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Comparative gait analysis of patients with different design of total knee arthroplasty

Упоредна анализа хода пацијената са уграђеним тоталним ендопротезама зглоба колена различитог дизајна

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SUMMARY

Introduction/Objective The essence of the treatment of degenerative knee joint diseases is pain relief, restoring motion range and stability of knee joints.

Methods In this study, 35 patients participated after having surgery of the knee joint. The patients had a posterior - stabilized (PS) endoprosthesis in one joint, and a posterior cruciate ligament retaining (CR) endoprosthesis in the other. Kinematic data was collected using a 3D optical system for tracking fluorescent markers in time. Based on these data, the following parameters were determined: degree of flexion, medio - lateral (ML) translation, lateral gap, medial gap and the angle of change between the transtibial and transfemoral axes.

Results The results show a more pronounced flexion degree with the PS prosthesis compared to the CR prosthesis. Also, the results show negligible values of the ML translation, lateral gap and medial gap in both types of prostheses. Using the non-parameter Wilcoxon test, a substantial difference in the angle change between the transtibial and transfemoral axes was confirmed, that is, in the flexion angles on the CR and PS prostheses.

Conclusion This study shows that there is no great difference in the use of the PS or CR designs of endoprostheses. Better behavior and range of motion in the knee joint were established with the implantation of the PS endoprosthesis. This conclusion is confirmed by the substantial difference in the degree of flexion of the knee joint and in the position of the transversal axes of the tibia and femur.

Keywords: Gait analysis, Gait kinematics, Gonarthrosis, PS endoprosthesis, CR endoprosthesis

САЖЕТАК

Увод/Циљ Суштина лечења дегенеративних обољења зглоба колена је ублажавање болова, обнављање опсега покрета и стабилности зглоба колена.

Методи У овој студији је учествовало 35 пацијената након операције зглоба колена. Пацијенти су имали уграђену ендопротезу зглоба колена са задњом стабилизацијом (ПС) на једном колену и ендопротезу са очуваним задњим укрштеним лигаментом (ЦР) на другом. Кинематски подаци су прикупљени коришћењем 3Д оптичког система којим се прате флуоресцентни маркери током времена. На основу ових података, одређени су следећи параметри: степен флексије, медијално-латерална (МЛ) транслација, латерални међупростор, медијални међупростор и промена угла између транстибијалне и трансфеморалне осе.

Резултати Резултатима је показан већи степен флексије код ПС у односу на ЦР ендопротезе. Такође, резултати показују занемарљиве вредности МЛ транслације, латералног међупростора и медијалног међупростора код оба типа ендопротеза. Коришћењем непараметријског Wilcoxon теста, потврђена је суштинска разлика у промени угла између транстибијалне и трансфеморалне осе, односно у степену флексије ЦР и ПС протеза.

Закључак Студијом је показано да не постоји велика разлика у коришћењу ПС или ЦР ендопротезе. Боље понашање и опсег покрета у зглобу колена се постиже уградњом ПС ендопротезе. Овај закључак је потврђен суштинском разликом у степену флексије зглоба колена и позицијама трансверзалних оса фемура и тибије.

Кључне речи: Анализа хода, Кинематика хода, Гонартроза, Ендопротеза са задњом стабилизацијом, Ендопротеза са очуваним задњим укрштеним лигаментом

INTRODUCTION

The basic role of knee arthroplasty is pain relief, restoration of knee joint motion range and stability [1]. Therapy success of implanted endoprostheses is most commonly defined by clinical and radiographic methods and tests based on the subjective feeling of patients about their pain and everyday functioning, such as the Knee Society Score (KSS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and EQ-5D [2, 3, 4, 5]. Functional comparisons of different implanted endoprostheses are difficult because of many subjective factors related to patients and their various postoperative expectations [6].

Therefore, examiners had a demanding task related to the application of the innovative objective methods for determining the level of physical activity, that is, the evaluation of operation success. The aim of this study is a simultaneous examination of motion analysis in both knees where due to gonarthrosis, a posterior-stabilized, that is, a cruciate-substituting endoprosthesis was implanted in one knee, and a cruciate-retaining endoprosthesis was implanted in the other.

METHODS

Patients

The examination was conducted at the Clinical Center of Kragujevac (Serbia). The selection of patients was done based on the following criteria:

The patient suffers from gonarthrosis that was diagnosed based on -anamnesis, clinical examination, and the analysis of radiographic records with the application of Kellgren-Lawrence (KL) classification [7, 8];

Based on the KL classification, gonarthrosis belongs to the third or fourth -stage of the disease;

All affected knees had a varus deformity with -deviation of the axis of 5–15°;

All the knee joints that were analyzed preoperatively had a flexion deformity of less than 10°;

The PS endoprosthesis was implanted in one knee joint, and -the CR endoprosthesis was implanted in the other;

The patient does not suffer from neurological, rheumatological, or similar diseases, that is, diseases that may affect the disruption of walking pattern.

In the examination, there were 35 patients who suffer from gonarthrosis (mean value of years 68,79 ± 5,98, mean value of weight 81,5±16,18 kg, and mean value of height 167,86 ± 8,51 cm). The patients were familiarized with the procedure of examination to which they voluntarily agreed. Gait analysis was done six months after the second arthroplasty. All the patients signed an agreement for participating in the study.

This study was done in accord with standards of the institutional Committee on Ethics.

Implant system

In the study, two endoprosthesis designs were used. The PS endoprosthesis was implanted in one knee (NexGen Complete Knee Solution Legacy Posterior Stabilized Knee, Zimmer, Warsaw, IN, USA), and the CR endoprosthesis was implanted in the other (DEPuySynthes, SIGMA, Primary Knee System, Cruciate Retaining design, DePuyOrthopaedics, Inc, Warsaw, IN, USA).

Clinical evaluation

All knee arthroplasties were done with a standard medial parapatellar incision. After the performed operation, verticalization and early rehabilitation were performed at the clinic. All the performed operations were done by the same group of surgeons.

Instrumentation and protocol

Kinematic data was collected using a 3D OptiTrack system (Natural Point, Inc., Oregon, www.naturalpoint.com). This system consists of 6 infrared cameras (V100:R2) all with a resolution of 640×480 pixels and a frame rate of 100fps.

Using the afore-mentioned system, the tracking of positions of the 8 fluorescent markers (10 mm diameter) in space was done. The markers were placed on anatomic positions [9,10] of the lower extremities to allow for repeatability of the examination, in the area of the great trochanter, on the medial and lateral femoral epicondyle, medial and lateral tibial epicondyle, on the center of the ankle joint and on the diaphysis of the femur and tibia (Figure 1).

Visualization was done using ARENA Software (Natural Point, Inc., Oregon, www.naturalpoint.com).

During the tracking protocol, patients moved without shoes at their own speed along a straight line (length 3m) towards the cameras. The tracking was repeated at least twice.

Kinematic data

The obtained data from the ARENA Software was extracted to a standard VICON .c3d recording format. Furthermore, data processing was done using the MATLAB program (The MathWorks, Inc, USA, www.mathworks.com), that is, an evaluation of the following parameters was made: flexion angle, ML translation, medial gap, lateral gap, and the change between the transfemoral and transtibial axes. Depending on the implant, the processed data was divided into the PS or CR group. The kinematic analysis was based on the principles of a three-dimensional body.

The mean value and standard deviation calculated for every observed parameter, while a comparison was made using the non-parameter Wilcoxon test.

RESULTS

The results for the examined prostheses (PS and CR) were shown using the mean values of change in the observed parameters for the stance phase and the swing phase (flexion angle, ML translation, medial gap, lateral gap, change between transfemoral and transtibial axes) listed in Table 1 and using movement curves shown in Figure 2. The values of the observed parameters were approximately equal.

The flexion angle (Figure 2a,b) shows that a patient's leg is slightly bent in the stance phase, and that it stays in that position until the swing phase starts. Also, Figure 3b shows that the flexion angle in the stance phase is more expressed in the PS endoprosthesis design (Table 1).

There is relatively little ML translation (Figure 2c,d, Table 1) in both endoprosthesis designs. However, in the first 30% of the gait cycle for both types of prostheses, it can be noticed that there is a slight medial motion and that with the beginning of the swing phase, the lateral motion starts, and at the end of this phase the medial motion starts again.

The lateral gap (Figure 2e,f, Table 1) is between -1 and 1 mm. These movements in the knee joint occur in the stance phase and are completely eliminated when the swing phase starts. With the CR endoprosthesis design, a gap increase is noticeable in the first 10% of the gait cycle, while in the PS design, the gap increase occurs in the first 30%. The medial gap (Figure 2g,h, Table 1) is almost constant. Its changes are very little, and their values represent hundredths of a millimeter.

The angle that the transtibial and transfemoral axes form (Figure 2i,j, Table 1) remains constant during the entire gait cycle in both endoprosthesis designs.

Figure 2. Graphic representation of the parameters: a) Degree of flexion-CR, b) Degree of flexion-PS, c) ML translation-CR, d) ML translation-PS, e) Lateral gap-CR, f) Lateral gap-PS, g) Medial gap-CR, h) Medial gap-PS, i) Angle change between the transtibial

and transfemoral axes-CR, and j) Angle change between the transtibial and transfemoral axes-PS

The non-parameter Wilcoxon test (Table 2) determines that there is no statistically substantial difference in the ML translation, and lateral and medial gap in the PS and CR prostheses. However, a substantial difference is determined in the angle change between the transtibial and transfemoral axes, that is, the flexion angles in the CR and PS prostheses. This change is not accidental – it occurs under the influence of systematic or experimental factors with a statistical significance of $p = 0.01$, a possible error of $p < 0.01$ and certainty of $P > 99\%$.

DISCUSSION

The analysis of the success of knee arthroplasty using various endoprosthesis designs has been a topic of many examinations that are usually based on the use of subjective tests and the matching of patients with different types of endoprostheses [2, 11-16]. In our examination, an objective index of the gait pattern was used after knee arthroplasty in the same patient with, in one knee joint, an implanted endoprosthesis with sacrifice of the posterior cruciate ligament, and in the other, an endoprosthesis with a preserved posterior cruciate ligament.

Over the past years, the design and technology of implanted endoprostheses has been significantly improved, and many producers have placed various implant designs on the market. The choice of implants, in the majority of cases, depends on a surgeon`s personal experience. Apart from the surgeon`s experience, the implantation of the CR or PS endoprosthesis designs depends on the pathoanatomic change of the knee joint and on ligament stability [11, 17, 16].

Currently, there are disagreements regarding the sacrifice or retention of the posterior cruciate ligament in total knee prosthesis implantation. Marczak D. et al. suggest that the proprioception property of patients shows better results with the PS endoprosthesis compared to the CR implant [12]. Additionally, there are similar claims by Vanlauwe J. et al, who suggest that the implantation of the PS endoprosthesis design shows slight flexion instability, slight clinical, radiologic laxity, greater freedom of movement, as well as slight complications after the implantation compared to the CR implant [13]. A complete knee arthroplasty with retention of the posterior cruciate ligament (CR) has its own advantages compared to implantation of the total knee endoprosthesis with sacrifice of the posterior cruciate ligament (PS). The advantages are, firstly, it is based on a natural rollback of the femoral condyle during extension in the knee, as well as low osteotomy of the distal femur [11]. The disadvantage of implantation of such an endoprosthesis design is poor balance of soft tissue, which can lead to loosening of the implant. There are certain indications when it is necessary to place an implant with posterior stabilization that replaces the posterior cruciate ligament (PCL) function, such as a lack or insufficiency of the PCL, contraction of the posterior capsule that demands release, as well as noticeable flexion contractures of the knee.

Considering the divided opinions among examiners and clinicians, and in order to obtain objective results about the behavior of the knee joint, after implantation of the CR and PS endoprostheses, kinematic data were collected using the 3D OptiTrack system. A similar methodology of 3D gait analysis was used by Bytyqi D. et al. and Prodanovic N. et al, who analyzed deformity of the gait pattern of the knee joint with degenerative change using the afore-mentioned methodology [14, 15]. The methodology has proved to be an excellent mode for diagnosing lesions of the anterior and posterior cruciate ligament, shown by Matić A. et al. and La Prade R.F. et al. in their examinations [18, 19].

The method of establishing contact between implant elements has a direct influence on the functionality and durability of implants. As already mentioned, there are disputes about the placement of PS and CR implants. However, various studies have shown that there is no substantial difference in their use [20, 21]. Koga Y. belongs to the group of examiners who think that better reduction in knee joint rotation is achieved through the use of the CR implant type because of the increased tension in the PCL [22]. Global analyses on the range of knee joint flexion have shown that rejection of the PCL increases the flexion angle by 2% [20]. Our results in Table 1 show that an increase in the degree of flexion occurs in the stance phase, while in the swing phase, the degree of flexion remains equal with the CR and PS prostheses. Similar results were obtained by Murakami K. et al. who analyzed the walking pattern after bilateral arthroplasty of the knee joint using a treadmill with radiographic supervision and a flat panel detector [23]. Victor J. et al. examined the comparison of motion range in both endoprosthesis designs and showed that there is a statistically greater range of motion after knee endoprosthesis implantation with sacrifice of the posterior cruciate ligament [24,25].

With the use of the computational model and simulation of real conditions, potential conclusions of implant application can be drawn. With this model, Smith CR et al. showed potential behavior of the PS endoprosthesis. Based on their results, it was shown that the use of this type of implant does not influence contact stresses, however it does affect ML distribution of the stress [26]. An examination of CR prosthesis behavior in vivo was conducted by Li C. et al. Their results showed that, compared to the osteoarthritis (OA) joint, there is an increase in ML translation. With the increase of this translation, a change in the knee mechanics occurs, e.g., there is a change in the distribution of force and stress in the knee [27]. Stress distribution is closely related to the realized contact [22], which our results showed. The ML translation is more noticeable with the use of the PS prosthesis rather than the CR implant. As the movement is more frequent in the gait cycle, contact is achieved on a greater surface, which influences the increased stress distribution in the ML direction.

The results show that there is a greater range of motion with the use of the PS implant. Similar results were obtained by Jiang C. et al. They think that these results can be connected to the removal of the PCL and a better balancing of the soft tissue [28].

In the gait analysis, we performed an examination of the medial and lateral gap. An increased gap occurs on the lateral side with the use of both types of endoprostheses, while the medial gap is non-existent. These gaps are noticeable in the stance phase (extensive and lateral gap). Christoph S. et al. proved that PCL resection does not influence the gap size. They analyzed the influence of PCL resection after knee arthroplasty [29].

In total arthroplasty of the knee joint, it is recommended that the transtibial and transfemoral axes be parallel [30], shown by the results in Figure 4e. There is a slight deviation for both endoprosthesis designs in the first 40% of the gait cycle due to the lateral gap occurring at the same moment.

This study has several shortcomings that must be considered. The main weakness of our research is that surgeries were done in two separate procedures, therefore the period from operation to movement recording is not identical for both knees. Secondly, the use of optical systems for gait analysis is not such a precise procedure as dynamic radiographic examination, however, compared to the afore-mentioned procedure, it is superior due to the possibility of 3D analysis and the ultimate safety of the patient (i.e., through lack of x-rays).

CONCLUSION

In this study, we examined the kinematic behavior of the knee joint with the application of objective methods after knee joint arthroplasty when the same patient was implanted using a PS endoprosthesis design on the one knee, and a CR on the other. The purpose of this surgical intervention is to restore the original knee joint kinematics and eliminate patients' discomfort. Even though there is no substantial difference between these two designs, better behavior and range of motion in the knee joint were achieved with the implantation of the PS endoprosthesis. This was confirmed by the substantial difference (shown using the Wilcoxon test) in the degree of flexion in the knee joint, and in the position of the transversal axes of the tibia and femur.

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Table 1. Values of the observed parameter values

Parameter	Posterior cruciate ligament		Cruciate ligament retaining	
	Stance	Swing	Stance	Swing
Flexion angle, °	13.98 ± 1.66	18.52 ± 7.67	11.35 ± 0.97	18.85 ± 7.21
Medio-lateral translation, mm	-0.19 ± 0.18	0.12 ± 0.31	-0.01 ± 0.18	-0.02 ± 0.34
Lateral gap, mm	-0.19 ± 0.33	0.03 ± 0.12	-0.11 ± 0.35	0.02 ± 0.12
Medial gap, mm	0.01 ± 0.04	0.01 ± 0.03	0.01 ± 0.02	-0.01 ± 0.03
Change between transfemoral and transtibial axes, °	0.06 ± 0.04	0.03 ± 0.01	0.11 ± 0.02	0.08 ± 0.01

Table 2. Wilcoxon test

Compared groups	Value
Flexion angle degree cruciate ligament retaining *vs*. Flexion angle degree posterior-stabilized	sig. = 0.00 **
Medio-lateral translation cruciate ligament retaining *vs*. Medio-lateral translation posterior cruciate ligament	sig. = 0.837
Lateral gap cruciate ligament retaining *vs*. Lateral gap posterior-stabilized	sig. = 0.945
Medial gap cruciate ligament retaining *vs*. Medial gap posterior-stabilized	sig. = 0.623
Change between transfemoral and transtibial axes cruciate ligament retaining *vs*. Change between transfemoral and transtibial axes posterior-stabilized	sig. = 0.00 **

Figure 1. Clinical anatomical position of markers on a patient

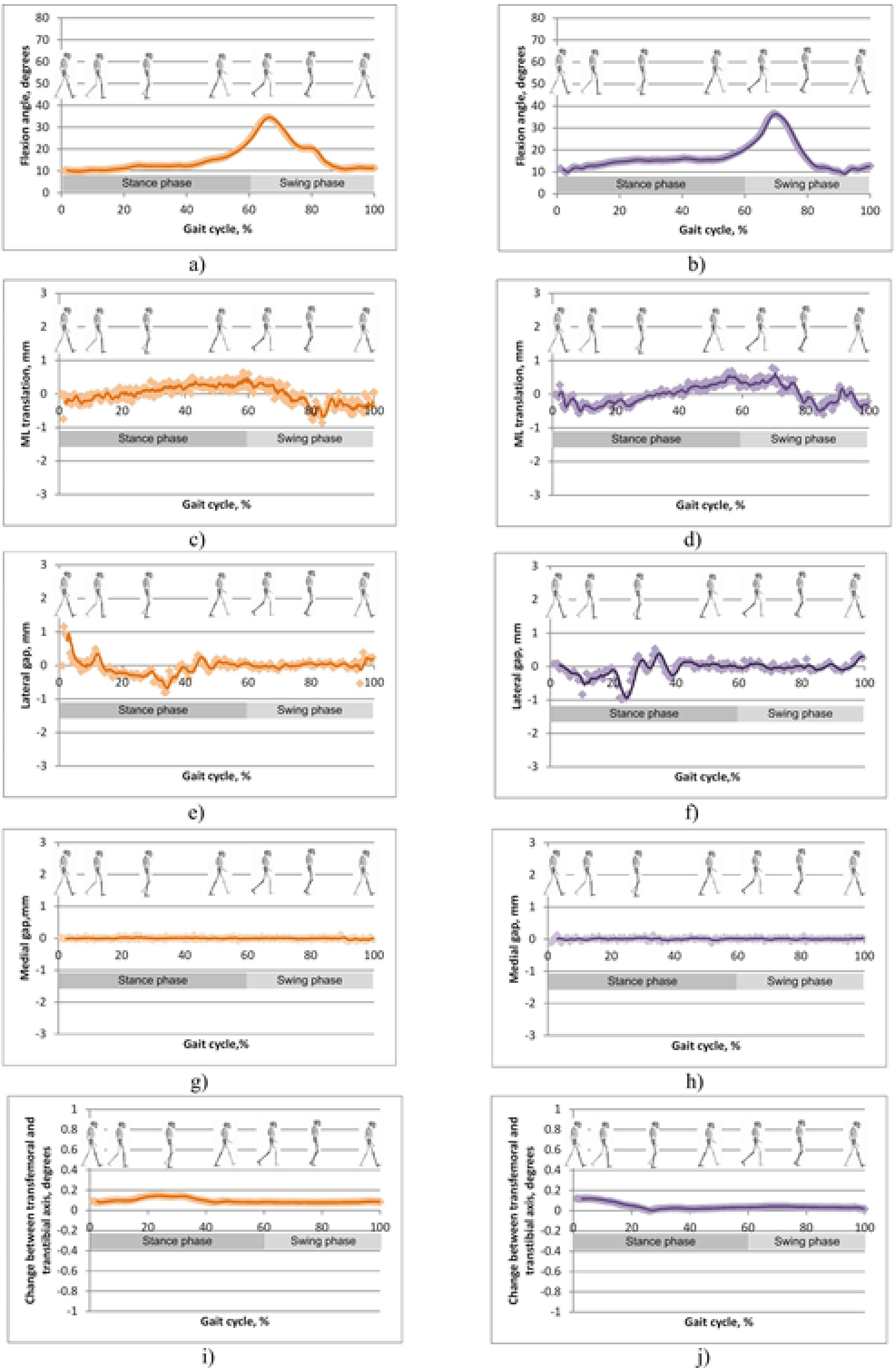

Figure 2. Graphic representation of the parameters: a) Degree of flexion-CR, b) Degree of flexion-PS, c) ML translation-CR, d) ML translation-PS, e) Lateral gap-CR, f) Lateral gap-PS, g) Medial gap-CR, h) Medial gap-PS, i) Angle change between the transtibial and transfemoral axes-CR, and j) Angle change between the transtibial and transfemoral axes-PS