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Can individual functional improvements be predicted in osteoarthritic patients after total knee arthroplasty?

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Abstract

Purpose Total knee arthroplasty (TKA) is an effective treatment for advanced osteoarthritis, and achieving optimal outcomes can be challenging due to various influencing factors. Previous research has focused on identifying factors that affect postoperative functional outcomes. However, there is a paucity of studies predicting individual postoperative improvement following TKA. Therefore, a quantitative prediction model for individual patient outcomes is necessary.

Materials and methods Demographic data, radiologic variables, intraoperative variables, and physical examination findings were collected from 976 patients undergoing TKA. Preoperative and 1-year postoperative Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores were assessed, and multivariate regression analysis was conducted to identify significant factors influencing one-year WOMAC scores and changes in WOMAC scores. A predictive model was developed on the basis of the findings.

Results The predictive accuracy of the model for 1-year WOMAC scores was poor (all adjusted $R^2 < 0.08$), whereas the model for changes in WOMAC scores demonstrated strong predictability (all adjusted $R^2 > 0.75$). Preoperative WOMAC scores, sex, and postoperative knee range of motion significantly affected all pain, stiffness, and physical function aspects of the WOMAC scores (all $P < 0.05$). Age, cerebrovascular disease, and patellar resurfacing were associated with changes in physical function (all $P < 0.05$).

Conclusions The developed quantitative model demonstrated high accuracy in predicting changes in WOMAC scores after TKA. The identified factors influencing postoperative improvement in WOMAC scores can assist in optimizing patient outcomes after TKA.

Keywords WOMAC, Knee arthroplasty, Predictive model, Functional improvement

Introduction

Total knee arthroplasty (TKA) is a widely performed and effective treatment for patients with advanced osteoarthritis, leading to positive and satisfactory outcomes [1]. However, defining what constitutes an optimal result can be subjective, as patients may still experience discomfort, functional impairment, and dissatisfaction even if the surgery is technically successful according to the surgeon's assessment [2]. Thus,

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patient-reported outcome measures (PROMs) have been developed to address the patient's perspective on outcomes [3]. These measures include subjective outcome assessments by patients and are widely used in clinical practice to evaluate the effectiveness of surgery in daily function. Among the various PROMs, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), is a widely used tool to evaluate PROMs after TKA. And its validity, reliability, and responsiveness have been well established [4].

The TKA outcomes are influenced by various factors, including patient-related and surgical factors [5]. The interaction of these factors plays a significant role in determining both patient function and overall outcomes. Therefore, considering these factors is crucial to achieving optimal outcomes after TKA as they provide valuable information about when and under what circumstances the optimal results can be achieved. However, an optimal outcome may have two aspects: achieving the best possible clinical score and attaining maximal improvement after surgery [6].

Prior research on this issue was limited to the qualitative identification of factors with a dichotomous impact on PROMs [7]. However, there are few studies that quantitatively predicted individual patient outcomes [8], such as determining the PROMs after TKA at a certain time. Therefore, the primary objective of this study was to develop a model that can quantitatively predict the outcome of an individual patient. To achieve this, we evaluated the factors contributing to the best WOMAC scores and the most significant improvement in WOMAC scores following TKA.

Materials and methods

With the approval of the institutional review board (H-2304-001-1416), a retrospective analysis of electronic medical records for patients who underwent primary TKA for knee osteoarthritis at the author's institute between January 2002 and January 2021 was performed. The study included patients with a minimum 1-year follow-up period who had completed WOMAC questionnaires. Exclusion criteria included patients with non-primary osteoarthritis, such as those with rheumatoid arthritis or posttraumatic arthritis. Additionally, patients with conditions affecting gait, a history of prior bony surgery, or those who underwent revision surgery during the follow-up period owing to aseptic loosening, instability, dislocation, postoperative infection, or periprosthetic fractures were excluded from the analysis, as these conditions are known to negatively affect PROMs[9]. The flowchart of patients' knees included in this study is presented in Fig. 1.

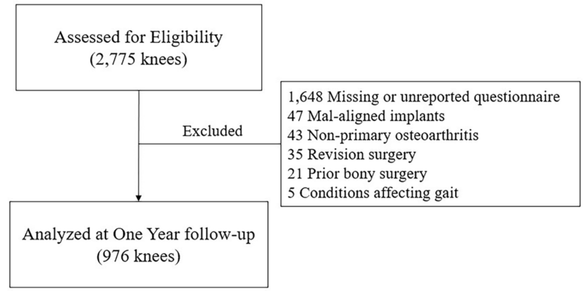

Fig. 1 Flowchart of the study

Data collection

Demographic factors and comorbidities (e.g., cerebrovascular disease, diabetes mellitus, hypertension, ischemic heart disease, chronic liver disease, and chronic renal disease) were collected. Cerebrovascular disease was defined as a history of stroke or transient ischemic attack without residual hemiparesis or hemiplegia. Radiologic variables were assessed both preoperatively and 1 year after surgery, including the hip-knee-ankle angle (HKAA) to evaluate coronal plane deformity, and the Blackburne–Peel ratio to assess joint line, patellar height, and the posterior tibial slope [10]. Patients with a Blackburne-Peel ratio below 0.54 or malaligned implants (a distal femoral angle deviating by more than 3° from 5° valgus, a posterior tibial angle deviating by more than 3° from the mechanical axis, and a posterior tibial slope outside the 0°–5° range), which are both poor predictors of PROMs, were excluded from the analysis[11, 12]. The radiologic measurements were performed by two orthopedic specialists specializing in knee surgery. Physical examination findings, such as knee flexion contracture (inability to fully extend the knee) and the knee flexion angle, were recorded preoperatively and 1 year after surgery. WOMAC scores, including subcategories of pain, stiffness, and physical function, were collected preoperatively and 1 year after TKA. These subcategories were scored on scales of 0–20 for pain, 0–8 for stiffness, and 0–68 for physical function, with higher scores denoting poorer outcomes [4]. The change (Δ) in WOMAC scores was calculated by subtracting the preoperative WOMAC score from the postoperative score at the one-year follow-up. Table 1 presents the demographic characteristics of the patients, while Table 2 displays the preoperative, one-year, and Δ WOMAC scores.

Perioperative protocols

All TKA procedures were performed by a single surgeon over 20 years of experience in knee surgery in a tertiary hospital. A parapatellar arthrotomy was performed,

Table 1 Demographic characteristics

N = 976	Mean ± SD	Range
Age (years)	74.7 ± 7.1	50 to 95
Sex (female)	94.4%	
Body mass index	26.7 ± 3.3	15.8 to 38.1
Preoperative HKAA*	9.9 ± 5.7	−21.3 to 30.8
Postoperative HKAA*	1.6 ± 2.1	−6.7 to 12.3
Cerebrovascular disease	10.5%	
Diabetes mellitus	26.7%	
Hypertension	38.1%	
Ischemic heart disease	10.7%	
Chronic liver disease	3.8%	
Chronic kidney disease	3.4%	
Patella resurfacing	66.1%	
Preoperative flexion contracture†	9.2 ± 7.7	−5 to 60
Preoperative flexion angle	124.7 ± 15.9	45 to 150
Postoperative flexion contracture†	0.4 ± 2.3	−5 to 20
Postoperative flexion angle	127.6 ± 10.6	70 to 150

* Positive values indicate varus, while negative values indicate valgus

† Negative values indicate recurvatum

Categorical variables are presented as percentages (%)

Continuous variables are presented as means ± standard deviations

HKAA Hip-knee-ankle angle, *SD* Standard deviation

followed by the excision of both cruciate ligaments. The modified gap balancing technique was utilized to achieve a neutral mechanical alignment targeting a neutral HKAA during bone cuts. Posterior stabilized and fixed implants were used. The decision for patellar resurfacing or preservation was based on the International Cartilage Repair Society (ICRS) grade of the patellar articular surface and was documented intraoperatively. Resurfacing was performed for a grade of 3 or higher, whereas preservation was preferred for patellae with a thickness below 20 mm to reduce the risk of patellar fracture[13]. All implants were fixed with cement.

Standardized rehabilitation protocols were implemented for all patients. Early postoperative ambulation and continuous passive motion exercises started on the day following surgery. Physical therapists began gentle passive range of motion (ROM) exercises three days postoperatively. Follow-up visits were scheduled at 1 month, 3 months, 12 months, and annually thereafter.

Statistical analysis

Multivariate regression analysis using the ordinary least squares method was conducted to identify variables affecting the one-year and ΔWOMAC scores. Variables were selected through univariate analysis with a significance level of 20%, and then multivariate analysis was conducted on selected variables with a *P*-value of less than 0.2. The final model was determined using variables with a significance level of 5%, and the model's goodness of fit was evaluated using adjusted R^2 values, considering a strong fit for adjusted $R^2 > 0.7$[14]. Collinearity of the variables was checked. Linear regression models were formulated for models showing strong fit, and age and sex were included in the final model irrespective of their statistical significance. Statistical analysis was performed using Python 3.10.12.

Categorization of age and preoperative WOMAC scores

We categorized age and preoperative WOMAC scores to investigate potential non-linear trends in the association between one-year WOMAC scores and ΔWOMAC scores. This approach aimed to identify the optimal age range and preoperative WOMAC score range, as multivariate regression assumes a linear relationship and may overlook non-linear associations. Age was categorized into four groups: below 60, 60–70, 70–80, and above 80 years. Preoperative WOMAC scores were classified based on quartile points, representing the lower 25%, median, and upper 25% of each score. Graphs were plotted to visualize curves, using the quartile boundaries as reference points for 1-year WOMAC scores and ΔWOMAC scores. The quartile points were 7, 9, and 11 for preoperative WOMAC pain; 2, 4, and 5 for preoperative WOMAC stiffness; and 26, 35, and 44 for preoperative WOMAC physical function scores. The differences between the categorized groups were analyzed using a one-way analysis of variance (ANOVA) test followed by Tukey's HSD test as a post-hoc analysis.

Table 2 Preoperative, 1-year, and change (Δ) in WOMAC scores

	Preoperative	1-Year	Change (Δ)*
WOMAC pain	9.3 ± 3.4 (1 to 20)	0.6 ± 1.2 (0 to 7)	−8.6 ± 3.1 (− 20 to 0)
WOMAC stiffness	3.9 ± 2.0 (0 to 8)	0.9 ± 1.1 (0 to 5)	−3.0 ± 1.9 (-8 to 5)
WOMAC physical function	35.3 ± 12.5 (5 to 68)	10.0 ± 6.8 (0 to 44)	−25 ± 12.0 (−67 to 10)

* Negative values indicate clinical improvement

Δ, Change in WOMAC scores; *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

Results

Improvements were observed 1 year postoperatively in all subscales of the WOMAC. The pain score decreased from 9.3 preoperatively to 0.6, the stiffness score improved from 3.9 to 0.9, and the physical function score improved from 35.3 to 10.0. Collinearity was observed among the preoperative WOMAC pain, stiffness, and physical function scores. Consequently, the regression models for the 1-year and ΔWOMAC pain, stiffness, and physical function scores included only their corresponding preoperative scores as dependent variables.

Factors affecting one-year WOMAC scores

The results of the multivariate regression analysis identifying factors influencing 1-year postoperative WOMAC scores are presented in Supplementary Tables 1–3. The regression models for 1-year WOMAC pain, stiffness, and physical function scores demonstrated poor goodness of fit, with adjusted R^2 values of 0.017, 0.036, and 0.078, respectively.

Factors affecting ΔWOMAC scores

The results of the multivariate regression analysis, identifying factors influencing the ΔWOMAC scores, are presented in Tables 3, 4 and 5. The regression models for ΔWOMAC pain, stiffness, and physical scores demonstrated strong goodness of fit, with adjusted R^2 values of 0.881, 0.755, and 0.761, respectively.

Regarding ΔWOMAC pain scores, females and a higher degree of postoperative knee flexion contracture were associated with higher scores ($P=0.015$ and $P=0.011$), indicating a small clinical improvement. Conversely, higher preoperative WOMAC pain scores were related to lower scores ($P=0.000$), indicating a large clinical improvement.

Regarding ΔWOMAC stiffness scores, females were associated with higher scores ($P=0.000$), whereas higher postoperative knee flexion angle and higher preoperative WOMAC stiffness scores were related to lower scores ($P=0.027$ and $P=0.000$).

Regarding ΔWOMAC physical function scores, old age, females, cerebrovascular disease, and a higher degree of postoperative knee flexion contracture were associated with higher scores ($P=0.000$, $P=0.000$, $P=0.004$, and $P=0.037$, respectively). In contrast, patellar resurfacing, higher postoperative knee flexion angle, and higher preoperative WOMAC physical function scores were related to lower scores ($P=0.001$, $P=0.007$, and $P=0.000$, respectively).

As the adjusted R^2 was above 0.7 for all ΔWOMAC score models, the following regression equations were generated:

Table 3 Regression analysis results of change (Δ) in WOMAC pain

	Univariate analysis			Multivariate analysis		
	Coefficient	*P*-value	95% CI	Coefficient	*P*-value	95% CI
Age (years)	0.035	0.013	[0.007, 0.062]	0.002	0.728	[−0.008, 0.011]
Sex (female)	−1.152	0.008	[−1.996, −0.307]	0.369	0.015*	[0.072, 0.665]
Body mass index	−0.038	0.209	[−0.097, 0.021]			
Preoperative HKAA	0.032	0.077	[−0.004, 0.068]	0.004	0.508	[−0.008, 0.017]
Postoperative HKAA	−0.018	0.716	[−0.112, 0.077]			
Cerebrovascular disease	0.005	0.987	[−0.634, 0.644]			
Diabetes mellitus	−0.205	0.363	[−0.646, 0.237]			
Hypertension	−0.002	0.994	[−0.404, 0.401]			
Ischemic heart disease	−0.500	0.122	[−1.132, 0.133]	−0.066	0.556	[−0.286, 0.154]
Chronic liver disease	−0.129	0.804	[−1.153, 0.895]			
Chronic kidney disease	0.312	0.572	[−0.770, 1.393]			
Patella resurfacing	−0.154	0.464	[−0.567, 0.259]			
Preoperative flexion contracture	−0.025	0.054	[−0.050, 0.000]	−0.003	0.524	[−0.012, 0.006]
Preoperative flexion angle	−0.001	0.854	[−0.013, 0.011]			
Postoperative flexion contracture	0.065	0.131	[−0.019, 0.149]	0.039	0.011*	[0.009, 0.070]
Postoperative flexion angle	−0.010	0.269	[−0.029, 0.008]			
Preoperative WOMAC pain	−0.975	0.000	[−0.998, −0.952]	−0.976	0.000*	[−0.999, −0.953]

Adjusted $R^2=0.881$

Δ, Change in WOMAC scores; *C.I.* Confidence interval, *HKAA* Hip-knee-ankle angle, *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

* statistically significant at $P<0.05$

Table 4 Regression analysis results of change (Δ) in WOMAC stiffness

	Univariate analysis			Multivariate analysis		
	Coefficient	**P-value**	**95% CI**	**Coefficient**	***P*-value**	**95% CI**
Age (years)	0.009	0.324	[−0.008, 0.025]	0.001	0.850	[−0.008, 0.009]
Sex (female)	−0.062	0.816	[−0.586, 0.462]	0.499	0.000*	[0.238, 0.760]
Body mass index	0.006	0.732	[−0.030, 0.043]			
Preoperative HKAA	0.003	0.804	[−0.019, 0.025]			
Postoperative HKAA	–004	0.894	[−0.062, 0.054]			
Cerebrovascular disease	0.123	0.541	[−0.272, 0.518]			
Diabetes mellitus	−0.205	0.140	[−0.478, 0.068]	0.040	0.574	[− 0.098, 0.178]
Hypertension	0.070	0.583	[−0.179, 0.318]			
Ischemic heart disease	−0.189	0.344	[−0.581, 0.202]			
Chronic liver disease	0.187	0.562	[−0.446, 0.820]			
Chronic kidney disease	−0.541	0.112	[−1.209, 0.127]	−0.188	0.279	[−0.527, 0.152]
Patella resurfacing	−0.021	0.872	[−0.276, 0.234]			
Preoperative flexion contracture	−0.019	0.015	[−0.035, −0.004]	−0.007	0.110	[−0.015, 0.002]
Preoperative flexion angle	−0.002	0.557	[−0.010, 0.005]	−0.001	0.537	[−0.006, 0.003]
Postoperative flexion contracture	−0.018	0.498	[−0.070, 0.034]			
Postoperative flexion angle	−0.010	0.078	[−0.022, 0.001]	−0.007	0.027*	[−0.014, −0.001]
Preoperative WOMAC stiffness	−0.942	0.000	[−0.976, −0.908]	−0.943	0.000*	[−0.977, −0.909]

Adjusted $R^2 = 0.755$

Δ, Change in WOMAC scores; *C.I.* Confidence interval, *HKAA* Hip-knee-ankle angle, *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

* statistically significant at $P < 0.05$

Table 5 Regression analysis results of change (Δ) in WOMAC physical function

	Univariate analysis			Multivariate analysis		
	Coefficient	***P*-value**	**95% CI**	**Coefficient**	***P*-value**	**95% CI**
Age (years)	0.109	0.043	[0.004, 0.215]	0.107	0.000*	[0.055, 0.160]
Sex (female)	−2.553	0.127	[−5.831, 0.726]	2.891	0.000*	[1.267, 4.515]
Body mass index	0.037	0.753	[−0.191, 0.265]			
Preoperative HKAA	0.123	0.081	[−0.015, 0.261]	0.018	0.611	[−0.050, 0.086]
Postoperative HKAA	0.056	0.763	[−0.309, 0.422]			
Cerebrovascular disease	1.724	0.172	[− 0.748, 4.195]	1.777	0.004*	[0.558, 2.996]
Diabetes mellitus	−1.272	0.144	[−2.980, 0.436]	−0.040	0.926	[−0.884, 0.805]
Hypertension	0.465	0.559	[− 1.094, 2.023]			
Ischemic heart disease	0.380	0.761	[−2.073, 2.833]			
Chronic liver disease	−0.831	0.681	[−4.794, 3.132]			
Chronic kidney disease	0.881	0.680	[−3.307, 5.068]			
Patella resurfacing	−3.987	0.000	[−5.566, −2.408]	−1.319	0.001*	[−2.123, −0.515]
Preoperative flexion contracture	−0.040	0.423	[−0.138, 0.058]			
Preoperative flexion angle	0.010	0.679	[−0.038, 0.058]			
Postoperative flexion contracture	0.237	0.155	[−0.090, 0.563]	0.179	0.037*	[0.010, 0.347]
Postoperative flexion angle	−0.061	0.092	[−0.133, 0.010]	−0.050	0.007*	[−0.087, −0.014]
Preoperative WOMAC physical function	−0.944	0.000	[−0.979, −0.910]	−0.945	0.000*	[−0.979, −0.910]

Adjusted $R^2 = 0.761$

Δ, Change in WOMAC scores; *CI* confidence interval, *HKAA* hip-knee-ankle angle, *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

* statistically significant at $P < 0.05$

ΔWOMAC pain = −0.095 + 0.002 × (*age*) + 0.369 × (*female* = *1*) + 0.039 × (*postoperative flexion contracture*)—0.976 × (*preoperative WOMAC pain*).

ΔWOMAC stiffness = 1.289 + 0.001 × (*age*) + 0.499 × (*female* = *1*)—0.007 × (*postoperative flexion angle*)—0.943 × (*preoperative WOMAC stiffness*).

ΔWOMAC physical function = 4.196 + 0.107 × (*age*) + 2.891 × (*female* = *1*) + 1.777 × (*cerebrovascular disease* = *1*)—1.319 × (*patellar resurfacing* = *1*) + 0.179 × (*postoperative flexion contracture*)—0.050 × (*postoperative flexion angle*)—0.945 × (*preoperative WOMAC physical function*).

The scores obtained from the regression equation represent the predicted postoperative WOMAC scores, calculated on the basis of preoperative key variables.

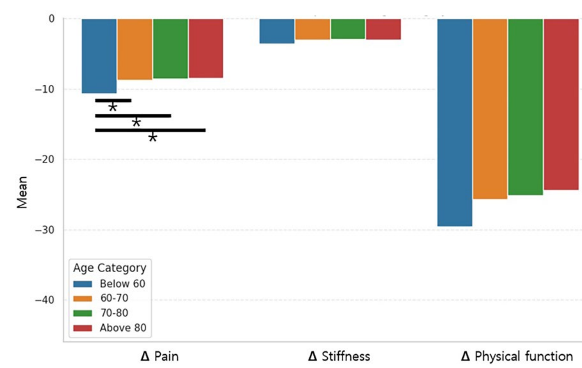

Fig. 3 Change (Δ) in WOMAC scores according to age category. *statistically significant at $P < 0.05$. *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

Categorization of age and preoperative WOMAC scores

Regarding age, physical function at 1 year was best in the 60 s and was poorest in patients above aged 80 years. The 1-year pain and stiffness scores were not significantly different between the quartile groups, and no trend was seen (Fig. 2). Patients below age 60 showed the most improvement in pain, and the amount of improvement decreased with increasing age ($P < 0.05$). Changes in stiffness and physical function also showed a similar trend, although not statistically significant (Fig. 3).

Figures 4 and 5 demonstrate the one-year WOMAC and ΔWOMAC scores according to preoperative WOMAC categories. One-year WOMAC scores showed an increasing trend as the scores of the quartile groups increased, consistent with the multivariate regression analysis. In contrast, ΔWOMAC scores displayed a decreasing trend as preoperative WOMAC stiffness increased, with statistically significant differences between each quartile group.

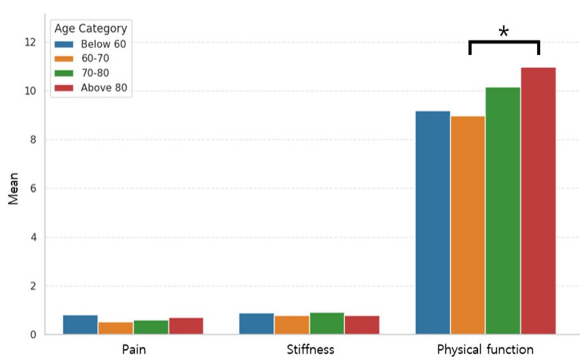

Fig. 2 The 1-year WOMAC scores according to age category. *statistically significant at $P < 0.05$. *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

Discussion

The most important finding of this study was the strong predictive correlation between perioperative factors and changes in WOMAC scores after TKA. Preoperative WOMAC scores, sex, and postoperative knee ROM significantly influenced the amount of change in all WOMAC scores. Additionally, age, cerebrovascular disease, and patellar resurfacing were related to ΔWOMAC physical function scores. The strength of our study lies in its ability to provide preoperative patient counseling, as it could predict the extent of improvements in WOMAC scores after surgery.

Previous studies addressed the optimal TKA outcomes, which can be divided into two aspects: obtaining the maximum clinical score value itself after surgery and achieving the greatest clinical improvement [6]. Prior research generally supported an association between better preoperative PROMs and improved postoperative PROMs [15, 16]. Meanwhile, poor preoperative PROMs predicted greater improvement. Vina et al. [17] found that patients with improvements after TKA had higher preoperative WOMAC scores, even if their postoperative results were not as good as those with better preoperative WOMAC scores. Thus, both postoperative absolute values and changes in PROMs should be considered. Meanwhile, although the definition of an improved outcome varies in the literature, previous research reported a minimum clinically important difference (MCID) for WOMAC total scores (the sum of pain, stiffness, and physical function scores) of 10 to 15 [18, 19]. While the analysis of MCID was not conducted in this study, the results demonstrated satisfactory outcomes that exceeded the MCID threshold.

The predictive accuracy of the model for 1-year WOMAC scores was found to be low, whereas the model for predicting changes in WOMAC scores demonstrated

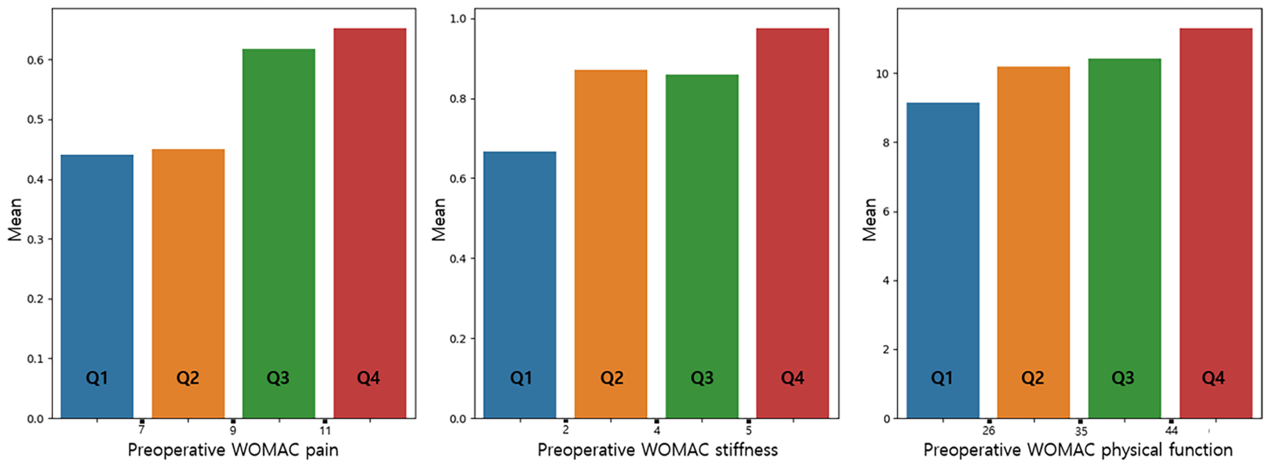

Fig. 4 The 1-year WOMAC scores according to preoperative WOMAC scores. There were no significant differences between the quartile groups in each WOMAC scores. *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

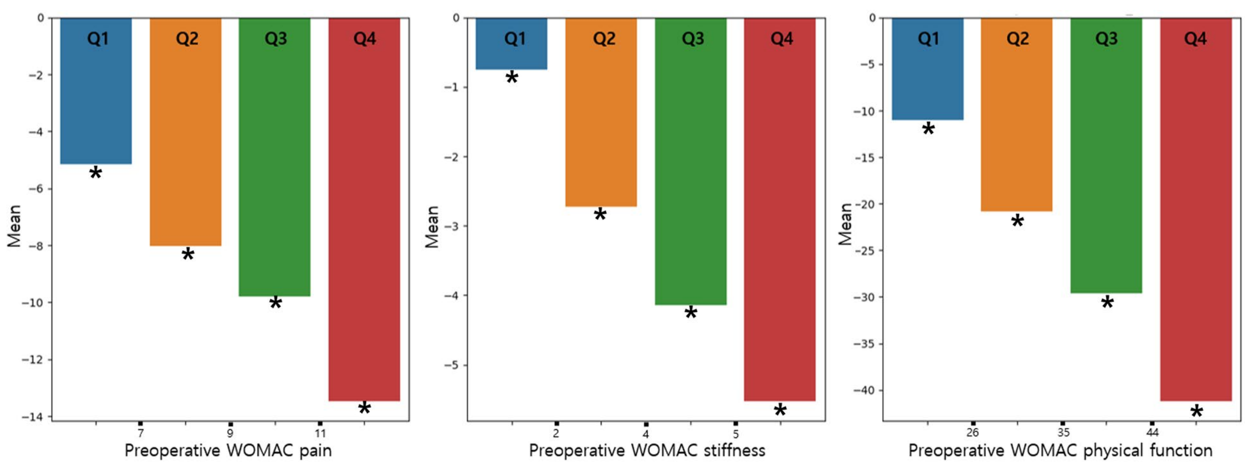

Fig. 5 Change (Δ) in WOMAC scores according to preoperative WOMAC scores. All quartile groups in each WOMAC scores are statistically different ($P < 0.05$) from one another (one-way analyses of variance test followed by Tukey's HSD post hoc analyses). *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

superior predictive accuracy. This discrepancy can be attributed to the phenomenon where the absolute post-operative WOMAC scores converged, as there were greater clinical improvements in the group with poor preoperative WOMAC scores. As a result, there was no substantial difference between the maximum postoperative PROM values in patients with poor preoperative PROMs and those with good preoperative PROMs. Interestingly, the 1-year WOMAC pain scores were not affected by preoperative WOMAC pain scores, possibly owing to the strong pain-relieving effect of TKA, resulting in low pain levels. However, the higher predictive power of ΔWOMAC scores can be explained by the diverse scattering of preoperative WOMAC scores.

Sex was a significant factor affecting all WOMAC scores, with inferior 1-year outcomes and changes observed in females compared to males. While the impact of sex on TKA outcomes may vary, it is generally accepted that women experience greater pain and functional impairment compared to men prior to TKA [20, 21]. A study reporting inferior TKA results for women suggested that women had more symptomatic joints than men, in which WOMAC scores were affected not only by the knee but by the overall condition [20]. In addition, according to Lingard et al. [22], women had a higher level of depression compared to men, which may have a greater impact on physical impairment after TKA.

Measures of knee ROM, such as flexion contracture and flexion angle, had an impact on all ΔWOMAC scores, one-year WOMAC stiffness and physical function scores. Patients with a large degree of residual flexion contracture reported little change in pain and function, whereas patients with higher postoperative flexion angles exhibited more improvement in stiffness and function. As this study was conducted on an East Asian population, it is important to note that cultural practices often involve spending time on the floor, including activities, such as kneeling and squatting for daily chores. In this cultural context, a lower flexion angle after TKA may result in a perceived sense of stiffness. To comfortably perform activities listed in the WOMAC physical function questionnaire, such as rising from bed, sitting, and engaging in light domestic duties, patients in this population may require higher flexion angles. Ritter et al. [23] reported that flexion contractures remaining after TKA deteriorated pain and function, as well as patient satisfaction. Similarly, Kubo et al. [24] reported that knee function was affected by the postoperative flexion angle after TKA.

Age was found to be a significant factor influencing 1-year and ΔWOMAC physical function scores after TKA. Advancing age was associated with inferior WOMAC scores, suggesting a negative impact of aging on functional outcomes after surgery. Interestingly, an age range of 60–70 years was identified as the period with maximal one-year physical function, which was visualized graphically (Fig. 2). Studies regarding age and PROMs have reported conflicting findings, with some showing no association, and others reporting older age as a predictor of poorer PROMs [15, 25, 26]. Results comparable to ours include those of Chang et al., who reported poorer WOMAC scores with increasing age [26] and Lee et al., who reported that optimal PROMs were achieved in patients between 70 and 80 years, with the best outcomes observed around 70 years [5].

Cerebrovascular disease was the only comorbidity significantly affecting 1-year and ΔWOMAC scores, particularly in physical function. A study by Singh et al. [27] based on a United States joint registry reported poor outcomes for patients with cerebrovascular disease, and recommended sharing the risk of poor functional outcomes with patients with cerebrovascular disease. Pomeroy et al. [28] reported that patients with neurologic disorders may present challenging conditions, including contractures, muscle weakness, and instability, affecting recovery. However, improvements in functional outcomes were still observed. With the expanding indications for TKA, patients with cerebrovascular disease may benefit from TKA with advances in perioperative management, and the results of this study could aid in decision-making for these patients.

Patellar resurfacing also influenced outcomes after TKA. Patients with patellar resurfacing showed worse 1-year WOMAC stiffness scores but better 1-year WOMAC scores and improved ΔWOMAC physical function scores. Some meta-analyses reported no differences between patellar resurfacing and non-resurfacing, except for secondary resurfacing rates, whereas some studies reported better functional results with patellar resurfacing [29, 30]. However, studies comparing stiffness after patellar resurfacing or non-resurfacing are limited. In addition, the WOMAC stiffness score is not always indicative of restricted knee ROM. Rather, it relates to initiating movement after prolonged inactivity instead of knee ROM [31]. Nevertheless, this study demonstrated a significant difference between patellar resurfacing and non-resurfacing groups in terms of stiffness and physical function, adding to the knowledge of patella management.

There were some limitations to this study. First, it had a relatively short follow-up period of only 1 year to assess clinical outcomes. Additionally, the regression model for 1-year WOMAC scores demonstrated poor predictability. In contrast, the predictability for ΔWOMAC scores was good. This could be because the study was based on the results of TKA performed at a single center, with the use of posterior stabilized and fixed implants. While this aspect may serve as a good controlling factor, its generalizability to other patients using different implants is limited. Furthermore, the absence of an analysis for the MCID is a limitation, as such analysis could provide further insights into clinically meaningful improvements. Lastly, the high proportion of female patients (over 90%), which reflects the demographic trends in South Korea where approximately 90% of TKAs are performed on women, may have influenced the study outcomes [32].

Conclusions

A quantitative model was developed to predict changes in postoperative WOMAC scores following TKA, demonstrating strong predictability. Preoperative WOMAC scores, sex, and postoperative knee ROM were identified as significant factors influencing all aspects of pain, stiffness, and physical function in the WOMAC assessment. Age, cerebrovascular disease, and patellar resurfacing were found to be associated with changes in physical function.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43019-024-00238-1.

Supplementary material 1: Table 1. Regression analysis results of one-year WOMAC pain. Table 2. Regression analysis results of one-year WOMAC stiffness. Table 3. Regression analysis results of one-year WOMAC physical function.

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Author contributions
S.E.K. contributed to the research, statistical analysis, and writing and editing of the manuscript; D.H.R contributed to planning, statistical analysis, and editing of the manuscript; M.C.L performed the surgery and contributed to planning data analysis and editing of the manuscript; H–S.H. conceived the study, contributed to planning, statistical analysis, and editing of the manuscript.

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Availability of data and materials
Data available on request from the authors.

Declarations

Ethics approval and consent to participate
This study was approved by the institutional review board of Seoul National University Hospital (IRB no. H-2304-001-1416). This study was performed in line with the principles of the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
D.H.R is chief executive officer of CONNECTEVE Co., Ltd, which is unrelated to this study. All other authors declare no conflicts of interest.

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References

1. Kahlenberg CA, Nwachukwu BU, McLawhorn AS, Cross MB, Cornell CN, Padgett DE (2018) Patient satisfaction after total knee replacement: a systematic review. Hss J 14(2):192–201. https://doi.org/10.1007/s11420-018-9614-8
2. Bourne RB, Chesworth BM, Davis AM, Mahomed NN, Charron KD (2010) Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? Clin Orthop Relat Res 468(1):57–63. https://doi.org/10.1007/s11999-009-1119-9
3. Gupta P, Czerwonka N, Desai SS, deMeireles AJ, Trofa DP, Neuwirth AL (2023) The current utilization of the patient-reported outcome measurement information system (PROMIS) in isolated or combined total knee arthroplasty populations. Knee Surg Relat Res 35(1):3. https://doi.org/10.1186/s43019-023-00177-3
4. Bae SC, Lee HS, Yun HR, Kim TH, Yoo DH, Kim SY (2001) Cross-cultural adaptation and validation of Korean Western Ontario and McMaster Universities (WOMAC) and Lequesne osteoarthritis indices for clinical research. Osteoarthr Cartil 9(8):746–750. https://doi.org/10.1053/joca.2001.0471
5. Lee SH, Kim DH, Lee YS (2020) Is there an optimal age for total knee arthroplasty?: A systematic review. Knee Surg Relat Res 32(1):60. https://doi.org/10.1186/s43019-020-00080-1
6. Losina E, Katz JN (2013) Total joint replacement outcomes in patients with concomitant comorbidities: a glass half empty or half full? Arthritis Rheum 65(5):1157–1159. https://doi.org/10.1002/art.37903
7. Batailler C, Lording T, De Massari D, Witvoet-Braam S, Bini S, Lustig S (2021) Predictive models for clinical outcomes in total knee arthroplasty: a systematic analysis. Arthroplast Today 9:1–15. https://doi.org/10.1016/j.artd.2021.03.013
8. Ramkumar PN, Karnuta JM, Navarro SM, Haeberle HS, Scuderi GR, Mont MA et al (2019) Deep learning preoperatively predicts value metrics for primary total knee arthroplasty: development and validation of an artificial neural network model. J Arthroplasty 34(10):2220-2227.e2221. https://doi.org/10.1016/j.arth.2019.05.034
9. Quinn J, Jones P, Randle R (2022) Clinical outcomes following revision total knee arthroplasty: minimum 2-year follow-up. Clin Orthop Surg 14(1):69–75. https://doi.org/10.4055/cios20206
10. Blackburne JS, Peel TE (1977) A new method of measuring patellar height. J Bone Joint Surg Br 59(2):241–242. https://doi.org/10.1302/0301-620x.59b2.873986
11. Behrend H, Graulich T, Gerlach R, Spross C, Ladurner A (2019) Blackburne-Peel ratio predicts patients' outcomes after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 27(5):1562–1569. https://doi.org/10.1007/s00167-018-5016-1
12. Kazarian GS, Haddad FS, Donaldson MJ, Wignadasan W, Nunley RM, Barrack RL (2022) Implant malalignment may be a risk factor for poor patient-reported outcomes measures (PROMs) following total knee arthroplasty (TKA). J Arthroplasty 37(6s):S129-s133. https://doi.org/10.1016/j.arth.2022.02.087
13. Kim SE, Choi BS, Ro DH, Lee MC, Han H-S (2024) Fixed-bearing and higher postoperative knee flexion angle as predictors of satisfaction in Asian patients undergoing posterior-stabilized total knee arthroplasty. Clin Orthop Surg. https://doi.org/10.4055/cios23166
14. Hamilton DF, Ghert M, Simpson AH (2015) Interpreting regression models in clinical outcome studies. Bone Joint Res 4(9):152–153. https://doi.org/10.1302/2046-3758.49.2000571
15. Bin Abd Razak HR, Tan CS, Chen YJ, Pang HN, Tay KJ, Chin PL et al (2016) Age and preoperative knee society score are significant predictors of outcomes among Asians following total knee arthroplasty. J Bone Joint Surg Am 98(9):735–741. https://doi.org/10.2106/jbjs.15.00280
16. Andrawis J, Akhavan S, Chan V, Lehil M, Pong D, Bozic KJ (2015) Higher preoperative patient activation associated with better patient-reported outcomes after total joint arthroplasty. Clin Orthop Relat Res 473(8):2688–2697. https://doi.org/10.1007/s11999-015-4247-4
17. Vina ER, Hannon MJ, Kwoh CK (2016) Improvement following total knee replacement surgery: exploring preoperative symptoms and change in preoperative symptoms. Semin Arthritis Rheum 45(5):547–555. https://doi.org/10.1016/j.semarthrit.2015.10.002
18. Clement ND, Bardgett M, Weir D, Holland J, Gerrand C, Deehan DJ (2018) What is the minimum clinically important difference for the WOMAC index after TKA? Clin Orthop Relat Res 476(10):2005–2014. https://doi.org/10.1097/corr.0000000000000444
19. Escobar A, Quintana JM, Bilbao A, Aróstegui I, Lafuente I, Vidaurreta I (2007) Responsiveness and clinically important differences for the WOMAC and SF-36 after total knee replacement. Osteoarthritis Cartilage 15(3):273–280. https://doi.org/10.1016/j.joca.2006.09.001
20. Escobar A, Quintana JM, Bilbao A, Azkárate J, Güenaga JI, Arenaza JC et al (2007) Effect of patient characteristics on reported outcomes after total knee replacement. Rheumatology 46(1):112–119. https://doi.org/10.1093/rheumatology/kel184
21. MacDonald SJ, Charron KD, Bourne RB, Naudie DD, McCalden RW, Rorabeck CH (2008) The john insall award: gender-specific total knee replacement: prospectively collected clinical outcomes. Clin Orthop Relat Res 466(11):2612–2616. https://doi.org/10.1007/s11999-008-0430-1
22. Lingard EA, Katz JN, Wright EA, Sledge CB (2004) Predicting the outcome of total knee arthroplasty. J Bone Joint Surg Am 86(10):2179–2186. https://doi.org/10.2106/00004623-200410000-00008
23. Ritter MA, Lutgring JD, Davis KE, Berend ME, Pierson JL, Meneghini RM (2007) The role of flexion contracture on outcomes in primary total knee

arthroplasty. J Arthroplasty 22(8):1092–1096. https://doi.org/10.1016/j.arth.2006.11.009
24. Kubo M, Maeda T, Kumagai K, Amano Y, Kawasaki T, Imai S (2021) Good postoperative flexion angle improves knee function and improvement of flexion angle increases patient satisfaction after total knee arthroplasty. J Arthroplasty 36(9):3137–3140. https://doi.org/10.1016/j.arth.2021.04.040
25. Williams DP, Price AJ, Beard DJ, Hadfield SG, Arden NK, Murray DW et al (2013) The effects of age on patient-reported outcome measures in total knee replacements. Bone Joint J 95-b(1):38–44. https://doi.org/10.1302/0301-620x.95b1.28061
26. Chang CB, Yoo JH, Koh IJ, Kang YG, Seong SC, Kim TK (2010) Key factors in determining surgical timing of total knee arthroplasty in osteoarthritic patients: age, radiographic severity, and symptomatic severity. J Orthop Traumatol 11(1):21–27. https://doi.org/10.1007/s10195-010-0086-y
27. Singh JA, Lewallen DG (2014) Cerebrovascular disease is associated with outcomes after total knee arthroplasty: a US total joint registry study. J Arthroplasty 29(1):40–43. https://doi.org/10.1016/j.arth.2013.04.003
28. Pomeroy E, Fenelon C, Murphy EP, Staunton PF, Rowan FE, Cleary MS (2020) A systematic review of total knee arthroplasty in neurologic conditions: survivorship, complications, and surgical considerations. J Arthroplasty 35(11):3383–3392. https://doi.org/10.1016/j.arth.2020.08.008
29. Aunan E, Næss G, Clarke-Jenssen J, Sandvik L, Kibsgård TJ (2016) Patellar resurfacing in total knee arthroplasty: functional outcome differs with different outcome scores: a randomized, double-blind study of 129 knees with 3 years of follow-up. Acta Orthop 87(2):158–164. https://doi.org/10.3109/17453674.2015.1111075
30. van Hemert WL, Senden R, Grimm B, Kester AD, van der Linde MJ, Heyligers IC (2009) Patella retention versus replacement in total knee arthroplasty; functional and clinimetric aspects. Arch Orthop Trauma Surg 129(2):259–265. https://doi.org/10.1007/s00402-008-0640-8
31. Thomas E, Peat G, Mallen C, Wood L, Lacey R, Duncan R et al (2008) Predicting the course of functional limitation among older adults with knee pain: do local signs, symptoms and radiographs add anything to general indicators? Ann Rheum Dis 67(10):1390–1398. https://doi.org/10.1136/ard.2007.080945
32. Koh IJ, Kim TK, Chang CB, Cho HJ, In Y (2013) Trends in use of total knee arthroplasty in Korea from 2001 to 2010. Clin Orthop Relat Res 471(5):1441–1450. https://doi.org/10.1007/s11999-012-2622-y