Measurement Methods of Balance Among Above-Knee Amputees: A Literature Review

Diz Üstü Amputelerde Denge Değerlendirme Yöntemleri: Literatür Taraması

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ABSTRACT

Aim: Balance rehabilitation in individuals with above-knee amputees has importance during the rehabilitation process. Various methods are used for balance assessment in individuals with above-knee amputees and determination is needed to ways that were mostly used in the literature. The aim of the study was a review of the methods utilized often to assess dynamic and static balance for individuals with above-knee amputees.

Method: PubMed/MEDLINE, Web of Science, Scopus, and Google Scholar were searched between 2010 – 2021 (up to May) years with "(transfemoral amputation OR above-knee amputation OR hip disarticulation) AND (static balance OR dynamic balance OR postural sway)" keywords groups. Studies read and analyzed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The Joanna Briggs Institute Critical Appraisal tools used to determine the quality of studies.

Results: Eight studies that included a total of 114 participants were selected. Among the studies, 1 were randomized cross over study, 3 were cross-sectional studies, 2 were non-randomized studies and others were cohort, and case-control studies. According to results of reviewed studies, while force plate was widely used in static and dynamic balance evaluation, clinical tests were also preferred for static evaluation.

Conclusion: Clinical balance scales used in individuals with lower limb amputation are not specifically developed for amputation. In addition, technological devices should be used for a more detailed balance assessment. The results may have been affected because the quality levels of the studies were not high, and the study designs included were varied. More accurate results can be achieved by designing future studies with a high population and randomized control.

Keywords: Above-knee amputation, berg balance test, force platform, posturography, timed up go.

ÖZ

Amaç: Denge rehabilitasyonu, diz üstü amputasyonu bulunan bireylerde rehabilitasyon sürecinde önem taşımaktadır. Diz üstü ampute olan bireylerde denge değerlendirmesi için çeşitli yöntemler kullanılmaktadır ve literatürde en çok kullanılan yöntemlerin belirlenmesine ihtiyaç duyulmaktadır. Çalışmanın amacı, diz üstü amputasyonu bulunan bireylerde dinamik ve statik dengeyi değerlendirmek için sıklıkla kullanılan yöntemlerin gözden geçirilmesidir.

Gereç ve yöntemler: PubMed/MEDLINE, Web of Science, Scopus ve Google Scholar veritabanları 2010 – 2021 (Mayıs ayına kadar) yılları arasında "(transfemoral amputasyon VEYA diz üstü ampütasyon VEYA kalça dezartikülasyonu) VE (statik denge VEYA dinamik denge VEYA postural

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salınım)" anahtar kelime grupları ile tarandı. Çalışmalar, Sistematik İncelemeler ve Meta-Analizler için Tercih Edilen Raporlama Öğeleri (PRISMA) çerçevesinde değerlendirildi. Çalışmaların kalitesini belirlemek için The Joanna Briggs Institute Critical Appraisal değerlendirme yöntemi kullanılmıştır.
Bulgular: Derlemeye toplam 114 katılımcıyı içeren sekiz çalışma dahil edildi. Çalışmalardan 1'i randomize çapraz çalışma, 3'ü kesitsel çalışma, 2'si randomize olmayan çalışma, diğerleri ise kohort ve vaka kontrol çalışmalarıydı. İncelenen çalışmaların sonuçlarına göre, kuvvet platformu statik ve dinamik denge değerlendirmesinde yaygın olarak kullanılırken, statik değerlendirme için klinik testlerin de tercih edildiği görülmüştür.
Sonuç: Alt ekstremite amputasyonu olan bireylerde kullanılan klinik denge ölçekleri özellikle amputasyon için geliştirilmemiştir. Ayrıca daha detaylı bir denge değerlendirmesi için teknolojik cihazlar kullanılmalıdır. Çalışmaların kalite düzeylerinin yüksek olmaması ve dahil edilen çalışma tasarımları farklı olması nedeniyle sonuçlar etkilenmiş olabilir. Gelecekteki çalışmaların yüksek popülasyonlu ve randomize kontrollü olarak tasarlanmasıyla daha doğru sonuçlara ulaşılabilir.

Anahtar Kelimeler: Berg denge testi, diz üstü amputasyonu, kuvvet platformu, posturografi, süreli kalk ve yürü.

Introduction

Amputation is defined as the permanent removal of all or part of the limb because of injury, disease, or surgery and can be done at the joint level (disarticulations) or anywhere in the bone above or below the joint level (1). More than 20% of lower limb traumas causing severe wound contamination and significant soft tissue loss can cause amputation (2). Lower extremity limb loss can be classified as major (such as trans-femoral, or trans-tibial amputation) and minor (such as toes or at the mid-foot level) limb loss (3).

Due to the mass asymmetry and absence of sensorimotor control of lower limbs, balance impairment and loss of function are common problems after lower limb amputation (4). The underlying cause of this increased postural sway is the lack of the correct sensory feedback mechanism of the affected limb (5). Previous studies reveal that the risk of falls and fall-related injuries is higher after lower limb amputation, nearly double (6,7). The factors such as remaining musculature and residual limb length can influence independent, functional mobility after amputation and gait (8).

More than 50% of lower limb amputees fall at least once a year, even after completing a comprehensive rehabilitation program. The consequences of falls include prolonged hospital stays, fear of falling again, social withdrawal, severe injuries, and fractures, and even death (9,10). However, selecting an appropriate test is difficult, particularly to predict the risk of falls (11). Therefore, investigation of balance is thought as very important to prevent falls.

Different balance assessment tools and methods such as Berg Balance Scale (BBS), Timed-up and Go (TUG), or Functional Reach Test can be used to measure the balance performance and postural sway (12). Moreover, there is some additional amputation-specific objective (Harold Wood Stanmore grading system, amputee mobility predictor or Houghton Scale) and subjective (Prosthesis Evaluation Questionnaire or Locomotor Capabilities Index) tests (13).It has been reported that static and dynamic balance are affected after big toe amputation on foot (14), which is the most common type of amputation. Considering the great effect of amputation of a relatively small area on balance, the importance of balance is more prominent in the case of amputation of the entire limb. Although the variety the number of balance tests has been used in the clinical research for a long time, a study was needed 1) to follow up the current evaluation methods, and 2) to group all the evaluation methods mentioned in the literature with and without prosthesis. For these reasons, the aim of this review is to examine the measurement methods which uses to assess static and dynamic balance in patients with above-knee amputation levels.

Material and Method

Search strategy

Articles related to lower limb amputation between January 2010 – May 2021 years were

searched in the electronic databases PubMed/MEDLINE, Web of Science, Scopus, and Google Scholar. Two groups of keywords related to "above knee level - amputations" and "balance" were determined. A combination that included the two groups' keywords as (transfemoral amputation OR above-knee amputation OR hip disarticulation) AND (static balance OR dynamic balance OR postural sway) was used as keywords.

Study selection criteria

The studies, 1) which about the amputee with trans-femoral amputation or hip disarticulation, 2) assessed the static or dynamic balance 3) and written in English, were included. Meta-analysis, reviews, case reports, conference papers, letters, editorials, thesis, and patents were excluded.

Data extraction and quality assessment

The review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (15). Firstly, the articles were selected by their titles and abstracts according to our inclusion and exclusion criteria. In the second step, the full texts of articles were screened and checked to meet the inclusion criteria by three authors (ÇD, GEU, and HE) independently. When any disagreements on data extraction or quality assessment between reviewers, the paper(s) was reviewed by a senior researcher (İY). By using the Mendeley, duplicated ones were excluded.

The main characteristic of the articles that subjects (number, ages), amputation level, outcome measures, the method of assessing balance (scale, questionnaire, test, tools etc.), protocol were saved. The assessment of the methodological quality and risk of bias of the included articles was carried out using The Joanna Briggs Institute (JBI) Critical Appraisal tools for a) Analytical Cross-Sectional Studies (8-Items), b) Cohort Studies (11-Items) c) non-Randomized (9-Items) and d) Randomized (13-Items) Controlled Trials (16). JBI is an international research organization from South Australia which develops and delivers evidence-based information, software, education, and training designed to improve healthcare practice and health outcomes (17). The possible answers for each item are a) Yes, b) No, c) Unclear or c) Not Applicable (18,19).

Results

Figure 1 displays a flow chart summarizing the results of the systematic search that identified a total of 101 clinical trials in the electronic databases PubMed, Web of Science, Scopus, and Google Scholar. After having screened the articles by title, removed duplicates, and excluded ineligible articles, 8 studies remained and were included in this review (Table 1).

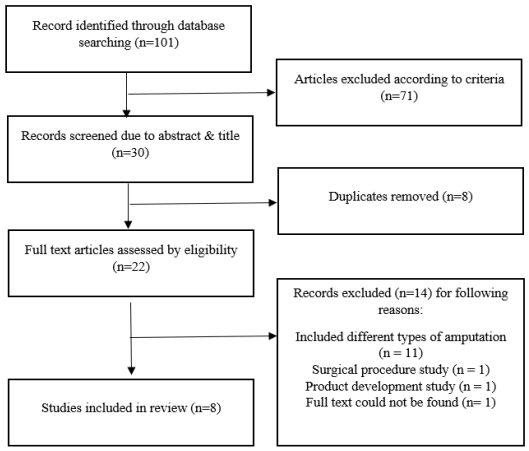

Figure 1: Flow chart illustrating the different phases of the search and study selection.

Study characteristics

Half (n= 4) of the studies were observational (3 cross-sectional & 1 cohort) in design, 2 of them were randomized crossover and 2 of them were non-randomized controlled. In most of the studies, the balance abilities of the TFAs were compared with age-matched and sex-matched control groups. Table 2 shows the characteristics of the 8 included studies.

The reviewed studies included a total of 74 LLA participants who had a transfemoral amputation. The highest average age of the participants with LLA was 60.8 ± 11.3 years and the lowest average age was 25.8 ± 3.27 years.

Outcome measures

Posturography

Static posturography was preferred in a study that was designed as cross-sectional and 12 patients with TFA and 12 controls participated (20). During the posturography, the Modified Clinical Test of Sensory Interaction on Balance (mCTSIB) was applied to participants.

Table 1: Summary of Study Appraisal Based On JBI Appraisal Checklist

Author	Design	Score based on appropriate JBI appraisal*													Overall appraisal	Total
		1	2	3	4	5	6	7	8	9	10	11	12	13		
Claret et al., 2019[20]	Cross-sectional	N	Y	N	Y	Y	N	Y	Y	NA	NA	NA	NA	NA	included	5 / 8
de Araujo et al., 2019[21]	Cross-sectional	N	Y	N	Y	N	N	Y	Y	NA	NA	NA	NA	NA	included	4 / 8
Highsmith et al., 2014[22]	Randomized A–B crossover	Y	Y	N	N	N	N	Y	U	Y	Y	Y	Y	Y	included	8/13
Kendell et al., 2016[23]	Cross-sectional	Y	Y	Y	Y	N	N	Y	Y	NA	NA	NA	NA	NA	included	6 / 8
Khiri et al., 2015[24]	Non-randomized controlled	Y	Y	N	Y	Y	Y	Y	Y	Y	NA	NA	NA	NA	included	8 / 9
Kumar et al., 2019[25]	Non-randomize controlled	Y	Y	N	Y	Y	Y	Y	Y	Y	NA	NA	NA	NA	included	8 / 9
McGrath et al., 2018[26]	Case - Control	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	NA	NA	NA	included	9 / 10
Wong et al., 2015[27]	Prospective Cohort	N	N	Y	Y	N	Y	Y	Y	Y	N	Y	NA	NA	Included	7 / 11

*Scored gained/maximum score, appropriate appraisal for either RCT, cohort (prospective or retrospective), cross-sectional or case-control study was used. RCT - 13 criteria, cohort - 11 criteria, cross-section - 8 criteria, Y=yes; N=no; U=unclear; NA=not applicable

Table 2: Studies Examining the Effects Of Balance Assessment In Transfemoral Amputees And Hip Disarticulation

Study	**Design**	**Participants (n)**	**Age (years)**	**Time after amputation & Prosthetic use**	**Stump length (cm / %)**	**Objective**	**Balance Measures**	**Additional Measures**
Claret et al., 2019[20]	Cross-sectional	Unilateral TFA (12) & Able bodied (12)	46.08±13.8 & 40.67±12.4	Min-Max: 1-50 years & NR	Min-Max: 13-28	To investigate the neuromuscular adaptations resulting from a disrupted sensorimotor system that was caused by a unilateral lower-limb amputation	Static posturographic test (force platform), BBS, TUG	Years since amputation, Prosthesis type, Length of stump in cm, Etiology
de Araujo et al., 2019[21]	Cross-sectional	Unilateral TFA (8) & Able bodied (8)	33.5 ± 5.6 & 27.2 ± 8.4	11.7 ± 2	NR	To compare static and dynamic postural control in sitting volleyball players with and without unilateral transfemoral amputation	Balance Master System	IPAQ
Highsmith et al., 2014[22]	Randomized A–B crossover	Unilateral TFA (20) & Able bodied (5)	46.5 ± 14.2 & 57.2 ± 15.7	17.7 ± 15.6 NR	70% ± 30	To determine overground walking performance in terms of time and postural stability by comparing two microprocessor prosthetic knee technology.	Timed Walking Tests LOS and Postural Stability (The Biodex Balance SD system)	Etiology, Hip flexion contracture angle (Thomas test),
Kendell et al., 2016[23]	Cross-sectional	Unilateral TFA (11)	57 ± 13	NR NR	NR	To assess plantar-pressure and temporal measures in measuring dynamic stability of TF amputees	Plantar pressure	Stride time Double support time
Khiri et al., 2015[24]	Non-randomized controlled	Unilateral TFA (5) & Able bodied (5)	44.2 ± 4.1 & 45 ± 4.5	19.6 ± 4.5 NR	NR	To compare stability, gait performance and energy consumption in TFA with able-bodied	CoP parameters obtained with force platform	Physical assessment Energy expenditure (Physiological cost index)
Kumar et al., 2019[25]	Non-randomize controlled	Unilateral TFA (5) & Able bodied (5)	25.8 ± 3.27 & 27 ± 2.0 9	NR 4.4 ± 0.54	85.96 % ± 7.28	To find the effect of vibrotactile feedback on the limit of stability during forward and backward weight shifting exercise in TFA.	CoP parameters obtained with force platform	Self-assessment questionnaires (for the vibrotactile sensory feedback system)

Table 2: Studies Examining the Effects Of Balance Assessment In Transfemoral Amputees And Hip Disarticulation (Tablo 2 devam)

Study	**Design**	**Participants (n)**	**Age (years)**	**Time after amputation & Prosthetic use**	**Stump length (cm / %)**	**Objective**	**Balance Measures**	**Additional Measures**
McGrath et al., 2018[26]	Case - Control	TFA (5) & Able bodied (5)	41.6 ± 14.3 & 27.4 ± 2.9	NR	NR	To investigate the efficacy of advanced prosthetic componentry with respect to their effects on inter-limb load distribution and balance ability.	CoP calculations obtained with force platform	-
Wong et al., 2015[27]	Prospective Cohort	TFA (8)	60.8 ± 11.3	NR	NR	To assess whether people older than 40 years with transfemoral amputations would demonstrate changes in balance confidence, balance ability, functional walking, and incidence of falls when using prostheses with MK compared with non-MK.	BBS, TUG	ABC, Prosthetic alignment with posture system, fear of falling and fall history, Houston Scale, K-level.

ABC: Activities-Specific Balance Confidence, BBS: Berg Balance Scale, CoP: Center of pressure, IPAQ: International Physical Activity Questionnaire, LOS: Limit of stability, NR: Not-reported, TFA: Trans-femoral amputee, TUG: Timed Up-and-Go test

According to mCTSIB, when the participants had stood on feet in different conditions (eyes open and firm surface, eyes close and firm surface, eyes open and foam surface, eyes close and foam surface) postural sway was assessed (degree/sec).

A dynamic postural control test (Balance Master Systems and Biodex Balance SD Systems) was used in two studies that were designed cross-sectional and randomized cross over, respectively (21, 22). Both studies utilizing the Limits of Stability (LOS) test during dynamic posturography assessment. In studies during the LOS test, researchers had been instructed to participants move to eight targets shown on the screen in front of them, fast and precisely as possible.

Force platform and plantar pressure

The center of pressure was calculated in 5 studies while standing and walking in TFA by using force platforms [Zebris force platform (Medical GmbH, Germany), Kistler force platform (AG, Winterthur, Switzerland)] and in-shoe plantar pressure measure (20,23-26) (wearable F-Scan Mobile system, Tekscan, Inc., Boston, MA, USA). A force plate platform was the most commonly used method to assess static balance performance by calculating the CoP while standing in four studies (20-22,25). The interested CoP parameters in the studies were the mean displacement of CoP from its overall mean position, excursion of the CoP in the mediolateral (ML) direction, the path length in the anteroposterior (AP) and ML direction; the velocity of the CoP in the AP and ML direction which were explained how calculated in content. The larger CoP excursions accepted as less balance control while standing. Trial durations were determined as 5, 14, 30, and 60 secs and the acquisition frequencies of data were 60 Hz, 100 Hz or 500 Hz while a cut-off frequency of 0.15 or 10 Hz to remove the noise. Among the studies, a maximum of 5 repeats was attempted. Data collection protocols and instructions were vary depending on the aim of the studies. The trails were recorded at the comfortable standing position while looking forward with arms on sides, with both feet (20,21,25) or only prosthetic side (22), on flat or facing down 5° slope surface with the closed (25) or opened eyes (20–22) conditions. In a non-randomize controlled study, the CoP was evaluated with a force plate while weight shifting exercises as dynamic balance assessment (25).

Only one study that was designed as cross-sectional used the in-shoe plantar pressure system as a dynamic balance assessment tool (23). The CoP motion, pressure-sensor cell loading, and gait timing of the unilateral TFA were analyzed while walking at the rigid and soft ground, on a ramp with a 7° incline and stairs with 12 steps. CoP directions change at AP and ML, cell triggering, maximum lateral force placement was collected at 120 Hz for each condition.

Clinic tools

There were three studies that used the BBS, TUG and, timed walking tests (TWT) for assessing the dynamic balance in TFA (20,22,27). For the TWT, 6-m as short distance, 38-m, and 75-m as a mid-distance were chosen and examined while both walking slow or fast instructed speed on even and uneven surfaces. The TUG test was applied by the same procedure in two reviewed studies by recording the time participants need to stand up from a chair, walk 3-mt/10-ft, turn around and walk the to chair back and sit down.

Discussion

The results of this study, which aimed to examine the measurement methods which uses to assess static and dynamic balance in patients with above-knee amputation levels, showed that the most commonly used methods are posturography and plantar pressure assessment and also clinical tool are also complimentary.

In individuals with LLA, balance states are directly related to their ability to walk and functional capacity. In addition, patients who have a better balance also have a better quality of daily life. Therefore, balance gain should be one of the important goals of the treatment in the physiotherapy and rehabilitation process for patients with LLA (28). To reveal an effective balance rehabilitation, it is essential to make objective balance assessments by using the correct, reliable, and valid methods firstly. Besides, there is no study investigating how the balance should be evaluated in individuals with LLA, the study conducted in patients with balance deficits reported that more technological approaches have become popular instead of clinical evaluation scales or tests (12). According to the results of our study, in which we examined balance assessment methods in

individuals with LLA, we determined that the use of technological approaches as well as clinical approaches has been common in recent years. In the studies we included in the review, we determined that the force platform is the most widely used tool for analyzing both static and dynamic activities such as standing and walking. In order to improve postural stability, which is one of the rehabilitation goals in individuals with LLA, it is important to determine the level of postural deterioration accurately and objectively. With a force platform, postural stability can be evaluated by analyzing the time-varying coordinates of the CoP (29,30). There is a common opinion that the CoP oscillation obtained with this analysis gives information about body oscillations and is valid in determining postural stability. Although there is very limited information about the CoP patterns in amputees, it is known that the CoP shifts towards the healthy limb when the prosthesis does not fully and correctly support the amputee limb (31). This result can guide physiotherapists on whether the prosthesis provides appropriate support for the patient, even in a practical CoP evaluation. In the studies included and in which the force platform was used for balance evaluation, it was observed that postural oscillation rates were more pronounced in the evaluations made with the eyes closed compared to the eyes open position. Impaired visual input may cause additional postural sway in patients, therefore, for a valid evaluation to be made on the force platform in individuals with LLA, the clinical condition of the patient should also be considered. In addition, as a result of Berg et al.'s study (32), a moderate correlation was found between BBS and CoP oscillations. This result may show us that a functional balance test such as BBS can be used in cases where there is no force platform or evaluation cannot be made due to the patient's condition.

Another technological method that provides information about postural stability in people with TFA is posturography. Although posturography has not been used as often as a force platform in the included studies, it is important in both static and dynamic balance assessment in terms of the objective data it provides. In two different studies in which dynamic postural control was evaluated by posturography, the use of the LOS test was preferred and the maximum distance that patients could change their center of gravity without changing the support base was calculated. Dynamic postural stability can provide information in addition to functional balance assessment, determination of fall risk, appropriateness of prosthesis design, and investigating rehabilitative progress.

Although researchers could use devices that are a component of motion analysis systems such as force platforms and posturography in their clinical settings, it has been observed that they use clinical tests as an integral part of the analysis. Clinical assessments such as timed performance tests and questionnaires are indirectly related to balance, but there is no standard clinical assessment tool specifically for use in amputees. BBS, TUG, and ABC were the most preferred clinical balance assessment tools in the included studies. Originally designed to assess the balance of elderly individuals, the BBS has been reported as a valid scale for the assessment of balance ability in people with LLA, both prosthetic and non-prosthetic wearers. However, BBS has been shown to be insufficient to discriminate between groups according to amputation etiology, level, and fall risk of people with LLA (33). The TUG test, like BBS, was developed to examine balance impairment in elderly people and is defined as a reliable, fast, and valid measure of physical balance and mobility in elderly individuals with LLA (34,35).

Timed walking tests do not directly provide information on balance, but balance and mobility are evaluated under the heading of activity according to the International Classification of Functioning, Disability and Health (ICF) perspective, and good balance has a positive effect on mobility. In addition, our results are included because providing gait stability is one of the aims of amputee rehabilitation (36) and they are frequently used in the included studies. Timed walking tests such as the 2-minute or 6-minute walk test, 10-m or 12-m are commonly used clinical tools in LLA.

As a result, clinical balance assessment tools in individuals with TFA can be used not to distinguish between different types of balance disorders, but to determine whether the person has balance problems. Moreover, clinical methods used in amputees are also used in people with many diseases in the literature. For this reason, there is a need to analyze the balance limitations experienced by amputees well and to develop for clinical measurement to

situation specific. Advanced equipment is needed for detailed balance analysis. Access to these devices is not possible in all clinics or clinicians are not equipped to use the devices, which may limit their use. However, we believe that more functional assessment methods, including sensors, will become commonplace in the near future for more precise and comprehensive balance assessment in a clinical setting.

Our limitations were mostly due to the quality levels of the studies included in this review. Although only randomized controlled trials were planned to be included in the review, the exclusion criteria were redefined with the approval of the senior researcher, due to the very small number of randomized controlled trials on the subject. In addition, the results of the included studies reflect data from a small population, and we think this influenced the results of the review. Although the review investigated levels of above-knee amputation, there were no studies investigating hip disarticulation among the included studies. Some studies reviewed included able-bodied control groups, but the sample sizes of the studies were low. Collecting single-level data can be difficult due to the complexity of the amputee population. The normative data of CoP are limited for studies focusing on the imbalance and biomechanical effects of LLA, so larger sample descriptive studies with different amputation levels in all age groups are needed. Future studies involving larger sample sizes and randomized controlled trials involving different above-knee amputation subtypes are needed.

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