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Recovery of balance function among individuals with total knee arthroplasty: Comparison of responsiveness among four balance tests

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Abstract.

Background and aim: Balance deficits are common after total knee arthroplasty (TKA); however the responsiveness of commonly used balance measurement tools has not been well defined. The objective of this prospective study was to compare the internal and external responsiveness of four measurement tools in assessing recovery of balance function following TKA. *Methods:* A total of 134 individuals with TKA (95 women; age: 66.3±6.6 years) completed the Balance Evaluation Systems Test (BESTest), Mini-BESTest, Brief-BESTest, and Berg Balance Scale (BBS) at 2, 4, 8, 12, and 24 weeks post-TKA. The Functional Gait Assessment (FGA) served as the anchor measure, and was also measured across these time points. Internal responsiveness was indicated by the standardized response mean (SRM), while external responsiveness was reflected by the degree of association of the changes of balance scores with those of FGA. *Results:* The SRM ranged from 0.60-1.14 for the BESTest, 0.40-0.94 for the Mini-BESTest, 0.27-0.91 for the Brief-BESTest, and 0.19-0.70 for the BBS, over time. The change in BESTest and Mini-BESTest scores predicted the change in the FGA scores across all time periods, except for the

Mini-BESTest between weeks 12-24, accounting for 13 %-27 %, and 12 %-24 % of the variance, respectively. The Brief-BESTest scores only predicted FGA scores between the weeks 2-4 (R^2=20 %). The changes in BBS scores were not associated with the FGA. *Conclusion:* The BESTest was the most responsive in measuring recovery of balance among individuals with TKA. The Mini-BESTest is a reasonable option during time constraints.

Keywords: balance; osteoarthritis; total knee arthroplasty; psychometrics; mobility

1. Introduction

Total Knee Arthroplasty (TKA) is recognized as a beneficial intervention for end-stage knee osteoarthritis. While TKA can improve ambulatory function, certain physical impairments (e.g., balance, knee muscle strength, proprioception) may persist [1,2]. Indeed, the fall rate has been reported to be as high as 33% 6 months post-operatively [3]. Considering the negative consequences of falls (e.g., peri-prosthetic fractures) [4], understanding balance problems in patients after TKA is clinically important. Balance measurement tools must have sufficient responsiveness to detect clinically meaningful changes as well as adequately assess the effectiveness of post-operative interventions. Internal responsiveness reflects the ability of a measure to change over a pre-specified time, while external responsiveness is the extent to which changes in a measure relate to corresponding changes in a clinical reference measure [5,6].

The Berg Balance Scale (BBS) has been widely used in the TKA population to assess balance performance [7]. The BBS has been largely responsive in detecting changes in balance ability in individuals with TKA and total hip arthroplasty after 5-7 weeks of home-based exercise [7]. Nevertheless, the BBS has shown considerable ceiling effects in individuals with Parkinson's disease [8] and chronic stroke [9], as well as less responsiveness than the BESTest in individuals with Parkinson disease

[10] and subacute stroke [11].

The Balance Evaluation Systems Test (BESTest) is another commonly used balance assessment tool. More recently, condensed versions of the BESTest, namely the 16-item Mini-BESTest [12] and the 8-item Brief-BESTest [13] have been developed. The BESTest has been shown to be more responsive than the Mini-BESTest in individuals with Parkinson disease [10] and subacute stroke [11]. It was also largely responsive in assessing changes in patients with different balance disorders following physiotherapy [14]. Importantly, the responsiveness of different balance tools has not been previously explored in the TKA population.

Thus, the purpose of this study was to compare the internal and external responsiveness of four commonly used balance assessments (i.e., three versions of the BESTest, and the BBS) in individuals with TKA. It was hypothesized that the BESTests would show greater responsiveness compared to the BBS, as the BBS has been subject to ceiling effects [8,9].

2. Methods

2.1. Participants

Individuals who were admitted to the Joint Replacement Centre of the Buddhist Hospital in Hong Kong for TKA from February 2013 to January 2014 and referred to out-patient physiotherapy were recruited. The implants used were cemented cruciate-substituting prostheses (Zimmer model: NexGen LPS-Flex, UK). The inclusion criteria consisted of individuals aged 50-85 years with diagnosed knee osteoarthritis with a first occurrence of TKA; as well as being able to follow verbal instructions and provide informed consent. Exclusion criteria were: TKA due to rheumatoid arthritis or traumatic injury; previous history of surgery in the lower limbs; and known medical diagnoses that affect balance (e.g., stroke). This study was approved by the Human Research Ethics Subcommittee in accordance with the Declaration of Helsinki.

2.2. Sample size estimation

A small to medium effect size was estimated (Cohen's d=0.40), because although the amount of recovery expected post-TKA should be more substantial in the first 12 weeks, considerable variability in the degree of recovery across patients was expected [15]. Moreover, some recovery, albeit at a slower rate, can still be expected between 12-24 weeks [15]; it is therefore important to have an adequate sample size to detect changes in balance at later stages of recovery, as well as differences in responsiveness among the four balance tests when the rate of recovery attenuates. Thus, in order to detect a significant difference in balance between two given time points, with a power of 0.90, an alpha of 0.01, and an attrition rate of 20%, a minimum of 136 individuals with TKA was required.

2.3. Procedures

For this prospective study, demographic information was obtained from medical records and patient interviews (Table 1). The participants attended the first out-patient physiotherapy and assessment session 2 weeks after TKA. The physiotherapy sessions typically consisted of electrotherapy for pain and edema control, mobilization and strengthening exercises, as well as gait and balance training, once or twice per week for 8-10 weeks.

The BESTest, BBS and the FGA were administered in a randomized sequence at 2, 4, 8, 12, and 24 weeks post-TKA. Participants were independently evaluated by one of the three raters who were physical therapists with over 10 years of experience. Based on the patient's performance on the BESTest, the therapist provided a rating according to the specific scoring criteria of the Mini-BESTest and Brief-BESTest. The inter-rater reliability has been previously reported to be excellent in the TKA population (BESTest: ICC=0.99; Mini-BESTest: ICC=0.96; Brief-BESTest: ICC=0.97; BBS: ICC=0.98; FGA: ICC=0.93) [16]. The various versions of the BESTest, BBS and FGA have all elicited good concurrent and convergent validity in individuals with TKA (r=0.67-0.93) [16].

2.4. Balance assessment tools

2.4.1 BESTest

The BESTest contains 36 items grouped into six specific postural control systems. Each item was scored on a 4-level ordinal scale from 0 (i.e., severely impaired balance) to 3 (i.e., no balance impairment), and was converted to a percentage for subsequent analyses [12].

2.4.2. Mini-BESTest

The Mini-BESTest contains 16 items from the original BESTest. Unlike the BESTest, each item is scored on a 3-level ordinal scale from 0 (severely impaired balance) to 2 (i.e., no balance impairment) [12].

2.4.3. Brief-BESTest

The Brief-BESTest is comprised of 8 items. The scoring method for each item was identical as described in the full BESTest [13].

2.4.4. BBS

The BBS is a 14-item functionally-oriented balance assessment. Each task was scored on a scale from 0 (i.e., severely impaired balance) to 4 (i.e., no balance impairment) [17].

2.4.5. Functional Gait Assessment (FGA)

The 10-item FGA served as the reference measure, as walking is an important activity of daily living, and improvement in balance was presumably a contributing factor to recovery of walking function. Indeed, one of the balance domains measured in the three BESTests is “Stability in Gait”. The reference measure should have a nontrivial relationship with the outcome measures [18]. Since a moderate relationship between FGA and BBS has been exhibited in individuals with TKA and other conditions; the FGA was considered to be a viable anchor measure [16,18]. Each item was scored on an ordinal scale from 0 (i.e., severely impaired balance) to 3 (i.e., no balance impairment) [19]. It has demonstrated moderate to excellent reliability and validity in a range of populations, including individuals with TKA [16,19,20].

2.5 Data analyses

The skewness of the distribution of scores was examined for each balance measure at the five different time points. Positive skewness >1 has been suggested to be indicative of a floor effect, while negative skewness <-1 may reflect a ceiling effect [21]. The presence of a ceiling effect may affect the ability of the measurement tool to detect recovery in balance function over time (i.e., responsiveness). Accordingly, bootstrapping (R Statistical Software with Bootstrapping methods, version 2.15.2, Bell Laboratories, Murray Hill, New Jersey, USA) was conducted to compare the degree of skewness in score distribution among the four balance measures (i.e., 6 comparisons: adjusted $\alpha<0.008$) at each time point. For a given balance test, the skewness of scores was also compared across all five time points using the bootstrapping method (10 comparisons: adjusted $\alpha<0.005$).

2.5.1. Internal responsiveness

To assess internal responsiveness, the balance scores were examined to determine whether they demonstrated a significant change over time. Because the data were not normally distributed, the non-parametric Friedman test was used ($\alpha<0.05$). Post-hoc Wilcoxon signed-rank tests were used next to compare the balance scores between two consecutive time points (i.e., 2 vs 4 weeks; 4 vs 8 weeks, 8 vs 12 weeks, 12 vs 24 weeks; 4 comparisons: adjusted $\alpha<0.012$). The Standard Response Mean (SRM) was also used as an indicator of internal responsiveness. Within-subject differences in balance scores between two consecutive assessment time points were calculated by dividing the mean change score by the standard deviation of the change score. SRM>0.80, 0.50-0.80 and 0.20-0.50 represent large, medium, and small internal responsiveness, respectively [6]. For a given time period, the SRM values between balance tests were compared using the Friedman test, followed by post-hoc Wilcoxon signed-rank test (6 comparisons: adjusted $\alpha<0.008$). For a given balance test, the same statistical tests were used to compare the SRM values across all four time periods (i.e., 6 comparisons, adjusted $\alpha<0.008$). Compared to other approaches that determine internal responsiveness (e.g., t-tests), the SRM removes the dependency on the sample size, which has been suggested to be irrelevant when calculating responsiveness [6].

2.5.2. External responsiveness

External responsiveness was established based on associations between the reference measure and the tested measures [6,22]. Since the data were not normally distributed, the Friedman test was used to determine whether a significant change in FGA scores emerged over time ($\alpha<0.05$). Post-hoc Wilcoxon signed-rank tests compared FGA scores between two consecutive time points (4 comparisons, adjusted $\alpha<0.012$). Separate simple linear regressions were performed to assess the strength of correlations between the change in scores of each balance test and that of the FGA for each of the four time periods (i.e., 2-4 weeks, 4-8 weeks, 8-12 weeks, 12-24 weeks). The R^2 value generated from the regression analysis reflected the extent to which the change in balance scores explained the change in the FGA scores. This analysis reflected the ability of the assessment tools to predict changes in the external standard [6]. The difference in R^2 values among the four balance tests was analyzed with Steiger's Z-tests (6 comparisons: adjusted $\alpha<0.008$) [23]. The R^2 values within balance assessments among the four time periods were compared using the Fisher's Z-tests (6 comparisons: adjusted $\alpha<0.008$).

3. Results

3.1. Participant characteristics

A total of 146 patients were recruited. Twelve withdrew from the study at different follow-up assessment sessions, leaving 134 individuals with complete data sets. Participant characteristics are summarized in Table 1. None of the participants required a walking aid during testing.

3.2. Score distribution

Table 2 shows the data on skewness of the score distributions. The skewness of the various versions of the BESTest ranged between -1 to 1 across all time points; however the BBS exhibited a skewness of <-1 across all time points. The three versions of the BESTest were less skewed than the BBS across all five time points ($p<0.008$). Both the Mini-BESTest and Brief-BESTest were less skewed at baseline compared to all other time points ($p<0.005$).

3.3. Internal responsiveness

Table 3 presents the improvement in balance scores across testing sessions. All four balance measures exhibited higher balance scores over time (Z range: 3.31-9.97, $p<0.012$), except the BBS scores from 12 to 24 weeks ($p=0.029$).

Table 4 shows the change in SRM values of the four balance measures over time. Generally, the SRM values demonstrated gradual reduction as time progressed. All balance tests demonstrated greater SRM during weeks 2-8 than weeks 12-24 (Z range: 3.59-6.50, $p<0.008$). Both the BESTest and Mini-BEST exhibited greater SRM in weeks 8-12 compared to weeks 12-24 (Z range: 2.69-5.55, $p<0.008$). The SRM of all balance tests were greater during weeks 2-4 than in weeks 8-12 (*Z* range: 3.16-3.78, $p<0.008$).

When comparing the magnitude of SRM between balance assessments, the BESTest was more responsive than the BBS and Brief-BESTest across all four time periods (*Z* range: 3.35-5.16, $p<0.008$). The BESTest was also more responsive than the Mini-BESTest across all time points (*Z* range: 3.02-3.94, $p<0.008$), except weeks 8-12 ($p<0.008$). The Mini-BESTest was more responsive than the BBS from week 2-12 (*Z* range: 2.65-3.94, $p<0.008$).

3.4. External responsiveness

FGA scores improved over time with recovery (*Z* range: 5.72-9.92, $p<0.012$; Table 3). The change in BESTest and Mini-BESTest scores explained 13-27 % and 12-24 % of the variance of the FGA change scores respectively, depending on the time period ($p<0.008$; Table 5). The change in Brief-BESTest scores was only associated with the change in FGA scores during weeks 2-4 ($R^2=0.20$). The change in BBS scores was not associated with the change in FGA scores across any of the 4 time periods. During weeks 2-4, the R^2 of the three versions of the BESTest were higher than the BBS (*Z* range: 2.63-4.42, $p<0.008$). The BESTest was also a stronger predictor of FGA scores relative to the Brief-BESTest during weeks 2-12 (*Z* range: 2.64-4.44, $p<0.008$). With respect to weeks 8-12, the BESTest was a better predictor than the Brief-BESTest (Z=4.44, p<0.008). No differences in prediction emerged between weeks 12-24 across the four balance tests. Lastly, the Brief-BESTest and FGA exhibited higher R^2 values between weeks 2-4 than weeks 8-12 (Z=3.05, p<0.008).

4. Discussion

4.1. Main findings

This study determined the internal and external responsiveness of the BESTest, the Mini-BESTest, the Brief-BESTest, as well as the BBS in individuals with TKA over several time points within a 24-week period. Overall, the findings support our hypothesis, as among the four balance measures evaluated, the BESTest demonstrated the highest internal and external responsiveness, while the BBS demonstrated the lowest across all measurement time points in individuals post-TKA.

The baseline function of our participants seems to be comparable with previous research. Although our participants scored approximately 10 points higher on the BBS than their counterparts [24] as well as community-dwelling elders at risk for falls [25], our participants were approximately 10 points lower on the BESTest compared to patients with knee osteoarthritis [26]. The BBS has been subject to relatively low test-retest reliability in individuals with chronic obstructive pulmonary disease [27] as well as balance disorders [14], and has exhibited ceiling effects [9,14,16], which may account for these discrepancies. More research may be necessary in order to establish normative functional status post-TKA.

4.2. Internal responsiveness

In general, the BESTest and the Mini-BESTest were more internally responsive and less negatively skewed than the BBS. The BBS was originally developed to assess static balance in frail elderly and consists of a number of less demanding tasks (e.g., sitting to standing with and without support) [17]. Accordingly, these test items may be relatively simple for individuals late in recovery, rendering the BBS less effective at discriminating among patients with different levels of impairment. In contrast, the inclusion of more challenging tasks in the three BESTests (e.g., postural responses to external perturbations) may afford these tests to be more sensitive at discriminating between individuals post-TKA over time. The Brief-BESTest may not have exhibited as high of internal responsiveness as the BESTest as it has been shown to be less accurate at discriminating among patients, and it has less internal consistency relative to the Mini-BESTest [13]. Our findings propose that the BESTest and Mini-BESTest may be more sensitive at detecting slight modulations in balance.

The responsiveness of the BBS within the first 12 weeks of recovery (SRM:0.32-0.70) was within the range reported in previous research on individuals with total hip arthroplasty and TKA (SRM:1.90) [7], community-dwelling elderly

(SRM:0.47) [7], multiple sclerosis (SRM:0.74) [28] as well as acute stroke (SRM:0.74) [29]. Perhaps this wide spectrum of responsiveness can be explained by the variance in the assessment time (i.e., between 1-14 weeks post-rehabilitation) [7,28,29], as longer durations between measurements likely lead to greater responsiveness. Equally, the rate and potential for recovery may also be influenced by the patient population. In contrast, the present findings differed from previous work as the BESTest has been shown to present comparable internal responsiveness to the BBS, but greater internal responsiveness than the Mini-BESTest after an average of 2 weeks of inpatient rehabilitation in individuals with subacute stroke [5]. The discordance in results is likely because of differences in the patient population and functional mobility, as only 10% of their patients were ambulatory at baseline [5]. However, other work has found the Mini-BESTest exhibit greater internal responsiveness relative to the BBS [28]. The sum of these findings lend support to the notion that internal responsiveness should be compared within populations and over a similar time frame.

4.3. External responsiveness

The BESTest and Mini-BESTest demonstrated good external responsiveness, as improvements in balance ability were positively associated with improvements in the FGA reference measure throughout the follow-up period. Once again, the BBS exhibited the poorest responsiveness, as the change in BBS scores was not related to the FGA. Among the four balance tools examined, the BBS retained the greatest negative skewness, which steadily increased from -1.77 at 2 weeks post-TKA to -2.85 at 24 weeks post-TKA (Table 2); thus this may be suggestive of a ceiling effect.

The comparability of external responsiveness among balance tests remains mixed. In line with the present results, the Mini-BESTest has exhibited higher external responsiveness than the BBS in individuals with spinal cord injury [28] as well as multiple sclerosis [29]. Conversely, similar external responsiveness has been observed between the BESTest and the Mini-BESTest among subacute stroke patients [5], as well as between the Mini-BESTest and the BBS among patients with various balance deficits [14]. In contrast, other work has exposed higher external responsiveness in the BBS compared to the BESTest in individuals with chronic obstructive pulmonary disease [30]. Perhaps the discrepancy in findings may stem from differences in impairment characteristics between patient populations [14,28,29,30], differences in number of assessment sessions, the time gap between sessions [14,28,29,30], as well as differences in rehabilitation programs [14,28,29,30]. Altogether, these studies highlight the importance of a patient-specific evaluation of responsiveness in commonly used balance assessment tools.

4.4. Limitations

These results may only be generalizable to individuals with unilateral TKA due to knee osteoarthritis. Additionally, although recovery from TKA should result in improvements in balance and gait, perhaps these improvements may not have been reflected in the same manner on the FGA as they were on the balance assessments.

5. Conclusion

The BESTest demonstrated the highest internal and external responsiveness and is the ideal balance assessment tool for individuals with TKA. The Mini-BESTest is a reasonable option if time constraints are a concern, while the BBS is the least favored assessment tool. These findings are important as they contribute to the knowledge on best practices for the evaluation and interpretation of balance during TKA recovery.

Conflict of interest statement

The authors have no conflict of interest to declare.

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