Instrumented platforms for balance and proprioceptive assessment in patients with total knee replacement: A systematic review and meta-analysis

Published Version:
Labanca, L., Iovine, R., Bragonzoni, L., Barone, G., Farella, G.M., Benedetti, M.G. (2020). Instrumented platforms for balance and proprioceptive assessment in patients with total knee replacement: A systematic review and meta-analysis. GAIT & POSTURE, 81, 230-240 [10.1016/j.gaitpost.2020.07.080].

Availability:
This version is available at: https://hdl.handle.net/11585/801836 since: 2025-01-11

Published:
DOI: http://doi.org/10.1016/j.gaitpost.2020.07.080

Instrumented platforms for balance and proprioceptive assessment in patients with total knee replacement: A systematic review and meta-analysis

L. Labanca [a,*], R. Iovine [b], L. Bragonzoni [c], G. Barone [c], G.M. Farella [a], M.G. Benedetti [a]

[a] Physical Medicine and Rehabilitation Unit, IRCCS-Istituto Ortopedico Rizzoli, Bologna, Italy
[b] Physical Medicine and Rehabilitation Unit, Ospedale SS. Salvatore, AUSL, Bologna, Italy
[c] Dipartimento di Scienze per la qualita` della vita, Universita` degli Studi di, Bologna, Italy

Keyword: TKR, Balance Proprioception Force platforms Rehabilitation, Functional assessment

ABSTRACT

Background: The functional outcome of total knee replacement (TKR) is usually satisfying. However, patients may show functional limitations for years after surgery, which have been ascribed to impairments in balance and proprioception, mainly during standing tasks. A number of instrumentations and parameters have been used, rising confusion for clinical decisions on the assessment of patients.
Research question: Which are the most widespread and consistent procedures to assess balance and proprioception following TKR?
Methods: A literature review was conducted in Pubmed, PEDro, and Cochrane database. From a total sample of 112 articles, 23 original studies published between 2008 and 2019 met inclusion criteria. The primary outcomes selected were variables related to balance and proprioception assessment in static and dynamic tasks performed with instrumented platforms. Data from papers using the same instrumentation, on patients with unilateral TKA and at least 12 months postoperatively were synthesized quantitatively in a random effect meta-analysis.
Results: Fourteen articles were appropriate for the review. A large variability was found both in the instrumentation and the parameters used. The Neurocom Balance Master System™ was the most used instrument (four articles). On a total population of 186 patients with unilateral TKR 12 months postoperatively, a low degree of heterogeneity was found adopting the random effect in the four tasks explored (Firm and Foam Surface both with Eyes Open and Eyes Closed).
Significance: This review found a large variability in the instrumentation used to assess balance and proprioception in patients operated on TKR. The meta-analysis demonstrated that the Neurocom Balance Master System™ for static assessment of balance showed an acceptable consistency and can be considered as a reference for further studies. However, balance and proprioception impairments following TKR have not been widely quantified by means of instrumented platforms. Further research is needed to address this issue and improve clinical practice.

1. Introduction

Knee osteoarthritis is a common condition in older individuals leading to limiting pain and disability. Usually, a conservative therapy as initial treatment is performed; when conservative treatments fail to improve symptoms, total knee replacement (TKR) is then proposed. Overall, the outcome of joint replacement is satisfactory for the patients. However, even one year after surgery, a number of patients show functional and balance limitations, which have been ascribed to deficits in the proprioceptive system [1,2]. There is evidence that both osteo- arthritis pathology and TKR alter the proprioceptive function of the knee [3], with impaired movement patterns, difficulties in walking and postural control [1,4–11]. Many studies have focused on the imple- mentation of rehabilitation protocols aimed at improving balance and proprioception, which are considered as important predictive factors for quality of life and function after primary TKR [1,12–20]. However, it has been reported that patients with TKR do not fully recover balance and proprioception in the long-term, remaining clearly below the "abilities" of their healthy matched controls [21]. Low balance and proprioception have been ascribed to the loss of knee receptors located in the structures such as the menisci, the cruciate ligaments and the cartilage, which are removed for the prosthesis implant [22] It is not known to what extent the receptors remaining after TKR surgery may compensate for the ones lost to restore proprioception and balance. It has been observed that standing balance tasks are effective to quantify impairments following TKR [1–4], as the maintenance of a standing posture requires a coordinated action of whole body sensitive information and related muscle activations [23]. The lack or inadequate information arising from the knee causes an alteration as first in the lower limb and then in the whole-body, which translates in an abnormal balance control. The evaluation of balance and proprioception during stance tasks is thus essential to monitor the postoperative recovery and the effectiveness of the rehabilitation. Standing balance and proprioception assessment has been usually carried out by means of instrumented platforms [22,30]. The platforms commonly used are laboratory force plates [24], as well as platform embedded in ad-hoc systems [3,25–29], or commercial plat- forms apparatus [4]. Platforms are static or dynamic with various degree of freedom, and are used to assess single-limb or double-limb stance tasks, performed with eyes open or eyes closed. Generally the body sway is recorded and is expressed using various parameters or indexes depending on the system used.

This large variety of instrumentations and parameters reported in literature making extremely difficult to accordingly address the clinical practice.

Thus, this study aimed to provide a systematic review of the instru- mented platforms used for balance and proprioception assessment in patients undergoing total knee replacement, and a meta-analysis of data to identify the most consistent procedures.

2. Methods

2.1. Population and diagnosis of interest

This review includes all studies that provide assessment of balance and proprioception by means of instrumented platforms in patients who underwent total knee replacement for osteoarthritis at different time points of the follow up.

2.2. Information sources, search strategy and inclusion criteria

A systematic review of MEDLINE, PEDro, and Cochrane database was performed in September 2019. The inclusion criteria were limited to articles published between May 1, 2008, and August 31, 2019. The terms and key words used for the research strategy were: 'total knee replace- ment' OR 'total knee arthroplasty' OR 'total knee prosthesis' OR 'TKA' OR 'TKR' AND 'propriocept*' OR 'balance' OR 'body sway' OR 'postural control' OR 'stance' OR 'instability' OR 'stability' AND 'platform' OR 'device' OR 'board' located within the title and/or abstract and/or keywords. The character * was used to include in the research both the terms proprioceptive, proprioception, and proprioceptors. In each article the use of instrumented platforms as evaluation tools was sought. Reference lists and citations of the included articles were manually screened to identify additional studies of interest. The literature search was limited to papers written in English. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and checklist were employed to guarantee review methodological quality. The study was registered in PROSPERO (N. CRD42020137897).

2.3. *Selection process and data extraction*

Two independent reviewers performed the search (LL, BG). There- after, the reviewers extracted the data and discussed the results. In case of disagreement in the appropriateness of the paper, a third author was consulted (MGB). The articles meeting the criteria based on their titles

and abstracts were included, and their full-text versions were then extracted. Those articles that did not meet the inclusion criteria were excluded. The two authors who selected the literature also independently extracted the following information from included studies: first author's name, publication year, aim of the study, devices' characteristics, and results.

2.4. *Evaluation of study bias*

Two researchers independently assessed the risk of bias. According to the "The systematic review of studies of diagnostic test accuracy" [31], the following items were evaluated: patient's spectrum bias, pa- tient selection bias, Index test information bias, and excluded data. Any disagreement was solved by discussion until a consensus was reached. Other biases included in the Manual were not appropriate for the present review and were not considered. The tool requires users to assign a judgment of low, high, unclear risk of bias. Two independent reviewers assigned the judgment and the Fleiss' Kappa measure was used for assessing the reliability of agreement between the two reviewers by the use of an independent observer. This measure calculates the degree of agreement in classification compared to what would be expected by chance and is scored between 0 and 1. Reliability from Kappa values was interpreted as < 0 = Poor agreement; 0.0–0.20 = Slight agreement; 0.21–0.40 = Fair agreement; 0.41–0.60 = Moderate agreement; 0.61–0.80 = Substantial agreement and 0.81–1.00 = Almost perfect agreement, according to Landis and Koch [32].

2.5. *Data synthesis: outcomes of interest*

The primary outcome selected for the review was the measure of balance and proprioception variables according to the device used in selected papers. Both static task and dynamic task assessment were considered. Studies retrieved are reported in Table 1 according to the patients and TKR implant characteristics, the time of assessment (pre- operative, pre-postoperative assessment), the device used and the vari- able output, mono or bilateral TKA implant, and the follow up length.

Due to the number of variables explored in the studies, it was decided to carry out a quantitative analysis involving a meta-analysis only on parameters common to at least four studies. To this purpose the following criteria were followed: static task on Neurocom Balance Master System™ (using the Modified Clinical Test of Sensory interaction on Balance-mCTSIB score, which corresponds to the center of gravity movement on the plate), only postoperative studies at least at 12 months after surgery, only unilateral TKR patients. The statistical analysis and the forest plot were carried out according to Neyeloff et al. [33] using Microsoft Excel.

The heterogeneity was assessed using I^2 index according to the following thresholds: 0 %–30 %=no heterogeneity; 30 %–50 %= low heterogeneity, 50 %–75 %= moderate heterogeneity, 75 %–100 %= high heterogeneity. The estimation of the expected value and its 95 % confidence interval was based on random effect analysis of variance.

3. Results

3.1. *Selected studies, reliability and risk of bias*

The databases searched from May 1, 2008 to August 31, 2019 yielded 128 articles of which 99 on PubMed database, 9 articles on PEDro database, and 19 articles on Cochrane Library. After the removal of duplicates, 112 reports were considered (15 removed). The analysis of complete full texts resulted in the exclusion of 89 articles in which no instrumented platforms were used for balance, proprioception or postural stability assessment.

Full-text articles assessed for inclusion were 23 [3–11,24–29,34–41]. The PRISMA flowchart of the article selection process is shown in Fig. 1. The level of agreement between the two reviewers was excellent and the consultation of a third reviewer was not necessary in any case. Of the twenty-three studies selected, ten were excluded [5,8,4–11,37,35–41] because of the presence of high risk of bias or unclear risk of bias, or because "study did not address this outcome" in the items "Patients Spectrum bias", "Patients Selection bias", and "Data Analysis bias" (Appendix A).

There was a complete agreement rate between the two reviewers in selecting these studies (K = 1). The most common sources of bias were related to the low number of participants and an unclear description of participants selection, recruitment and randomization.

3.2. *Effect in the assessment in the studies*

In order to assess the consistency of effects across studies, we selected only the studies in which common evaluating instruments, task and parameters were used (Table 2). The group of studies selected for meta- analysis included: Bakiran et al. [25], Vandekerckhove et al. [26], separating Cruciate Retaining (CR) and Posterior Stabilized (PS) knee prosthesis (cumulative data were not available), Bascuas et al. [34] and Schwartz et al. [35]. These two latter were assessed only for post- operative values. The Neurocom Balance Master System™, which is a computerised dual-force platforms systems with a visual display giving feedback for performance of the tasks, allows clinicians to explore the three sensory (somatosensory, visual, and vestibular) inputs involved in postural stability during a steady state balance assessment, was used in all the studies. The outcome measure considered was the Modified Clinical Test of Sensory Interaction on Balance (mCTSIB), which assess static balance by measuring postural sway in the four standard trials: standing in erect position on firm and foam surfaces with eyes open and closed conditions. The dual-force platforms system records the ampli- tude, the direction and the speed of movement of the center of pressure for each condition and during quiet standing for 20 s. The parameter reported in all studies involved in this meta-analysis was the speed of center of pressure sway expressed as degrees (°) per second (s) during the mCTSIB.

On a total population of 186 patients operated on TKR at a minimum follow up of 12 months, a moderate- to-high degree of heterogeneity among the results was found in all the four conditions of balance assessment included (Figs. 2 and 3). Respectively, an I^2 = 73 % was found for the Test on Firm Surface with Eyes Open, I^2 = 51 % for the Test on Firm Surface with Eyes Closed, I^2 = 89 % for the Test on Foam Surface with Eyes Open, and I^2 = 70 % for the Test on Foam Surface with Eyes Closed. The random effect was used for the evaluation of the confidence intervals.

3.3. Other studies

The second group included the studies of Goetz et al. [28], Gotz et al. [29], and Isyar et al. [27], which used the Biodex Balance System, consisting in a circular platform free to move in the anterior-posterior and medial-lateral axes simultaneously with various degree of freedom, providing stability indexes and a fall risk index as common outcome. Due to the small number of studies and the high heterogeneity of examined tasks, no quantitative analysis was indeed possible in this group (Table 3).

For the same reason, no analysis was possible for individual studies retrieved in the search which used a miscellaneous group of devices: Nintendo Wii Balance Board [4], FDM plate [36], Gravicorder [6], PosturoMed [7], and a Kistler forceplate [24]. These studies used various instrumented platforms and various stance tasks, providing a number of outcome parameters and follow up. Additional information on these studies is reported in Table 1.

4. Discussion

This systematic review and meta-analysis on the instrumented plat- forms used for balance and proprioception assessment in patients who underwent TKR provided a very heterogeneous number of studies differing for the instrumentation and the parameters used. Furthermore, different TKR population, age, follow up, rehabilitation trials after surgery, implant model and comorbidities which not always were appropriately specified, were included in the experimental studies.

In order to make the meta-analysis as homogeneous as possible, four studies were selected as they used similar platforms, measure outcome, task for measuring balance, and TKR follow up. The Neurocom Balance Master System™, providing mCTBS score for postural sway velocity, resulted to be the most used instrumentation to assess static balance, though it was also used in dynamics and during different motor tasks (rhythmic weight shift, sit to stand, squat etc.). Notwithstanding the restrictive criteria for the meta-analysis, a moderate-to-high heterogeneity on the index parameter to evaluate balance was found (mCTSIB), depending on patient's sample size, and different confidence intervals of reported values, which were removed by the random effect model. When considering the mean values of the sway velocity provided by the mCTSIB in the four conditions of static postural assessment, it is interesting to note that they are below the reference value produced by the Company [42]. Unfortunately, none of the four studies included pro- vided a control group. Even if the device and the parameters used have shown to be consistent across studies for the measure of balance in patients with TKR, it is not clear if the measure has enough sensitivity to avoid clinical bias (i.e. implant model). This should be investigated by future studies.

All of the studies in the present review addressed static or dynamic balance assessment. In a previous review [22], we found that only 4 studies resulted actually able to provide a direct measurement about knee proprioceptive skills, by means of joint positions sense tests consisting in passively or actively reaching an object, quantifying the error between the position reached by the subjects and the exact target position required by the examiner, while nine studies proposed an indirect measurement of proprioception abilities before and after TKR, mainly evaluating balance.

Balance, in fact, can be considered as an indirect measurement of proprioception, since it is an essential parameter for dynamic postural control [36], representing proprioceptive function [11]. Furthermore, since TKR did not affect any substantial changes about visual and vestibular elements of balance, the main changes measured in balance may be attributable to proprioception [34]. Hence balance and proprioception are strictly related and impairments in kinaesthesia and proprioception result in negative effects on standing balance [43].

While there is some evidence in literature stating specific rehabilitative exercises are effective in improving proprioception and balance after TKR, there is no complete agreement on the positive effect of TKR in improving standing balance after surgery [22]. Studies with positive outcomes concluded that improvement was not caused exclusively by increase in proprioception, but it could be due also to other factors, such as the decrease in joint effusions, pain and/or inflammation, changes inv resting length and muscle activation [11].

However, although the assessment of balance and proprioception impairments after TKR is relevant for the implication in disability, risk of fall and quality of life, it is difficult to disentangle which is the factor or the factors leading to deficits in proprioception because of the variety of outcome measures, assessment instrumentations and procedures used in the large number of studies in literature.

In conclusion, balance and proprioception impairment before and after total knee replacement by means of instrumented platforms has not been widely studied. Moreover, a large number of instruments has been used making difficult to draw consistent information and rising confu- sion for the clinical practice. The present meta-analysis demonstrated that the Neurocom Balance Master System™, one of the most used in- struments, showed enough consistency of the static measure in terms of postural sway velocity in the four studies included, and can be consid- ered as a reference for further studies on balance and proprioception in patients who underwent TKR.

It is strongly suggested, however, to plan further clinical trials in the future in order to compare TKR patients with healthy control, and to compare the effects of the various implant models and rehabilitation procedures on functional outcome. In addition, measurements related to the knee joint and other single-joints and single body segments contri- bution should be integrated to instrumented platforms assessments to better understand how knee proprioceptive deficits affects whole body balance control, and how the improvements during rehabilitation re- flects on it.

Finally, it should be mentioned that balance and proprioception impairments are common among various populations of orthopedic or neurological patients. The results of this systematic review cannot be generalized, as literature search was strictly focused on TKR patients. However, it would be of high clinical relevance for future studies to investigate which are most reliable procedures to assess balance and proprioception impairments also in other pathologies.

References

[1] F. Domínguez-Navarro, C. Igual-Camacho, A. Silvestre-Mun˜oz, S. Roig-Casasús, J. M. Blasco, Effects of balance and proprioceptive training on total hip and knee replacement rehabilitation: a systematic review and meta-analysis, Gait Posture 62 (2018) 68–74, https://doi.org/10.1016/j.gaitpost.2018.03.003.

[2] A. Ouattas, E. Wellsandt, N.H. Hunt, C.K. Boese, B.A. Knarr, Comparing single and multi-joint methods to detect knee joint proprioception deficits post primary unilateral total knee arthroplasty, Clin. Biomech. Bristol Avon (Bristol, Avon) 68 (2019) 197–204, https://doi.org/10.1016/j.clinbiomech.2019.06.006.

[3] S. Bakırhan, S. Angın, V. Karatosun, B. Ünver, I. Günal, Physical performance parameters during standing up in patients with unilateral and bilateral total knee arthroplasty, Acta Orthop. Traumatol. Turc. 46 (2012) 367–372, https://doi.org/10.3944/aott.2012.2684.

[4] R.A. Clark, F.J. Seah, H.C. Chong, C.L. Poon, J.W. Tan, B.F. Mentiplay, Y.H. Pua, Standing balance post total knee arthroplasty: sensitivity to change analysis from four to twelve weeks in 466 patients, Osteoarthr. Cartil. 25 (2017) 42–45, https://doi.org/10.1016/j.joca.2016.08.009.

[5] G.C. Gauchard, G. Vançon, P. Meyer, D. Mainard, P.P. Perrin, On the role of knee joint in balance control and postural strategies: effects of total knee replacement in elderly subjects with knee osteoarthritis, Gait Posture 32 (2010) 155–160, https:// doi.org/10.1016/j.gaitpost.2010.04.002.

[6] Y. Ishii, H. Noguchi, M. Takeda, J. Sato, Y. Kishimoto, S. Toyabe, Changes of body balance before and after total knee arthroplasty in patients who suffered from bilateral knee osteoarthritis, J. Orthop. Sci. 18 (2013) 727–732, https://doi.org/ 10.1007/s00776-013-0430-1.

[7] A´. Pethes, Z. Bejek, R.M. Kiss, The effect of knee arthroplasty on balancing ability in response to sudden unidirectional perturbation in the early postoperative period, J. Electromyogr. Kinesiol. 25 (2015) 508–514, https://doi.org/10.1016/j. jelekin.2015.02.010.

[8] G. Stan, H. Orban, C. Orban, D. Petcu, P. Gheorghe, The influence of total knee arthroplasty on postural control, Chirurgia 108 (2013) 874–878.

[9] D. Thewlis, S. Hillier, S.J. Hobbs, J. Richards, Preoperative asymmetry in load distribution during quiet stance persists following total knee arthroplasty, Knee Surg. Sports Traumatol. Arthrosc. 22 (2014) 609–614, https://doi.org/10.1007/ s00167-013-2616-7.

[10] D. Vahtrik, J. Ereline, H. Gapeyeva, M. P¨a¨asuke, Postural stability in relation to anthropometric and functional characteristics in women with knee osteoarthritis following total knee arthroplasty, Arch. Orthop. Trauma Surg. 134 (2014) 685–692, https://doi.org/10.1007/s00402-014-1940-9.

[11] S.D. Cho, C.H. Hwang, Improved single-limb balance after total knee arthroplasty, Knee Surg. Sports Traumatol. Arthrosc. 21 (2013) 2744–2750, https://doi.org/ 10.1007/s00167-012-2144-x.

[12] P. Jogi, A. Zecevic, T.J. Overend, S.J. Spaulding, J.F. Kramer, Force-plate analyses of balance following a balance exercise program during acute post-operative phase in individuals with total hip and knee arthroplasty: a randomized clinical trial, SAGE Open Med. 7 (4) (2016), https://doi.org/10.1177/2050312116675097, 2050312116675097. eCollection 2016.

[13] A.C.M. Chan, X.H. Ouyang, D.A.M. Jehu, R.C.K. Chung, M.Y.C. Pang, Recovery of balance function among individuals with total knee arthroplasty: comparison of responsiveness among four balance tests, Gait Posture 59 (2018) 267–271, https:// doi.org/10.1016/j.gaitpost.2017.10.020.

[14] S. Roig-Casasús, J.M. Blasco, L. Lo´pez-Bueno, M.C. Blasco-Igual, Balance training with a dynamometric platform following total knee replacement: a randomized controlled trial, J. Geriatr. Phys. Ther. 41 (2018) 204–209, https://doi.org/ 10.1519/JPT.0000000000000121.

[15] J.J. Negus, D.P. Cawthorne, J.S. Chen, C.J. Scholes, D.A. Parker, L.M. March, Patient outcomes using Wii-enhanced rehabilitation after total knee replacement – the TKR-POWER study, Contemp. Clin. Trials 40 (2015) 47–53, https://doi.org/ 10.1016/j.cct.2014.11.007.

[16] C.D. Liao, L.F. Lin, Y.C. Huang, S.W. Huang, L.C. Chou, T.H. Liou, Functional outcomes of outpatient balance training following total knee replacement in patients with knee osteoarthritis: a randomized controlled trial, Clin. Rehabil. 29 (2015) 855–867, https://doi.org/10.1177/0269215514564086.

[17] V. Fung, A. Ho, J. Shaffer, E. Chung, M. Gomez, Use of Nintendo Wii Fit™ in the rehabilitation of outpatients following total knee replacement: a preliminary randomised controlled trial, Physiotherapy 98 (2012) 183–188, https://doi.org/ 10.1016/j.physio.2012.04.001.

[18] S.R. Piva, A.B. Gil, G.J. Almeida, A.M. DiGioia, T.J. Levison, G.K. Fitzgerald, A balance exercise program appears to improve function for patients with total knee arthroplasty: a randomized clinical trial, Phys. Ther. 90 (2010) 880–894, https://doi.org/10.2522/ptj.20090150.

[19] K. Doma, A. Grant, J. Morris, The effects of balance training on balance performance and functional outcome measures following total knee arthroplasty: a systematic review and meta-analysis, Sports Med. 48 (2018) 2367–2385, https:// doi.org/10.1007/s40279-018-0964-7.

[20] H.T. Oh, G. Hwangbo, The effects of proprioception exercise with and without visual feedback on the pain and balance in patients after total knee arthroplasty, J. Phys. Ther. Sci. 30 (2018) 124–126, https://doi.org/10.1589/jpts.30.124.

[21] M. Moutzouri, N. Gleeson, E. Billis, E. Tsepis, I. Panoutsopoulou, J. Gliatis, The effect of total knee arthroplasty on patients' balance and incidence of falls: a systematic review, Knee Surg. Sports Traumatol. Arthrosc. 25 (2017) 3439–3451, https://doi.org/10.1007/s00167-016-4355-z.

[22] L. Bragonzoni, E. Rovini, G. Barone, F. Cavallo, S. Zaffagnini, M.G. Benedetti, How proprioception changes before and after total knee arthroplasty: a systematic review, Gait Posture 72 (2019) 1–11, https://doi.org/10.1016/j. gaitpost.2019.05.005.

[23] Y. Ivanenko, V.S. Gurfinkel, Human postural control, Front. Neurosci. 12 (2018) 171, https://doi.org/10.3389/fnins.2018.00171.

[24] L. Quagliarella, N. Sasanelli, V. Monaco, G. Belgiovine, A. Spinarelli, A. Notarnicola, L. Moretti, B. Moretti, Relevance of orthostatic posturography for clinical evaluation of hip and knee joint arthroplasty patients, Gait Posture 34 (2011) 49–54, https://doi.org/10.1016/j.gaitpost.2011.03.010.

[25] S. Bakirhan, S. Angin, V. Karatosun, B. Unver, I. Günal, A comparison of static and dynamic balance in patients with unilateral and bilateral total knee arthroplasty, Eklem Hastalik. Cerrahisi 20 (2009) 93–101.

[26] P.J. Vandekerckhove, R. Parys, T. Tampere, P. Linden, L. Van den Daelen, P. C. VerdonK, Does cruciate retention primary total knee arthroplasty affect proprioception, strength and clinical outcome? Knee Surg. Sports Traumatol.

Arthrosc. 23 (2015) 1644–1652, https://doi:010.1007/s00167-014-3384-8

[27] M. I˙syar, I. Saral, O. Güler, E. Çakar, M. Mahirog˘ullari, Can prosthesis design of total knee arthroplasty affect balance? Eklem Hastalik. Cerrahisi 26 (2015) 72–76, https://doi.org/10.5606/ehc.2015.18.

[28] J. Goetz, S. Schiessl, C. Baier, S. Dullien, K. Mueller, J. Grifka, F. Koeck, Postural stability after patient-specific interpositional knee spacer or total knee arthroplasty: a comparative study, Int. Orthop. 41 (2017) 67–73, https://doi.org/ 10.1007/s00264-016-3266-4.

[29] J. Go¨tz, J. Beckmann, I. Sperrer, C. Baier, S. Dullien, J. Grifka, F. Koeck, Retrospective comparative study shows no significant difference in postural stability between cruciate-retaining (CR) and cruciate-substituting (PS) total knee implant systems, Int. Orthop. 40 (2016) 1441–1446, https://doi.org/10.1007/ s00264-015-3067-1.

[30] A. Hadamus, D. Białoszewski, Objective assessment of knee proprioception and sensorimotor function in patients with primary gonarthrosis before and after knee replacement, Ortop. Traumatol. Rehabil. 19 (2017) 403–414, https://doi.org/ 10.5604/01.3001.0010.5820.

[31] J.M. Campbell, M. Kulgar, S. Ding, D.P. Carmody, S.J. Hakonsen, Y.T. Jadotte, S. White, Z. Munn, Chapter 9: diagnostic test accuracy systematic reviews, in: E. Aromataris, Z. Munn (Eds.), Joanna Briggs Institute Reviewer's Manual, The Joanna Briggs Institute, 2017. Available from, https://reviewersmanual.joannabri ggs.org/.

[32] J.R. Landis, G.G. Koch, The measurement of observer agreement for categorical data, Biometrics 33 (1977) 159–174, https://doi.org/10.2307/2529310.

[33] J.L. Neyeloff, S.C. Fuchs, L.B. Moreira, Meta-analyses and Forest plots using a Microsoft excel spreadsheet: step-by-step guide focusing on descriptive data analysis, BMC Res. Notes 5 (2012) 52, https://doi.org/10.1186/1756-0500-5-52.

[34] I. Bascuas, M. Tejero, S. Monleo´n, R. Boza, J.M. Muniesa, R. Belmonte, Balance 1 year after TKA: correlation with clinical variables, Orthopedics 36 (2013) e6–12, https://doi.org/10.3928/01477447-20121217-11.

35] I. Schwartz, L. Kandel, A. Sajina, D. Litinezki, A. Herman, Y. Mattan, Balance is an important predictive factor for quality of life and function after primary total knee replacement, J. Bone Joint Surg. Br. 94 (2012) 782–786, https://doi.org/10.1302/ 0301-620X.94B6.27874.

[36] F. Baumann, O¨. Bahadin, W. Krutsch, J. Zellner, M. Nerlich, P. Angele, C. O. Tibesku, Proprioception after bicruciate-retaining total knee arthroplasty is comparable to unicompartmental knee arthroplasty, Knee Surg. Sports Traumatol. Arthrosc. 25 (2017) 1697–1704, https://doi.org/10.1007/s00167-016-4121-2.

[37] A. Notarnicola, G. Maccagnano, A. Fiore, A. Spinarelli, L. Montenegro, M. Paoloni, F. Pastore, S. Tafuri, B. Moretti, Baropodometry on patients after total knee arthroplasty, Musculoskelet. Surg. 102 (2018) 129–137.

[38] Y.H. Pua, R.A. Clark, P.H. Ong, Evaluation of the Wii Balance Board for walking aids prediction: proof-of-concept study in total knee arthroplasty, PLoS One 23 (2015), https://doi.org/10.1371/journal.pone.0117124, 10(1):e0117124.

[39] J. Shin, H. Lee, W. Bae, J. Kim, Comparison of sit-to-stand and static standing balance ability between patients with total knee arthroplasty and elderly healthy subjects, J. Back Musculoskelet. Rehabil. 31 (2018) 425–430, https://doi.org/ 10.3233/BMR-170969.

[40] A.K. Stensdotter, J. Bjerke, M. Djupsjo¨backa, Postural sway in single-limb and bilateral quiet standing after unilateral total knee arthroplasty, Gait Posture 41 (2015) 769–773, https://doi.org/10.1016/j.gaitpost.2015.02.005.

[41] D.M. Venema, G.M. Karst, Individuals with total knee arthroplasty demonstrate altered anticipatory postural adjustments compared with healthy control subjects, J. Geriatr. Phys. Ther. 35 (2012) 62–71, https://doi.org/10.1519/ JPT.0b013e3182353ee4.

[42] Balance Master® System Operator's Manual Version 8.1, 2004. March 23.

[43] C.B. Swanik, S.M. Lephart, H.E. Rubash, Proprioception, Kinesthesia, and balance after total knee arthroplasty with cruciate-retaining and posterior stabilized prostheses, J. Bone. Jt. Surg. 86 (2004) 328–334, https://doi.org/10.1007/s12306- 017-0505-9.

Table 1
General description of included studies.

		Author (year)	Patients	Platform System	Description	Task	Static Tasks Explored Variables	Dynamic Tasks Explored Variables
ASSESSMENT STUDIES	POSTOPERATIVE	Bakirhan (2009) [25]*	80 pts, 35 unilateral, 45 bilateral, cemented, TKA with cruciate retaining (NexGen®, Zimmer, USA) Follow up:preop, 6 and 12 months postop	Balance Master System (version 8.0, NeuroCom Inc, USA)	Dual force plate	Stand in erect position on the firm and foam surfaces with eyes open and closed conditions Movements simulating functional activities	*Modified Clinical Test of Sensory Interaction on Balance (mCTSIB), Unilateral stance (US)*	*Limit of stability (LOS), Rhythmic weight shift (RWS)*
		Bakirhan (2012) [3]*	80 pts, 35 unilateral, 45 bilateral, cemented, TKA with cruciate retaining (NexGen®, Zimmer, USA) Follow up:preop, 6 and 12 months postop	Balance Master System (version 8.0, NeuroCom Inc, USA)	Dual force plate	Sit-to-stand tests		*Weight Transfer, Rising Index, Left/right weight symmetry*
		Vandekerckhove (2015) [26]*	45 pts, 27 cruciate-retaining (CR), 18 cruciate substituting (PS) design (Scorpio®, Stryker, Kalamazoo, Michigan,USA) Follow up: 2.9 yrs CR, 3.1 yrs PS	Balance Master system® (Neurocom, Clackamas, OR, USA)	Dual force plate	Stand in erect position on the firm and foam surfaces with eyes open and closed conditions Movements simulating functional activities	*Modified Clinical Test of Sensory Interaction on Balance (mCTSIB), Unilateral stance (US)*	*Limits of stability test (LOS), Rhythmic weight shift test (RWS), Weight-bearing squat (WBS)*
		Isyar (2015) [27] *	41 pts, 21PCL-substitution 20 PCL-retaining Follow-up: 25.6 months	Biodex Balance System (BBS; Biodex Medical Systems Inc., Shirley, NY, USA)	Multi-axial unstable, gradually lockable platform	Standing open eyes upright on the platform tilting 20° in the sagittal and transverse plane	*Static OSI*	*Medial/lateral stability index (MLSI), Anterior/ posterior stability index (APSI), Overall stability index (OSI)*
		Gotz (2016) [29]	40 pts CR (20) and PS (20) (PFC Sigma, DePuy, Warsaw, IN, USA) Follow up: 5.3 months	Biodex Balance System (Biodex, Shirley, NY, USA)	Multi-axial unstable, gradually lockable platform	Standing open eyes upright on the platform tilting 20° in the sagittal and transverse plane on double leg and single leg stance		*Medial/lateral Overall stability index (OSI)*
		Clark (2017) [4]	466 pts Follow up: 4 and 12 weeks postop	Nintendo Wii Balance Board	Low cost posturography system	Quiet standing with eyes open	*COP path length, m-l and a-p displacement, RMS amplitude and velocity, signal frequency content*	
		Goetz (2017) [28]*	40 pts, patient-specific IKS (20) or bikondylar TKA (20) Follow up: 15.7 months	Biodex Balance System (Biodex, Shirley, NY, USA)	Multi-axial unstable, gradually lockable platform	Standing open eyes upright on the platform tilting 20° in the sagittal and transverse plane on double leg and single leg stance	*Static OSI*	*Overall stability index (OSI)*
	PRE/POST-OPERATIVE	Quagliarella (2011) [24]*	Preop (one or two days): 240 pts, 181	Kistler 9286 (Kistler	Piezoelectric Force plate	Stand barefoot on the force	*Δ EO/EC, COP medio-lateral and*	

(*continued on next page*)

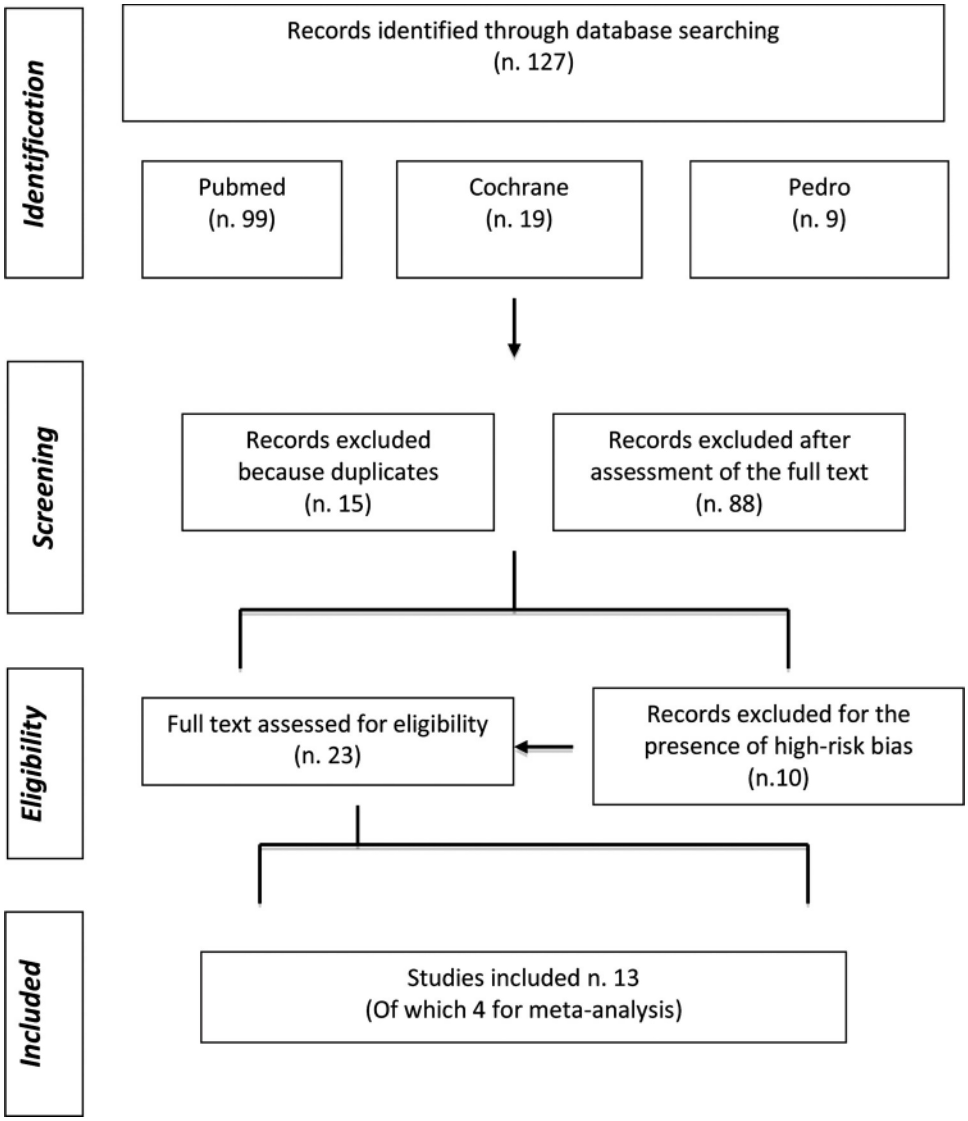


Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow chart.

Study	*Pts*	*Mean mCTSIB (deg/s)*	*SD*	*95%CI lower*	*95%CI upper*	*Weight*
Test on Firm Surface Eyes Open						
Bakiran, 2009	35	0.27	0.1	0.24	0.30	30%
Vandek CR, 2015	27	0.30	0.1	0.26	0.34	23%
Vandek PS, 2015	18	0.30	0.1	0.25	0.35	15%
Bascuas, 2013	44	0.3	0.1	0.26	0.34	17%
Schwartz, 2012	62	0.38	0.2	0.33	0.43	16%
Pooled Value	186	0.31		0.27	0.34	
Heterogeneity: I^2 =73%						
Test on Firm Surface Eyes Closed						
Bakiran, 2009	35	0.37	0.2	0.30	0.44	20%
Vandek CR, 2015	27	0.40	0.2	0.32	0.48	15%
Vandek PS, 2015	18	0.50	0.2	0.41	0.59	10%
Bascuas, 2013	44	0.42	0.2	0.36	0.48	24%
Schwartz, 2012	62	0.47	0.2	0.42	0.52	31%
Pooled Value	186	0.43		0.39	0.47	
Heterogeneity: I^2 =51%						

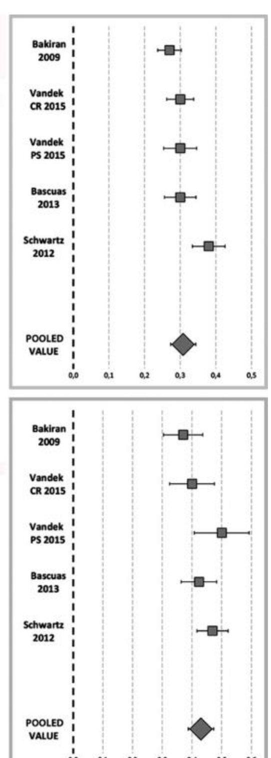
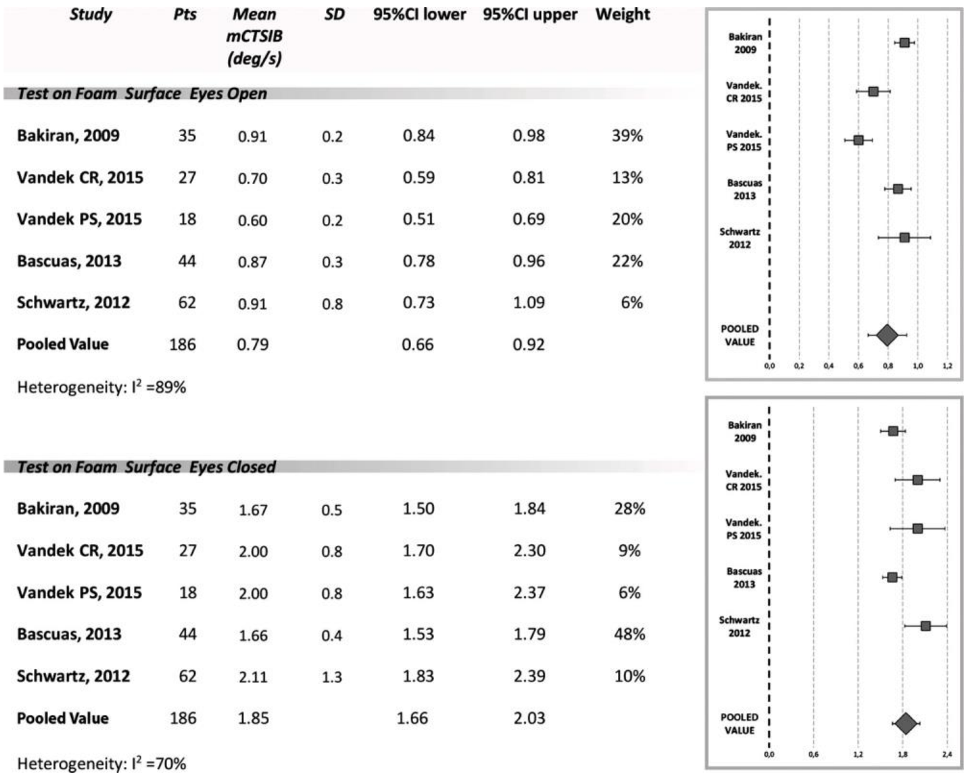


Fig. 2. Heterogeneity among the results of balance assessment performed on firm surfaces.



Study	Pts	Mean mCTSIB (deg/s)	SD	95%CI lower	95%CI upper	Weight
Test on Foam Surface Eyes Open						
Bakiran, 2009	35	0.91	0.2	0.84	0.98	39%
Vandek CR, 2015	27	0.70	0.3	0.59	0.81	13%
Vandek PS, 2015	18	0.60	0.2	0.51	0.69	20%
Bascuas, 2013	44	0.87	0.3	0.78	0.96	22%
Schwartz, 2012	62	0.91	0.8	0.73	1.09	6%
Pooled Value	186	0.79		0.66	0.92	
Heterogeneity: I^2 =89%						
Test on Foam Surface Eyes Closed						
Bakiran, 2009	35	1.67	0.5	1.50	1.84	28%
Vandek CR, 2015	27	2.00	0.8	1.70	2.30	9%
Vandek PS, 2015	18	2.00	0.8	1.63	2.37	6%
Bascuas, 2013	44	1.66	0.4	1.53	1.79	48%
Schwartz, 2012	62	2.11	1.3	1.83	2.39	10%
Pooled Value	186	1.85		1.66	2.03	
Heterogeneity: I^2 =70%						

Fig. 3. Heterogeneity among the results of balance assessment performed on foam surfaces.

Table 3
Data from studies using Biodex Balance System.

Follow up			*15.7 months*		*6 months*			*25.6 months*		
			Goetz 2017		*Gotz 2016 CR*	*CS*		*Isyar 2017 PCL-S*	*PCL-R*	
OSI			*median*	*n pts*	*median*	*median*	*n pts*	*mean rank*	*mean rank*	*n pts*
two-leg	**stance**		1.9	20	2.4	2.89	20 + 20			21 + 20
one-leg	**stance**	**operated-on**	1.35		1.4	1.55				
one-leg	**stance**	**non-operated-on**	1.5		1.6	1.6				
two-leg	**stance**	**6**						17.3	23.7	
two-leg	**stance**	**8**						17.2	23.8	
APSI-6								16.6	24.4	
APSI-								16.2	24.9	

8		
MLSI-6	20.2	20.7
MLSI-8	20.4	21.7
FRI-6	19.3	21.7
FRI-8	18.8	22.2

OSI: Overall Stability Index; **APSI**: anterior-posterior stability index; **MLSI**: medial-lateral stability index; **FRI**: fall risk index; **n pts**: number of patients.