Osmangazi Tıp Dergisi
Osmangazi Journal of Medicine

*Araştırma Makalesi*
*Research Article*

# *How does Plantar Pressure Distribution Change Early after Total Knee Arthroplasty? A Pilot Study*

## *Total Diz Artroplastisi Sonrası Erken Dönemde Plantar Basınç Dağılımı Nasıl Değişir? Pilot Çalışma*

Meltem Isintas Arik, Ozgen Aras, Hakan Akkan, Nilay Yurekdeler Sahin, Vedat Kurt, Cihan Caner Aksoy, Alaaddin Oktar Uzumcugil

Kutahya University of Health Sciences Department of Physical Therapy and Rehabilitation, Kutahya, Turkey

**Abstract:** To evaluate how the static and dynamic plantar overload distribution patterns change following total knee arthroplasty (TKA) surgery using a pressure platform. Ten patients who met the inclusion criteria were included (mean age 68.5±7.9 years). Evaluations were performed prior to the surgery and on the 15th day after the surgery. Static balance parameters (anterior-posterior and total load distribution of the foot, ratio of weight bearing of the right and left foot, elliptic area of the pressure center and oscillation speed) were measured and recorded by Zebris™ FDM-2 (Zebris® Medical GmbH, Germany) device. Maximum strength produced in the posterior foot during walking, time percent of the walking cycle produced by this strength and middle foot maximum pressure values were found to be significantly decreased ($p<0,05$). Rotation degrees of the foot were found to be decreased in the patients, though not statistically significant. No significant differences were found in the total weight load on the foot, elliptic area, center of pressure (COP), line length and mean COP rate during static standing between the pre-surgical and post-surgical measurement results ($p>0,05$). Weight load measurement values on the forefoot of the opere side during standing were found to be significantly increased following surgery, while the weight load on the rear foot was found to be significantly decreased ($p<0,05$). The weight load on the rear foot and forefoot upon static stance was decreased and increased, respectively 15 days after the surgery in patients who underwent TKA surgery. The evaluations using force platform before and after surgery may be useful for orthopedic surgeons because TKA surgery used to correct knee alignment also affect loading parameters in early period.

**Key Words:** foot; gait analysis; knee osteoarthritis; pedobarography; total knee arthroplasty.

Isintas Arik M, Aras O, Akkan H, Yurekdeler Sahin N, Kurt V, Aksoy CC, Uzumcugil AO. 2019. How does Plantar Pressure Distribution Change Early after Total Knee Arthroplasty? A Pilot Study, *Osmangazi Journal of Medicine* , 41(4): 388-396
**Doi:** 10.20515/otd.441904

**Özet:** Total diz artroplasti (TDA) cerrahisi sonrasında ayak tabanındaki statik ve dinamik yüklenme paternlerinin nasıl değiştiğini basınç platformu ile değerlendirmektir. Çalışmaya dahil olma kriterlerini karşılayan 10 hasta (yaş ortalaması 68.5±7.9) alındı. Değerlendirmeler cerrahi öncesinde ve cerrahi sonrası 15. günde yapıldı. Statik denge parametreleri (ayak ön-arka ve total yük dağılımları, sağ-sol ayaklardaki ağrılık taşıma oranı, basınç merkezi elips alanı ve salınım hızı) Zebris™ FDM-2 (zebris® Medical GmbH, Germany) cihazı ile ölçülerek kaydedildi. Olguların yürüme sırasında hasta tarafta arka ayakta oluşan maksimum kuvveti, bu kuvvetin oluştuğu yürüme siklusundaki zaman yüzdesi ile orta ayak maksimum basınç değerleri anlamlı olarak azaldığı bulundu ($p<0,05$). Olguların ayak rotasyon dereceleri cerrahi sonrası azaldığı fakat bu azalmanın istatistiksel olarak anlamlı olmadığı görüldü. Olguların, ayakta statik duruşta, ayağa binen toplam yük, elips alanı, basınç merkezi (center of pressure (COP)) çizgi uzunluğu ve COP ortalama hızı cerrahi öncesi ve sonrası ölçüm değerleri arasında anlamlı bir fark bulunmadı ($p>0,05$). Hasta tarafta ayakta duruşta ön ayağa binen yük ölçüm değerleri cerrahi sonrası anlamlı olarak artarken, arka ayağa binen yük ölçüm değerleri anlamlı derecede azaldığı görüldü ($p<0,05$). TDA cerrahisi geçiren diz osteoartritli hastalarda cerrahi sonrası 15. günde statik duruş sırasında arka ayağa binen yük azalmış, ön ayağa binen yük artmıştır. Cerrahi öncesi ve sonrası kuvvet platformu kullanılarak yapılan değerlendirmeler, ortopedik cerrahlar için yararlı olabilir çünkü diz uyumunu düzeltmek için kullanılan TDA cerrahisi, erken dönemde yükleme parametrelerini de etkilemektedir.

**Anahtar Kelimeler:** ayak; diz osteoartriti; pedobarografi; total diz artroplastisi; yürüme analizi.

Isıntaş Arık M, Aras O, Akkan H, Yürekdeler Şahin N, Kurt V, Aksoy CC, Üzümcügil AO. 2019. Total Diz Artroplastisi Sonrası Erken Dönemde Plantar Basınç Dağılımı Nasıl Değişir? Pilot Çalışma, *Osmangazi Tıp Dergisi*, 41(4): 388-396
**Doi:** 10.20515/otd.441904

***ORCID ID of the authors:*** M.I.A. 0000-0001-8162-9641; O.A. 0000-0002-5915-881X; H.A. 0000-0001-7920-1128; N.Y.Ş. 0000-0002-0350-340X; V.K. 0000-0002-7623-9101; C.C.A. 0000-0003-0538-3613; A.O.U. 0000-0002-0787-7767

***Geliş Tarihi / Received*** 10.07.2018

***Kabul Tarihi / Accepted*** 19.09.2018

***Online published*** 19.09.2018

*Yazışma Adresi /* Correspondence Address
**Meltem ISINTAS ARIK**
mail: meltem.iarik@ksbu.edu.tr

## 1. Introduction

Knee osteoarthritis is a degenerative joint disease characterized by pain and stiffness. These symptoms arise due to abrasion of the articular surface and affect directly the functional ability of the individual (1-3). Total knee arthroplasty (TKA) surgery, used in the degenerative situations where the treatment options such as medical treatment, exercise treatment and electrotherapy modalities are inadequate is a method that improves functional ability, decreases pain and restores the anatomic alignment of the tibiofemoral joint (4, 5).

Conditions, such as walking in a low speed with short steps and increased length between the two feet during walking, are frequently seen in patients with knee arthroplasty (6, 7). These changes may be secondary to the disease itself, while they may be part of a compensatory condition developed by the patient to decrease the load of the side affected from osteoarthritis (8). These changes can be monitored by three-dimensional (3D) motion analysis systems and the effect of the surgery on these conditions may be demonstrated. However, 3D motion analysis equipment is expensive and is unavailable in all clinics. Therefore, in place of 3D motion analysis, use of platforms including sensors that evaluate the plantar contact patterns allow the analysis of both the order of lower extremity alignment and also contact patterns during standing and walking.

Chandler et al. (9) reported that surgery could affect the alignment of the foot by re-arranging the alignment of the lower extremity and thus change the function of the foot. Alignment between hip and ankle joint that passes through the knee joint is considered, when coronal alignment of the lower extremity is mentioned and this is accepted as the neutral mechanical alignment. However, vectors produced by weight bearing are transferred through the posterior foot which is named floor reaction point rather than the ankle joint. Therefore, alignment of the posterior foot gains importance following TKA and may even affect the operating time of the prosthesis (10). It is also thought that the lower limb alignment is one of the important factors affecting the duration of use and life of the implant in TKA (10-12).

In the present study, we aimed to evaluate the changes in the plantar static and dynamic load patterns following TKA using a pressure platform. Our hypothesis was that preoperative loading patterns will change in the early postoperative period.

## 2. Material and Methods

The total of 18 volunteer patients who were diagnosed with osteoarthritis according to American Rheumatology (ACR) criteria and planned for surgery were included in the study. (13). The study was conducted at a private hospital in Kutahya city. This study was approved by the Ethics Board for Clinical Research of the University of Osmangazi (approval number 80558721/274) and was supported by the Scientific Research Unit of the University of Dumlupinar (2014-45). All patients were provided information on the applications and measurements prior to the initiation of the study and they signed a volunteering informed consent. The study was conducted in accordance with the principles of the Declaration of Helsinki.

The inclusion criteria as follows; diagnosed as primary knee osteoarthritis by an orthopedic surgeon, planned to undergo a TKA operation, with an age between 45 and 80 years, have a body mass index (BMI) under 40 kg/m2, underwent unilateral total knee arthroplasty and accepted to participate in the study. Patients who had bilateral total knee endoprosthesis, another neurological or musculoskeletal disease of the lower extremity that might affect walking, uncontrolled systemic diseases, loss of active range of motion that affects walking and who had balance issues due to neurological problems were excluded from the study (14).

Total knee arthroplasty operations were performed by the same surgeon using the same technique. A cemented prosthesis was used and the posterior ligament was removed.

Demographics (age, length, body weight, occupation and past medical history) of the patients who accepted to participate in the study were obtained by a face to face interview method and were recorded. Patients' pain severity was assessed using a visual analogue scale.

Static stance and dynamic pressure distribution parameters of the patients were measured and recorded instantly using a Zebris™ FDM-2 (zebris® Medical GmbH, Germany) device. During the evaluation, the patients were asked to walk in a pace that they felt comfortable, in order that at least 8 steps would be walked on the walking analysis platform on a 5-meter walking platform (3 meters of a platform and 2 meters of a walking analysis platform). The localization of the foot (anterior-middle-posterior foot) where the maximal strength (N) and maximum pressure (N/cm$^2$) on the feet during walking were intensified was obtained digitally and in graphic form. In addition, rotation degrees of the foot were recorded. Static stance evaluation of the patients was performed at the same place by the same researcher. During the evaluation, the participant was asked to stand upright with the arms free on the sides, eyes fixed at a point 3 meters away anteriorly and by maintaining this posture as much as possible for 60 seconds as was described by Freitas et al. (15). Percentage of weight load on the sick and healthy feet in static standing position (%), mean maximum strength (N), mean maximum pressures for forefoot, mid-foot and rear foot were recorded separately. In addition, degree of foot rotation ($^0$), mean rate (mm/sec) of the center of pressure (COP), length of the route followed (mm) and the area of the circle that was drawn (mm$^2$) was evaluated. Patients walked independently during the evaluations.

Interviews with 18 patients were performed during the study period and their first evaluations were done. Second evaluation of the patients who underwent TKA was performed 15 days after the operation during the follow-up visit. The second evaluation of 8 patients could not be performed since they did not show up at the follow-up visit; therefore the study was completed with the data obtained from 10 patients (Figure 1).

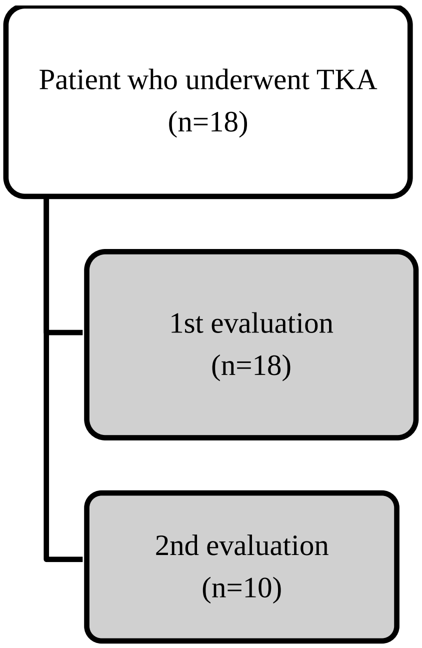


**Figure 1.** Flow chart

***Statistical Analysis***

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 13 software (SPSS Inc., Chicago, IL, USA). Descriptive statistics were expressed in mean ± standard deviation (Sd), and mean rank and sum of ranks values. The Wilcoxon signed-rank test among the non-parametric statistical tests was performed to determine the difference. A *p* value of <0.05 was considered statistically significant.

## 3. Results

The study was completed by performing the preoperative and postoperative evaluations of 10 (9 females and 1 male) patients. Among the study group, three patients were operated on their left knees and 7 on right knee. Demographics of the patients are shown in Table 1.

When pain intensity before and after surgery was compared, the severity of postoperative pain (p = 0,007) and resting pain (p = 0,011) decreased significantly (Table 2).

Maximum strength produced in the posterior foot during walking, time percentage of the walking cycle produced by this strength and maximum pressure values of the mid-foot were significantly decreased (p=0,012). Degrees of foot rotation were decreased following surgery, though not significant (Table 2).

No statistically significant differences were found in the total weight load on the foot, elliptic area, center of pressure (COP) line length and mean COP rate during static standing between the pre-surgical and post-surgical measurement results (p=0,677). Weight load measurement values on the forefoot of the operated side during standing were found to be significantly increased following surgery, while the weight load on the rear foot was found to be significantly decreased (p=0,016) (Table 3).

**Table 1.**
Demographic Information

| Variables | N | X±Sd |
|---|---|---|
| **Age (years)** | 10 | 68.50±7.86 |
| **Height (cm)** | 10 | 154.00±0.04 |
| **Weight (kg)** | 10 | 82.48±15.46 |
| **BMI (kg/m$^2$)** | 10 | 34.97±7.09 |

***cm**: centimeter, **kg**: kilogram, **BMI**: Body Mass Index, **m$^2$**: square meter, **N**: total, **X**: mean, **Sd**: standart deviation*

**Table 2.**
Measurement results of the pain intensity, maximum forces that occur during gait and the distribution of forces according to the foot regions

| | | **Pre-op Median (Min.-Max.)** | **Post-op Median (Min.-Max.)** | **z** | **p** |
|---|---|---|---|---|---|
| **Pain intensity (cm)** | Rest | 6.00 (0.00 – 10.00) | 2.00 (0.00 – 5.00) | **-2.536** | **0.011*** |
| | Activity | 8.00 (0.00 – 10.00) | 3.00 (0.00 – 6.00) | **-2.680** | **0.007*** ** |
| **Maximum Force, Rear Foot (N)** | Operated | 879.55 (595.30 – 945.00) | 0.00 (0.00 – 888.30) | **-2.501** | **0.012*** |
| | Non-operated | 801.30 (0.00 – 901.50) | 850.15 (0.00 – 918.50) | -1.365 | 0.172 |
| **Time Maximum Force, Rear Foot (% of stance phase)** | Operated | 26.50 (26.00 – 42.00) | 0.00 (0.00 – 34.00) | **-1.990** | **0.047*** |
| | Non-operated | 28.00 (0.00 -23.00) | 31.00 (0.00 – 42.00) | -0.704 | 0.481 |
| **Maximum Force, Forefoot (N)** | Operated | 781.60 (0.00 – 986.50) | 781.60 (0.00 – 986.50) | -0.153 | 0.878 |
| | Non-operated | 866.05 (582.40 – 939.60) | 846.90 (0.00 – 989.90) | -0.051 | 0.959 |
| **Time Maximum Force, Forefoot (% of stance phase)** | Operated | 42.00 (7.00 – 49.00) | 43.00 (0.00 – 49.00) | -0.178 | 0.858 |
| | Non-operated | 45.50 (40.00 – 47.00) | 42.50 (0.00 – 51.00) | -1.330 | 0.183 |
| **Average Maximum Force, Forefoot (N)** | Operated | 543.55 (280.40 – 716.30) | 364.10 (268.20 – 656.30) | -1.480 | 0.139 |
| | Non-operated | 449.10 (275.20 – 670.10) | 432.25 (339.90 – 731.80) | -0.357 | 0.721 |
| **Average Maximum Force, Midfoot (N)** | Operated | 304.10 (200.50 – 449.90) | 258.05 (193.40 – 447.20) | -1.582 | 0.114 |
| | Non-operated | 295.45 (156.90 – 394.90) | 274.65 (198.40 – 464.50) | -0.357 | 0.721 |
| **Average Maximum Force, Rear Foot (N)** | Operated | 328.85 (276.80 – 419.50) | 371.30 (231.90 – 467.90) | -1.174 | 0.241 |
| | Non-operated | 403.45 (260.50 – 460.40) | 376.60 (262.20 – 475.50) | -0.663 | 0.507 |
| **Average Maximum Pressure, Forefoot ($N/cm^2$)** | Operated | 26.45 (13.00 – 41.80) | 17.75 (13.90 - 35.10) | -1.378 | 0.168 |
| | Non-operated | 26.85 (15.00 – 30.00) | 25.50 (16.50 – 38.60) | -0.459 | 0.646 |
| **Average Maximum Pressure, Midfoot ($N/cm^2$)** | Operated | 15.20 (10.20 – 21.80) | 12.80 (9.10 – 16.30) | **-2.201** | **0.028*** |
| | Non-operated | 17.70 (8.00 – 23.20) | 13.40 (8.30 – 22.50) | -0.663 | 0.507 |
| **Average Maximum Pressure, Rear Foot ($N/cm^2$)** | Operated | 17.40 (14.20 – 22.70) | 19.65 (14.30 – 27.40) | -1.072 | 0.284 |
| | Non-operated | 19.00 (13.10 – 26.60) | 19.30 (12.40 – 27.60) | -1.021 | 0.307 |

| | | | | | |
|---|---|---|---|---|---|
| **Foot rotation ($^0$)** | Operated | 14.95 (4.60 – 21.10) | 11.65 (7.80 – 22.50) | -1.684 | 0.092 |
| | Non-operated | 12.45 (-0.30 – 20.40) | 13.00 (0.00 – 22.50) | -0.358 | 0.720 |

***Min:** minimum, **Max:** maximum, **cm:** centimeter **N:** newton, **%:** percent, **N/cm$^2$**: newton/square centimeter, **$^0$:** degree, z: Wilcoxon signed-rank test, *P<0,005, **p<0,001*

**Table 3.**
Measurement results of static posture parameters

| | | Pre-op Median (Min.-Max.) | Post-op Median (Min.-Max.) | z | p |
|---|---|---|---|---|---|
| **Average Forces, Forefoot (%)** | Operated | 46.50 (7.00 – 61.00) | 52.50 (35.00 – 63.00) | -2.403 | 0.016* |
| | Non-operated | 45.00 (15.00 – 55.00) | 36.00 (20.00 – 51.00) | -1.688 | 0.091 |
| **Average Forces, Rear Foot (%)** | Operated | 53.50 (39.00 – 93.00) | 47.50 (32.00 – 65.00) | -2.403 | 0.016* |
| | Non-operated | 55.00 (45.00 – 85.00) | 64.00 (49.00 – 80.00) | -1.688 | 0.091 |
| **Average Forces, Total (%)** | Operated | 49.50 (44.00 – 59.00) | 46.50 (27.00 – 60.00) | -1.740 | 0.082 |
| | Non-operated | 50.50 (41.00 – 56.00) | 53.50 (40.00 – 73.00) | -1.740 | 0.082 |
| **Ellipse Area (mm$^2$)** | | 592.50 (128.00 – 1220.00) | 417.00 (281.00 – 1651.00) | -0.765 | 0.444 |
| **COP Path Length (mm)** | | 528.50 (225.00 – 702.00) | 508.00 (370.00 – 712.00) | -0.868 | 0.386 |
| **COP Average Velocity (mm/sn)** | | 9.50 (4.00 – 26.00) | 9.00 (6.00 – 13.00) | -0.416 | 0.677 |

***min:** minimum, **max:** maximum, **mm$^2$:** square millimeter, **mm:** millimeter, **mm/sn:** millimeter/second, z: Wilcoxon signed-rank test, *P<0,005, **p<0,001*

## 4. Discussion and Conclusion

In this study in which the postoperative 15th day results of the patients who underwent total knee arthroplasty for primary knee osteoarthritis were analyzed, the strength produced in the rear foot was found to be decreased during walking, weight load on the forefoot was found to be increased and the load on the rear foot was found to be decreased during static stance.

It is known that osteoarthritis causes varus or valgus deformities in the knee joint, which also results in abnormal coronal alignment. These abnormal alignment is compensated by the subtalar joint. In patients with osteoarthritis, the varus alignment in the knee joint is associated with the valgus alignment in the rare foot and the valgus alignment in the knee joint is associated with the varus alignment in the rare foot (16, 17). The deformity in the rear foot has been reported to be improved following TKA surgery in some studies (9, 10, 16, 18). However, there are very few studies evaluating the changes occurring in the pressure and strength of the sole following TKA (19). It is reported in the literature that the knee arthroplasty surgeons are concerned that the presence of a noteworthy foot or ankle joint deformity might result in an abnormal load on the knee prosthesis and this in turn may cause early mechanical problems in the prosthesis (10). In a study by Voronov et al. (20), a minimal change was found in the load on the foot following correction of the knee deformity by TKA and this condition was reported as the compliance ability of the subtalar joint complex to the load changes.

The association between the range of motion of the knee and plantar pressure patterns was evaluated in patients with medial knee OA in a study by Saito et al. (8). The pathway of the center of pressure was found to be shorter and more straighter in patients with OA. Lesser weight load of the body on the first metatarsal was reported to cause the pathway of the center of pressure to shift to the lateral and follow a more straight line. In a study by Voronov et al. (20), pressure on the first metatarsal was reported to be low in patients with OA and this pressure was reported to be significantly increased after TKA. In our results, the center of pressure path length was decreased after surgery similar to that of Saito et al. (8), but this decrease was not statistically significant. In this present study, maximum plantar pressure in static stance position was found to be significantly increased in the forefoot and significantly decreased in rear foot. However, whether weight bearing was higher in the first metatarsal part or in the lateral part is unclear since no data was obtained on this issue through the device.

Toe-out walking in patient with medial knee OA has been reported to be associated with knee adduction moment (21, 22). Shull et al. (21) demonstrated that toe-in walking in patients with knee OA decreased the first peak knee adduction momentum. Saito et al. (8), on the other hand, reported in their study that a similar result could be obtained in plantar pressure analysis although they had not evaluated the degrees of toe-in and toe-out, suggesting that toe-out walking could be associated with the lateral shift of the terminal point of the pathway followed by the center of pressure. In this present study, although the toe-in and toe-out degrees were not specifically evaluated, the decrease in the degree of foot rotation measured by the device, although did not reach statistically significance, may give an idea on the subject. Based on this result, to report that a surgeon can decrease the foot rotation degree may not be a wrong conclusion.

In a pedobarographic analysis performed in postoperative 6th month by Güven et al. (19) in patients who underwent knee arthroplasty, total plantar strength, plantar strength and pressure values in the forefoot and in addition the contact area in the forefoot and mid-foot were found to be decreased in static evaluation, and dynamic evaluation demonstrated that plantar pressure was decreased in only the mid-foot. No significant changes in the rear foot in static and dynamic evaluations were reported. This present study also demonstrated that mid-foot pressure was decreased during walking and weight load on the forefoot increased in static stance and the load on the rear foot decreased.

Cho et al. (10) emphasized that an active treatment might be necessary when the deformity and pain in the posterior foot continued to be present for more than 6 weeks. Therefore, we probably were not able to determine clearly the possible changes in the sole of the foot mediated by the rear foot in the 2nd week. One of the limitations of this study is that we were unable to repeat the evaluations at sixth weeks and the follow-up period was not long enough.

Another limitation is the small number of the study. Since we were unable to evaluate the knee and rear foot alignments by radiographic measurements, no clear results could be demonstrated on how the alignment changes were reflected to the sole, which can be deemed as another limitation of the study.

In conclusion, weight load on the rear foot was decreased and weight load on the forefoot was increased in the 15th day after the surgery in static stance in patients who underwent TKA for OA. TKA surgery to restore the knee alignment may also affect loading parameters in the early period. Evaluations using force platform before and after surgery may also be useful for orthopedic surgeons. Errors in component alignment can also provide information for the surgeons about the abnormal gait. Studies with long term follow-up that evaluate the alignments in the knee and rear foot by radiographic measurements and that analyze the associations with those measurements and static and dynamic pressure distribution are needed.


### *Acknowledgement*

*This study was supported by the Scientific Research Unit of the University of Dumlupinar (2014-45)*


## REFERENCES


1. Butler RJ, Barrios JA, Royer T, Davis IS. Frontal-plane gait mechanics in people with medial knee osteoarthritis are different from those in people with lateral knee osteoarthritis. Physical therapy. 2011;91(8):1235-43.
2. Dillon CF, Rasch EK, Gu Q, Hirsch R. Prevalence of knee osteoarthritis in the United States: arthritis data from the Third National Health and Nutrition Examination Survey 1991-94. The Journal of rheumatology. 2006;33(11):2271-9.
3. Jordan JM, Helmick CG, Renner JB, Luta G, Dragomir AD, Woodard J, et al. Prevalence of knee symptoms and radiographic and symptomatic knee osteoarthritis in African Americans and Caucasians: the Johnston County Osteoarthritis Project. The Journal of rheumatology. 2007;34(1):172-80.
4. Tanaka S, Kubota K, Yoshimura O, Kobayashi R, Minematsu A, Hosoda M, et al. Gait Analysis after Total Knee Arthroplasty - Comparison of Cemented Type and Cementless Type. Journal of Physical Therapy Science. 2000;12(2):101-5.
5. Yoshida Y, Joseph Zeni J, Snyder-Mackler L. Do Patients Achieve Normal Gait Patterns 3 Years After Total Knee Arthroplasty? Journal of Orthopaedic & Sports Physical Therapy. 2012;42(12):1039-49.
6. Piva SR, Gil AB, Almeida GJM, DiGioia IIIAM, Levison TJ, Fitzgerald GK. A Balance Exercise Program Appears to Improve Function for Patients With Total Knee Arthroplasty: A Randomized Clinical Trial. Physical therapy. 2010;90(6):880-94.
7. Turcot K, Armand S, Lübbeke A, Fritschy D, Hoffmeyer P, Suvà D. Does knee alignment influence gait in patients with severe knee osteoarthritis? Clinical Biomechanics. 2013;28(1):34-9.
8. Saito I, Okada K, Nishi T, Wakasa M, Saito A, Sugawara K, et al. Foot Pressure Pattern and its Correlation With Knee Range of Motion Limitations for Individuals With Medial Knee Osteoarthritis. Archives of physical medicine and rehabilitation.94(12):2502-8.
9. Chandler JT, Moskal JT. Evaluation of knee and hindfoot alignment before and after total knee arthroplasty. The Journal of Arthroplasty.19(2):211-6.
10. Cho W-S, Cho H-S, Byun S-E. Changes in hindfoot alignment after total knee arthroplasty in knee osteoarthritic patients with varus deformity. Knee Surgery, Sports Traumatology, Arthroscopy. 2017;25(11):3596-604.
11. Bankes MJK, Back DL, Cannon SR, Briggs TWR. The effect of component malalignment on the clinical and radiological outcome of the Kinemax total knee replacement. The Knee.10(1):55-60.
12. Matsuda S, Miura H, Nagamine R, Urabe K, Harimaya K, Matsunobu T, et al. Changes in knee alignment after total knee arthroplasty. The Journal of Arthroplasty. 1999;14(5):566-70.
13. Altman R. Development of criteria for the classification and reporting of osteoarthritis. Classification of osteoarthritis of the knee. Arthritis Rheumatology. 1986;29:1039-49.
14. Mandeville D, Osternig LR, Chou L-S. The effect of total knee replacement surgery on gait stability. Gait & Posture.27(1):103-9.
15. Freitas SMSF, Wieczorek SA, Marchetti PH, Duarte M. Age-related changes in human postural control of prolonged standing. Gait & Posture.22(4):322-30.
16. Mullaji A, Shetty GM. Persistent Hindfoot Valgus Causes Lateral Deviation of Weightbearing Axis after Total Knee Arthroplasty. Clinical Orthopaedics and Related Research®. 2011;469(4):1154-60.
17. Norton AA, Callaghan JJ, Amendola A, Phisitkul P, Wongsak S, Liu SS, et al. Correlation of Knee and Hindfoot Deformities in Advanced Knee OA: Compensatory Hindfoot Alignment and Where It Occurs. Clinical Orthopaedics and Related Research®. 2015;473(1):166-74.
18. Hara Y, Ikoma K, Arai Y, Ohashi S, Maki M, Kubo T. Alteration of Hindfoot Alignment After Total Knee Arthroplasty Using a Novel

Hindfoot Alignment View. The Journal of Arthroplasty.30(1):126-9.
19. Güven M, Kocadal O, Akman B, Şayli U, Altıntaş F. Pedobarographic Analysis in Total Knee Arthroplasty. J Knee Surg. 2017;30(09):951-9.
20. Voronov ML, Pinzur MS, Havey RM, Carandang G, Gil JA, Hopkinson WJ. The Relationship Between Knee Arthroplasty and Foot Loading. Foot & Ankle Specialist. 2012;5(1):17-22.
21. Shull PB, Shultz R, Silder A, Dragoo JL, Besier TF, Cutkosky MR, et al. Toe-in gait reduces the first peak knee adduction moment in patients with medial compartment knee osteoarthritis. Journal of Biomechanics.46(1):122-8.
22. Guo M, Axe MJ, Manal K. The influence of foot progression angle on the knee adduction moment during walking and stair climbing in pain free individuals with knee osteoarthritis. Gait & Posture.26(3):436-41.