the peak value of R_{yMSt} for O limb was (5.4 ± 1.9)%BW and for NO limb (9.2 ± 2.7)%BW where in acceleration phase the peak value of R_{yTSt} was (7.1 ± 2.4)%BW for O limb and for NO limb (10.8 ± 2.4)%BW (Fig. 2).

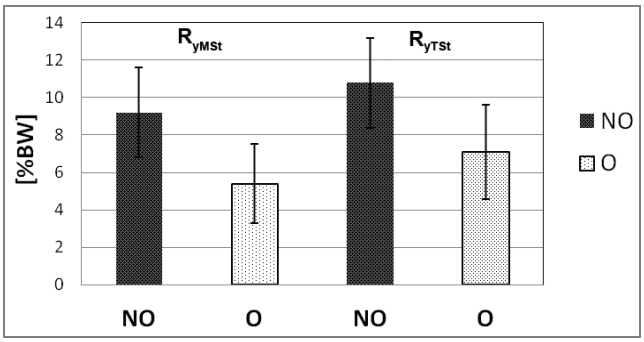

Fig. 2. Peak values of antero-posterior component of GRF for lower limbs during: mid stance – RyMSt and terminal stance – RyTSt in three-point crutch gait

4. Discussion

The main result of this study was that the level of weight bearing on the operated lower limbs was significantly higher during three-point crutch gait than during static trial (free standing). This fact suggests a very intuitive and rather not relevant to physicians indications character of the limbs loading by patients who underwent THA at an early stage of rehabilitation. The results obtained in this study, almost two times higher values of the R_z component during gait as compared to the static trial, suggest that the usefulness of weighing scales in the clinically applied training of partial weight bearing of the O limb should be reconsidered [16], [27]. Also Cichy et al. [2] observed significantly lower maximum pressure exerted by the operated limb during static test one month after surgery.

Nowadays, when dynamometric measurement systems are more readily available, one should think of implementing new standards, training and rehabilitation sessions consisting in learning crutch gait in relatively natural yet monitored and controlled conditions. It is also worth considering the use of balance systems to evaluate postural stability disorders in patients with hip pathologies [22].

Recommendations concerning the degree of weight bearing on the O limb were very variable (30–100%BW), depending on the physician and physiotherapists who were giving them. In contrast to these instructions, the patients examined showed surprisingly similar and low values of GRF of O limb in their early post-hospital period. The partial weight bearing after THA is still a subject to discuss. That kind of analysis can be found in works of Hol et al. [8], Eng et al. [11] and others [26]. Pozowski et al. [19] claim that full postoperative loading of the limb is possible only for patients who are properly selected and qualified for the appropriate surgery procedure. Together with concerning some doubts what level of load on the O limb is best for the patients it is also important to verify patients' ability to follow physicians recommendations during walking. Some authors maintain that indicated level of weight bearing is possible to perform [16], [27] while other research results deny that thesis [14], [23]. This study presents the real characteristics of O and NO limb loads during a three-point crutch gait in patients after THA in the first week after discharge from the orthopaedic units.

The main limitation of the study was poor physical condition of the patients which decided on the number of repetitions. The results obtained during this study confirm the findings of McCrory et al. [17], who carried out their study on individuals with unilateral THA, although performed on a treadmill with integrated force plates, with average walking speed of 0.8 m/s.

An interesting interpretation of the lower limb asymmetry that remains after knee arthroplasty during the rehabilitation period, was presented by Christiansen et al. [1]. They stated that this asymmetry arises mainly from habits and compensatory mechanisms already present before the surgical procedure. These compensations are also present in THA patients. They are the subject to concern during three-point crutch locomotion where the center of gravity shifts towards NO side. This tendency was observed in the patients examined and manifested itself in significantly greater load put on the crutches on the NO side in comparison with the O one. It is undoubtedly a problem that should be considered in further research projects on the pathomechanics of gait in patients after joint arthroplasty. It also justifies the necessity for directing more attention to the process of selection and education of such locomotion patterns performed with the use of mobility aids that are most advantageous biomechanically and functionally. The authors plan to set the measurement walkway in one of the orthopaedic units and try to monitor the learning process of walking among patients after THA.

5. Conclusion

The patients under examination showed surprisingly similar level of loading on the O limb during crutch locomotion. The weight bearing on the O limb was lower during static trial (free standing) than during three-point crutch gait. The maximum loads on the crutches were significantly higher on the NO limb side. Clinically applied training of partial weight bearing of the O limb should be reconsidered.

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