Turkish Journal of Clinics and Laboratory

To cite this article: Dogruoz F, Yapar A, Egerci OF, Kose O, Ozcan O. Short-term results of soft tissue balance obtained with 'manual gap balancing' in varus knees; a prospective study supported by gait analysis. Turk J Clin Lab 2024; 2: 226-233

Research Article

Short-term results of soft tissue balance obtained with 'manual gap balancing' in varus knees; a prospective study supported by gait analysis

Varus dizlerde 'manuel gap balancing' ile elde edilen yumuşak doku dengesinin kısa dönem sonuçları; yürüyüş analiziyle desteklenen prospektif bir çalışma

Fırat Dogruoz*[1], Aliekber Yapar[1], Omer Faruk Egerci[1], Ozkan Kose[1], Ozal Ozcan[2]

[1]Department of Orthopaedics and Traumatology, Antalya Training and Research Hospital, Antalya, Turkey,
[2]Department of Orthopaedics and Traumatology, Afyon Kocatepe University, Afyonkarahisar, Turkey.

Abstract

Aim: The aim of this study was to investigate the contribution of medial ligament release using the manual gap balance method in patients with varus deformity to alignment and functional outcomes.

Material and Methods: The study included 14 female and 8 male patients who underwent total knee arthroplasty. Telemetric radiographs of the lower extremities and valgus stress radiographs of the knees to be operated on were taken for each patient one day before and 1.5 months after the operation. The functional evaluation of patients was conducted using the HSS (Hospital for Special Surgery, 1970) scoring system. Simultaneously, gait analyses were conducted. The patients were divided into groups based on their stress radiographs.

Results: The mean valgus angle in postoperative static radiographs was 2.5 degrees. A statistically significant change in rotational deformity was observed in both swing and stance phases after surgery compared to preoperative values. Improvement in coronal plane varus knees was statistically significant. No significant change was found in the flexion-extension angles of sagittal plane kinematics. It was found that there was a statistically significant difference in the data for single support, double support, and stance percentage ($p<0.05$).

Conclusion: In conclusion, it was observed that the soft tissue balance achieved through manual gap balancing without the use of technological equipment was sufficient and satisfactory in terms of functional scores, walking parameters, and alignment data.

Keywords: manual gap balancing, varus knee, gait analysi

Corresponding author*: Fırat Dogruoz, Department of Orthopaedics and Traumatology, Antalya Training and Research Hospital, Antalya, Turkey
E-mail: firatdogruoz@hotmail.com
Orcid: 0000-0003-0819-3196
Doi: 10.18663/tjcl.1469649
Recevied: 17.04.2024 accepted: 14.06.2024

Öz

Amaç: Bu çalışmanın amacı varus deformitesi bulunan hastalarda 'manual gap balancing' yöntemi ile yapılan medial bağ gevşetmesinin, dizilime ve fonksiyonel sonuçlara olan katkısını araştırmaktır.

Gereç ve Yöntemler: Çalışmaya total diz artroplastisi uygulanan 14 kadın, 8 erkek hasta dahil edildi. Her hastanın alt ekstremite koronal plan telemetrik grafileri ve opere edilecek dizlerinin valgus stress grafileri operasyondan 1 gün önce ve operasyondan 1,5 ay sonra çekildi. Hastaların fonksiyonel değerlendirmesi HSS (Hospital for Special Surgery, 1970) skorlama sistemi kullanılarak yapıldı. Eş zamanlı olarak hastaların yürüme analizleri yapıldı. Hastalar stress grafilerine göre gruplara ayrıldı.

Bulgular: Postoperatif statik radiografilerdeki valgus açı ortalaması 2,5 derece idi. Koronal planda varus dizlerdeki düzelme istatistiksel olarak anlamlı idi. Dizdeki rotasyonel deformitedeki değişimin ameliyat sonrası, ameliyat öncesi değerlere göre hem salınım hemde basma fazında istatistiksel olarak anlamlı olduğu görüldü. Sagittal plan kinematiklerinden fleksiyon ekstansiyon açılarında anlamlı bir değişim saptanmadı. Tek destek, çift destek ve stance yüzdesi verilerindeki farklılığın istatistiksel olarak anlamlı olduğu saptandı ($p<0,05$).

Sonuç: Bu çalışma sonucunda, teknolojik ekipmanlar kullanmadan , 'manual gap balancing' ile elde edilen yumuşak doku dengesinin, fonksiyonel skorlar, yürüme parametreleri ve dizilim verileri ışığında yeterli ve tatminkar olduğunu görüldü.

Anahtar kelimeler: Manuel bağ dengesi, varus diz, yürüme analizi

Introduction

Total knee arthroplasty is the preferred method for treating end-stage knee osteoarthritis and is becoming increasingly common. As osteoarthritis progresses in the knee joint, there is a deterioration in the mechanical axis [1]. This deterioration is not limited to a single plane, as rotational deformity occurs in correlation with the progression of the disease [2]. As the varus angulation increases, the internal rotation deformity becomes more pronounced [3]. As the angulation in the coronal plane increases in the varus direction, contracture occurs in the structures on the medial side of the knee [4]. The success of total knee arthroplasty surgery depends on the extent to which dynamic deformities are corrected [5]. Soft tissue release has a greater effect on lower limb alignment in varus knees than in valgus knees, as previously shown [6]. The objective of knee arthroplasty is to achieve proper bone incisions and successful soft tissue balance, resulting in good alignment [7].

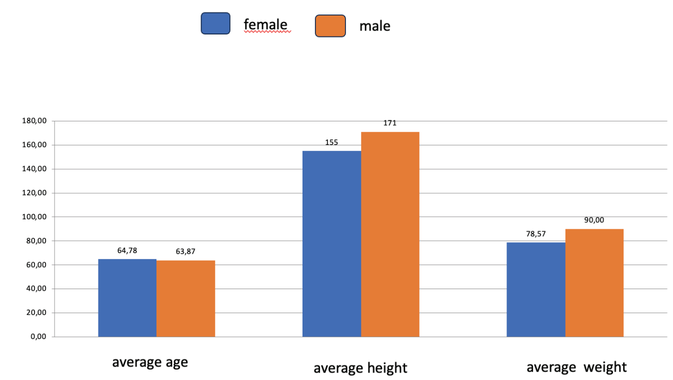
In recent years, orthopedic specialists have had access to a variety of technological equipment to ensure a well-balanced prosthesis application. Examples of such equipment include mechanical or digital tensiometers, sensor-guided systems, and navigation systems. Despite the increasing use of new systems developed in parallel with technology, the manual gap balance method remains the most widely used method in practical applications. In our study, we investigated the contribution of medial ligament release to alignment and functional outcomes in patients with varus deformity according to coronal plane stress radiograph data, coronal plane telemetric radiograph data, HSS scores and gait analysis kinematics.

Material and Methods

The candidate patient population consisted of individuals with chronic pain and functional limitations caused by osteoarthritis who were admitted to the outpatient clinic of the Orthopedics and Traumatology Clinic of a tertiary care university hospital between January and April 2015. Despite other treatment modalities, these individuals continued to experience pain and a decline in daily living skills. The study excluded patients with vestibular and neurological issues, lower extremity malalignment caused by factors other than osteoarthritis, and postoperative infections.

Thirty-six knees of 8 male and 14 female patients with stage 4 gonarthrosis according to Kellygren-Lawrence classification and no additional orthopedic complaints were included in the study. One patient was excluded due to their refusal to undergo surgery, three patients were excluded due to their inability to adapt to gait analysis, and four patients were excluded due to suboptimal radiographic examinations. To ensure control and reliability of the gait analysis data, a control group of 100 volunteers from the same age group without any neurological or orthopedic complaints was formed. The averages of the demographic data of the participants are shown in Graph 1.

TJCL Volume 15 Number 2 p: 226-233



The gait characteristics and kinematic data of both the patients and control group were obtained using the 3D motion analysis system Codamotion CX1 (Charnwood Dynamics®, UK). The participants were instructed to walk at a normal speed on a 6 m platform while measurements were taken (Figure 1). No external interventions were made, and the participants were allowed to walk as naturally as possible. The 3D images were projected on the monitor using one camera, one power plate, and 14 coda-markers.

Figure 1. Gait Analysis Laboratory image.

Each patient walked on the platform ten times. Patients scheduled for double knee surgery were walked separately for each lower extremity. The patients with the best power plate response were selected, and their gait cycles were analyzed using Codamotion Analysis Software V6.xx to obtain kinematic and temporo-spatial data.

Telemetric radiographs (Dia-RadX3c) were used to determine the pre- and postoperative lower extremity alignment of the patients in the study. The angulations in the coronal plane were measured using the midpoint of the femoral head, the midpoint of the knee, and the midpoint of the ankle as reference points (Figure 2). Valgus stress radiography was used to determine preoperative and postoperative medial ligament tension. A modified telos device was designed to standardize the stress radiography. The device allowed for obtaining full AP radiographs while applying a force of 100 N (10 kg-F) to force the patient's knee into valgus (Figure 3).

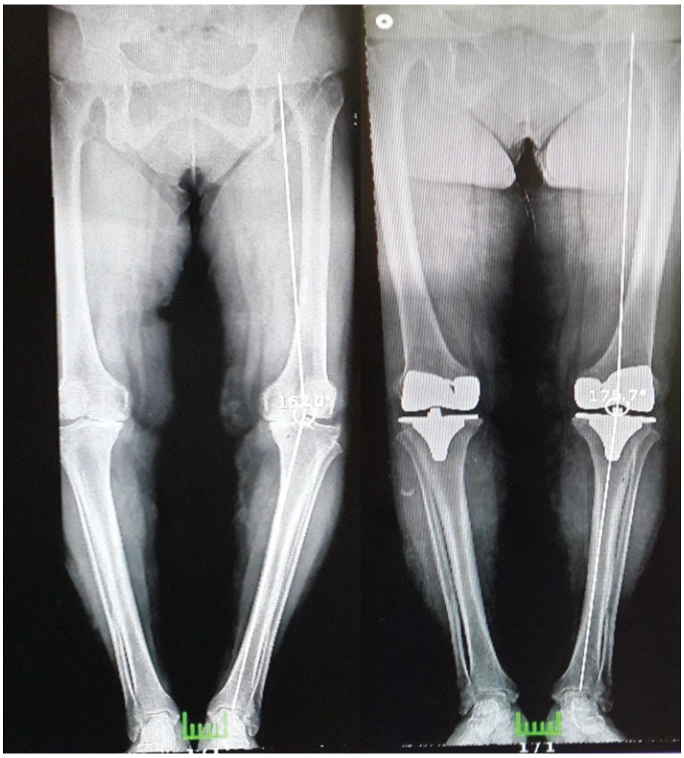


Figure 2. Preoperative and Postoperative Lower Extremity Alignment on Telemetric Graphs.

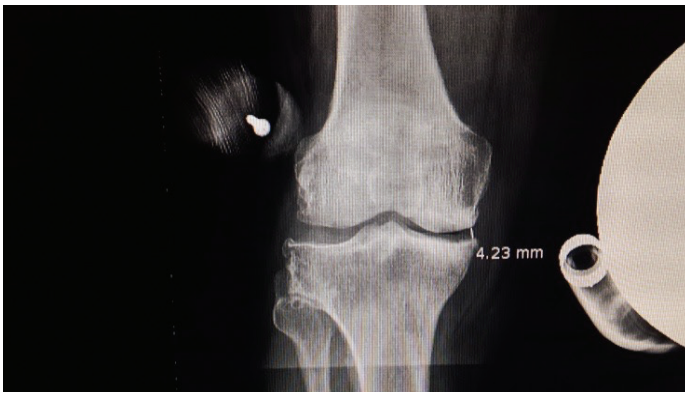


Figure 3. Detection of Medial Collateral Ligament Stretch on Stress Radiograph.

The surgical procedure was performed by the same surgeon, and a mobile bearing posterior stabilizer system (Tıpsan®) prosthesis was symmetrically applied to all patients. The technique involved subperiosteal elevation of the superficial medial collateral to the posteromedial corner, a 90-degree tibial incision parallel to the ground plane, a distal femoral incision at 5 degrees valgus, a posterior condyle incision at 3 degrees external rotation, and excision of medial osteophytes in the tibia and femur. The surgeon did not use a tensiometer device to verify soft tissue balance. Instead, they relied on lamina separators and prosthesis trials to achieve what they deemed to be satisfactory soft tissue balance (Figure 4).

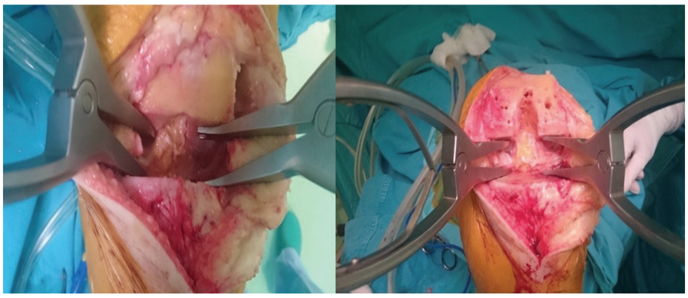


Figure 4. Intraoperative imaging of soft tissue balance control with manual gap balancing in a patient with varus deformity.

The functional evaluation of patients was conducted using the HSS (Hospital for Special Surgery, 1970) scoring system. Preoperative and postoperative HSS scores were recorded for each knee of every patient. The study was approved by Institutional Ethics Committee (Approval number:2015/4-100)

Statistical analysis

Statistical analysis of the data was conducted using SPSS version 20.1 (SPSS Inc. USA) software. The distribution of the variables was analyzed using the Kolmogorov-Smirnov test. When a normal distribution was found, the preoperative and postoperative results were analyzed using the paired t-test. The control and patient group data were compared using the Student t-test. A p-value of less than 0.05 was considered to denote statistical significance.

Results

This study compared preoperative and postoperative values of kinematic and temporospatial data obtained from gait analysis, radiographic alignment data, stress radiography data, and HSS scores. We objectively evaluated the results by comparing preoperative and postoperative gait analysis data with control group data.

X-ray

Table 1 shows a statistically significant difference ($p<0.05$) in the HSS scores, telemetric radiograph data in the coronal plane lower extremity alignment, and stress radiograph data evaluating the medial ligament tension of patients after surgery. The post-op static radiographs had a mean valgus angle of 2.5 degrees, and there was a statistically significant improvement in varus knees in the coronal plane.

Table 1. Preoperative and postoperative comparison of kinematic data

	Paired Differences	t	Sig. (2-tailed)
Preop-Postop axis	9.39	9.33	0
Preop-Postop stress radiograph	-1.97	-8.19	0
Preop-Postop (flexion-extension) (Swing phase)	6.61	0.19	0.84
Preop-Postop (flexion-extension) (Stance phase)	9.43	1.87	0.07
Preop-Postop varus-valgus (Swing phase)	7.57	5.59	0
Preop-Postop varus-valgus (Stance phase)	6.07	4.42	0
Preop-Postoperative Knee Rotation (Swing phase)	13.76	4.19	0
Preop-Postoperative Knee Rotation (Stance phase)	12.67	3.93	0
Preop-Postoperative Ankle Alignment (Swing phase)	-0.32	-2.17	0.03
Preop-Postoperative Ankle Alignment (Stance phase)	1.49	-1.27	0.21
Preop-Postop HSS Score	-9.74	-10.39	0

Kinematics

Statistically significant changes were found in the coronal plane angles of the knee during both the stance and swing phases, as obtained from gait analysis ($p<0.05$). This data confirms our telemetric graph data.

The statistical analysis revealed a significant change in both the stance and swing phases of rotational deformation in the knee after surgery compared to preoperative values ($p<0.05$). In the gait analysis, no statistically significant change was found in flexion-extension angles of sagittal plane kinematics in both preoperative and postoperative stance and swing phases ($p>0.05$). Although the preoperative ankle alignment angles of the patients showed a significant difference with the control group in the swing phase, there was no statistically significant difference found in the postoperative comparison ($p>0.05$). However, there was no statistically significant difference between the preoperative group and the control group in the stance phase ($p>0.05$).

The study evaluated the kinematics of patients grouped as having tight knees and non-tight knees based on medial collateral ligament tensions (Table2). Significant differences were found in the swing and stance phases of the coronal plane knee kinematics in the tight knees group ($p<0.05$), but not in the non-tight knees group (p=0.051). Both groups showed statistically significant changes in the rotational deformity of the knee during the swing phase (p<0.05). The study found that there was no statistically significant improvement in rotational deformity in tight knees (p>0.05), while a statistically significant difference was observed in the other group (p<0.05).

Table 2. Comparison of kinematic data of tight and non-tight knees

	Paired Differences	t>7mm	t<7mm	Sig. >7mm	Sig. <7mm
Axis	9.74	6.58	6.81	0	0
Flexion-extansion swing phase	12.07	-0.10	0.42	0,91	0.67
Flexion-extansion stance phase	14.94	1.33	1.27	0,20	0.21
Varus Valgus swing phase	8.01	2.15	5.94	0,05	0
Varus Valgus stance phase	5.55	1.67	4.38	0,11	0
Knee Rotation swing phase	23.31	3.59	2.52	0,003	0.02
Knee Rotation stance phase	19.60	4.46	1.90	0,001	0.07
Ankle Alignment swing phase	-0.65	-2.36	-1.03	0,03	0.31
Ankle Alignment stance phase	6.89	-0.10	-1.59	0,91	0.12
HSS Score	-9.73	-7.08	-7.74	0	0

Temporospatial

The study analyzed preoperative and postoperative values of temporospatial parameters and found statistically significant differences (p<0.05) in single support, double support, and stance percentage data (Table3). However, no statistically significant difference was found in other data (p>0.05). The difference in mean speed values among gait parameters was not statistically significant (p>0.05). However, upon closer examination of the mean values, it was observed that the mean speed of the patients increased during the postoperative period (mean=0.599).

There were no statistically significant differences between preoperative and postoperative results in parameters such as double step interval, step length, double step time, and step time (p>0.05). However, when the data averages were analyzed, an increase in stride length was observed (mean=0.446).

The study compared cadence values, which express the number of steps per unit time, before and after the operation. No significant difference was found between the preoperative and postoperative values (p>0.05). However, when the averages were taken into consideration, a decrease in cadence values was observed. Statistically significant changes were observed in the stance percentage, single support phase, and double support phase among the gait parameters (p<0.05). There were no statistically significant differences found in sagittal plane hip, knee, and ankle angles in gait parameters when correlated with sagittal plane kinematics of gait analysis (p>0.05).

Table 3. Comparison of Temporospatial Data

	Paired Differences	t>7mm	Sig. (2-tailed)
spead	0.02	-0.91	0.36
stride lenght	0.005	-1.81	0.07
stride time	0.06	-0.21	0.83
strides minute	2.47	0.71	0.48
step lenght	0.003	-1.75	0.08
step time	0.03	-0.06	0.95
step minute	6.53	1.09	0.28
percent stance	4.71	2.55	0.01
single support	-0.007	-2.43	0.02
double support	0.07	2.19	0.03
hip range	0.73	-1.36	0.18
hip max	1.86	-0.80	0.42
hip min	2.89	0.07	0.94
knee range	5.02	1.86	0.07
knee max	5.40	1.50	0.14
knee min	2.003	-0.48	0.63
ankle range	1.54	-0.33	0.73
ankle max	1.49	-0.28	0.77
ankle min	1.78	0.07	0.94

Discussion

The study differs from other similar studies in two ways. Firstly, there are few studies in the literature that evaluate short-term gait parameter results. Although this may seem like a disadvantage, we believe that the changes in early gait analysis data after total knee arthroplasty are important contributions to the literature. In studies using gait analysis, patients are typically divided into preoperative and postoperative groups. However, we had the opportunity to examine whether grouping patients with tight and non-tight knees separately when analyzing gait data using the TDP application would yield different results between these groups. In this study, the postoperative HSS scores increased significantly. The decrease in patients' pain scores and the improvement in deformity were the most significant factors contributing to this difference, despite the early postoperative period.

Kinematics;

One of the primary objectives of knee replacement is to achieve coronal plane balance [8]. Our study evaluated the change in coronal plane lower extremity alignment through radiological analysis of lower extremity telemetric radiographs and gait analysis kinematics, based on the improvement in mechanical axis. The postoperative coronal plane angles obtained from gait analysis demonstrated a significant improvement. Fang et al. emphasized the significance of coronal plane balance for successful knee surgery and recommended a target alignment range of 2.4 to 7.2 degrees [9]. In the mechanical axis, we achieved an average of 5.6 degrees with an average correction of 7.8 degrees.

Chronic osteoarthritis can cause not only coronal plane changes but also rotational problems in the knee joint. Patients with advanced varus deformity may develop internal rotation deformity in the femur and tibia [10]. Felix et al. (year) examined the effect of coronal plane changes on the transverse plane and found a relationship with increased tibial internal rotation [11]. Our study's gait analysis data of the preoperative patient group supported this finding. Upon evaluating the axial plan data of gait analysis in the post-operative patient group, it was evident that there was an improvement in the rotational movement of the knee joint. Bytygi et al. conducted a study on a group of patients with osteoarthritis and reported that the tibia was in external rotation in the osteoarthritic group compared to the normal population [12]. However, our study's data contradicts the findings of Bytygi et al.

Kramers-de Quervain et al. investigated the effect of two different prosthesis systems on the gait patterns of patients with bilateral gonarthrosis. They found a decrease in postoperative sagittal plane flexion-extension movements during a 2-5 year follow-up period [13]. Similarly, Agarval et al. compared the operated side with the non-operated side and found that the maximum knee flexion angle was lower on the operated side, with no difference in extension angles [14]. In our study, we observed a slight decrease in the maximum knee flexion angle. Rahman et al. discovered that the primary impact of surgery on the gait cycle was an increase in the range of motion during the swing phase [15]. Based on our study's findings and the general literature, we concluded that minor changes in the range of motion along the sagittal plane axis did not significantly affect the results.

Levinger et al. investigated the changes in dynamic foot function following total knee replacement and found that hindfoot movements changed to compensate for the malalignment of the proximal skeleton [16]. This finding suggests that changes in hindfoot movements may affect ankle mechanics in the chronic process of osteoarthritis. In our study, we observed that the ankle alignment of patients with gonarthrosis did not differ from that of the normal population during the stepping phase. These findings suggest that the difference in the swing and stance phases is not caused by a fixed ankle deformity, but rather a dynamic result of ankle malalignment during the swing phase. However, further studies are needed to evaluate the change in ankle alignment due to gonarthrosis and contribute to the literature.

The patients were evaluated based on the degree of contracture in the medial ligament structures. The results showed varying changes in rotational deformity. According to the literature, tight knees are expected to have more rotational problems [3, 17]. However, our findings indicate that the improvement in rotational deformity in tight knees was not as significant as in the other group. Notably, patients with advanced varus angulation experienced noticeable rotational changes. The results indicate a possible contracted internal lateral ligament in the patient, despite the less advanced deformity in the mechanical axis of the lower extremity. Further kinematic studies are required to explain the less noticeable rotational change in postoperative tight knees compared to the other group.

Temporospatial;

Although there was a slight increase in the average walking speed (velocity) of the patients in terms of temporospatial (time-distance) variables, it was not significant. The average walking speed in the preoperative group showed a slight increase in the postoperative period. However, the average speed in the control group was significantly higher than both the preoperative and postoperative groups. In the study conducted by Backowicz et al., walking speed had increased when compared to the preoperative group, despite being slower than the control group [18]. Our study yielded similar results. However, in the study conducted by McClelland et al., which had one-year follow-up data, there was a significant increase in walking speed in the postoperative group [19]. Similarly, an increase was observed in parameters such as step width, step length, double support time, and step time. Although not statistically significant, we believe that these improvements in early walking parameters are important in demonstrating the positive effect of kinematic balance on walking functions. The increase in step length resulted in a decrease in cadence values, which are defined as the number of steps per minute, as expected.

The stance phase ratio is the proportion of the stance phase to the entire gait cycle. A decrease in the stance phase during a normal gait cycle indicates a decrease in stability [20]. In our study, a decrease in postoperative stance percentage was also observed. In a study by Wu et al., which examined parameters in a very short period of time after surgery (2 weeks), a significant shortening of the stance phase was observed [21]. We believe that normal values will be reached in long-term follow-ups with the decrease in pain and increase in muscle strength.

Prolongation of the swing phase and shortening of the stance phase are considered as an indicator of normalisation in gait parameters in chronic osteoarthritis patients with very long stance phase [20]. In our study, it was found that the duration of the single support phase was prolonged and the duration of the double support phase was shortened in the gait cycle. The changes in these parameters were more noticeable than the other parameters. Decreasing stance percentage created a relative increase in the swing phase. Since the single support phase can be considered equivalent to the swing of the other limb, the prolongation of the swing phase explains the prolongation of the single support phase [22]. The prolongation of the single support phase duration explains the shortening of the double support phase duration. At the same time, an increase in speed causes a decrease in the duration of the double support phase [23]. In our study, the decrease in the duration of the double support phase can be completely explained by the increase in speed.

We investigated whether there were differences in temporospatial parameters between the groups based on the level of angulation in the stress radiograph. The change in walking speed was more pronounced in the relaxed knees than in the tight knees. As the deformity increased, the postoperative increase in mean speed disappeared.As a marker of normalization, the duration of the single support phase was prolonged more noticeably in the tight knees.

Limitations;

The study involved a relatively small number of patients, which may limit the generalizability of the findings. A larger sample would allow for more robust statistical analysis and could better represent the varied patient demographics that undergo this procedure. The study primarily focused on short-term outcomes. Long-term follow-up is necessary to determine the durability of the improvements in gait and alignment, and whether these changes lead to better overall functional outcomes and patient satisfaction over time.

Conclusion

In conclusion, it was observed that the soft tissue balance achieved through manual gap balancing without the use of technological equipment was sufficient and satisfactory in terms of functional scores, walking parameters, and alignment data.

Conflict of Interest

The authors declare that they have no conflict of interest.

Funding

No funding has been received for this research.

Ethical Approval

The study was approved by Institutional Ethics Committee (Approval number:2015/4-100)

Author contributions

Each author has participated in the design of the study, has contributed to the collection of the data, has participated in the interpretation of the results and writing of the manuscript, and assumes full responsibility for the content of the manuscript.

Acknowledgements

The manuscript submitted does not contain information about medical device(s)/drug(s).

References

1. Colyn W, Bruckers L, Scheys L, Truijen J, Smeets K, Bellemans J. Changes in coronal knee-alignment parameters during the osteoarthritis process in the varus knee. J ISAKOS. 2023 Apr;8(2):68-73.
2. Fujii T, Sato T, Ariumi A, Omori G, Koga Y, Endo N. A comparative study of weight-bearing and non-weight-bearing 3-dimensional lower extremity alignment in knee osteoarthritis. J Orthop Sci. 2020 Sep;25(5):874-879.
3. Matsui Y, Kadoya Y, Uehara K, Kobayashi A, Takaoka K. Rotational deformity in varus osteoarthritis of the knee: analysis with computed tomography. Clin Orthop Relat Res. 2005 Apr;(433):147-51.
4. Schwarzkopf R, Hadley S, Abbasi M, Meere PA. Computer-assisted surgery patterns of ligamentous deformity of the knee: a clinical and cadaveric study. J Knee Surg. 2013 Aug;26(4):233-8.
5. Karasavvidis T, Pagan Moldenhauer CA, Haddad FS, Hirschmann MT, Pagnano MW, Vigdorchik JM. Current Concepts in Alignment in Total Knee Arthroplasty. J Arthroplasty. 2023 Jul;38(7 Suppl 2):S29-S37. doi: 10.1016/j.arth.2023.01.060. Epub 2023 Feb 10. PMID: 36773657.

6. Hohman DW Jr, Nodzo SR, Phillips M, Fitz W. The implications of mechanical alignment on soft tissue balancing in total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2015 Dec;23(12):3632-6.
7. JN, I., Surgical techniques and instrumentation in total knee arthroplasty. In: Scott WN (Ed), Insal l& Scott's surgery ofthe knee, 5th ed. Churchill Livingstone, Elsevier, Philadelphia 2012, pp. 39-804.
8. Colyn W, Bruckers L, Scheys L, Truijen J, Smeets K, Bellemans J. Changes in coronal knee-alignment parameters during the osteoarthritis process in the varus knee. J ISAKOS. 2023 Apr;8(2):68-73.
9. Fang DM, Ritter MA, Davis KE. Coronal alignment in total knee arthroplasty: just how important is it? J Arthroplasty. 2009;24(6 Suppl):39-43.
10. Van Rossom S, Wesseling M, Smith CR, Thelen DG, Vanwanseele B, Dieter VA, Jonkers I. The influence of knee joint geometry and alignment on the tibiofemoral load distribution: A computational study. Knee. 2019 Aug;26(4):813-823.
11. Stief F, Böhm H, Dussa CU, Multerer C, Schwirtz A, Imhoff AB, Döderlein L. Effect of lower limb malalignment in the frontal plane on transverse plane mechanics during gait in young individuals with varus knee alignment. Knee. 2014 Jun;21(3):688-93.
12. Bytyqi D, Shabani B, Lustig S, Cheze L, Karahoda Gjurgjeala N, Neyret P. Gait knee kinematic alterations in medial osteoarthritis: three dimensional assessment. Int Orthop. 2014 Jun;38(6):1191-8.
13. Kramers-de Quervain IA, Stüssi E, Müller R, Drobny T, Munzinger U, Gschwend N. Quantitative gait analysis after bilateral total knee arthroplasty with two different systems within each subject. J Arthroplasty. 1997 Feb;12(2):168-79.
14. Agarwal A, Miller S, Hadden W, et al. Comparison of gait kinematics in total and unicondylar knee replacement surgery. Ann R Coll Surg Engl. 2019 Jul;101(6):391-398.
15. Rahman J, Tang Q, Monda M, Miles J, McCarthy I. Gait assessment as a functional outcome measure in total knee arthroplasty: a cross-sectional study. BMC Musculoskelet Disord. 2015 Mar 22;16:66.
16. Levinger P, Menz HB, Morrow AD, et al. Dynamic foot function changes following total knee replacement surgery. Knee. 2012 Dec;19(6):880-5.
17. Kaneda K, Harato K, Oki S, et al. Increase in tibial internal rotation due to weight-bearing is a key feature to diagnose early-stage knee osteoarthritis: a study with upright computed tomography. BMC Musculoskelet Disord. 2022 Mar 15;23(1):253.
18. Bączkowicz D, Skiba G, Czerner M, Majorczyk E. Gait and functional status analysis before and after total knee arthroplasty. Knee. 2018 Oct;25(5):888-896.
19. McClelland JA, Webster KE, Feller JA. Gait analysis of patients following total knee replacement: a systematic review. Knee. 2007 Aug;14(4):253-63.
20. Simonsen EB, Contributions to the understanding of gait control. Dan Med J, 2014. 61(4): p. B4823.
21. Wu X, Chu L, Xiao L, et al. Early Spatiotemporal Patterns and Knee Kinematics during Level Walking in Individuals following Total Knee Arthroplasty. J Healthc Eng. 2017;2017:7056469. doi: 10.1155/2017/7056469. Epub 2017 Jul 31. PMID: 29065637; PMCID: PMC5554991.
22. Umberger BR. Stance and swing phase costs in human walking. J R Soc Interface. 2010 Sep 6;7(50):1329-40.
23. Lee TH, Tsuchida T, Kitahara H, Moriya H. Gait analysis before and after unilateral total knee arthroplasty. Study using a linear regression model of normal controls -- women without arthropathy. J Orthop Sci. 1999;4(1):13-21.