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Kinematic gait parameters changes in patients after total knee arthroplasty. Comparison between cruciate-retaining and posterior-substituting design

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Purpose: The patients expect optimal knee function after Total Knee Arthroplasty. It is necessary to apply appropriate surgical technique and supervised physical therapy. The optimal management of posterior cruciate ligament remains controversial. Both implant designs, i.e., cruciate retaining and posterior substituting, allow the orthopedic surgeon to achieve excellent clinical outcomes, as measured by commonly used questionnaires. Such methods of assessment may poorly reflect the functional status of patients. Therefore, three-dimensional gait analysis is recommended to evaluate the outcomes of surgical intervention. This study sought to determine differences in kinematic gait parameters and Knee Society Score between cruciate-retaining and posterior-substituting patients. *Methods:* 23 individuals after cruciate-retaining total knee arthroplasty and 19 individuals after posterior-substituting total knee arthroplasty were subjected to gait analysis using three-dimensional motion capture system BTS Smart DX 7000. In addition, gait was assessed in 21 patients with knee osteoarthritis and in 30 healthy individuals. *Results:* The study did not reveal differences between cruciate-retaining and posterior-substituting groups, both in terms of Knee Society Score and kinematic gait parameters. There were also no differences in kinematic gait parameters between patients from the knee osteoarthritis group and total knee arthroplasty groups. The analyzed parameters in all of the groups differed significantly from those found in healthy individuals. *Conclusions:* Surgical technique and implant design do not affect values of kinematic gait parameters evaluated under natural walking speed. Several months after surgery the patients still demonstrated alterations in gait pattern, similar to those recorded in patients with knee osteoarthritis.

Key words: *total knee arthroplasty, gait analysis, cruciate retaining, posterior substituting*

1. Introduction

Total knee arthroplasty (TKA) is a common orthopaedic procedure option, which provides permanent pain relief, as well as improvement in joint function and quality of life in patients with advanced knee osteoarthritis (OA) [17]. The surgical technique involves excision of the posterior cruciate ligament (PCL) and its substitution with a posteriorly stabilized (PS) tibial insert, or preservation of the ligament and implantation of a cruciate retaining (CR) tibial insert. Both methods provide femoral rollback in knee flexion, which serves to increase range of movements, knee stability, and moment arm of the extensor mechanism, thereby reducing the shear forces acting at the bone–implant interface [3], [19].

Some authors suggest that with the cruciate-retaining implants knee kinematics is unpredictable and largely depends on appropriate PCL tensioning during the surgery [14]. Numerous studies show that retention of the PCL during the TKA surgery does not guarantee proper function of this ligament [3], [18]. Up to now, the optimal management of PCL (excision

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vs. retention) remains controversial. Studies on biomechanics, proprioception and stability of the knee after total arthroplasty using cruciate-retaining or posterior-substituting technique yield inconsistent results and do not provide definitive conclusions.

Both types of implants allow the orthopedic surgeon to achieve good or excellent clinical and functional outcomes, as measured by commonly used questionnaires [13]. However, it should be kept in mind that such methods of assessment are not completely objective, as they are largely based on the patients' subjective complaints. In our opinion, gait analysis gives a more complete picture of the knee function, its possible disturbances, and their effect on the patient's locomotion. The total knee replacement is currently regarded as the best treatment option for restoration of normal knee kinematics in osteoarthritic knees. The primary goal of this study was to analyze a possible impact of the surgical technique and implant design (cruciate-retaining vs. cruciate-substituting) on the clinical and functional results of treatment, measured with the Knee Society Score (KSS) and on kinematic gait parameters measured with a three-dimensional motion analysis system in patients who underwent a total knee arthroplasty.

We hypothesized that there were no significant differences in KSS scores and in values of kinematic gait parameters between patients with the CR implants and those with the PS total knee replacement. The second hypothesis to be tested was that the gait pattern, in terms of kinematic parameters, recorded in patients after total knee replacement was similar to the pattern found in healthy individuals.

2. Material and methods

Gait analysis was performed in 42 patients (42 knees) who underwent total knee replacement. Of those, 23 individuals (23 knees) were operated with the PCL retaining technique (CR group), and 19 patients (19 knees) with excision of the ligament and implantation of the posteriorly stabilized implant (PS group). The preoperative diagnosis in all of the patients was osteoarthritis (grade 4 acc. to Kellgren-Lawrece's scale). They received the P.F.C Sigma implants (DePuy Orthopaedics Inc, Warsaw, IN, USA) via medial parapatellar approach. All surgeries were performed by single surgeon (DK) using standardized technique, which included the necessary soft tissue release to obtain a good balance. In all knees, the femoral and tibial components were fixed with cement. Patella was not replaced in any of the cases. Postoperative treatment included physical therapy consisting of patella mobilization, isometric exercises, passive ROM, quadriceps/hamstrings strengthening and gait training. Weight-bearing was allowed as tolerated with canes under supervision of physiotherapist on the second postoperative day. The mean follow-up time was 14.4 (range: 12.1–16.3) months in the CR group and 15.5 (range: 12.3-16.9) months in the PS group. Gait parameters were measured also in 21 patients diagnosed with unilateral knee osteoarthritiss (grade 4) scheduled for total knee replacement (OA group). The control group consisted of 30 individuals who reported no history of lower limb disorders and had been pain-free in the lower limb over the previous year. There were no statistically significant differences between aforementioned group in terms age, gender, body weight, height and body mass index. Clinical characteristics of the patients are summarized in Table 1.

The gait analysis was performed with a high performance three-dimensional, six-camera motion capture system BTS Smart DX 7000 (Bioengineering Technology System, Milan, Italy). Fourteen-millimeter passive reflective markers were fastened bilaterally with adhesive tape over 19 anatomical landmarks (i.e., anterior superior iliac spine, sacrum, greater trochanter, lateral femoral condyle, head of fibula, lateral malleolus, head of the 5th metatarsal and heel). Two thermoplas-

Table 1. Details of patients in all groups. For age, weight and height there are mean values (standard deviation in brackets)

	OA group	CR group	PS group	K group
Knees (*n*)	21	23	19	30
Gender (male/female) (*n*)	5/16	4/19	5/14	11/19
Age (years)	65.95 (7.19)	68.13 (6.49)	65.68 (5.62)	65.68 (5.62)
Body weight (kg)	89.05 (14.86)	84.43 (15.33)	87.42 (13.05)	80.67 (10.34)
Body height (m)	1.66 (0.09)	1.63 (0.10)	1.65 (0.08)	1.64 (0.10)
BMI < 30/BMI > 30 (*n*)	8/13	9/14	7/12	14/16

BMI – body mass index.

tic bands with two markers were secured on the lateral aspect of both thighs and lower legs, according to the protocol described by Davies [5]. The marker data were sampled at 500 Hz. After calibration in standing position, the patients were instructed to walk with a self-selected speed along the walkway. Velocity was not dictated because it has been shown that gait speed other than natural, results in significant variability of outcomes. Each patient had to repeat walks until we recorded six to eight passes free from artifacts, and these records were selected for further analysis. Temporo-spatial parameters and average peak values of knee flexion/extension at predefined points of the gait cycle were recorded and subjected to statistical analysis (Fig. 1).

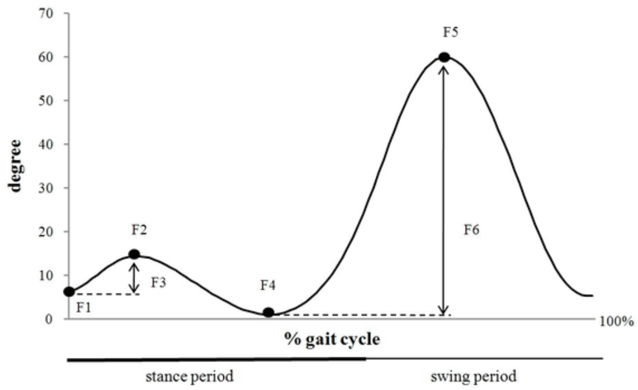

Fig. 1. Peak values of knee joint kinematics at defined points of the gait cycle. F1 – initial contact, F2 – maximum loading response angle, F3 – total flexion during weight acceptance, F4 – minimal angle at terminal stance, F5 – maximal flexion at swing, F6 – total flexion during the gait cycle

The clinical and functional assessment was performed with the Knee Society Score (KSS), which currently is one of the most widely used scoring system for evaluation of treatment outcomes after total knee replacement [9]. Knee Range of Movements, extension leg and flexion contracture was measured with half-circle 2-increment goniometer. The evaluation of limb axis was based on digital full-leg AP radiographs of the lower limbs in the standing position (including hips, knees, and ankles). To minimize interobserver variations, one person (GH) performed clinical, functional and radiographic assessment.

The statistical analysis was performed with the Statistica 7.0 software suite (StatSoft Inc., Tulsa, OK, USA). ANOVA rang Kruskal–Wallis test and Tukey post hoc test for unequal numbers were used to examine differences between the groups in anthropometric, spatio-temporal and kinematic parameters. The distribution of variables in groups was compared with chi-square test. In all tests, a p-value less than 0.05 was considered statistically significant.

3. Results

Treatment outcomes in all of the patients who underwent TKA were rated as good or excellent. In both PS and CR groups, the patients received significantly better scores in the KSS clinical and functional rating systems than patients from the OA group ($p = 0.00012$). There were no statistically significant differences in either KSS Knee Score or KSS Functional Score between the CR and the PS group ($p = 0.48$ and $p = 0.99$, respectively). Measurements of passive ROM, which is one of the parameters in-

Table 2. Knee Society Score ratings and passive knee flexion (mean values, standard deviation in brackets)

	Knee score	Functional score	Pasive flexion (°)
OA group	59.67 (9.72)	44.29 (13.07)	105.24 (13.55)
CR group	86.17 (8.94)	75.47 (12.76)	99.78 (12.75)
PS group	88.79 (10.72)	75.86 (10.73)	107.89 (11.46)
Control group			128.89 (8.42)
Intergroup comparison p (X,Y)			
p (OA, CR)	$p = 0.00012$*	$p = 0.00012$*	$p = 0.36$
p (OA, PS)	$p = 0.00012$*	$p = 0.00012$*	$p = 0.87$
p (OA, K)	X	X	$p = 0.00015$*
p (CR, PS)	$p = 0.48$	$p = 0.99$	$p = 0.13$
p (CR, K)	X	X	$p = 0.00015$*
p (PS, K)	X	X	$p = 0.00015$*

$p(X, Y)$ – level of significance for intergroup differences,
* – statistically significant differences.

Table 3. Spatio-temporal parameters (mean values, standard deviation in brackets)

	Velocity (m/s)	Cadence (step/min)	Step length (m)	Double limb support (% gait cycle)	Single limb support (% gait cycle)	Normalized limb support (% gait cycle)
OA group	0.54 (0.16)[a]	79.23 (12.65)[a]	0.38 (0.08)[a]	37.44 (8.45)[a]	30.15 (5.53)[a]	67.59 (4.86)[a]
CR group	0.61 (0.17)[b]	87.00 (13.81)[b]	0.42 (0.07)[b]	32.65 (6.75)[b]	33.32 (5.91)[b]	65.97 (4.57)[b]
PS group	0.58 (0.16)[c]	83.06 (8.02)[c]	0.40 (0.09)[c]	34.79 (6.73)[c]	32.98 (4.52)[c]	67.77 (3.89)[c]
K group	1.05 (0.21)[abc]	105.79 (11.85)[abc]	0.54 (0.07)[abc]	24.24 (4.46)[abc]	37.96 (3.01)[abc]	62.20 (2.36)[abc]

Significant difference between groups: [a] – OA and K, [b] – CR and K, [c] – PS and K.

Table 4. Knee flexion/extension during gait cycle (mean values, standard deviation in brackets)

	F1 (°)	F2 (°)	F3 (°)	F4 (°)	F5 (°)	F6 (°)
OA group	9.20 (7.80)[a]	13.94 (9.17)	4.74 (5.19)[a]	8.23 (8.98)[a]	44.48 (9.86)[a]	36.25 (11.04)[ad]
CR group	6.10 (4.91)	12.47 (5.01)	6.37 (2.68)[b]	7.43 (6.36)[b]	49.40 (6.59)	41.97 (5.33)[b]
PS group	5.74 (4.86)	10.87 (5.45)	5.13 (4.89)[c]	6.64 (6.41)[c]	44.95 (10.28)[c]	38.31 (8.78)[c]
K group	3.28 (.89)[a]	14.22 (5.32)	10.95 (4.7)[abc]	0.85 (4.31)[abc]	54.86 (5.34)[ac]	54.01 (5.92)[abc]

Significant difference between groups: [a] – OA and K, [b] – CR and K, [c] – PS and K, [d] – OA and CR.

cluded in the KSS score, showed no differences between the OA patients and patients who received TKA, regardless of the type of implant (Table 2).

There were also no significant differences in passive range of movements (ROM), spatio-temporal parameters and knee flexion/extension gait parameters between the CR and PS groups, as well as between the OA group and patients from either CR or PS group (see Table 3 and 4). On the other hand, the analyzed gait parameters differed significantly from those recorded in healthy individuals from the control group. Several months postoperatively, despite excellent treatment outcomes, the patients still demonstrated gait pattern, similar to those showed in patients with diagnosed knee osteoarthritis awaiting surgery.

4. Discussion

The statistical analysis showed that both study groups and the control group were found to be homogenous in terms of gender, age, height, body weight, BMI and the side of the surgery. Previously conducted studies indicated that both age and the BMI have a significant impact on the gait parameters [4].

All of the patients included in the study were overweight or obese, and their average age was over 60 years. Therefore, age and body weight influenced the measured parameters in a similar way.

Retaining of the PCL during the TKA surgery is thought to have many theoretical advantages, associated with preservation of the rollback mechanism and a more conservative resection of soft tissues and bone [3], [14], [19]. The authors of this study tried to verify this presumption. We performed clinical and functional assessment of patients after total knee replacement. However, we were unable to prove superiority of one implant type over the other. The statistical analysis of KSS scores showed no significant differences in the measured parameters between the CR ant the PS group ($p > 0.05$). These findings were in line with the majority of related studies [7], [22], [24]. Some authors [23], [25], however, reported significantly better knee flexion with PS implants, whereas others associate better knee flexion with the CR designs [11]. The reason for such discrepancies between those reports is unclear. It is possible that they might be related to different length of the follow-up period and patient selection.

The statistical analysis of the measured spatio-temporal and kinematic parameters did not reveal significant differences between the patients from the CR and the PS groups. Our findings are similar to results published by Bolanos, Ishii, Banks and Michaud [10], [16], who concluded that kinetic and kinematic gait parameters were not influenced by the type of implant used for the TKA surgery. There are few studies which report better kinematic gait parameters in patients with the CR implants. These studies, however, have serious limitations due to small size of the study group and weak statistical analysis [17] or flaws in selection criteria and methods of assessment [8].

In our opinion, it is worth mentioning that in spite of excellent clinical and functional outcomes, the patients in both the CR and the PS groups demonstrated significantly worse passive knee flexion than individuals from the control group. Similar findings were reported by Kim et al., and Incavo, who found that neither PS nor CR implant would guarantee restoration of normal knee kinematics [8], [14]. Inadequate balancing of the PCL in patients with CR implant design may even lead to abnormal anterior translation of the femorotibial articular contact point, resulting in limitation of knee flexion.

Another important finding from our study was that gait pattern in patients who underwent TKA surgery is different from the pattern recorded in healthy individuals, regardless of implant design. The changes in gait are usually presented as alterations in kinematic parameters which do not improve after surgery and remain significantly different from parameters recorded in healthy individuals ($p < 0.05$). At follow-up, performed a dozen months after the index surgery, we still recorded compensatory mechanisms aimed at reduction of knee loading. The compensatory mechanisms were similar to those demonstrated by patients with knee osteoarthritis and were still present in patients from the study groups despite permanent pain relief and excellent functional outcomes measured with the KSS system. In this regard, our findings are in agreement with results reported by other authors [10], [15]. The duration of the double limb support phase and the normalized limb support were inversely proportional to gait velocity and were increased in patients with knee OA who underwent the TKA surgery. Conversely, the duration of the single limb support in this group of patients was decreased. These results were in line with data published by other authors [6], [20]. The alterations in gait pattern demonstrated by patients with knee OA are related to pain and decreased joint function. They are aimed at reducing loads acting across the affected knee joint. This goal is achieved by reduction in walking speed, increased double limb support time and shortened single limb support time, which allows the patient to extend the period when his/her body weight is supported on both legs [12]. However, the correlation between increased double limb support time and reduction in knee loading has not been fully understood and requires further research.

Previous studies on human gait show that changes in walking speed may strongly influence the kinetic and kinematic gait parameters, even in patients without musculoskeletal disorders [12]. Unfortunately, reduction in walking speed is an inherent feature of the knee OA and it is not possible to assess its effect separately from alteration of gait resulting from this condition [1]. Currently, there are no studies that analyze impact of walking speed on gait biomechanics in patients who underwent TKA for knee OA. The results obtained with the use of a treadmill with a predetermined cadence were difficult to interpret and did not clarify this problem [1]. The correlation between gait velocity and kinematic parameters in patients affected by knee OA remains unclear. Therefore, differences in gait parameters between the groups under study cannot be explained by changes in velocity alone.

The statistical analysis of the remaining kinematic parameters showed that parameters measured in patients who underwent TKA were closer to the values found in patients with knee OA than to those recorded in patients from the control group. This was clearly visible in the case of angular parameters describing knee motion in the sagittal plane. The values of all measured parameters (F1 to F6) in both groups that underwent TKA surgery were close to the values obtained in the OA group ($p < 0.05$). Similar results were reported with the results published by other authors [10], [20].

After the TKA surgery there was no improvement in the kinematic gait parameters, despite pain relief and better knee function confirmed by higher KSS scores. The patients diagnosed with knee OA usually live with this condition for a few years before they decide to undergo a total knee replacement. Progression of degenerative changes typically result in limitation of both flexion and extension of the knee during the gait cycle. This was demonstrated in our study (parameters F1, F4 and F5) and is consistent with the results reported by other authors [2], [20]. Gait alterations, measured after total knee replacement, could be explained as residual abnormalities in gait pattern acquired before the surgery. Alternatively, they can result from inadequate postural control due to the loss of proprioception. Surgical resection of one or both of cruciate ligaments during knee replacement procedure usually impairs proprioception. However, the mechanical and sensory quality of the posterior cruciate ligament decreases with age and in the course of osteoarthritis. Therefore, some authors question if the function of these ligaments is still adequate at the time of knee replacement surgery [21].

5. Conclusions

Surgical technique and implant design (CR or PS) do not affect values of kinematic gait parameters evaluated under natural walking speed. Gait pattern recorded in patients after total knee replacement is not similar to the pattern found in healthy individuals in terms of the kinematic parameters. Several months postoperatively, despite excellent treatment outcomes, the patients still demonstrated gait patterns similar to those recorded in patients with diagnosed knee osteoarthritis awaiting surgery.

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