Acta Orthop. Belg., 2020, **86**, 294-302

ORIGINAL STUDY

An evaluation of the influence of force- and weight bearing (a)symmetry on patient reported outcomes after total knee arthroplasty

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It has been reported that balance impairments and asymmetrical movement patterns occur in patients after total kne arthroplasty (TKA). The purpose of this study was to evaluate if force- and weight-bearing asymmetry correlate with patient-reported outcomes (PROMs).

Twenty patients were prospectively analysed up to 6 months after TKA. Quadriceps- and hamstring force were measured using a hand-held dynamometer. Vertical ground reaction forces during sit-to-stand, stair descending and squatting were assessed by force plates. Patients were asked to complete the KOOS, OKS and 2011 KSS.

The symmetry-ratios during sit-to-stand, squat and stair-descent improved significantly. Preopera-tive quadriceps-force was positively correlated with KOOS-Symptoms (r=0.583, p=0.037). The pre-operative load-symmetry ratio during STS was negatively correlated with improvement in KOOS Pain (r=-0.675, p=0.011) and Symptoms (r=-0.674, p=0.008). In deep flexion, preoperative bodyweight ratio was positively correlated with postoperative OKS (r=0.601, p=0.039), KSS-Satisfaction (r=0.675, p=0.011) and improvement in KSS-Satisfaction (r=0.684, p=0.029).

Weight bearing and force asymmetry do exist before TKA and take up to at least 6-months to fully recover. The more symmetry in muscle-force and weight-bearing is found preoperatively, the better the PROMs will be at 6 months after surgery.

Keywords : total knee arthroplasty ; functional rehabilitation ; weight distribution ; patient-reported outcome measures.

No benefits or funds were received in support of this study. The authors report no conflict of interests.

INTRODUCTION

Previous studies indicated that patients with symptomatic knee osteoarthritis (OA) and patients after total knee arthroplasty (TKA) demonstrate balance impairments during standing as well as during gait *(1)*. In some patients, these asymmetrical loadings can be found during functional activities for a longer period of time. The underlying mechanism is not yet fully comprehended. Knee pain and muscle weakness in the surgical limb are potential contributing factors, although elements of motor learning may also propagate these movement asymmetries *(1)*.

In order to be able to perform demanding activities, these patients adopt movement patterns that produce asymmetrical loading, with load

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transfer to other joints in order to compensate. This weight distribution, and thus balance, affects mobilisation and activities of daily living *(10)*.

Further on, it is well known that 10-30% of the TKA patients are dissatisfied with the result, however, the reasons for this dissatisfaction are not yet fully understood *(2,13,14)*. Therefore, the aim of this paper is to analyze whether there is a correlation between patient reported outcome measures (PROMs) and (1) the quadriceps- and hamstrings-force asymmetry, (2) the weight bearing asymmetry during the sit to stand test, (3) weight bearing asymmetry during stair descending and (4) weight bearing asymmetry during squatting in TKA patients.

MATERIALS AND METHODS

Twenty patients that were planned for primary TKA were prospectively analysed. There were three test moments scheduled for each patient : preoperatively, 3 months and 6 months postoperatively. Preoperative, all patients were tested. At three months 17 patients and at 6 months 18 patients returned to our motion analysis lab for the testing procedure. The missed visits were due to organizational reasons in some patient's transport.

Quadriceps and hamstring force were measured using maximum voluntary isometric contraction. This was tested by a single investigator using a hand-held dynamometer (Microfed Handheld Dynamometer ®, HHD) *(21)*. To measure the strength of the Quadriceps, the patient had to settle with the knee in 60° flexion. The HHD was placed on the distal third of the anterior part of the lower leg. Concurrently, was asked to provide maximum strength during extension. The hamstring force was measured in a prone position. The leg was placed in a 30° flexed position and the HDD was fixed on the distal third of the posterior part of the lower leg. Three trials were performed on both sides, the maximum generated volitional force was retained to quantify quadriceps and hamstrings strength. The force was normalized for body weight (N/kg) to enable comparison between patients. Quadriceps-force ratio (Q4-ratio) is calculated by dividing the normalized quadriceps force of the TKA-leg by the normalized quadriceps force of the contralateral leg.

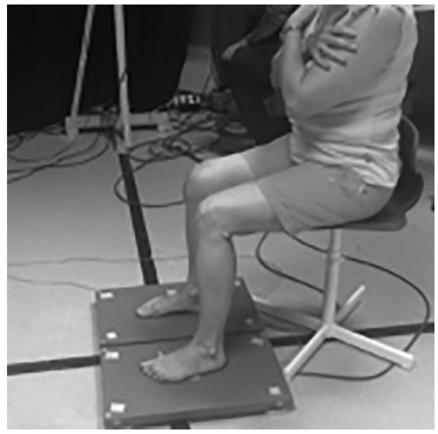

Figure 1. — Site-to-stand

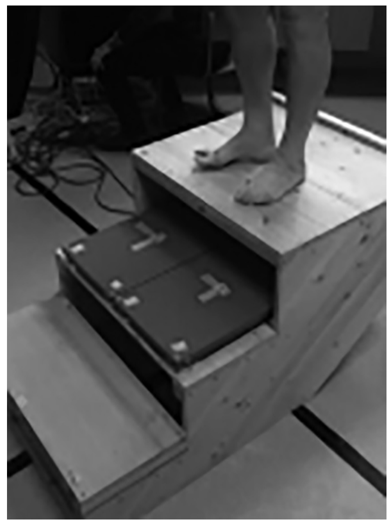

Figure 2. — Squat

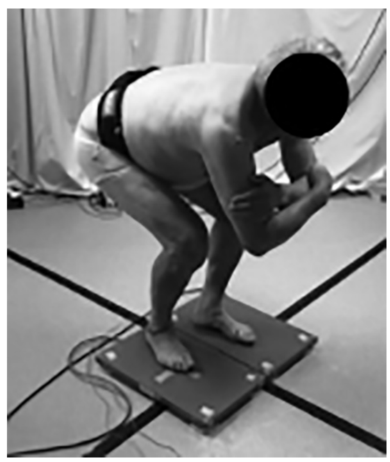

Figure 3. — Stair descent

Vertical ground reaction forces (vGRF) over the operated and non-operated limb were assessed by placing an individual force plate (Kistler 9260AA3, Kistler Instrumente AG, Winterthur, Switserland) under each foot during the test procedure.

First, the patient was asked to sit on a height-adjustable chair. The latter to make sure a knee flexion of slightly more than 90° was obtained while sitting. Next, the patient had to stand up five times (sit-to-stand test, STS) (Figure 1).

The second test consisted of a squat movement. The patient had to squat as far as possible without lifting the heels from the force plates (Figure 2). For both aforementioned tests, the hands had to be placed on the contralateral shoulder.

The third test consisted of a staircase descending test. Both force plates were placed on the same stair and a standard height of 21 cm for each stair was used. These exercises were performed twice, the first time the operated limb had to be placed on the stair with the force plates and the second time the non-operated limb had to be placed on this stair as first (Figure 3). If the patient was not able to do this test safely, a hand was offered. This was noted for further analysis.

Fluorescent markers were applied on several reference points. These markers were necessary to track the movement of the limbs during the different exercises. These were placed on the following anatomical landmarks : supero-lateral part of the shoulders, both iliac crests, both greater trochanters, both lateral joint spaces, both lateral malleoli and both heads of metatarsal I. Eight OptiTrack® cameras (Flex13, Natural Point Inc., Corvallis, USA) were used in combination with the optical motion caption software Motive®. By knowing the position of the limb, a precise calculation of the flexion angles could be performed.

Both preoperative and at 6 months postoperatively, three different questionnaires were used.

The KOOS consists of 42 knee-related items, and each item was scored from 0 to 4. Five subscales of symptoms, pain, activities of daily living (ADL), sports and quality of life (QOL) were converted to 100 points. Decreasing scores indicate worsening of knee symptoms *(16).*

The 2011 KSS consists of a total of 34 questions divided into four subscales which are rated separately. The clinician reported objective subscale (seven items ; 100 points, not further evaluated in this study) and the patient reported subscales : symptoms (three items ; 25 points) satisfaction (five items ; 40 points), expectation (three items ; 15 points) and functional activity subscale (19 items ; 100 points). The higher the score, the better the outcome in all subscales *(18)*.

The OKS consists of twelve questions assessed on a Likert scale with values from 0 to 4, a summative score is then calculated where 48 is the best possible score (least symptomatic) and 0 is the worst possible score (most symptomatic) *(5)*.

Dutch translations of all these scores have been validated for use in Dutch speaking countries or regions including Flanders where this study was conducted *(6,7,20)*.

The force plate and optical motion captured data were synchronically captured using a custom Matlab script (Mathworks, Massachusetts, USA).

During STS, the maximal vertical ground reaction force from each leg was recorded, providing insight in the weight distribution. This was used to create the load-symmetry ratio (*9*).

$$\text{Load-Symmetry Ratio} = \frac{\text{Maximal Vertical Ground Reaction Force on TKA leg (N)}}{\text{Maximal Vertical Ground Reaction Force on contra-lateral leg (N)}}$$

When the load-symmetry ratio (LSR) equals one, an ideal weight distribution over both legs during the sit-to-stand test is assumed. The closer to zero, the lesser weight there is placed on the operated leg.

During the squat test, the following formula was used :

$$\text{\%Bodyweight-TKA} = \frac{\text{LSR x 100}}{\text{LSR + 1}}$$

$$\text{\%Bodyweight-nTKA} = 100 - \frac{\text{(LSR x 100)}}{\text{(LSR + 1))}}$$

This weight distribution was evaluated in function of the flexion-angle of each leg.

Referring to the paper by Rossi et al, two critical angles were evaluated : 30° flexion and 60° flexion *(17)*. These angles are concerned to be early flexion and deep flexion. The 0° (full extension) moment was additionally evaluated.

During the step-down exercise, the force was measured during the landing phase.

$$\text{Stair-Ratio}=\frac{\text{Maximal Vertical Ground Reaction Force on TKA leg (N)}}{\text{Maximal Vertical Ground Reaction Force on contra-lateral leg (N)}}$$

Statistical analysis was carried out at a 95% confidence level (α=0.05) by using SPSS-version 25 (IBM Corp., Chicago, IL, USA). Shapiro-Wilk test of normality was used, a normal distribution was seen for all relevant variables. Differences between different time frames and sides were evaluated by using a paired student-t test. Pearson-correlation was used to evaluate the correlation between the tests and PROMs.

RESULTS

Patient characteristics are summarized in Table I .

Table I. — Patient characteristics

Study population (n = 20)	Min	Max	Mean	SD
Male = 4, Female = 16				
Age (y)	53	86	67	8,48
BMI (kg/m²)	23,4	38,6	30	3,78

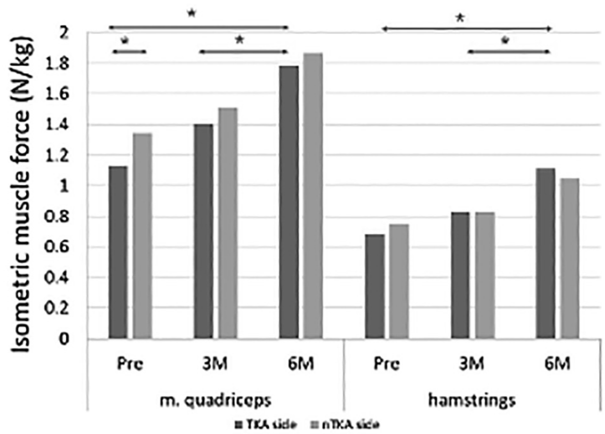

Figure 4. — Graph showing the isometric muscle force evolution *<0.05

Mean values for quadriceps-force normalized for bodyweight (Q4) (N/kg) are shown in Table II. Preoperative a significant difference is found between both sides, meaning a Q4 asymmetry. The Q4-ratio was significantly improved 6 months postoperative compared to preoperative (p=0.008, CI=0.035 ; 0.18). No significant Q4-ratio improvement was seen between preoperative and 3 months postoperative nor from 3 months post-operative till 6 months. Concerning the hamstring-force, no significant differences were found. However, an overcompensation of the hamstrings force in the operated leg is noted at three and six months postoperative, represented by the force-ratio > 1

Table II:. — Quadriceps force normalized for bodyweight (Q4) (N/kg) for both TKA and nTKA side

		Mean	SD	Min	Max	P value	CI	
							lower	upper
Preop	Q4 TKA	1.13	.43	.40	1.86	**0.002**	-.33	-0.09
	Q4 nTKA	1.34	.53	.47	2.34			
	Q4 ratio	.85	.11	.57	1.00			
3 months	Q4 TKA	1.40	.39	.78	2.20	0.102	-2.25	0.02
	Q4 nTKA	1.51	.45	.94	2.52			
	Q4 ratio	.94	.15	.62	1.21			
6 months	Q4 TKA	1.78	.51	.85	2.76	0.270	-0.25	0.07
	Q4 nTKA	1.87	.60	.91	3.01			
	Q4 ratio	.97	.15	.73	1.22			

Table III. — Hamstrings force normalized for bodyweight (Hs) (N/kg) for both TKA and nTKA side

		Mean	SD	Min	Max	P value	CI	
							lower	upper
Preop	Hs TKA	0.68	.37	.25	1.42	0.215	-0.18	0.05
	Hs nTKA	0.75	0.42	.26	1.59			
	Hs ratio	0.95	0.27	0.50	1.51			
3 months	Hs TKA	.0.83	0.26	.46	1.21	0.914	-0.08	0.09
	Hs nTKA	0.83	0.28	.47	1.40			
	Hs-ratio	1.03	0.29	0.69	1.40			
6 months	Hs TKA	1.11	0.30	.60	1.58	0.126	-0.02	0.15
	Hs nTKA	1.04	0.35	.58	1.94			
	Hs- ratio	1.08	0.13	0.80	1.31			

Table IV. — Load-symmetry ratio (LSR) during STS

	Mean	SD	Min	Max
LSR preop	0.85	0.11	0.63	1.03
LSR 3 months	0.87	0.10	0.70	1.04
LSR 6 months	0.95	0.11	0.75	1.12

(Table III). In Figure 4 the evolution of the isometric muscle force over time is shown.

Table IV and Figure 5 show the load symmetry ratio during STS. An increasing symmetry is seen between the different time-frames. No significant difference was found between preoperative LSR

Table V. — Percentage bodyweight on each leg during squat exercise.
Three different flexion angles as well as three different time-frames are shown. Significant values are shown in bold

		Mean	SD	Min	Max	P-value	Lower	Upper
% Bodyweight at 0°								
preop	**TKA**	46.14	6.50	30.06	53.03	**0.016**	-13.80	-1.64
	nTKA	53.86	6.50	46.97	69.94			
3m	**TKA**	48.68	7.24	38.33	62.88	0.463	-10.09	4.80
	nTKA	51.32	7.24	37.12	61.67			
6m	**TKA**	49.57	4.78	40.70	60.29	0.706	-5.62	3.89
	nTKA	50.43	4.78	39.71	59.30			
% Bodyweight at 30°								
preop	**TKA**	42,95	8,96	23,47	59,19	**0.004**	-23.01	-5.20
	nTKA	57,05	8,96	40,81	76,53			
3m	**TKA**	44,35	7,72	28,12	52,84	**0.008**	-19.25	-3.37
	nTKA	55,65	7,72	47,16	71,88			
6m	**TKA**	47,64	9,41	36,22	64,46	0.331	-14.76	5.31
	nTKA	52,36	9,41	35,54	63,78			
% Bodyweight at 60°								
preop	**TKA**	42,83	7,60	20,40	53,62	**0.003**	-22.75	-5.91
	nTKA	57,17	7,60	46,38	79,60			
3m	**TKA**	43,24	6,82	31,87	53,58	**0.001**	-20.79	-6.26
	nTKA	56,76	6,82	46,42	68,13			
6m	**TKA**	46,30	7,15	35,26	60,98	0.065	-15.31	0.52
	nTKA	53,70	7,15	39,02	64,74			

Table VI: maximal vGRF adjusted for bodyweight for both operated and non-operated side. Load-symmetry ratios are also shown

		Mean	SD	Min	Max	P-value	Lower	Upper
preop	vGRF/BW TKA	9.91	2.41	6.85	16.01	0.332	-0.56	0.20
	vGRF/BW nTKA	10.09	2.54	6.35	16.01			
	LSR	0.99	0.06	0.79	1.08			
3m	vGRF/BW TKA	9.58	2.57	6.06	16.39	0.026	-1.55	-0.11
	vGRF/BW nTKA	10.41	2.76	6.08	16.60			
	LSR	0.93	0.10	0.63	1.02			
6m	vGRF/BW TKA	9.61	2.61	5.94	16.49	0.002	-0.70	-0.19
	vGRF/BW nTKA	9.92	2.74	5.72	17.49			
	LSR	0.96	0.05	0.90	1.06			

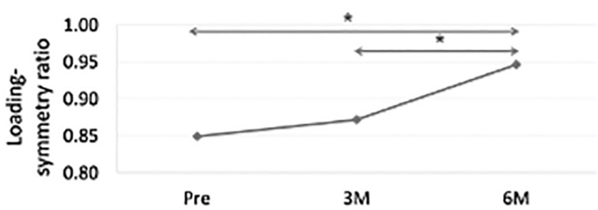

Figure 5. — Visualisation of the load-symmetry ratios during STS *<0.05

and 3 months (p=0.960), but a significant difference is found from three months to six-months (p=0.001) and from preoperative to 6 months (p=0.013). At six months, this ratio is close to 1, resembling a symmetrical distribution between the two limbs.

Table V and Figure 6 show the percentage of bodyweight placed on each leg during a squat-exercise. A significant asymmetry is seen in the preoperative faze at all flexion angles. In extension, this asymmetry is already corrected at 3 months and stays symmetric at 6 months postoperative. At 30° and 60°, the asymmetry remains till 3 months postoperative and is almost corrected 6 months postoperative.

Table VI shows the maximal vertical ground reaction force adjusted for bodyweight. Significant higher vGRF is found on the non-operated leg at 3 months and 6 months. A significant decrease in load-symmetry ratio is seen between preoperative and 3 months (p=0.046, CI=0.001 ;0.13).

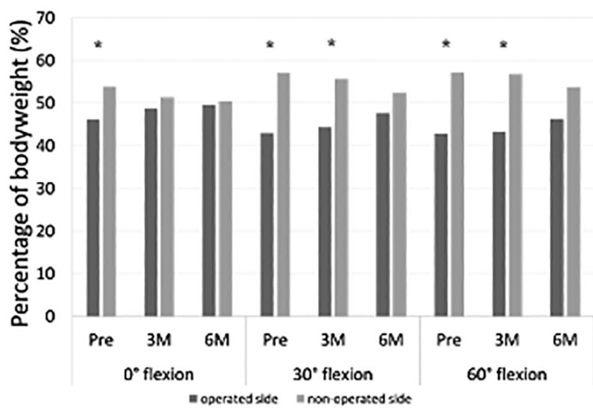

Figure 6. — Visualisation of the asymmetry during a squat exercise. Improvement of weight-bearing on the operated leg is seen. * significant difference (p < 0.05)

As the goal was to evaluate if asymmetry is connected to PROMs, only the correlated ratios with PROMs are described.

Preoperative Q4-ratio is positively correlated with KOOS-Symptoms at 6 months (r 0.583, p=0.037 and r=-0.555, p=0.049) and negatively correlated with improvement in KOOS-QOL (r=-0.676, p=0.022)

Preoperative bodyweight ratio in extension is negatively correlated with postoperative KOOS-Symptoms (r=-0.562, p=0.030), with improvement in KOOS-Symptoms (r=-0.621, p=0.013) and improvement in KOOS-Pain (r=-0.664, p=0.010).

The six-month postoperative bodyweight ratio in extension is negatively correlated with the improvement in KOOS-Pain (r=-0.680, P=0.008), improvement in OKS (r=-0.698, P=0.005). and improvement in KOOS-ADL (r=-0.558, P=0.038)

Preoperative bodyweight ratio at 30° flexion is positively correlated with postoperative OKS (r=0.562, p=0.044), with postoperative KOOS-ADL (r=0.588,p=0.021), with postoperative KSS satisfaction (r=0.509, p=0.044). The three-month postoperative bodyweight ratio at 30° flexion is positively correlated with postoperative KOOS-ADL (r=0.606, p=0.013).

Preoperative bodyweight ratio at 60° flexion is positively correlated with postoperative OKS (r=0.601, p=0.039), with postoperative KSS-Satisfaction(r=0.675, p=0.011) and KSS-satisfaction improvement (r=0.684, p=0.029).

Preoperative load-symmetry ratio was negatively correlated with improvement in KOOS-Pain (r=-675, p=0.011) and improvement in KOOS-Symptoms (r=-0.674,p=0.008).

Improvement in OKS was negatively correlated with vGRF ratio during STS preoperatively (r=-0.561, p=0.046)

DISCUSSION

This study investigated the influence of the muscle-force ratio and weight bearing asymmetry on patient reported outcome measures (PROMs). Although some significant results were found, a few limitations should be considered. As 40% of the patients with a unilateral TKA are candidate for a TKA on the contra-lateral side, we cannot consider these as healthy controls *(11)*. Although there were statistically significant findings within this dataset, larger patient groups would permit more substantial comparisons. However, the nature of these exhaustive studies generally leads to relatively small study groups as reflected in the number of drop-outs after the initial testing. As no significant difference is found at 6 months postoperative, this can possibly be attributed to this small sample size. Another limitation is the relatively short follow-up period as further improvement could occur later on. Nonetheless, a steep clinical improvement is usually noticed between three to six months after TKA, followed by a significantly slower, more gradual improvement up to two years postoperatively *(8)*.

A first finding of this study was the significant quadriceps-force asymmetry during the preoperative testing with less force in the arthritic-knee limb. This asymmetry was eliminated and significantly improved at 6 months postoperatively. A poorer preoperative quadriceps-force symmetry was correlated with poorer postoperative KOOS Symptoms scores and with more improvement in KOOS QOL. The found relation between quadriceps-force asymmetry and poorer PROMs is confirmed by the findings of previous authors suggesting the close relationship between quadri-ceps strength and physical function *(12,15)*. Concerning the hamstring-force there were no significant findings. However, it should be noted that an overcompensation of the hamstrings force in the operated leg is seen at three- and six months.

Secondly, we found an increasing load-symmetry during STS, from 0.85 preoperatively to 0.87 at 3 months and to 0.95 at 6 months postoperatively. These results are similar to the ones by Christiansen et al., they furthermore compared their patients to a healthy population of the same age and did not find any significant differences between TKA patients 6 months postoperative and their healthy controls *(3,4)*. A poor preoperative load-symmetry ratio during STS was correlated with less improvement in postoperative pain and symptoms. In the study by Christiansen et al., pain was correlated fairly with weight bearing asymmetry in people with unilateral knee OA before surgery, there was no indication of a relationship after surgery at any time up to 6 months. These findings are confirmed in this paper. They suggests that after surgery, factors other than pain, such as the quadriceps strength impairments mentioned, fear, or unresolved habitual movement patterns, may be associated most with WB asymmetry *(3,4)*.

Analogous results are found during the squat exercise. Preoperatively, significantly lesser weight is placed on the arthritic leg at 0°, 30° and 60°. A corrected and symmetric weight distribution is found at all flexion angles at six-months postoperative. In general, we have found that a better preoperative weight bearing symmetry is correlated with better postoperative PROMs and this for all flexion angles. However, during stance (0°) a negative correlation was found with postoperative pain and symptoms was found preoperatively as well as at six months postoperative. At three months, we have also found a positive correlation between weight bearing ratio at 30° and KOOS ADL, meaning that the more symmetry the better the activities of daily living. Therefore, Rossi et al. proposed squatting as a better indicator for asymmetry than normal stance *(17)*. This is confirmed by our study as the symmetry during stance phase was recovered at 3 months post TKA, while the deep squat symmetry took up to 6 months to become symmetric. This can be explained by the higher peek forces in the knee joint during squatting which demands more muscle activation *(17)*.

During stair descending, no significant difference in maximal vGRF was found preoperatively. However, at 3 months and 6 months a higher vGRF was measured over the non-operated leg. This is in accordance to Stacoff et al. *(19)*. It is possible that patients do not trust their TKA after surgery which makes them land gently on this leg by controlling their landing with their non-operated limb. A decrease proprioception and a possible unstable sensation in the operated leg, might cause a shorter stance phase on this leg and thus a more uncontrolled landing with the non-operated leg on the force plates. Lastly, the acquired way of stair descending, as taught by the physiotherapists, is to descend the stairs with the operated leg first. This might cause the insecure feeling and makes the patient inexperienced of this way of stair descending.

While rehabilitation programs are currently focusing on the range of motion, muscle force and functional activities, the symmetry between both legs is often being neglected *(4,23)*. White et al. showed that by using force-plates as biofeedback training, weight symmetry can be achieved between both legs after total hip arthroplasty *(22)*. This is consistent with Zeni. et al who proposed biofeedback training as a valuable contribution to TKA rehabilitation *(23)*. It should be mentioned that this training should start in the preoperative phase as there is a hypothesis that states that the earlier the symmetry is achieved, the better the functional outcomes are *(3,20)*. This is also confirmed by our findings since preoperative symmetry was correlated with postoperative PROMs. On the other hand, it's also important to achieve this symmetry to reduce the load on the contralateral side and so reduce the pain and overload in that knee. As we have found that it takes up to 6 months before symmetry is achieved, one might propose to wait to surgically treat the other symptomatic limb, as by decreasing the load in that knee, symptoms might decrease as well. Future research could focus on the feasibility of this knowledge in the rehabilitation programs for TKA patients with for example the use of exergames, balance boards, Nintendo Wii® or separate scales.

CONCLUSION

Weight bearing, and muscle-force asymmetry do exist before TKA surgery and take up to at least 6-months to fully recover. The more symmetry in muscle-force and weight-bearing is found preoperatively, the better the PROMs will be 6 months postoperatively. No clear correlation between postoperative symmetry and PROMs was found.

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