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ORIGINAL STUDY

Rectus femoris transfer improves stiff knee gait in hemiplegic adults following stroke or traumatic brain injury

Alex Vermeiren, Lynn Bar-On, Anja Van Campenhout

From the University Hospital Leuven, Leuven, Belgium

The aim of this study was to provide quantitative evidence of the effect of rectus femoris (RF) transfer surgery on improving gait in adults suffering from stiff knee gait (SKG) following stroke or traumatic brain injury (TBI).

Retrospective cohort study

University hospital, department of orthopaedic surgery

Hemiplegic patients with decreased peak knee flexion in swing, reduced total knee range of motion and spasticity of the RF demonstrated by a positive Duncan Ely test and a pathologic dynamic electromyography of the RF.

Ten right hemiplegic patients had a distal RF transfer. Pre- and postoperative kinematic, kinetic, and spatiotemporal parameters derived from 3D gait analysis and parameters from clinical examinations were retrospectively compared.

All patients (average age 40 ± 29 years) had an improvement of their gait. Statistically significant improvements were observed in walking velocity and peak knee flexion in swing (19.93° ±11.80°), knee flexion velocity at toe-off (110.26° ± 65.74°) and total knee range of motion (20.78° ± 0.66°).

RF transfer improves knee flexion in swing in adult patients suffering from SKG following stroke or TBI and is thus a reliable treatment option.

Keywords : rectus femoris transfer ; stiff knee gait ; stroke ; traumatic brain injury ; adults.

Abbreviations

CE	clinical exam
CP	cerebral palsy
GA	gait analysis
EMG	electromyography
MBB	motor branch block
MMT	manual muscle testing scale
NMB	neuromuscular block
RF	rectus femoris
ROM	range of motion
sEMG	surface electromyography
SKG	stiff knee gait
SMC	selective motor control scale
TBI	traumatic brain injury

INTRODUCTION

In typical gait, the swing phase is characterized by flexion of the hip, knee and ankle, thus drawing the foot up and away from the ground as the

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■ Alex Vermeiren[1].
■ Lynn Bar-On[3,4]
■ Anja Van Campenhout[1,2]
[1] *University Hospital Leuven, Department of Orthopaedics, Pellenberg, Belgium.*
[2] *KU Leuven, Department of Development and Regeneration, Leuven, Belgium.*
[3] *KU Leuven, Department of Rehabilitation Sciences, Leuven, Belgium.*
[4] *University Hospital Leuven, Clinical Motion Analysis Laboratory, Leuven, Belgium.*
Correspondence : Alex Vermeiren, Grote Markt 31b3, 2300 Turnhout, Belgium, +32 473 62 43 22.
E-mail : alex.vermeiren@hotmail.com

limb moves forward. Knee flexion is especially important for foot clearance as without sufficient knee flexion in swing phase, the foot of the swinging limb will strike the ground causing the person to trip and possibly fall *(13)*. This gait pattern with insufficient knee flexion in swing phase is referred to as stiff knee gait (SKG) and was first described by Sutherland and Davids in 1993 *(16)*. SKG is often observed in patients with upper motor neuron lesions such as cerebral palsy (CP) *(21)* and also after brain lesions acquired later in life such as stroke or traumatic brain injury (TBI) *(1)*. The aetiology of SKG in patients with acquired brain damage can be diverse. It can be due to increased activity of the rectus femoris (RF) and sometimes also of the vastus muscles, decreased peak hip flexion due to weakness of hip flexors, decreased ankle plantar flexion moment or inadequate push-off due to weakness of plantar flexors *(1,18)*.Often, the primary cause of SKG is overactivity or spasticity of the RF muscle *(12)*. The RF is normally activated during the transition from stance to swing phase to initiate hip flexion and to control knee flexion *(13)*. After brain damage however, it can be overactive leading to excessive prolonged contraction during swing phase and loss of knee flexion. Consequently, patients with SKG often try to compensate for the inadequate foot clearance with ipsilateral hip circumduction and pelvic elevation, or with contralateral hip hiking. In CP, various non-invasive and invasive interventions for managing SKG have been described, with distal RF transfer to one of the hamstring tendons being the current standard surgical treatment *(12,17,19)*. The goal of this surgery is to eliminate the prolonged extending action of the spastic RF muscle during swing phase and to improve knee flexion, thus reducing the need for compensatory mechanisms. Performing a transfer of the distal part preserves the proximal part of the RF and saves some of the hip flexion moment, which in turn also induces knee flexion in swing *(4)*. Further, transferring the muscle instead of releasing it provides better knee flexion in swing and knee range of motion (ROM) (*4,11,14)* and prevents it from reattaching to the patella.

For SKG in patients with acquired brain lesions, treatment is currently mostly limited to conservative measures such as a motor branch block (MBB) of a branch of the femoral nerve using phenol or a local anaesthetic or a neuromuscular block (NMB) by injecting botulinum toxin into the muscle. Temporary effects have been reported with increase in knee flexion during swing phase limited to a range of 2 to 15° with an average of 9° after MBB and 7° after NMB *(18)*.

To the best of our knowledge there has only been one study thus far that has evaluated the outcome of RF transfer - albeit adding fractional lengthening of the vastus muscles - in patients with SKG following stroke or TBI. They reported a high patient satisfaction rate regarding clinical and functional outcome, but had limited quantitative measures of post-surgical gait *(10)*.

In order to evaluate the effect of a RF transfer on SKG in patients with acquired brain lesions a retrospective cohort study was done comparing pre- and postoperative clinical evaluation and 3D gait analysis (GA). An improvement of the sagittal plane kinematics of the knee with increase of knee flexion during swing phase after a RF transfer in patients with SKG after acquired brain lesion was hypothesized.

MATERIAL AND METHODS

Study sample

From the surgical database of the University Hospital Leuven all patients that had a RF transfer procedure documented with a 3D GA pre- and postoperatively between 2003 and 2012 were identified. Patients that were older than 18 years at time of surgery and had a SKG due to an acquired brain lesion were included. The following criteria needed to be met to be a surgical candidate for RF transfer. Firstly, SKG had to be present on the preoperative 3D GA as decreased peak knee flexion in swing and decreased total ROM throughout the gait cycle. Further, spasticity of the RF muscle had to be present. This was identified by means of a positive Duncan Ely test *(8,9)* and a pathologic dynamic electromyography (EMG) of the RF, defined as continuous or prolonged activity of the muscle during swing phase of gait (figure 1)

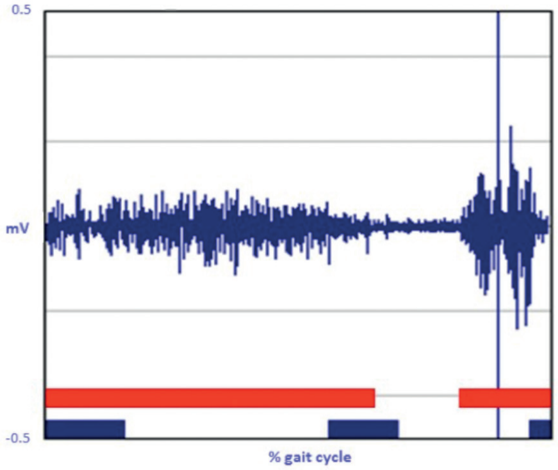

Fig. 1. — Example of pathological surface electromyography (sEMG) collected from the rectus femoris during one gait cycle. The bars indicate the pathological (red) and typical (blue) timing of sEMG activation

If the patient presented with ankle plantar flexion and knee recurvatum (due to pathological plantar flexion/knee extension couple), treatment of the equinus was done first and the patient was re-evaluated to decide on the necessity of a RF transfer. Typically, patients that did not have an improvement of SKG after intensive rehabilitation and conservative treatment were referred to the surgical department. Exclusion criteria were concomitant osteotomies of the lower limbs, as the alteration in lever-arms changes gait drastically, a psoas lengthening, which also might change the beginning of swing phase, or the absence of a qualitative good pre- and postoperative gait analysis. Previous or concomitant soft tissue surgeries such as gastrocnemius or Achilles tendon lengthening's were not exclusion criteria.

Surgical procedure

All RF transfers were performed by a senior orthopaedic surgeon (AVC). In all transfers, the RF muscle was dissected completely free from the vastus muscles, allowing the RF to function on its own and creating a straight transfer trajectory. The transfer of the RF was made to the gracilis or the semitendinosus muscle and fixed using the Pulvertaft weave technique with the knee in 30° flexion to achieve the necessary amount of tension (figure 2). The beneficial outcome of transferring the distal RF to either knee flexor has been demonstrated, indicating that this decision can be based on surgeon preference, dimensions of the hamstrings tendons or possible concomitant procedures *(15)*. To avoid creating an extension contracture or inadequacy of the vastus medialis, the gap between the vastus lateralis and medialis muscles was closed over the vastus intermedius muscles with the knee in 90° flexion.

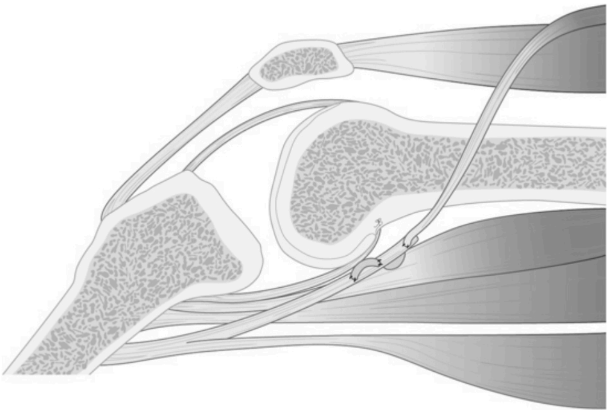

Fig. 2. — Sagittal view of the knee showing a distal rectus femoris transfer to one of the hamstring tendons. The tendons are fastened to one another using the Pulvertaft weave technique.

Postoperative protocol consisted of use of a passive motion machine for the first two weeks to prevent the transferred muscle from adhering due to scar tissue. During this healing period the patient used a knee immobilizer allowing immediate full weight bearing. Thereafter, gait rehabilitation was done focusing on hip and knee flexion during swing.

Measurements

Retrospective data from the clinical exam (CE) and 3D GA that were obtained before and after the RF transfer procedure were collected.

All subjects underwent a standardized full clinical lower limb assessment by a trained physical therapist on the day of the GA, including hip, knee and ankle passive and active ROM, strength as assessed with the manual muscle testing scale (MMT) *(7),* selectivity assessed with selective motor control scale (SMC) *(5)* and spasticity of the RF, with the Duncan Ely test *(9)*.

Subjects walked barefoot on a 10m walkway at self-selected comfortable speed. Spatiotemporal, kinematic and kinetic measurements were collected using a VICON system with 8 infrared cameras (Nexus capturing system measuring at 100 Hz, with lower limb Plug-In-Gait marker set, VICON, Oxford Metrics, Oxford, UK) and two AMTI force plates (Advanced Mechanical Technology, Inc., Watertown, MA, USA). Surface EMG (sEMG) data was collected from the RF and vastus lateralis muscles on both limbs using a telemetric Zerowire system (Cometa, Milan, IT) at a sample rate of 2000 Hz. sEMG electrodes were placed according to a standardized procedure *(6)*. At least three valid barefoot walking trials with good marker visibility and an artefact-free sEMG signal were collected and the results for these trials were averaged before further analysis. Relevant CE, spatiotemporal, kinematic, and kinetic parameters (table I) were selected. The presence of pathological EMG activity was visualised per gait cycle and qualitatively described. Compensatory gait movements (i.e. leg circumduction and hip hiking) were derived from video analysis. A comparison of ROM and gait parameters before and after surgery was done and tested for clinical significance using the Wilcoxon Signed Rank test because of small sample size and a non-normal data distribution. Pre- and postoperative scores on the Duncan Ely, MMTS and SMC scale were compared using the Fisher exact test. Statistical significance was defined as $p < 0.05$.

This study was approved by the ethical committee of the university hospital (MP01846).

RESULTS

In the 10 year period a total of 116 patients had RF transfer procedure of which 65 had a bilateral procedure, bringing the total to 181 RF transfers. Only 14 were done in adults with acquired brain lesions; the others were mostly CP patients. Four patients were excluded: 1 had inadequate GA quality preoperatively, 2 had a concomitant femur derotation procedure and 1 patient had a hip fracture with problematic healing 6 months after the RF transfer.

All ten subjects, 4 men and 6 women, had a right hemiplegia and were on average 40±29 old at the time of surgery. Eight had developed SKG following stroke and two following TBI. Time between the incident and the pre-operative analysis was at least one year with an average of 1517 days (SD 1906 days). Time between surgery and the post-operative analysis was at least four months with an average of 320 days (SD 256 days). Seven of the ten subjects underwent concomitant lengthening of the gastrocnemius aponeurosis or the Achilles tendon on the affected side because of lack of ankle dorsiflexion on CE. None of these patients demonstrated knee hyperextension during stance phase in the preoperative GA.

Clinical examination

Passive and active ROM of the knee and hip remained unchanged. The number of patients scoring one or less on the Duncan Ely for assessing RF spasticity of the RF halved postoperatively. Knee extensor strength improved significantly post-transfer. The number of subjects scoring 3+ or higher for knee flexors and hip flexors strength remained the same or increased slightly. The same was true for selective motor control of these muscle groups. (table I).

Spatiotemporal parameters

Walking speed increased significantly post-operatively. There was a small, but statistically not significant, increase in cadence, step and stride length (Table I).

Kinematics

Peak knee flexion in swing, total knee ROM during gait and knee flexion velocity at toe-off increased significantly (table I). Results of the individual patients are presented in able 2, demonstrating an improved knee flexion in swing in every patient. (table II). Median timing of peak knee flexion decreased slightly with the interquartile range almost three times as narrow post-operatively but not statistically significant (table I). There was no significant change in peak hip flexion. Most postoperative kinematic

Table I. — Pre- and post-operative median and inter quartile range values (IQR)

Parameters	Preoperative	Postoperative	p-value
Clinical exam (n=10)			
Hip flexion ROM (deg)	125 (0)	125 (0)	1,000
Hip extension ROM (deg)	0 (0)	0 (0)	0,180
Knee flexion ROM (deg)	130 (0)	130 (0)	0,317
Knee extension ROM (deg)	0 (5)	5 (5)	0,739
Ankle ROM -knee in 0deg (deg)	2.5 (8.75)	5 (8.75)	0,057
Ankle ROM -knee in 90deg (deg)	7.5 (5)	15 (7.5)	0.008*
Duncan Ely spasticity (scale 0-2)	1.5 (0.88)	0 (1)	0,683
Knee extension strength (scale 0-5)	4 (0)	4 (0)	0,900
Knee extension selectivity (scale 0-4)	1.75 (0.5)	1.75 (0.5)	0,800
Knee flexion strength (scale 0-5)	3.25 (0.88)	3.5 (0.5)	0.014*
Knee flexion selectivity (scale 0-4)	1 (0.5)	1.5 (0)	0,556
Hip flexion strength (scale 0-5)	3 (0.75)	3.75 (0.5)	0,222
Hip flexion selectivity (scale 0-4)	1.5 (1)	1.5 (0.25)	0,107
Spatiotemporal parameters (n=10)			
Walking speed (m/s)	0.653 (0.40)	0.70 (0.43)	0.028*
Cadance (strides/min)	86.65 (33.7.40)	92.20 (24.99)	0,173
Stride length- affected leg (m)	0.93 (0.43)	0.96 (0.34)	0,310
Step length- affected leg (m)	0.45 (0.30)	0.51 (0.18)	0,080
Kinematics (n=10)			
Peak knee flexion in swing (deg)	25.11 (21.73)	45.10 (12.90)	0.005*
Timing of peak knee flexion (% gait cycle)	75.70 (13.02)	72.30 (4.70)	0,508
Knee flexion velocity at toe-off (deg/s)	70.04 (79.66)	149.60 (167.98)	0.005*
Total knee ROM during gait (deg)	24.10 (13.48)	47.41 (25.76)	0.005*
Peak hip flexion (deg)	35.1 (8.08)	40.54 (9.61)	0,203
Kinetics (n=7)			
Knee extension moment at toe-off (Nm)	0.086 (0.044)	0.060 (0.110)	0,031
Hip flexion moment at toe-off (Nm)	0.154 (0.168)	0.237 (0.201)	0,889
Peak ankle plantar flexion moment in stance phase (Nm)	0.958 (0.316)	0.798 (0.291)	0.043*
Compensation mechanisms (n=10)	8	2	Na

parameters tended to approximate normal range values, as presented in figure 3.

Only 2 patients out of the 8 that demonstrated compensations for the SKG preoperatively still used them postoperatively.

Kinetics

In three out of ten subjects, measurement of kinetic parameters was not feasible due to the stride length being too short, the stride width being

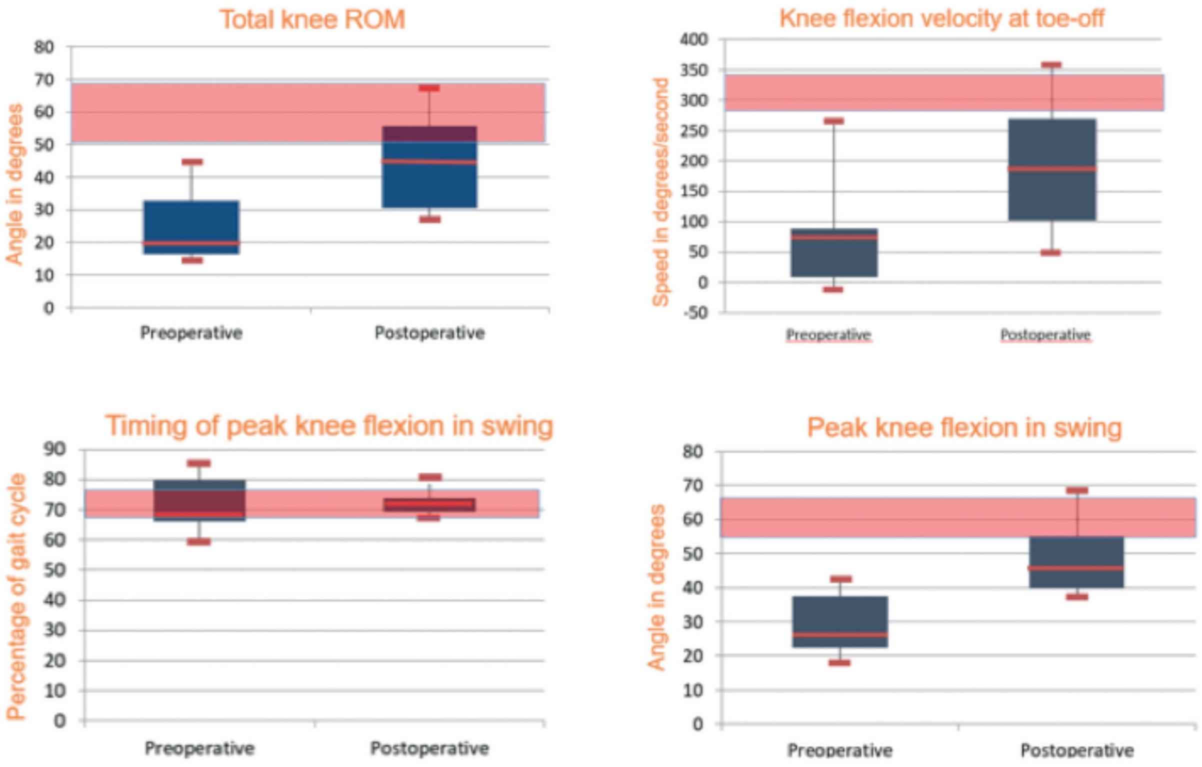

Fig. 3. — Box-and-whisker plots comparing pre- and postoperative kinematic parameters. Blue (dark) boxes represent interquartile ranges (Q1-Q3) and the red line in the blue boxes represents the median. The transparent red (light) box represents normal range values in an age-matched population

too narrow or the walking speed being too low. For the remaining seven patients, no statistical significant changes were found regarding knee extension moment or hip flexion moment at toe-off. Peak ankle planter flexion moment in stance phase (-0.21 ± 0.21Nm; $p < 0.05$) significantly decreased, most likely due to most of the subjects having undergone concomitant gastrocnemius or Achilles tendon lengthening which is known to reduce ankle push-off power *(6)* (table I).

Dynamic sEMG

As required to be a candidate for RF transfer all pts demonstrated pathologic activity of the RF during swing phase, although this activity was often of small amplitude. Also the vastus lateralis muscle presented often with only a minimal EMG activity even at the physiological active phases; only in 2 patients a true pathological activity during swing phase was recorded.

DISCUSSION

Significant kinematic improvements of the knee in swing phase with improved peak knee flexion, improved knee flexion velocity at toe-off and an increase in total knee ROM were found after RF transfer in a cohort of 10 adults with SKG due to acquired brain lesion. These ameliorations were even somewhat better than those reported in studies on RF transfer in CP. Increases in mean peak knee flexion in swing reported by Perry *(12)* and Sutherland et al. *(17)* were 16.0° and 16.2° compared to 19.9° for this adult group. Similar results for mean total knee ROM and knee flexion velocity at toe-off were found.

Table II. — Improvement of sagittal plane knee kinematics for the individual patients

Subject	PKF (deg)	Total knee ROM (deg)	KFV (deg/s)
1	38.16	34.63	160.5
2	13.54	17.15	66.84
3	21.68	13.48	93.37
4	14.43	17.75	107.25
5	15.45	13.75	103.4
6	43.33	47.16	265.76
7	14.72	20.4	113.93
8	22.16	13.52	37.25
9	14.65	13.71	19.04
10	1.01	16.21	135.3
Median	15.09	16.68	105.33
IQR	7.56	6.02	56.48

Knee extensor strength, both in clinical exam (MMT) and in gait (knee extension moment at toe-off), was well maintained (or even improved) and did not suffer from the lack of the RF in the knee extensor apparatus after the transfer. Further, no significant change in peak hip flexion or hip flexion moment at toe-off was noted, indicating that the impact of RF transfer on hip flexion is minimal.

While walking velocity increased, only a slight but not statistically significant increase, in stride length was observed. This probably reflects the lack of strength in pull- and push-off and lack of balance and selectivity which is common in patients with gait problems due to upper motor neuron lesions. Slow speed and limited stride length is a known factor in limiting knee flexion in swing. But even with a remaining limited stride length, the patients were able to demonstrate better knee flexion in swing postoperatively, which demonstrates that the spasticity of the RF truly limited knee flexion in swing and could be corrected by a transfer of this muscle.

The same is true for the significant decrease in ankle plantar flexion moment in the postoperative gait. As 7 out of 10 patients needed a lengthening of the plantar flexors, a decrease in ankle plantar flexion moment was inevitable. Despite the fact that reduced ankle push-off power is also described as a possible cause of SKG *(18,6)*, even patients that underwent the combination of RF transfer and lengthening of plantar flexors had an improved knee ROM. Single event multilevel surgery will correct multiple levels in the same surgical episode if multiple problems coexist. It will allow the patient to demonstrate an optimal gait corrected were possible at all levels needing only one surgical episode and one postoperative rehabilitation.

It is important to note however that patients with short and/or spastic plantar flexors can walk with a pathological plantar flexion/knee extension couple leading to a recurvatum knee during stance *(18)*. The hyperextended knee might then have problems moving adequately into knee flexion at the beginning of swing. After correction of the ankle equinus and secondary knee recurvatum gait, SKG can resolve if there is no coexistent RF spasticity. In such cases it is important to treat the equinus first, conservatively if possible, before deciding to add a RF transfer in a later stage if still necessary. None of the included patients presented with knee hyperextension preoperatively as they already passed this selection.

Namdari et al. reported on a RF transfer with fractional lengthening of the vastus muscles in 37 patients with SKG following stroke or TBI *(10)*. Using clinical observation, they reported an insignificant increase of knee flexion from 8° (0-15°) to 33° (20-50°) in 21 patients. No patients reported weakness or buckling after the combination of RF transfer with lengthening of the vastus muscles. However, in this study it was not specified how kinematics or strength were assessed. It is therefore hard to compare to the current findings or to make conclusions on the necessity and outcome of adding a procedure to the vastus muscles. The concomitant spasticity of the vasti and secondary shortening has been demonstrated in patients with acquired brain lesion so adding this procedure might be an option for those patients with spastic short vasti. As a quantitative evaluation of the sEMG of the vasti was not done, neither by Namdari et al *(10)*, nor in the present study, further study is necessary to demonstrate whether adding a vastus procedure in certain patient might further improve outcome.

Study limitations

Use of a retrospective design with limited follow-up, lack of a control group and lack of measures of functional outcome are limitations to this study. While the majority of parameters from CE and GA showed a trend towards improvement, the small sample size may have limited findings of statistical significance. As the average follow-up is limited to about 7 months, the long lasting effect of the transfer has not been demonstrated in patients with acquired brain injury. In patients with CP long term results showed that the improvement is maintained *(3)*. SKG limits clearance of the foot during swing phase thereby causing tripping and falling and limiting a functional gait. The patients from this study mentioned feeling more comfortable walking on uneven surfaces after the RF transfer, but their functional gain was not assessed quantitatively.

CONCLUSION

This study provides the first quantitative evidence of significant improvements in sagittal knee kinematics thereby demonstrating that a RF transfer has a valid potential to improve gait in patients with SKG following stroke or TBI. Therefore, transfer of knowledge from the surgical treatment developed for SKG in patients with CP to adults with acquired brain injury can be made.

Despite a yearly increase in the stroke-population and the fact that 17 to 46% of first-time stroke patients suffer from lasting spasticity – with a detrimental effect on quality of life and daily functioning *(20)* - the majority of these patients are still treated conservatively with often limited results. By adding knowledge about gait-improving surgery for this patient group, more patients might be evaluated for surgery and receive a RF transfer to improve their SKG.

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