ORIGINAL STUDY — CASE REPORT

acta orthopaedica belgica, 2024, 90, 147-153

doi.org/10.52628/90.1.11515

Patient with knee osteoarthritis demonstrates improved knee adduction moment after knee joint distraction: a case report

H.M. EIJKING[1], L. VERLAAN[1], P. EMANS[1], T. BOYMANS[1], K. MEIJER[2], R. SENDEN[3]

[1]*Department of Orthopaedic Surgery, CAPHRI School for Public Health and Primary Care, Maastricht University Medical Center, Maastricht, The Netherlands;* [2]*Department of Nutrition and Movement Sciences, NUTRIM School for Nutrition, Toxicology and metabolism, Maastricht University Medical Center, Maastricht, The Netherlands;* [3]*Department of Physical Therapy, Maastricht University Medical Center, Maastricht, The Netherlands.*

Correspondence at: H.M. Eijking, Maastricht University Medical Center, Department of Orthopaedic Surgery, 6202 AZ Maastricht, The Netherlands, Email: henriette.eyking@maastrichtuniversity.nl

In this article we report a case of a 53-year-old patient diagnosed with end-stage osteoarthritis (OA) of the knee. The patient underwent treatment with knee joint distraction (KJD) with the aim to postpone total knee arthroplasty and prevent potential revision surgery. To assess the effect of KJD, a 3D gait analysis was performed preoperative and one year postoperative. In this patient, preoperative 3D gait analysis revealed an increased knee adduction moment (KAM) compared to healthy levels. Postoperative the KAM decreased, approaching healthy levels, suggesting potential improvements in disease status or in gait. Consequently, further investigation into the effectiveness of Knee Joint Distraction (KJD) as a treatment option for relatively young patients with knee OA is warranted. Gait analysis has emerged as an effective tool for assessing treatment outcomes of innovative treatment such as KJD at the individual level.

Keywords: knee osteoarthritis, knee joint distraction, biomechanics, gait analysis, gait pattern.

INTRODUCTION

Knee osteoarthritis (OA) is a high incident joint disease with total knee arthroplasty (TKA) as final surgical treatment option[1]. Although TKA is considered an effective treatment, the prosthesis has a finite lifespan, carrying the risk of revision surgery. Revision surgeries are not only costly but also associated with elevated morbidity and complications[2,3]. Therefore, there is a growing need for joint-preserving treatments for relatively young patients with knee OA, with the aim of postponing TKA and minimizing the chance of a revision surgery[4]. Knee joint distraction (KJD) has emerged as an innovative joint-preserving surgical treatment for end-stage knee OA. During KJD, an external fixation frame, affixed to the bone with bone pins, gradually separated the distal femur and proximal tibia. Successful KJD treatment could improve patients' symptoms and functional limitations, while also, reducing societal and healthcare costs[4,5]. However, further research with longer follow-up periods and larger sample sizes are needed to substantiate the effectiveness of KJD before its integration into the routine clinical care.

Gait assessment is a commonly employed clinical practice for evaluating patient functionality. Three dimensional (3D) gait analysis provides an accurate, reliable, and objective means of measuring spatio-temporal, kinematic and kinetic parameters[6,7]. Several gait parameters, such as the knee adduction moment (KAM), knee flexion (KF) angle and several spatiotemporal parameters, have been recognized as biomarkers of disease status and progression in knee OA patients[8]. A biomarker is considered a biomarker when it serves as an indicator of normal biological processes, pathogenic processes, or responses to exposure or intervention, including therapeutic interventions[9]. The KAM is associated with the distribution of forces within the knee joint. An increase in KAM corresponds with increased medial knee-joint forces. Numerous studies have investigated KAM in patients with knee OA[10-13], demonstrating its relevance to the onset and progression of the condition. Specifically, the peak load during early stance and the cumulative load throughout the gait cycle are strong predictors of medial compartment knee OA presence, severity and rate of progression[14-16]. The KAM is calculated using an inverse dynamics approach that applies Newton-Euler equations. To estimate the KAM magnitude, 3D kinematics and kinetics from both foot/ankle and shank/knee, along with body segment inertial parameters, are used as input[17].

Figure 1. — Anterior Posterior (AP) weightbearing radiographic images from the right knee with a medical history of anterior cruciate ligament replacement. Image (a) shows preoperative end-stage knee OA (a). Image (b) shows increased joint space of the medial compartment direct postoperative after placement of the distraction frame. Image (c) shows direct postoperative knee status after removal of the frame And knee status one and a half year after KJD is showed in image (d).

Table 1. — Patient and healthy control person demographics.

	Age (years)	Gender	Length (cm)	Weight (kg)	BMI (kg/m^2)	Side
Patient	53	Male	186	88.0	25.4	Right
Control	53	Male	189	85.3	23.9	Right

To our knowledge, the use of 3D gait analysis in knee OA patients before and after KJD has not been previously documented. This case report presents the case of a 53-year-old male diagnosed with unilateral right knee OA, treated with KJD, subsequently compared to a healthy control.

CASE REPORT

We present a case involving a 53-year-old male diagnosed with end-stage knee OA, classified as Kellgren Lawrence grade 3. Based on clinical and radiographic examination (Fig. 1a) an indication for TKA exists. The patient's medical history included a prior anterior cruciate ligament reconstruction and psoriatic arthritis. Patient demographics are shown in Table 1. Given the patient's relatively young age, KJD was proposed as an experimental alternative.

An external fixation frame was utilized to bridge the knee joint. The frame consisted of 2 monotubes (Saturn Aluminium Stryker Mono Tube Fixator (Red), both fixed with two bone-pins in both the distal femur and proximal tibia. Tension was applied until a 5 mm distraction was achieved, as confirmed by radiography (Fig. 1b). The patient was encouraged to load the distracted joint to enhance synovial fluid dynamics, facilitating cartilage nourishment. Six weeks after initial placement, the external fixation frame was removed under anesthesia. Following frame removal a complication emerged: a limitation in range of motion, which was addressed with manipulation under anesthesia. The patient was discharged from the hospital with a prescribed six-week period of enforced rest of the knee joint.

3D gait analysis was conducted using the Computer Assisted Rehabilitation Environment (CAREN) system both preoperative and one year postoperative. The CAREN system (Motek Medical, Amsterdam, the Netherlands) consists of an instrumented dual belt (force plates 1000Hz) treadmill mounted on a movable platform. This setup is complemented by twelve infrared camera's (100Hz, Bonita, Vicon Motion Systems, Oxford, UK) and three 2D cameras for motion capturing. The treadmill is surrounded by a 180° semi-cylindric screen, projecting a speed-matched virtual environment. In total, twenty-six reflective markers were attached to the patient at specific bony landmarks according to the Human Body Lower Limb Model (HBM-II)[18]. Custom algorithms programmed in Matlab[19] were used to compute gait parameters, including spatiotemporal parameters, as well ass joint kinematics and kinetics in sagittal, frontal and transversal planes. During gait analysis, data of 250 consecutive steps were registered. Mean and

Table 2. — Spatiotemporal parameters presented as means (standard deviation) for the knee osteoarthritis patient pre- and 1 year postoperative and the healthy control. Aside from comfortable speed, spatiotemporal parameters were measured at equal walking speed of 1.65 m/s.

Spatiotemporal parameters	Preoperative R	1 year postoperative R	Control R
Comfortable speed [m/s]	1.65	1.62	1.47
Walking speed [m/s]	1.65	1.65	1.47
Step time [s]	0.45 (0.01)	0.46 (0.01)	0.52 (0.01)
Stance time [s]	0.57 (0.01)	0.56 (0.01)	0.61 (0.01)
Swing time [s]	0.36 (0.01)	0.38 (0.01)	0.43 (0.01)
Step length [m]	0.76 (0.02)	0.77 (0.02)	0.76 (0.01)
Step width [m]	0.19 (0.03)	0.24 (0.03)	0.17 (0.03)

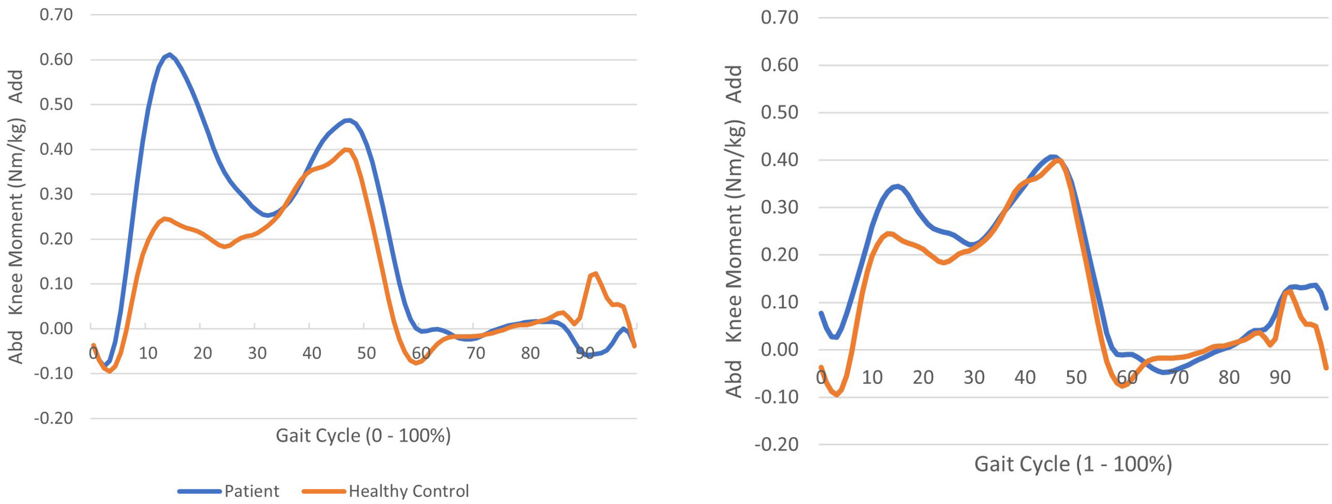


Figure 2. — (a) Knee Adduction Moment (KAM) during one gait cycle. The blue line corresponds with the patient with end-stage osteoarthritis of the right knee (preoperative) and the orange line corresponds with the healthy control. (b) KAM during one gait cycle at one year postoperative (blue) compared to the healthy control (orange).

standard deviation were calculated for spatiotemporal parameters, while for kinetics and kinematics, joint angles were calculated per cycle, with time normalized 0-100%.

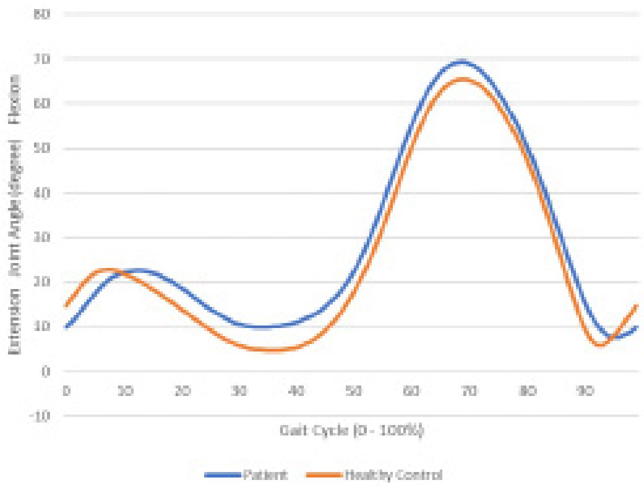
The gait of the knee OA patient was compared with that of an age and gender-matched healthy individual who had no complaints that could affect gait. The demographics of both individuals are presented in Table 1.

Preoperatively, a comfortable self-selected walking speed was established for both the patient and the healthy individual, from now on referred to as control. Postoperatively, gait analysis was conducted at this preoperative selected speed to eliminate the influence of walking speed on gait parameters.

The spatiotemporal parameters are summarized in Table 2. Minimal changes in spatiotemporal parameters of the affected side were observed one year postoperative compared to the preoperative assessment. Furthermore, the patient's preferred comfortable speed remained nearly identical, 1.66 m/s postoperatively compared to 1.65 m/s preoperatively. Additionally, step width increased from 0.19 preoperatively to 0.24 postoperatively.

In comparison to the control, the patient walked at a faster pace (1.65 m/s vs 1.47 m/s), maintained a similar step length, but demonstrated a reduced step time (Table 2). Moreover, the patient's step width was slightly lower. Apart from the step width, no noticeable changes in spatiotemporal were observed. This may be due to the identical walking speed. The only notable alteration observed was a larger step width postoperatively.

Knee adduction moments compared to the control, for both the pre- and one-year postoperative condition, are shown in Fig. 2a and 2b, respectively. Preoperative, the patient showed increased KAM peaks compared



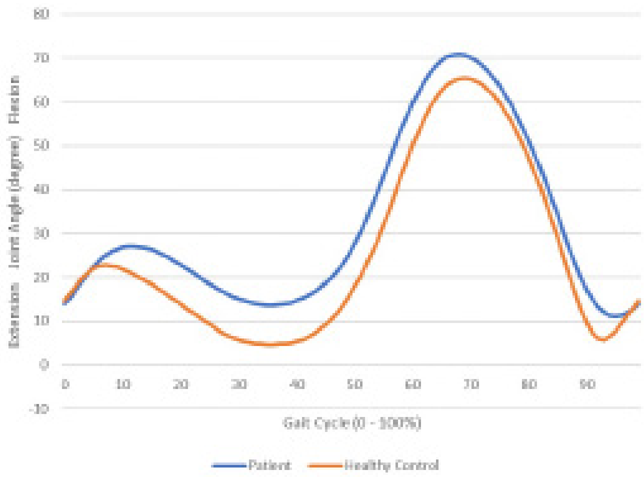


Figure 3. — (a) Knee flexion (KF) angels during one gait cycle. The blue line corresponds with the patient with osteoarthritis of the knee (preoperative) and the orange line corresponds with the healthy control. (b) The KF during one gait cycle at one year postoperative (blue) compared to the healthy control (orange). One year postoperative, KF angles did not seem to change substantially after Knee Joint Distraction.

Table 3. — Knee Injury and Osteoarthritis Outcome Score (KOOS), Visual Analogue Scale of pain (VAS pain) and Intermittent and Constant Osteoarthritis Pain (ICOAP). ADL, activities of daily living, QOL, quality of life knee-related.

	KOOS					VAS	ICOAP
	Pain	Symptoms	ADL	Sports	QOL		
Preoperative	41.67	32.14	48.53	30.00	25.00	70.00	56.82
3 months postoperative	52.78	35.17	69.12	30.00	56.25	70.00	38.64
1 year postoperative	55.56	35.71	69.12	30.00	56.25	55.00	47.73

to the control. After surgery, the two peaks decreased, approaching healthy levels, however, they remained slightly higher than the peaks observed in the control group.

KAM peaks are shown in figure 2a and 2b, for the pre- and postoperative condition and compared to the control. The first and second KAM peak decreased postoperative (0.34 Nm/kg (95% CI 0.29; 0.40) and 0.41 Nm/kg (95% CI 0.39; 0.43), compared to preoperative (0.61 Nm/kg (95% CI 0.59; 0.63) and 0.47 Nm/kg (95% CI 0.46; 0.47), respectively), approaching healthy levels.

KF angles are shown in Fig. 3a and 3b, for the pre- and postoperative condition and compared to the control. Compared to preoperative, the postoperative results showed a small increase in peak knee flexion (27.1° (95% CI 25.74; 28.55) vs. 22.6° (95% CI 22.17; 22.93)) during stance phase and is followed by a small reduction in knee extension (9.83° (95% CI 9.41°; 10.24°) vs. 13.72 (95% CI 13.03; 14.42). In addition, the knee flexion angles from the control, 22.8° (95% CI 22.64; 22.93) and 65.5° (95% CI 65.39; 65.65), were exceeded postoperatively.

In this study two treatment related complications occurred. First, a limitation in range of motion after frame removal was experienced 3 months postoperative. The limitation in range of motion was treated with manipulation under anesthesia. One year postoperative a good range of motion was achieved. Second, the knee OA patient in this study experienced a pin tract infection during KJD which was treated with oral antibiotics for 2 weeks until the frame was removed.

To assess changes in pain, function, and quality of life perception, we utilized the Knee Injury and Osteoarthritis Outcome Score (KOOS) on a scale of 0 to 100, where 100 represents no complaints or excellent function, the Visual Analogue Scale for pain (VAS pain during activity) on a scale of 0 to 100, with 0 indicating no pain, and the Intermittent and Constant Osteoarthritis Pain (ICOAP) questionnaire, also on a scale of 0 to 100, with 0 representing the best possible outcome. These assessments were conducted preoperatively, at 3 months, and 1 year postoperatively. It is worth noting that the minimal clinically important difference (MCID) for KOOS subscales are, as defined by Lyman et al., are 7 for KOOS symptoms, 18 for KOOS pain, 16 for KOOS ADL, 17 KOOS QOL[20]. The KOOS sport subscale has negligible value for evaluating KJD outcomes in this setting, as most patients are not normally engaging in activities measured by this subscale[21].

The results are presented in Table 3. The KOOS (sub) scores exhibited an increase postoperatively compared to the preoperative values, with the exception of the sports subscore, which remained unchanged. The subscores KOOS ADL and KOOS QOL exceeded the MCID. Both the VAS pain score and ICOAP demonstrated a decrease postoperatively in comparison to the preoperative scores. Despite improvements observed in the self-assessment questionnaires, the knee OA patient expressed dissatisfaction after KJD.

DISCUSSION

In this case report, we observe a decrease in first and second KAM peak at one year postoperative. These postoperative KAM peaks are more consistent with the KAM peaks from the control. The KAM peaks are indicative for disease status and progression of knee OA[10,22]. This postoperative decrease may potentially correlate with the increased step width, pain relieve or joint repair[23-26]. Notably, there was no significant difference between the pre- and postoperative walking speed, thereby walking speed did not affect the results. The remaining postoperative difference between patient and control might be attributed to the higher walking speed of the patient, compared to the control, during gait analysis. Increased walking speed generates greater energy, resulting in higher ground reaction forces and increased KAM peaks[27]. These findings suggest an improved disease status or reduced disease progression one year after KJD.

Knee OA often leads to decreased knee flexion or extension during gait[28]. If KJD were to improve disease status, one would expect no further decrease in knee flexion or extension. The one year postoperative results from this study reveal only minor differences in knee flexion and extension compared to preoperative state. When compared to the control, knee flexion and extension in the knee OA are almost equivalent. The minor changes observed fall within the system error range and, therefore, cannot be considered clinically relevant. The limitation in range of motion observed after frame removal, which was treated with manipulation under anesthesia, does not appear to effect the range of motion at one year postoperative. Due to a potential role of limited flexion 3 months post-operative, we did not examine the gait 3 months post-operative and only show the PROMS.

Spatiotemporal parameters serve as indicators for knee OA severity[29]. The knee OA patient exhibited reduced step-, stance- and swing time compared to the control, which can be attributed to the higher walking speed of the knee OA patient. Typically, step length decreases when walking speed increases[30], but this trend was not observed in this study. Surprisingly, the preferred comfortable walking speed did not increase postoperatively and remained nearly equal to the preoperative preferred walking speed. This lack of improvement in walking speed may be explained by the limitation in range of motion experienced directly after frame removal. However, one year postoperative full range of motion was achieved, eliminating this as a factor limiting walking speed. Step width was larger in preoperative knee OA patient compared to the control, and it even further increased postoperative (table 2). As step-width increases, peak medial ground reaction force and therefore peak KAM decrease[31]. This suggest that increasing step-width may be a strategy for reducing KAM, however the mechanism behind this strategy remains unknown. Aside from step width, only few differences in spatiotemporal parameters are evident. This might be explained by the fixed walking speed.

Since walking speed affects all gait parameters, a limitation of this study is the difference in walking speed between the knee OA patient and the control group. Future research should conduct gait analysis at matched walking speed for patients and controls. Additionally, a larger sample size and longer follow-up period is recommended. Gait analysis appears to be an effective tool for objectively evaluating the effects of innovative treatments at individual level. Therefore, it is recommended to ex-pand the implementation of gait analysis to assess the outcome of treatments such as KJD.

Previous studies have reported clinical improvements following Knee Joint Distraction (KJD)[26]. In this study, we observed clinical improvements as measured by self-reported questionnaires for activities of daily living and knee-related quality of life. Despite the improved outcomes indicated by these self-assessment questionnaires, the patient was not satisfied. It is important to recognize that KJD should not be perceived as a straightforward or uncomplicated treatment option for patients. Enhancing patient education and promoting awareness regarding expected outcomes may contribute to improve patient satisfaction.

CONCLUSION

This case report demonstrates a notable decrease in KAM peaks during gait in a patient with knee OA one year after KJD. This decrease aligns the patient's KAM peaks more closely with those observed in the healthy control. Notably, KF angles did not exhibit significant changes after KJD. These findings might correspond with improved disease status and a deceleration in disease progression. However, additional research focusing on standardizing walking speed for both patients and controls, extending the duration of follow-up, and increasing the sample size is warranted.

Funding: this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector.

Declaration of Competing Interest: the authors declare that they have no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

REFERENCES

1. Bijlsma JW, Berenbaum F, Lafeber FP. Osteoarthritis: an update with relevance for clinical practice. The Lancet. 2011;377(9783):2115-26.
2. Bayliss LE, Culliford D, Monk AP, Glyn-Jones S, Prieto-Alhambra D, Judge A, et al. The effect of patient age at intervention on risk of implant revision after total replacement of the hip or knee: a population-based cohort study. The Lancet. 2017;389(10077):1424-30.
3. van der Woude J, Nair S, Custers R, Van Laar J, Kuchuck N, Lafeber F, et al. Knee joint distraction compared to total knee arthroplasty for treatment of end stage osteoarthritis: simulating long-term outcomes and cost-effectiveness. PLoS One. 2016;11(5):e0155524.
4. Jansen MP, Boymans TA, Custers RJ, Van Geenen RC, Van Heerwaarden RJ, Huizinga MR, et al. Knee joint distraction as treatment for osteoarthritis results in clinical and structural benefit: a systematic review and meta-analysis of the limited number of studies and patients available. Cartilage. 2020:1947603520942945.
5. Lafeber FP, Intema F, Van Roermund PM, Marijnissen AC. Unloading joints to treat osteoarthritis, including joint distraction. Current opinion in rheumatology. 2006;18(5):519-25.
6. McClelland JA, Webster KE, Feller JA. Gait analysis of patients following total knee replacement: a systematic review. The Knee. 2007;14(4):253-63.
7. Seeger J, Schikschneit J, Schuld C, Rupp R, Rickert M, Jahnke A, et al. Instrumented gait analysis in patients with medial osteoarthritis of the knee after mobile-bearing unicompartmental knee arthroplasty. The Knee. 2018;25(3):392-7.
8. Duffell LD, Jordan SJ, Cobb JP, McGregor AH. Gait adaptations with aging in healthy participants and people with knee-joint osteoarthritis. Gait & posture. 2017;57:246-51.
9. Amur S. Biomarker terminology: speaking the same language. US Food & Drug administration: Silver Spring, MD, USA. 2019.
10. Baliunas A, Hurwitz D, Ryals A, Karrar A, Case J, Block J, et al. Increased knee joint loads during walking are present in subjects with knee osteoarthritis. Osteoarthritis and cartilage. 2002;10(7):573-9.
11. Kaufman KR, Hughes C, Morrey BF, Morrey M, An K-N. Gait characteristics of patients with knee osteoarthritis. Journal of biomechanics. 2001;34(7):907-15.
12. Landry SC, McKean KA, Hubley-Kozey CL, Stanish WD, Deluzio KJ. Knee biomechanics of moderate OA patients measured during gait at a self-selected and fast walking speed. Journal of biomechanics. 2007;40(8):1754-61.
13. Sharma L, Hurwitz DE, Thonar EJM, Sum JA, Lenz ME, Dunlop DD, et al. Knee adduction moment, serum hyaluronan level, and disease severity in medial tibiofemoral osteoarthritis. Arthritis & Rheumatism. 1998;41(7):1233-40.
14. Mündermann A, Dyrby CO, Andriacchi TP. Secondary gait changes in patients with medial compartment knee osteoarthritis: increased load at the ankle, knee, and hip during walking. Arthritis & rheumatism. 2005;52(9):2835-44.
15. Thorp LE, Sumner DR, Block JA, Moisio KC, Shott S, Wimmer MA. Knee joint loading differs in individuals with mild compared with moderate medial knee osteoarthritis. Arthritis & Rheumatism: Official Journal of the American College of Rheumatology. 2006;54(12):3842-9.
16. Foroughi N, Smith R, Vanwanseele B. The association of external knee adduction moment with biomechanical variables in osteoarthritis: a systematic review. The Knee. 2009;16(5):303-9.
17. Lewinson RT, Worobets JT, Stefanyshyn DJ. Calculation of external knee adduction moments: A comparison of an inverse dynamics approach and a simplified lever-arm approach. The Knee. 2015;22(4):292-7.
18. Van den Bogert AJ, Geijtenbeek T, Even-Zohar O, Steenbrink F, Hardin EC. A real-time system for biomechanical analysis of human movement and muscle function. Medical & biological engineering & computing. 2013;51(10):1069-77.
19. Hak L, Houdijk H, Steenbrink F, Mert A, van der Wurff P, Beek PJ, et al. Stepping strategies for regulating gait adaptability and stability. Journal of biomechanics. 2013;46(5):905-11.
20. Lyman S, Lee Y-Y, McLawhorn AS, Islam W, MacLean CH. What are the minimal and substantial improvements in the HOOS and KOOS and JR versions after total joint replacement? Clinical orthopaedics and related research. 2018;476(12):2432.
21. Haydel A, Guilbeau S, Roubion R, Leonardi C, Bronstone A, Dasa V. Achieving validated thresholds for clinically meaningful change on the knee injury and osteoarthritis outcome score after total knee arthroplasty: findings from a university-based orthopaedic tertiary care safety net practice. JAAOS Global Research & Reviews. 2019;3(11).
22. Astephen JL, Deluzio KJ, Caldwell GE, Dunbar MJ. Biomechanical changes at the hip, knee, and ankle joints during gait are associated with knee osteoarthritis severity. Journal of orthopaedic research. 2008;26(3):332-41.
23. Favre J, Erhart-Hledik JC, Chehab EF, Andriacchi TP. General scheme to reduce the knee adduction moment by modifying a combination of gait variables. Journal of Orthopaedic Research. 2016;34(9):1547-56.
24. Intema F, Van Roermund PM, Marijnissen AC, Cotofana S, Eckstein F, Castelein RM, et al. Tissue structure modification in knee osteoarthritis by use of joint distraction: an open 1-year pilot study. Annals of the rheumatic diseases. 2011;70(8):1441-6.
25. Wiegant K, Van Roermund P, Intema F, Cotofana S, Eckstein F, Mastbergen S, et al. Sustained clinical and structural benefit after joint distraction in the treatment of severe knee osteoarthritis. Osteoarthritis and cartilage. 2013;21(11):1660-7.
26. van der Woude J-TA, Wiegant K, Van Roermund PM, Intema F, Custers RJ, Eckstein F, et al. Five-year follow-up of knee joint distraction: clinical benefit and cartilaginous tissue repair in an open uncontrolled prospective study. Cartilage. 2017;8(3):263-71.
27. Telfer S, Lange MJ, Sudduth AS. Factors influencing knee adduction moment measurement: a systematic review and meta-regression analysis. Gait & posture. 2017;58:333-9.
28. Campbell TM, McGonagle D. Flexion contracture is a risk factor for knee osteoarthritis incidence, progression and earlier

arthroplasty: data from the osteoarthritis initiative. Annals of Physical and Rehabilitation Medicine. 2021;64(2):101439.
29. Kiss RM. Effect of severity of knee osteoarthritis on the variability of gait parameters. Journal of Electromyography and Kinesiology. 2011;21(5):695-703.
30. Jordan K, Challis JH, Newell KM. Walking speed influences on gait cycle variability. Gait & posture. 2007;26(1):128-34.
31. Schmitz A, Noehren B. What predicts the first peak of the knee adduction moment? The Knee. 2014;21(6):1077-83.