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Title: Toe Grip Strength and Its Relationship with Balance and Mobility in Knee Osteoarthritis: Implications for Physical Therapy Assessment and Intervention

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To appear in: ***Physical Treatments***

Received date: 2025/07/10
Revised date: 2025/09/15
Accepted date: 2025/09/20
First Online Published: 2025/09/23

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Please cite this article as:

Dsouza CJ, Rebello SR, Miqdad Ashraf M, Alankar AS, Lewis CP, Mendonca GA. Toe Grip Strength and Its Relationship with Balance and Mobility in Knee Osteoarthritis: Implications for Physical Therapy Assessment and Intervention. ***Physical Treatments.*** Forthcoming 2026.

DOI: http://dx.doi.org/10.32598/ptj.2026.738.1

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Abstract:

Purpose: Knee osteoarthritis (OA) significantly impacts mobility in older adults. Abnormal foot mechanics, including hallux dysfunction, may alter knee joint kinematics and exacerbate symptoms. This cross-sectional study aimed to assess toe grip strength (TGS) and examine its relationship with dynamic balance and mobility in patients with knee OA.

Methods: A total of 147 participants aged 45–75 years with Grade 2 knee OA of at least three months' duration were included. TGS was measured using a pinch gauge dynamometer, and balance and mobility were evaluated using the Functional Reach Test (FRT) and the Timed Up and Go (TUG) test respectively. Pain intensity was assessed with the Visual Analogue Scale (VAS) and Western Ontario and McMaster Universities (WOMAC) OA Index for knee function were also recorded. Spearman's rank correlation, linear regression, and multiple regression analyses were performed.

Results: TGS showed a strong correlation with both FRT ($r = 0.942$) and TUG ($r = -0.832$), which were statistically significant ($P < 0.001$). These relationships remained significant after adjusting for age, BMI, and OA duration. Regression analysis showed that FRT alone explained 91.3% of the variance in TGS, while TUG explained 74%. In a combined model ($R^2 = 0.922$), FRT emerged as the stronger predictor. No significant correlations were found between TGS and either VAS or WOMAC scores.

Conclusion: This cross-sectional study reports that TGS is strongly and independently associated with balance and mobility in patients with knee OA, highlighting its potential to serve not only as a simple, clinically useful screening tool but also a potential target for interventions aimed at improving lower limb functional performance. However, it does not appear to reflect pain severity or self-reported knee function.

Keywords: hallux, knee, muscle strength dynamometer, osteoarthritis, rehabilitation

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Highlights:

- Toe grip strength can influence balance in patients with knee OA.
- Toe grip strength can be related to improved mobility performance.
- Balance is a stronger predictor of toe grip strength.
- Toe grip strength may serve as a simple indicator in knee OA rehabilitation.

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Plain Language Summary:

Knee osteoarthritis (OA) is a common condition that affects millions of older adults, causing pain, stiffness, and reduced mobility. While the focus is often on the knee joint itself, recent studies suggest that foot function, especially the ability to grip with the toes, may also play a role in balance and mobility. This study looked at toe grip strength (TGS) in 147 adults who had knee OA. We wanted to see whether stronger TGS was linked to better balance and mobility. To do this, we measured how hard people could press with their toes using a special device, and then tested their balance and walking ability using two standard tools: the Functional Reach Test (FRT) and the Timed Up and Go (TUG) test. The results indicated that people with stronger toe grip had much better balance and mobility. Even after accounting for other factors like age and body weight, the relationship remained strong. Interestingly, toe grip strength was not related to how much pain people reported or how they rated their overall knee function. These findings suggest that TGS may be an important but often overlooked factor in managing knee OA. Simple exercises to improve toe grip might help patients improve their balance and mobility, making daily tasks easier and potentially reducing the risk of falls. Since the test is quick and easy, it could be a valuable tool in physical therapy assessments.

Introduction

Recent global estimates indicate that knee osteoarthritis (OA) affected approximately 375 million people in 2021, and its prevalence is projected to approach 1 billion worldwide by 2050 driven by ageing populations and rising obesity [1,2]. However, knee OA poses a significant public health issue in India, particularly among individuals aged 40 and older. Data also suggest an earlier onset influenced by genetic, lifestyle, and environmental factors [3,4]. These studies also indicate that more than one-third of the population in rural South India are diagnosed with this condition, with significant associations with obesity, diabetes, hypertension, sedentary lifestyle, menopause, and the practice of squatting for toileting.

Excessive mechanical loading on joint surfaces significantly contributes to the onset and progression of knee OA, often resulting from abnormal knee joint loading caused by disrupted kinematic interactions between the foot and knee [5]. Abnormal foot posture or altered foot movement may contribute to degenerative changes in knee joint cartilage by causing improper loading [6]. As a result, the foot is increasingly considered during lower-limb assessments.

The first metatarsal joint plays a crucial role in maintaining the structural integrity of the foot arch, supporting body weight, and evenly distributing mechanical stress during ambulation [7,8]. Dysfunction at this joint, such as reduced toe grip strength (TGS) due to hallux impairment, may disrupt the biomechanical chain, influencing proximal joints. When TGS is weak, individuals tend to compensate by increasing dorsiflexion at the ankle, which leads to higher muscular demand around the ankle and elevated torque at the knee and hip during walking [9,10].

TGS plays a vital role in mobility among older adults and may contribute to dysfunction in proximal joints [11,12]. Balance impairments are particularly pronounced in individuals with knee OA, likely due to reduced muscle strength and joint position sense. These deficits lead to greater difficulty in walking and an increased risk of falls compared to those without OA [13].

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Furthermore, falls in this population can result in severe injuries, fear of movement, or even fatal outcomes, adding a substantial financial strain to healthcare systems [14,15]. Therefore, assessing balance impairments is essential for optimizing rehabilitation strategies.

A common gait abnormality in individuals with knee OA is the failure to maintain consistent toe-ground contact throughout the stance phase until toe-off, suggesting a possible relationship between compromised toe flexor strength and altered gait mechanics in this population. Given the association between the forefoot, hallux and rearfoot through the midfoot, hallux dysfunction may indirectly influence knee kinematics in OA by altering rearfoot motion patterns during gait [16]. Uritani et al. highlighted the importance of assessing toe flexor strength as a predictive and preventive measure for walking dysfunction and falls [17]. They also observed a link between preoperative TGS and postoperative functional mobility in patients who underwent total knee replacement (TKR) [18]. Given that TKR represents an end-stage intervention, this link emphasizes the critical role of TGS in mobility and recovery.

Nevertheless, there remains a notable gap in the mechanical linkage between TGS and knee biomechanics. While some studies have examined broad association trends, few have explored how toe strength directly contributes to dynamic balance and mobility impairments in knee OA. Moreover, biomechanical explanations tying TGS to compensatory movement patterns in proximal joints are underrepresented, particularly in resource-limited settings where early intervention could be pivotal.

To the best of our current understanding, there is a lack of published evidence examining the correlation between these factors in individuals with knee OA in the Indian context. As life expectancy rises and obesity becomes more prevalent, India is on the brink of a substantial OA burden, emphasizing the need for region-specific research. In rural areas, limited access to diagnostic imaging and specialized orthopaedic services frequently contribute to delayed identification and management of the condition, often until it has progressed to more advanced

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stages. The growing prevalence of OA is set to escalate disability and deteriorate quality of life, presenting a significant challenge for India's resource-limited public health system and imposing a heavy economic strain on the country [3,19].

Accordingly, the present study aimed to investigate the relationship between TGS and both dynamic balance and mobility in patients with knee OA. We hypothesised that TGS deficits would correlate with diminished performance in assessments of dynamic balance and mobility. Understanding these associations, especially the functional and mechanistic underpinnings, may aid in developing targeted physical therapy strategies to enhance lower limb function and mobility in this population.

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Materials and Methods

Study design and setting: This observational study employed a cross-sectional design and was conducted over a three-month period, from December 2023 to February 2024, recruiting participants from a tertiary care hospital and community settings in a South Indian city. Individuals meeting the inclusion criteria were enrolled after obtaining written informed consent, following a comprehensive explanation of the study's objectives, potential benefits, and associated risks. Reporting adhered to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) criteria for observational research.

Eligibility Criteria: Participants included individuals aged between 45 and 75 years with a diagnosis of knee OA confirmed by an orthopedic specialist, based on the American College of Rheumatology criteria [20], with a history of the condition for more than three months. The orthopedic surgeon also assessed the severity of knee OA from an anteroposterior weight-bearing film using the Kellgren and Lawrence scale [21], and only those with Grade 2, characterized by definite osteophytes and possible joint space narrowing, were included. This was to reduce heterogeneity, as advanced grades are associated with substantial structural damage and functional loss, potentially confounding the relationship between TGS and mobility. Eligible participants were required to ambulate independently without using assistive devices or caregiver support, and possess a minimum education level equivalent to completion of 4th grade. Exclusion criteria encompassed any neuromuscular or musculoskeletal disorders, prior TKR, lumbar spine surgery, or surgical procedures involving the lower extremities.

After completion of the screening procedure, demographic information was recorded, all outcome measures were evaluated on the same day and were carried out by a single researcher (MA) to reduce inter-rater variability. The most affected knee was identified through participant-reported symptoms of pain and functional limitation, further confirmed with radiographic findings of Grade 2 OA. In cases of bilateral OA, the knee with greater symptom severity as reported by the participant was selected for assessment.

- TGS: The strength of the flexor hallucis longus was measured with a pinch gauge dynamometer [22,23], which has demonstrated excellent intra-rater reliability (ICC = 0.94–0.98) in previous studies [24,25]. Participants were seated with their feet flat on the floor, and the dynamometer was positioned beneath the hallux, aligning its proximal end just below the distal crease of the first metatarsophalangeal joint (Figure 1). The examiner stabilized the device manually. Participants were instructed to press downward with maximal effort for three seconds, ensuring the heel remained in contact with the ground. Three trials were conducted, with a rest period of less than five seconds between attempts.

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Figure 1: Assessment of Toe Grip Strength

- Functional Reach Test (FRT): Participants stood near a wall without touching it and raised the arm closest to the wall to 90^0 of shoulder flexion maintaining a closed fist [26]. The initial position of the third metacarpal head was marked on a yardstick affixed to the wall. Participants then reached as far as possible without taking a step. The final position was recorded, and the reach distance was calculated as the difference between the start and end positions. An average of three trials was noted.
- Timed Up and Go Test (TUG): Participants wore their regular footwear, and did not use assistive devices during testing. Initially, each participant was seated in a chair with an armrest [27,28]. At the therapist’s cue, they stood up, initiating the timer, walked a distance of three meters at a comfortable pace, turned, walked back, and sat down completely, at which point timing stopped. The timing ended when the participant was completely seated. Two practice trials were conducted prior to recording one final measurement for statistical analysis.
- Visual Analog Scale (VAS): Pain intensity was assessed using a 100 mm horizontal line, marked with the descriptors "no pain" at 0 mm and "worst possible pain" at 100

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mm [29]. Participants were asked to indicate their current level of pain by placing a mark on the line. The pain score was quantified by measuring the distance in millimeters from the 0mm point to the participant's mark using a standard ruler.

- Western Ontario and McMaster Universities (WOMAC) OA Index: This questionnaire consists of three scales and a total of 24 items, each scored on a 5-point ordinal scale. A higher score on the scale reflects increased symptom severity [30].

Sample size: The a priori sample size for testing the association between TGS and mobility/balance outcomes was calculated for a two-tailed correlation test using the Fisher z transformation, assuming an expected effect size of r = 0.23 (based on the smallest relevant correlation reported by Uritani et al. [31]), with a significance level of 5% and a statistical power of 80%. This indicated a minimum requirement of 146 participants; we recruited 147, thereby exceeding the target.

Statistical methods: Descriptive statistics, including means and standard deviations, were used to summarize the demographic variables and outcome measures. The Kolmogorov–Smirnov test was applied to assess the normality of data distribution. As the variables were not normally distributed, Spearman's rank correlation was performed to examine the relationship of TGS with TUG and FRT. The correlation coefficient (r) was interpreted as follows: 0–0.25 (negligible), 0.25–0.50 (fair), 0.50–0.75 (moderate to good), and ≥0.75 (good to excellent) [32]. Partial correlation analysis was conducted to explore the associations between outcome measures while controlling for age, BMI, and duration of OA. Scatter plots were used to depict relationships between TGS with TUG and FRT. Simple linear regression was used to assess the predictive value of FRT and TUG on TGS, while a multiple regression model, including both TUG and FRT, was constructed to evaluate their combined effect on TGS.

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Multicollinearity diagnostics were performed using the Variance Inflation Factor (VIF) and tolerance statistics to ensure the validity of regression models. Statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA), and a p-value of less than 0.05 was considered statistically significant.

Results

Out of the 186 participants assessed for eligibility, 39 did not satisfy the inclusion criteria. A total of 147 participants with knee OA were included in the analysis. The mean age was 59.3 ± 7.8 years, with an average BMI of 25.3 ± 4.2 kg/m². The mean duration of knee OA was 3.8 ± 3.9 years (Table 1).

Table 1: Demographic characteristics of the study participants

Variable	N	Mean (SD)
Age (years)	147	59.31 (7.83)
BMI (kg/m^2)	147	25.32 (4.23)
Duration of Knee OA (years)	147	3.80 (3.90)

BMI- Body Mass Index; N- Sample size; OA- Osteoarthritis; SD- Standard deviation

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Statistical analysis was therefore performed on 147 participants, comprising 70 males (47.65%) and 77 females (52.4%). Of the participants, 38% had right knee involvement, 46% had left knee involvement, and 16% had bilateral knee involvement. Descriptive statistics for outcome measures are presented in Table 2.

Table 2: Descriptive characteristics of the primary and secondary outcome measures

Outcome Measures	N	Mean (SD)
TGS (kgs)	147	8.50 (1.48)
TUG (secs)	147	8.29 (2.08)
FRT (cms)	147	11.72 (2.56)
VAS	147	5.35 (1.01)
WOMAC	147	53.95 (10.58)

FRT- Functional Reach Test; N- Sample size; SD- Standard deviation; TGS- Toe Grip Strength; TUG- Timed Up and Go; VAS- Visual Analog Scale; WOMAC- Western Ontario and McMaster University

A good-to-excellent positive correlation was observed between TGS and the FRT ($r = 0.942$; $P<0.001$), indicating that individuals with higher TGS achieved greater reach distances in the reach test. Similarly, a good-to-excellent negative correlation was found between TGS and the TUG ($r = -0.832$; $P <0.001$), suggesting that individuals with greater TGS completed the TUG in less time [Table 3]. Although TGS showed a negligible correlation with both VAS ($r = 0.001$; $P= 0.989$) and WOMAC ($r = 0.012$; $P= 0.887$), these correlations were not statistically significant [Table 3].

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Table 3: Spearman's rank Correlation between outcome measures			
Outcome Measures		r-value	P-value
TGS	TUG	-0.832	<0.001*
	FRT	0.942	<0.001*
	VAS	0.001	0.989
	WOMAC	0.012	0.887

*Statistically significant correlation

FRT- Functional Reach Test; P- level of significance; r- correlation coefficient; SD- Standard deviation; TGS- Toe Grip Strength; TUG- Timed Up and Go; VAS- Visual Analog Scale; WOMAC- Western Ontario and McMaster University

After controlling for age, BMI, and knee OA duration, TGS remained strongly associated with TUG (r = –0.735; P<0.001) and FRT (r = 0.892; P<0.001), confirming that these relationships were independent of confounding variables (Table 4). The scatter plot diagrams illustrate good-to-excellent linear relationships: a positive association between TGS and FRT (Figure 2.A.), and a negative association between TGS and TUG [Figure 2.B.].

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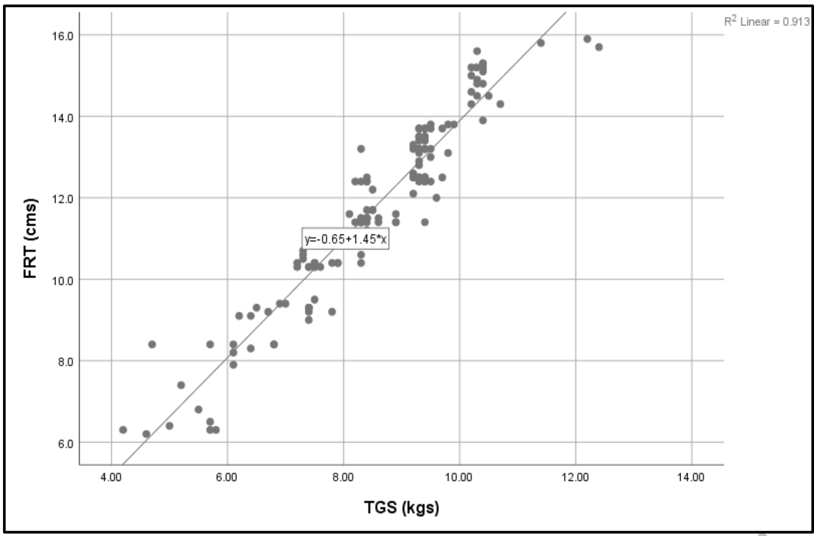

Figure 2.A: Scatter plot diagram depicting the correlation between Toe Grip Strength and Functional Reach Test

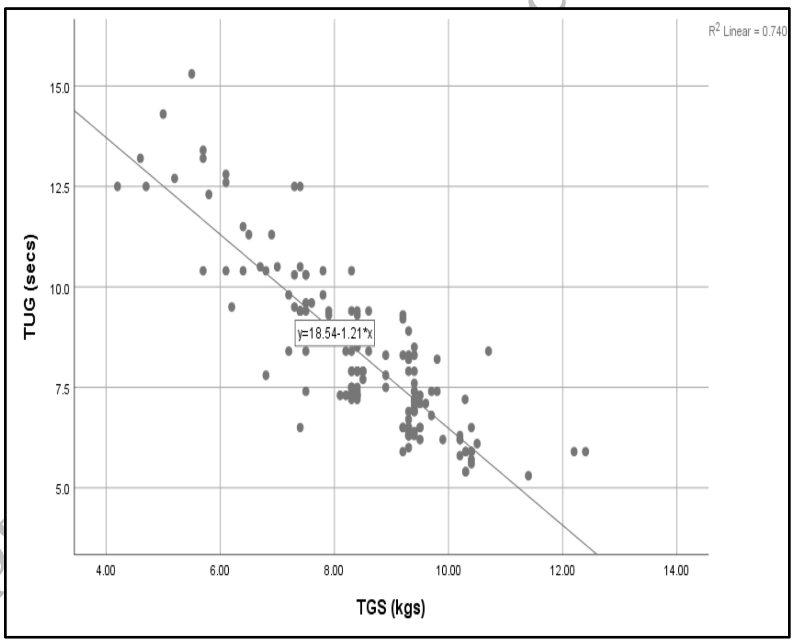

Figure 2.B: Scatter plot diagram depicting the correlation between Toe Grip Strength and Timed Up and Go Test

Table 4: Partial correlation between outcome measures after controlling for age, BMI and duration of knee OA				
Control Variables			TUG	FRT
Age BMI Duration of Knee OA	TGS	r-value	-.735	.892
		P-value	<0.001*	<0.001*
		N	147	147

*Statistically significant correlation

BMI- Body Mass Index; FRT- Functional Reach Test; N- Sample size; OA- osteoarthritis; P- level of significance; r- correlation coefficient; TGS- Toe Grip Strength; TUG- Timed Up and Go.

Regression analysis [Table 5] showed that both FRT and TUG are strong predictors of TGS. FRT alone explained 91.3% of the variance in TGS ($\beta = 0.628$; $P < 0.001$), while TUG accounted for 74% ($\beta = -0.613$; $P < 0.001$). In the combined model, both remained significant ($R^2 = 0.922$), with FRT emerging as the stronger predictor. This finding indicates that balance exerts a greater influence on TGS than mobility. Collinearity diagnostics confirmed the absence of multicollinearity was not present (all VIF values < 2.0; tolerance > 0.5). Thus, the high R^2 values reflect robust associations between functional balance, mobility, and TGS.

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Table 5: Simple and multiple regression analysis showing the predictive relationships of TUG and FRT with TGS

	r	R^2	Regression	Unstandardised β	Standardised β	t	P
TGS vs TUG	0.860	0.740	constant	13.584		52.671	<0.001*
			TUG	-0.613	-0.860	20.304	<0.001*
TGS vs FRT	0.956	0.913	Constant	1.144		5.965	<0.001*
			FRT	0.628	0.956	39.065	<0.001*
TGS vs TUG & FRT	0.960	0.922	Constant	3.342		5.802	<0.001*
			TUG	-.126	-.177	-4.023	<0.001*
			FRT	.529	.806	18.340	<0.001*

*Statistically significant

β – regression coefficient/standardised coefficient; FRT- Functional Reach Test; P- level of significance; r- correlation coefficient; R^2- coefficient of determination; t- t value; TGS- Toe Grip Strength; TUG- Timed Up and Go.

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Discussion

The present study investigated the association between TGS and functional measures of mobility and balance in individuals with knee OA. We found that both the TUG and FRT were significant predictors of TGS. Among these, FRT explained a greater proportion of variance in TGS than TUG, highlighting that balance capacity contributes more strongly to toe flexor strength than mobility performance. The results underscore the potential impact of TGS on functional ability and mobility in patients with knee OA.

A systematic review of observational studies found that greater toe flexor strength is associated with improved postural stability in individuals aged 60 and above [33]. Yong-Wook et al. reported that elderly non-fallers had significantly stronger muscles in the hallux and second toe, as well as better balance than fallers; toe flexor strength also correlated moderately with

FRT, suggesting its role in fall prevention [34]. Similarly, Menz et al. highlighted that flexor strength of the toes alongside other ankle and foot features can potentially predict functional performance and balance in older adults [10]. Unsurprisingly, interventions aimed at strengthening toe grip in younger adults have also demonstrated improvements in tasks requiring dynamic balance [35,36].

The foot, a complex and adaptable structure with multiple degrees of freedom, helps control the center of mass. Extrinsic and intrinsic toe flexors play a crucial role in foot function, whether the foot is unloaded or in contact with the ground. In an upright stance, the toe flexors must produce adequate and timely plantar flexor torque to help prevent the center of mass from excessive forward displacement beyond the base of support [9]. Consequently, balance stability depends on the effective activation of the extrinsic toe flexors to produce plantar flexor force at the ankle joint. This highlights the significance of toe grip strength in maintaining postural control and preventing falls [33]. Toe flexors not only generate mechanical force but also contribute sensory feedback through proprioceptors, aiding neuromuscular control of standing balance and gait. Impaired proprioception may therefore partly explain the strong association observed with FRT and TUG [37,38].

Interestingly, the lack of a significant correlation between TGS and WOMAC may highlight a dissociation between neuromuscular performance and subjective symptom perception in knee OA. This aligns with prior literature suggesting that functional impairments may not always parallel pain reports [39]. This observation underscores the need to explore both biomechanical and psychosocial dimensions of OA.

Our findings align with previous research demonstrating that TGS is significantly weaker in individuals with knee OA compared to control subjects. While the causal link between TGS and knee OA has not yet been established, diminished TGS may lead to compromised dynamic balance during standing and reduce propulsive force, thereby increasing mechanical stress on

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the knee joint [40]. This observation underscores the importance of TGS in the functional biomechanics of an osteoarthritic knee. While it is plausible that diminished TGS contributes to altered biomechanics, potentially increasing knee joint loading; however, this remains a hypothesis requiring confirmation in mechanistic and longitudinal studies. A previous investigation in 665 Japanese older adults found that TGS was independently correlated with TUG performance but not with FRT. These findings highlight the potential of TGS-focused physical therapy to improve functional mobility [17]. Evidence from European and North American cohorts similarly supports the association between foot muscle strength and functional performance, suggesting that the observed relationships are not restricted to Asian populations [37,41].

Prior studies, such as those by Poojari et al., have also demonstrated a correlation between reduced TGS and fear of pain among knee OA patients, suggesting a potential psychosomatic link that influences TGS [23]. Furthermore, a multicenter cross-sectional study identified that TGS negatively correlates with age and positively with the isometric strength of knee extensors in OA patients. In the control group, TGS was similarly associated with age and the TUG test, emphasizing the interplay between forefoot function and knee OA progression [31]. These findings suggest that improving TGS could serve as a practical therapeutic strategy to mitigate the progression of knee OA.

The findings of our study align with emerging evidence supporting functional, muscle-targeted interventions in knee OA management. For instance, Tedeschi highlighted the role of neuromuscular coordination and proprioceptive training in restoring function and performance, emphasizing the importance of strengthening specific muscle groups for optimal recovery [42]. Our results reinforce this perspective by identifying TGS as a potential marker of dynamic balance and mobility, suggesting that distal muscle activation and control may influence overall lower limb performance. Similarly, a randomized controlled trial has demonstrated that

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structured remote interventions can significantly improve functional outcomes in OA patients [43].

Further evidence suggests that decreased TGS on the affected limb is correlated with a history of falls in older adults with knee OA, reinforcing the importance of incorporating TGS strengthening in physical therapy interventions to reduce fall risk [36]. Furthermore, longitudinal studies have established a relationship between preoperative TGS and postoperative functional performance in patients undergoing TKR, with stronger preoperative TGS associated with better postoperative TUG outcomes [19]. These findings suggest that TGS may serve as a functional marker and therapeutic target for improving the outcomes of knee OA.

Limitations & Recommendations

The study was limited to individuals with mild to moderate knee OA, indicating that future investigations should include cases with severe OA to achieve a comprehensive understanding. Participant recruitment from both hospital and community settings may have introduced selection bias, limiting generalizability. Additionally, the influence of other foot muscles needs to be investigated, and comparisons between males and females are warranted to explore potential gender-based differences. Replication of these findings in independent cohorts across diverse populations is warranted to strengthen external validity and confirm the robustness of the observed associations. Although our study was conducted in an Indian cohort, the biomechanical role of TGS remains universal. Nevertheless, caution is warranted when extrapolating findings to populations with differing lifestyles, footwear habits, or genetic predispositions. Lastly, as this was a cross-sectional study, causality cannot be inferred. Determining whether reduced TGS contributes to functional decline or vice versa requires longitudinal research.

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Conclusion

TGS was significantly correlated with dynamic balance and mobility, with individuals with lower TGS taking longer to complete the TUG and achieving shorter reach distances in the FRT. TGS did not show a significant relationship with pain levels or knee function. These findings suggest that incorporating TGS screening into clinical assessments and considering toe flexor strengthening in rehabilitation programs may represent feasible strategies for improving functional outcomes.

Conflict of interest: The authors declare no competing interests.

Funding source: Rajiv Gandhi University of Health Sciences Undergraduate Short-Research Grant (UG23PHY529).

Ethical approval: Approved by the Institutional Ethics Committee (Ref No: FMIEC/CCM/553/2023) on 09/10/2023. All procedures were conducted in compliance with the principles outlined in the Helsinki Declaration, 2000.

Registration number: The study was prospectively registered with the Clinical Trials Registry of India (CTRI/2023/12/060974; https://ctri.nic.in) on 29/12/2023.

Patient consent declaration: Written informed consent was obtained from all participants following a detailed explanation of the study's purpose. Consent included permission for participation as well as for the use of anonymized data for research and educational purposes.

Authors' contributions: All authors contributed to conceptualization, data curation, methodology/formal analysis/validation, project administration, funding acquisition, writing – original draft, writing - review & approval of the final version of the manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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