

Active Flexion in Weight Bearing Better Correlates with Functional Outcomes of Total Knee Arthroplasty than Passive Flexion

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Purpose: Correlations between maximum flexion and functional outcomes in total knee arthroplasty (TKA) patients are reportedly weak. We investigated whether there are differences between passive maximum flexion in nonweight bearing and other types of maximum flexion and whether the type of maximum flexion correlates with functional outcomes.

Materials and Methods: A total of 210 patients (359 knees) underwent preoperative evaluation and postoperative follow-up evaluations (6, 12, and 24 months) for the assessment of clinical outcomes including maximum knee flexion. Maximum flexion was measured under five conditions: passive nonweight bearing, passive weight bearing, active nonweight bearing, and active weight bearing with or without arm support. Data were analyzed for relationships between passive maximum flexion in nonweight bearing by Pearson correlation analyses, and a variance comparison between measurement techniques via paired t test.

Results: We observed substantial differences between passive maximum flexion in nonweight bearing and the other four maximum flexion types. At all time points, passive maximum flexion in nonweight bearing correlated poorly with active maximum flexion in weight bearing with or without arm support. Active maximum flexion in weight bearing better correlated with functional outcomes than the other maximum flexion types.

Conclusions: Our study suggests active maximum flexion in weight bearing should be reported together with passive maximum flexion in nonweight bearing in research on the knee motion arc after TKA.

Keywords: Knee, Arthroplasty, Active flexion, Outcome

Introduction

Knee motion arc is widely used as an outcome measure after total knee arthroplasty (TKA) and is a major component of vari-

ous scoring systems^{1,2}. Currently, much effort is being expended to allow for greater flexion and high-flexion activities that are frequently required in certain religions and traditional Asian lifestyle³⁻⁶. However, concern has been expressed regarding the longevity of TKA due to the high-flexion activities enabled by increases in maximum flexion; these activities can increase stresses on the articulating surfaces and implant-bone interfaces⁷⁻¹¹. Furthermore, it is debatable as to whether increased flexion provides real benefit¹²⁻¹⁶.

It appears reasonable that greater flexion after TKA improves clinical outcome^{13,16,17}. However, several studies have reported only weak or modest correlations between the degree of maximum flexion and functional outcomes in patients with TKA^{3,18}. One possible explanation for this is passive maximum flexion without weight bearing does not accurately represent the amount of knee motion arc required for functional activities under weight

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bearing conditions with muscle function. For example, it has been reported that maximum flexion in weight bearing is smaller than that in nonweight bearing¹⁹.

We, therefore, investigated 1) whether substantial differences exist between passive maximum flexion in nonweight bearing and other types of maximum flexion (active nonweight bearing [ANWB], passive weight bearing [PWB], and active weight bearing with arm support [AWB-a] or active weight bearing without arm support [AWB-b]) and 2) whether any of the maximum flexion types better correlates with functional outcomes and patient satisfaction.

Materials and Methods

We prospectively recruited 219 patients (373 knees) who visited the operating surgeon's outpatient clinic to form four cohorts representing the patient groups at four different time points (preoperative and postoperative 6, 12, and 24 months) from November 2003 to July 2006. We included patients with primary osteoarthritis and excluded those with postoperative complications that might affect outcome and those with systemic comorbidities that prevented patients from experiencing the maximum benefits of TKA. Fourteen knees in nine patients were excluded for the following reasons: a diagnosis other than primary osteoarthritis (6 knees) and serious medical problems unrelated to surgery, such as a cerebrovascular accident, Parkinson's disease (7 knees), and periprosthetic infection (1 knee). Consequently, we included 359 knees of 210 patients: 86 knees of 49 patients before TKA; 99 knees of 63 patients 6 months postoperatively; 86 knees of 48 patients 12 months postoperatively; and 88 knees of 50 patients 24 months postoperatively. Outcomes with respect not to the unit of patients but to the unit of knees were analyzed in each analytical trial. No demographic differences were evident among knees grouped by time points before or after surgery (Table 1). Clinical

information was prospectively collected using predesigned datasheets and maintained in a database by a single investigator (TKK). This information included demographic data, preoperative clinical status, and postoperative outcomes evaluated at 6, 12, and 24 months postoperatively. This study received Institutional Review Board approval, and all patients provided informed consent.

Preoperative clinical status and postoperative outcomes were evaluated using knee motion arc (flexion contracture and maximum flexion), American Knee Society (AKS) knee and function scores including patient category², the patellofemoral scoring system proposed by Feller et al.²⁰, the Western Ontario and McMaster Universities Arthritis Index (WOMAC) scales²¹, Short-Form 36 (SF-36) scores²², and patient satisfaction. Patient satisfaction was evaluated using the grading system developed by the British Orthopaedic Association²³⁻²⁵, which involves four satisfaction levels: enthusiastic, satisfied, not committed, and disappointed. A single investigator (TKK) evaluated patient satisfaction using a questionnaire for all patients during follow-up visits. A single investigator (TKK) measured five types of maximum flexion: 1) ANWB, 2) passive nonweight bearing (PNWB), 3) PWB, 4) AWB-a, and 5) AWB-b (Fig. 1). Active maximum flexion in nonweight bearing was measured to the nearest 5° using a goniometer with the patient placed in supine position while actively bending knees (Fig. 1A). Passive maximum flexion in nonweight bearing was measured when an investigator applied a bending force without causing pain (Fig. 1B). Passive maximum flexion in weight bearing was measured while the patient kneeled on the affected knee (Fig. 1C). When a patient could not kneel on both knees, he/she kneeled only on the involved knee (Fig. 1D). Active maximum flexion in weight bearing with arm support was measured while squatting with arm support on knees (Fig. 1E). Active maximum flexion in weight bearing without arm support was measured while squatting with the arms free (Fig. 1F). For all

Table 1. Comparison of Demographic Data and Clinical Status at Different Time Points before and after Surgery

Variable	Preoperative (49 patients)	6 mo (63 patients)	12 mo (48 patients)	24 mo (50 patients)	p-value
No. of female patients (%)	39 (90.7)	59 (93.7)	48 (98.0)	44 (95.7)	0.205
Age (yr)	69.1 (5.4)	67.7 (6.9)	68.1 (5.1)	67.9 (6.9)	0.676
Height (cm)	153.1 (6.6)	153.0 (5.3)	152.8 (6.1)	152.7 (5.8)	0.985
Weight (kg)	62.2 (11.0)	63.7 (8.5)	61.1 (8.4)	62.1 (9.4)	0.548
Body mass index (kg/m ²)	24.5 (3.8)	27.2 (3.3)	26.0 (3.0)	26.6 (3.8)	0.394
No. of bilateral TKAs (%)	23 (34.8)	36 (36.4)	38 (44.2)	31 (40.3)	0.108

Values are presented as mean (standard deviation) unless otherwise indicated.

TKA: total knee arthroplasty.

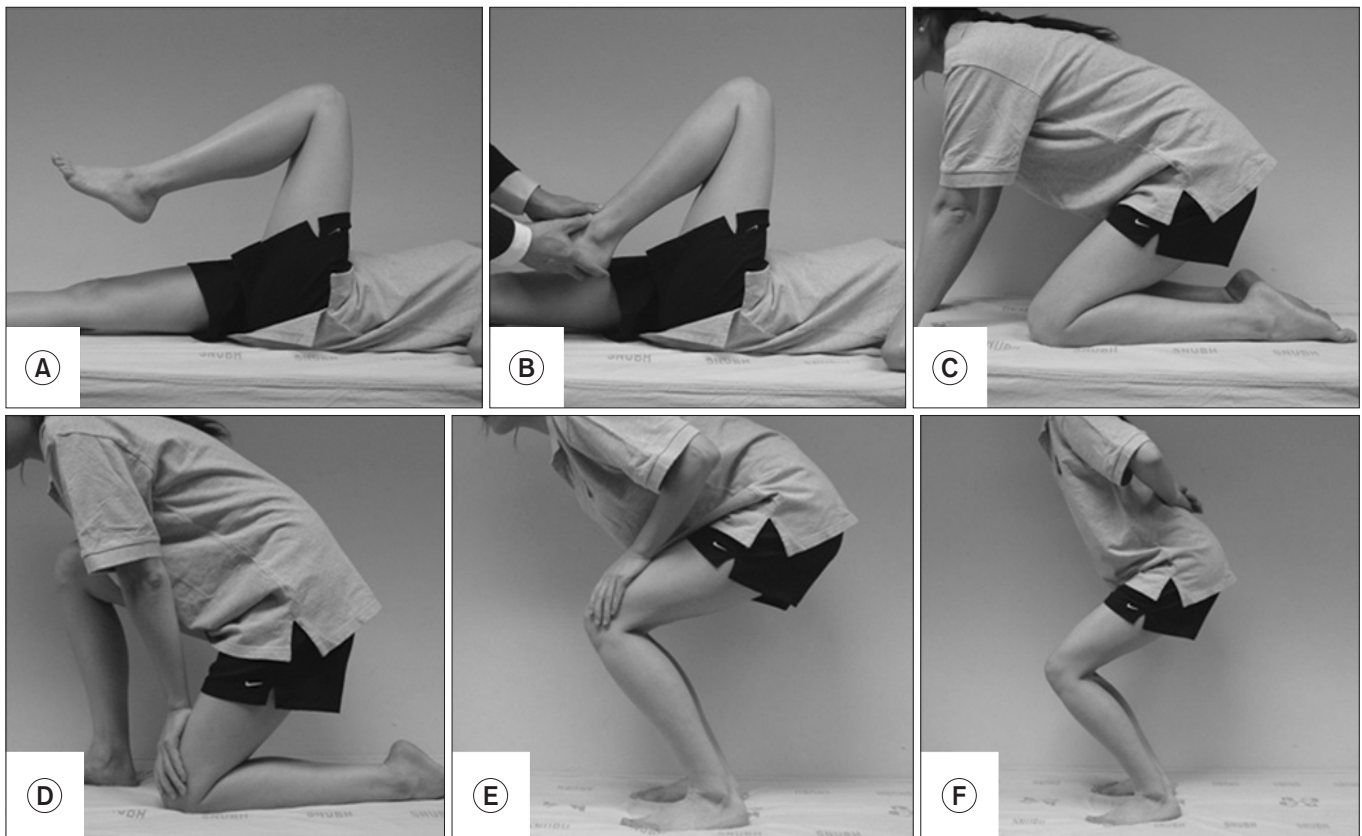


Fig. 1. Photographs showing how the five types of maximum flexion were measured. (A) Active maximum flexion in nonweight bearing was measured with the patient placed in supine while actively bending the knee. (B) Passive maximum flexion in nonweight bearing was measured while an investigator applied a bending force without causing pain. (C) Passive maximum flexion in weight bearing was measured with the patient kneeling on the affected knee. (D) When the patient could not kneel on both knees, he/she knelt only on the involved knee. (E) Active maximum flexion in weight bearing with arm support was measured while squatting with arm support on knees. (F) Active maximum flexion in weight bearing without arm support was measured while squatting with the arms free.

measurements, the center of the goniometer was kept on the knee joint axis with the distal arm pointing to the lateral malleolus and the proximal arm pointing to the greater trochanter.

All surgeries were performed by a single surgeon (TKK). Two hundred ninety-eight TKAs were performed as bilateral procedures and the other sixty-one as unilateral procedures. One hundred ninety-four knees were implanted with a fixed-bearing posteriorly stabilized prosthesis (Genesis II; Smith & Nephew, Memphis, TN, USA) and 165 knees with a mobile-bearing posteriorly stabilized prosthesis (e.motion-PS; B. Braun-Aesculap, Tuttlingen, Germany). No differences ($p=0.115$) were found between patients evaluated at 6, 12, and 24 months postoperatively in terms of implant type proportions. In all cases, a medial parapatellar arthrotomy approach was used, patellae were resurfaced, and implant fixations were carried out with cement. All patients underwent the same postoperative rehabilitation protocol. Patients learned how to perform quadriceps strengthening

exercises and how to use a walking aid at a physiotherapy unit preoperatively. Patients were encouraged to perform quadriceps-strengthening exercises once they had returned to the ward on the operation day. One day after surgery, patients were allowed to walk to the toilet using a walking aid and received a 50-minute continuous passive motion (CPM) session with a range of motion (ROM) of 0° to 30° . CPM sessions continued for 2 weeks postoperatively and ROMs were gradually increased as tolerated. On the second postoperative day, patients began to dangle legs and perform active ROM exercises. From the 3rd to the 14th postoperative day, patients underwent a daily physiotherapy session at our rehabilitation center.

Statistical analysis was performed using SPSS ver. 12.0 (SPSS Inc., Chicago, IL, USA). Temporal patterns of the five types of maximum flexion were compared. The Kolmogorov-Smirnov test was used to confirm that the data of the 5 types of flexion were normally distributed. Differences between adjacent time

points (preoperative vs. 6 months; 6 months vs. 12 months; and 12 months vs. 24 months) were determined by analysis of variance with the post hoc analyses. Maximum flexion differences by the types were determined using the paired *t*-test. Partial correlation analysis adjusted for confounding factors (age, gender, body mass index, bilaterality, type of implant, and patient category as determined by the AKS) was performed to assess the relationship. Relationships between passive maximum flexion in nonweight bearing and other maximum flexion types were evaluated by Pearson correlation analyses. To determine whether our sample size had sufficient power to detect significant correlations, a priori power analysis was performed using a two-sided hypothesis test and an alpha level of 0.05. We regarded a correlation coefficient of greater than 0.3 as being clinically important. Eighty-five cases were required to detect a clinically important correlation with the power of 80%. The levels of correlation detectable given

our sample size of 86, 99, 86, and 88 knees were 81%, 86%, 81%, and 82%, respectively, which indicated the study had sufficient power to detect clinically important correlations.

Results

Substantial differences existed between passive maximum flexion in nonweight bearing and the other four flexion types (Fig. 2). Passive maximum flexion in nonweight bearing was greatest followed by PWB or ANWB, AWB-a, and AWB-b at all time points (Fig. 2). Temporal patterns of maximum flexion also differed for the five maximum flexion types (Fig. 2). Passive maximum flexion in nonweight bearing after surgery peaked at 12 months. Passive maximum flexion in weight bearing decreased after surgery, and no differences were observed among the three postoperative time points ($p>0.05$). Active maximum flexion in nonweight bearing decreased after surgery and showed similar levels at 6 and 12 months postoperatively but then reduced further at 24 months. In contrast, active flexion in weight bearing with or without arm support increased after surgery and maintained similar levels at the three different time points. In term of overall correlation, passive maximum flexion in nonweight bearing weakly correlated with active maximum flexion in weight bearing with ($r=0.41$, $p=0.001$) or without ($r=0.38$, $p=0.002$) arm support but strongly correlated with ANWB ($r=0.93$, $p<0.001$) and PWB ($r=0.86$, $p<0.001$) (Table 2).

Active weight bearing types of maximum flexion better correlated with functional outcomes than the other flexion types. Furthermore, correlation patterns between maximum flexion and clinical outcome scales differed by maximum flexion type and the time after surgery (Tables 2–6). Preoperatively, active weight bearing with or without arm support correlated with AKS function score, chair rising and stair climbing scores of the patellofemoral scoring system, and the role physical and vitality scales of the SF-36 (Table 3). It was notable that the anterior knee pain

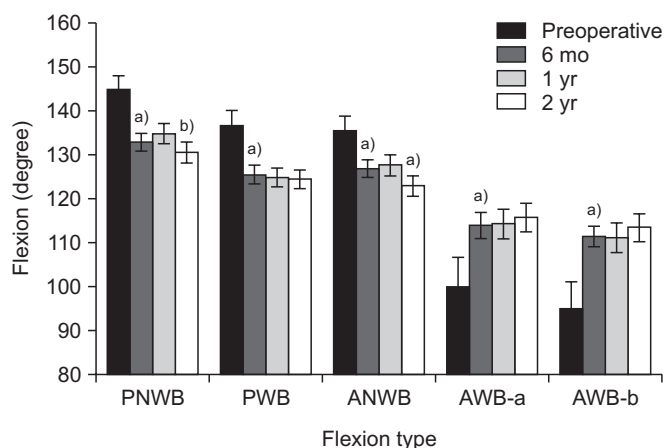


Fig. 2. Bar graph showing the temporal patterns of the five types of maximum flexion. Statistical significance of the differences from the previous adjacent time point is shown with two footnotes. PNWB: passive nonweight bearing, PWB: passive weight bearing, ANWB: active nonweight bearing, AWB-a: active weight bearing with arm support, AWB-b: active weight bearing without arm support. ^{a)} $p<0.01$, ^{b)} $p<0.05$.

Table 2. Correlations between the Passive Nonweight Bearing Flexion and Other Four Types of Flexion

Time point	PWB	ANWB	AWB-a	AWB-b
Preoperative (n=86)	0.86 (<0.001)	0.93 (<0.001)	0.41 (0.001)	0.38 (0.002)
6 mo (n=99)	0.83 (<0.001)	0.93 (<0.001)	0.27 (0.007)	0.37 (<0.001)
1 yr (n=86)	0.78 (<0.001)	0.91 (<0.001)	0.28 (0.008)	0.37 (<0.001)
2 yr (n=88)	0.77 (<0.001)	0.91 (<0.001)	0.56 (0.008)	0.67 (<0.001)
Overall	0.84 (<0.001)	0.93 (<0.001)	0.17 (0.002)	0.23 (<0.001)

Values are presented as Pearson correlation coefficients (p-value).

PWB: passive weight bearing, ANWB: active nonweight bearing, AWB-a: active weight bearing with arm support, AWB-b: active weight bearing without arm support.

Table 3. Comparison of the Correlations between the Five Different Types of Maximum Flexion and Clinical Outcome Scales in 86 Knees before Surgery

Outcome scale	PNWB	PWB	ANWB	AWB-a	AWB-b
American Knee Society					
Pain score	0.11 (0.363)	0.13 (0.305)	0.17 (0.173)	0.16 (0.193)	0.14 (0.255)
Knee score	0.26 (0.039)	0.18 (0.169)	0.33 (0.007)	0.10 (0.434)	0.08 (0.502)
Function score	-0.10 (0.410)	-0.02 (0.866)	-0.03 (0.825)	0.25 (0.041)	0.30 (0.016)
Patellofemoral scoring system					
Anterior knee pain	-0.43 (0.000)	-0.37 (0.003)	-0.44 (0.000)	-0.29 (0.019)	-0.29 (0.017)
Chair rising	0.10 (0.408)	0.06 (0.647)	0.09 (0.458)	0.29 (0.019)	0.24 (0.055)
Stair climbing	0.11 (0.365)	0.17 (0.182)	0.18 (0.151)	0.48 (0.000)	0.49 (0.000)
WOMAC ^{a)}					
Pain score	0.02 (0.901)	0.10 (0.421)	-0.01 (0.964)	0.07 (0.556)	0.08 (0.546)
Stiffness score	0.01 (0.929)	0.10 (0.456)	-0.03 (0.813)	0.10 (0.419)	0.08 (0.546)
Function score	0.11 (0.396)	0.11 (0.381)	0.12 (0.323)	0.06 (0.624)	0.03 (0.806)
Short-Form 36					
Physical functioning	0.10 (0.441)	0.07 (0.600)	0.05 (0.696)	0.15 (0.239)	0.13 (0.317)
Role physical	-0.00 (0.989)	0.15 (0.241)	-0.00 (0.992)	0.23 (0.064)	0.23 (0.070)
Bodily pain	-0.22 (0.071)	-0.16 (0.201)	-0.25 (0.045)	-0.02 (0.849)	-0.04 (0.746)
General health	0.17 (0.172)	0.03 (0.827)	0.12 (0.349)	0.10 (0.440)	0.08 (0.549)
Vitality	-0.04 (0.746)	0.08 (0.548)	-0.04 (0.726)	0.21 (0.086)	0.25 (0.047)
Social functioning	-0.10 (0.440)	0.00 (0.991)	-0.13 (0.319)	0.11 (0.386)	0.10 (0.444)
Role emotional	-0.04 (0.728)	0.05 (0.676)	-0.07 (0.578)	0.09 (0.456)	0.08 (0.523)
Mental health	-0.06 (0.635)	0.12 (0.369)	-0.10 (0.422)	0.09 (0.471)	0.09 (0.490)
Physical component summary	0.06 (0.616)	-0.01 (0.946)	0.04 (0.751)	0.19 (0.135)	0.17 (0.174)
Mental component summary	-0.09 (0.496)	0.08 (0.552)	-0.12 (0.353)	0.11 (0.367)	0.11 (0.375)

Values are presented as correlation coefficients (p-value).

PNWB: passive nonweight bearing, PWB: passive weight bearing, ANWB: active nonweight bearing, AWB-a: active weight bearing with arm support, AWB-b: active weight bearing without arm support, WOMAC: Western Ontario and McMaster Universities Arthritis Index.

^{a)}To facilitate comparisons, correlation analyses were performed using standardized WOMAC scores (worst score=0, best score=100).

scale of the patellofemoral scoring system showed an inverse correlation with all types of maximum flexion, indicating that the higher the maximum flexion was, the more severe the anterior knee pain. At 6 months postoperatively, the AKS and WOMAC scales did not correlate with any of the five types of maximum flexion (Table 4). At 12 months postoperatively, active weight bearing maximum flexion with or without arm support positively correlated with many of the outcome scales, whereas passive flexion types and active flexion in nonweight bearing showed only weak correlations with some of the outcome scales (Table 5, Fig. 3). Only active maximum flexion in weight bearing with or without arm support positively correlated with patient satisfaction. At 24 months postoperatively, no correlation was evident between active maximum flexion in weight bearing without arm support; however, AWB-a positively correlated with anterior knee pain by

all three WOMAC scales (Table 6).

Discussion

Although much effort is being expended to obtain greater flexion to allow higher-flexion activities, it remains debatable as to whether increased flexion provides real benefit¹²⁻¹⁶⁾. Previous studies have reported that correlations between the degree of maximum flexion and functional outcomes are only weak or modest^{3,18)}. One possible explanation for this lack of correlation between the degree of maximum flexion and functional outcomes is that passive maximum flexion in nonweight bearing, which is typically used to evaluate knee motion arc, fails to represent the amount of knee motion arc required for functional activities. In the present study, we investigated whether substantial

Table 4. Comparison of the Correlations between the Five Different Types of Maximum Flexion and Clinical Outcome Scales in 99 Knees at 6 Months after Surgery

Outcome scale	PNWB	PWB	ANWB	AWB-a	AWB-b
American Knee Society					
Pain score	-0.11 (0.266)	-0.05 (0.607)	-0.09 (0.376)	0.14 (0.183)	0.03 (0.739)
Knee score	-0.04 (0.694)	-0.04 (0.706)	0.02 (0.883)	0.16 (0.122)	0.16 (0.121)
Function score	-0.08 (0.416)	0.02 (0.844)	-0.08 (0.410)	0.06 (0.543)	0.11 (0.285)
Patellofemoral scoring system					
Anterior knee pain	0.06 (0.550)	0.07 (0.493)	0.09 (0.392)	0.08 (0.434)	0.10 (0.307)
Chair rising	-0.06 (0.532)	-0.02 (0.864)	-0.05 (0.604)	0.06 (0.556)	0.01 (0.897)
Stair climbing	-0.13 (0.193)	-0.05 (0.657)	-0.15 (0.132)	0.18 (0.080)	0.16 (0.123)
WOMAC ^{a)}					
Pain score	-0.10 (0.362)	-0.10 (0.318)	-0.13 (0.201)	-0.05 (0.622)	-0.05 (0.637)
Stiffness score	-0.02 (0.780)	-0.04 (0.704)	-0.08 (0.472)	0.13 (0.228)	0.14 (0.181)
Function score	-0.08 (0.438)	-0.10 (0.340)	-0.15 (0.141)	0.00 (0.973)	0.04 (0.722)
Short-Form 36					
Physical functioning	-0.15 (0.140)	-0.16 (0.115)	-0.21 (0.038)	-0.16 (0.113)	-0.11 (0.294)
Role physical	-0.17 (0.097)	-0.18 (0.084)	-0.25 (0.015)	-0.10 (0.318)	-0.15 (0.139)
Bodily pain	-0.20 (0.055)	-0.23 (0.026)	-0.27 (0.007)	-0.09 (0.412)	-0.12 (0.240)
General health	-0.02 (0.852)	0.01 (0.891)	0.01 (0.911)	-0.96 (0.353)	-0.15 (0.144)
Vitality	-0.26 (0.010)	-0.25 (0.014)	-0.32 (0.002)	-0.11 (0.279)	-0.29 (0.004)
Social functioning	-0.08 (0.468)	-0.11 (0.302)	-0.15 (0.154)	-0.11 (0.275)	-0.09 (0.376)
Role emotional	-0.04 (0.715)	-0.01 (0.911)	-0.13 (0.229)	-0.17 (0.103)	-0.15 (0.146)
Mental health	-0.12 (0.230)	-0.10 (0.340)	-0.13 (0.226)	0.03 (0.799)	-0.06 (0.598)
Physical component summary	-0.21 (0.045)	-0.25 (0.018)	-0.28 (0.007)	-0.14 (0.194)	-0.15 (0.143)
Mental component summary	-0.13 (0.220)	-0.10 (0.324)	-0.18 (0.086)	-0.06 (0.583)	-0.10 (0.348)
Patient satisfaction	0.18 (0.074)	0.15 (0.147)	0.13 (0.205)	-0.20 (0.050)	-0.11 (0.281)

Values are presented as correlation coefficients (p-value).

PNWB: passive nonweight bearing, PWB: passive weight bearing, ANWB: active nonweight bearing, AWB-a: active weight bearing with arm support, AWB-b: active weight bearing without arm support, WOMAC: Western Ontario and McMaster Universities Arthritis Index.

^{a)}To facilitate comparisons, correlation analyses were performed using standardized WOMAC scores (worst score=0, best score=100).

differences exist between passive maximum flexion in nonweight bearing and the four other flexion types and identified the maximum flexion type that best correlates with functional outcomes, including patient satisfaction.

Knee motion arc, a major component of many scoring systems^{1,2)}, is typically measured in passive maximum flexion in nonweight bearing^{3,14,18,26-28)}, but other types of maximum flexion measured in an active mode or in a weight bearing condition are also used^{19,29-31)}. Our study demonstrates substantial differences exist between passive maximum flexion in nonweight bearing and the other four flexion types. Active maximum flexions in weight bearing with or without arm support were smaller than passive or active maximum flexions in nonweight bearing. Our

study concurs with the findings of a fluoroscopy-based study¹⁹⁾, which reported active flexion in weight bearing was smaller than passive flexion during nonweight bearing in normal subjects (135° vs. 139°) and TKA patients (127° vs. 113°). Furthermore, despite the greater PNWB flexion in the current study compared to the previous study (135° vs. 127°, respectively), the patients in both studies had similar degrees of active flexion in weight bearing (114° or 111° vs. 113°, respectively). Our study also demonstrates the five maximum flexion types had different temporal patterns. For example, active maximum flexion in weight bearing with or without arm support increased after surgery and remained at a constant level throughout the postoperative period, whereas the passive and ANWB types decreased after surgery, improved

Table 5. Comparison of the Correlations between the Five Different Types of Maximum Flexion and Clinical Outcome Scales in 86 Knees at 12 Months after Surgery

Outcome scale	PNWB	PWB	ANWB	AWB-a	AWB-b
American Knee Society					
Pain score	0.16 (0.149)	0.12 (0.290)	0.23 (0.044)	0.40 (0.000)	0.37 (0.000)
Knee score	0.28 (0.010)	0.23 (0.039)	0.31 (0.004)	0.36 (0.001)	0.35 (0.001)
Function score	-0.18 (0.098)	-0.18 (0.099)	-0.03 (0.787)	0.28 (0.008)	0.32 (0.003)
Patellofemoral scoring system					
Anterior knee pain	0.15 (0.176)	0.12 (0.299)	0.18 (0.108)	0.41 (0.000)	0.42 (0.000)
Chair rising	-0.05 (0.643)	0.13 (0.254)	-0.07 (0.512)	0.15 (0.167)	0.09 (0.423)
Stair climbing	-0.24 (0.026)	-0.10 (0.362)	-0.14 (0.198)	0.16 (0.138)	0.18 (0.108)
WOMAC ^{a)}					
Pain	0.24 (0.029)	-0.20 (0.072)	0.23 (0.036)	0.41 (0.000)	0.49 (0.000)
Stiffness	0.00 (0.990)	0.09 (0.415)	-0.02 (0.835)	0.27 (0.013)	0.26 (0.019)
Function	0.13 (0.237)	0.18 (0.112)	0.12 (0.280)	0.51 (0.000)	0.52 (0.000)
Short-Form 36					
Physical functioning	-0.06 (0.596)	-0.03 (0.795)	-0.05 (0.642)	0.40 (0.000)	0.36 (0.001)
Role physical	0.09 (0.435)	0.03 (0.784)	0.05 (0.627)	0.45 (0.000)	0.48 (0.000)
Bodily pain	0.08 (0.467)	0.03 (0.811)	0.09 (0.441)	0.33 (0.002)	0.35 (0.001)
General health	-0.08 (0.479)	-0.20 (0.075)	0.01 (0.934)	0.06 (0.578)	0.05 (0.657)
Vitality	-0.15 (0.188)	-0.16 (0.154)	-0.11 (0.337)	0.16 (0.143)	0.14 (0.210)
Social functioning	0.07 (0.520)	0.04 (0.750)	0.03 (0.770)	0.33 (0.002)	0.32 (0.003)
Role emotional	0.07 (0.514)	0.07 (0.554)	0.08 (0.445)	0.37 (0.000)	0.44 (0.000)
Mental health	-0.06 (0.608)	-0.02 (0.869)	-0.03 (0.815)	0.06 (0.593)	0.08 (0.477)
Physical component summary	0.02 (0.845)	0.07 (0.537)	0.02 (0.843)	0.41 (0.000)	0.38 (0.000)
Mental component summary	-0.01 (0.935)	0.00 (0.972)	0.01 (0.905)	0.20 (0.066)	0.24 (0.029)
Patient satisfaction	0.12 (0.274)	0.12 (0.278)	0.15 (0.164)	0.31 (0.003)	0.36 (0.001)

Values are presented as correlation coefficients (p-value).

PNWB: passive nonweight bearing, PWB: passive weight bearing, ANWB: active nonweight bearing, AWB-a: active weight bearing with arm support, AWB-b: active weight bearing without arm support, WOMAC: Western Ontario and McMaster Universities Arthritis Index.

^{a)}To facilitate comparisons, correlation analyses were performed using standardized WOMAC scores (worst score=0, best score=100).

between 6 and 12 months, and then decreased. In addition, correlation strengths between PNWB and active weight bearing types were weak except at 24 months after surgery. Our findings suggest each maximum flexion type represents a different functional aspect of the knee motion arc and adequate comparisons between studies require detailed information on the measuring methods used.

We found active maximum flexion in weight bearing better correlated with functional outcomes than the other maximum flexions. Furthermore, correlation patterns depended on maximum flexion types and the time after surgery. Previous studies have reported weak or modest correlations between passive maximum flexion in nonweight bearing and functional outcomes^{3,18,29}. On

the other hand, we found active maximum flexion in weight bearing correlated better than the other maximum flexion types with functional outcome scales at all time points, particularly at 12 months after surgery, which suggests active maximum flexion in weight bearing is a better measure of knee function than passive maximum flexion in nonweight bearing. Active flexion in weight bearing types were positively correlated with functional outcomes at almost all time points whereas the other flexion types were inversely correlated, which suggests patients with greater passive maximum flexion in nonweight bearing have poorer functional outcomes. It is not clear why active maximum flexion in weight bearing types better correlate with the functional outcomes than the other types. We speculate that active

Table 6. Comparison of the Correlations between the Five Different Types of Maximum Flexion and Clinical Outcome Scales in 88 Knees at 24 Months after Surgery

Outcome scale	PNWB	PWB	ANWB	AWB-a	AWB-b
American Knee Society					
Pain score	-0.11 (0.347)	-0.03 (0.790)	-0.22 (0.062)	0.10 (0.397)	0.07 (0.569)
Knee score	0.06 (0.640)	0.12 (0.350)	-0.10 (0.433)	0.15 (0.233)	0.16 (0.192)
Function score	-0.08 (0.512)	-0.22 (0.076)	-0.10 (0.396)	-0.18 (0.139)	-0.19 (0.117)
Patellofemoral scoring system					
Anterior knee pain	-0.12 (0.340)	0.06 (0.635)	0.01 (0.923)	0.20 (0.097)	0.08 (0.501)
Chair rising	-0.25 (0.030)	-0.13 (0.277)	-0.25 (0.031)	-0.06 (0.601)	-0.10 (0.411)
Stair climbing	-0.09 (0.476)	-0.17 (0.171)	-0.12 (0.34)	-0.17 (0.159)	-0.19 (0.112)
WOMAC ^{a)}					
Pain score	-0.19 (0.125)	0.02 (0.876)	-0.18 (0.152)	0.26 (0.033)	0.15 (0.227)
Stiffness score	0.13 (0.300)	0.21 (0.108)	0.09 (0.451)	0.24 (0.048)	0.23 (0.067)
Function score	-0.12 (0.335)	0.02 (0.886)	-0.12 (0.325)	0.30 (0.015)	0.17 (0.182)
Short-Form 36					
Physical functioning	-0.33 (0.007)	-0.19 (0.142)	-0.47 (0.000)	-0.01 (0.907)	0.11 (0.363)
Role physical	-0.22 (0.078)	-0.13 (0.30)	-0.24 (0.051)	0.05 (0.707)	0.03 (0.782)
Bodily pain	-0.30 (0.015)	-0.22 (0.083)	-0.39 (0.001)	-0.03 (0.836)	-0.11 (0.375)
General health	0.11 (0.376)	0.05 (0.691)	0.09 (0.453)	0.16 (0.212)	0.23 (0.059)
Vitality	0.04 (0.761)	-0.02 (0.882)	-0.10 (0.412)	0.17 (0.159)	0.10 (0.439)
Social functioning	-0.24 (0.052)	-0.23 (0.077)	-0.25 (0.038)	-0.12 (0.325)	-0.18 (0.157)
Role emotional	-0.06 (0.632)	-0.04 (0.746)	-0.10 (0.412)	0.14 (0.270)	0.05 (0.667)
Mental health	-0.23 (0.062)	-0.04 (0.783)	-0.19 (0.127)	0.02 (0.902)	-0.09 (0.459)
Physical component summary	-0.31 (0.012)	-0.24 (0.059)	-0.45 (0.000)	0.00 (0.980)	-0.04 (0.741)
Mental component summary	-0.07 (0.598)	-0.02 (0.886)	-0.06 (0.622)	0.10 (0.424)	-0.01 (0.963)
Patient satisfaction	0.06 (0.617)	0.01 (0.935)	-0.03 (0.777)	0.13 (0.269)	0.05 (0.654)

Values are presented as correlation coefficients (p-value).

PNWB: passive nonweight bearing, PWB: passive weight bearing, ANWB: active nonweight bearing, AWB-a: active weight bearing with arm support, AWB-b: active weight bearing without arm support, WOMAC: Western Ontario and McMaster Universities Arthritis Index.

^{a)}To facilitate comparisons, correlation analyses were performed using standardized WOMAC scores (worst score=0, best score=100).

flexion types in weight bearing reflect the functional motion arc under the weight bearing conditions with muscle function more efficiently than other types. Another possible explanation would be that greater passive or active flexions in nonweight bearing are associated with unequally larger flexion gaps which might incapacitate the normal functions of the prostheses. Furthermore, our findings of lacking or inverse correlations between passive flexion and functional outcomes might concur with those of a previous study which concluded knees with maximum flexions ranging from 128° to 132° had better functional outcomes in terms of AKS pain, knee, and function scores than knees with maximum flexions of greater than 132°¹⁶⁾. Moreover, our finding that despite substantial passive maximum flexion in nonweight

bearing, active maximum flexion in weight bearing remained at low levels may explain why TKA patients experience substantial residual functional deficits^{6,32)}. On the other hand, the presence of considerable differences between passive flexion in nonweight bearing degrees and other types and flexion and the finding of better correlation of active flexion in weight bearing degrees with functional outcomes indicate that active flexion in weight bearing degrees should be reported along with passive flexion in nonweight bearing degrees. Our literature review of studies reporting motion arc as a major outcome variable found that many studies still included only passive flexion in nonweight bearing degrees³³⁻⁴⁴⁾.

Several limitations to our study should be noted. First, we in-

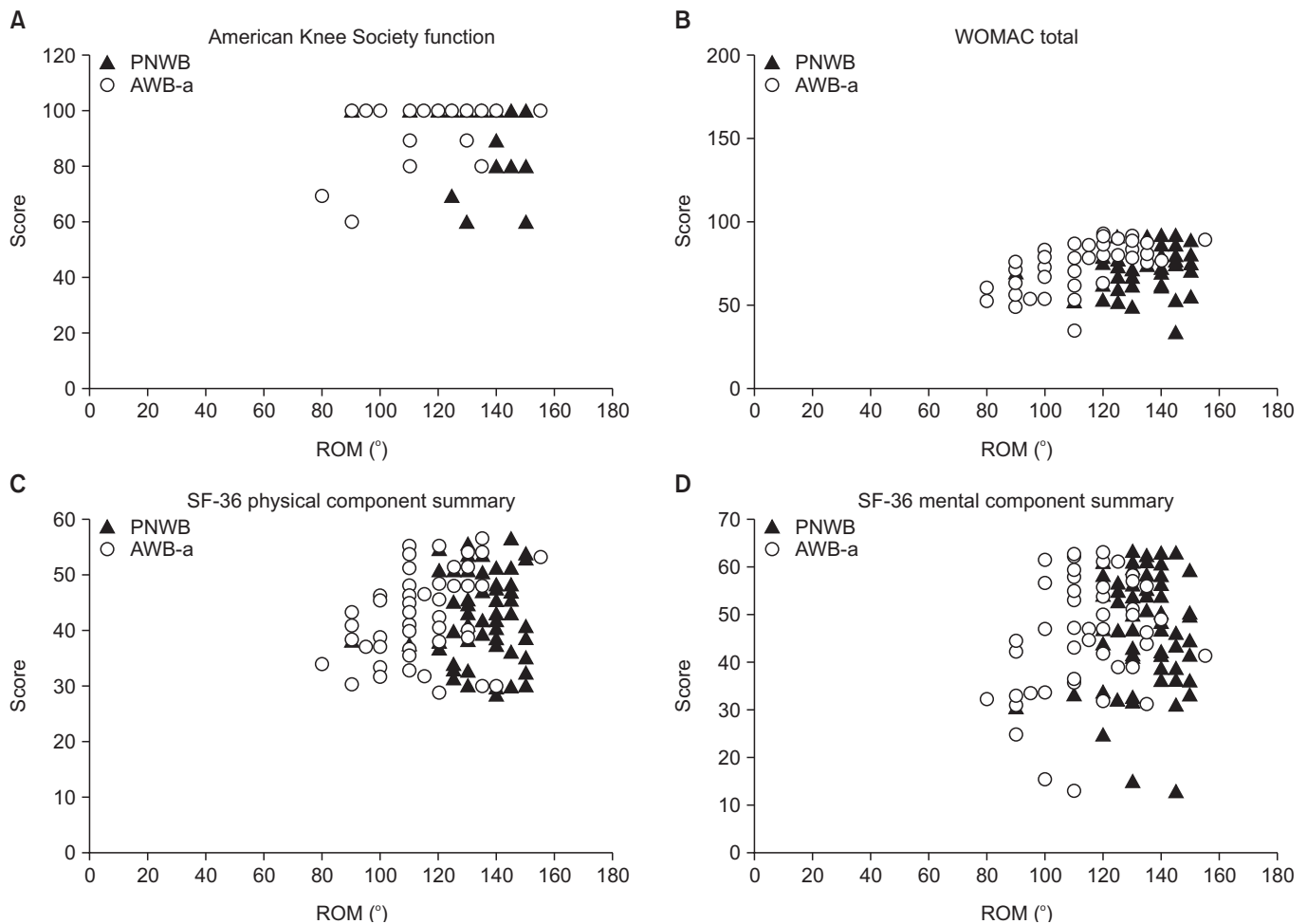


Fig. 3. American Knee Society function score (A), Western Ontario and McMaster Universities Arthritis Index (WOMAC) total score (B), Short Form-36 (SF-36) physical component summary (C), and SF-36 mental component summary (D) were compared between the passive nonweight bearing (PNWB) and the active weight bearing with arm support (AWB-a). ROM: range of motion.

cluded four different groups of patients that visited an outpatient clinic; an ideal study design would have involved a single cohort of patients, because this would have excluded confounding factors arising from differences among study populations. However, it was not practically possible to recruit patients who were prepared to undergo the same maneuvers at each follow-up visit, and we were concerned over the possibility of compromised consistency of flexion measurements if they were performed throughout a 2 year period. We did not apply any selection criteria to form the cohorts except the defined inclusion criteria, which would exclude any selection bias, and there were no significant differences in patient factors between the four groups (Table 1). We could see no reasons not to believe the four cohorts being representative of patient groups at the four time points. Second, the majority of our patients were elderly women, and thus, our findings are not easily extrapolated to other study populations

with different ages and gender compositions. However, the study populations were recruited without any selection bias, and the gender ratio of our cohort was similar to those of typical Korean TKA series^{14,18,45}. Third, this study involved manual measurements of flexion degrees using a goniometer, which is subject to certain inaccuracy⁴⁶. Previous studies documented that the measurements of flexion degrees using a clinical goniometer has satisfactory inter- and intra-observer reliabilities (intraclass correlation coefficient; range, 0.98 to 0.99)⁴⁷, but the accuracy with references of standard radiographic flexion assessment could vary with the investigator (difference between radiographic assessment and manual measurement with a goniometer, range, 1.7° to 14.7°)^{46,48}. However, the other more sophisticated methods described⁵ would not be available for regular follow-up visits, and the majority of clinical studies reporting motion arc have used a clinical goniometer^{3,12-16,18,25,26,29,49-54}. In our study, only the single

investigator (TKK) with 6-year experience in measuring flexion with a goniometer performed the measurement under the direct supervision by the operating surgeon (TKK), which would assure satisfactory accuracies and reliabilities.

Conclusions

Our study demonstrates substantial differences exist between passive maximum flexion in nonweight bearing and the other flexion types examined, particularly with active maximum flexion in weight bearing, which better correlated with functional outcomes. We, therefore, suggest active maximum flexion in weight bearing should be reported with passive maximum flexion in nonweight bearing in future research intended to increase knee motion arc after TKA.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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