Three-Dimensional Muscle-Tendon Geometry after Rectus Femoris Transfer

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Introduction

Rectus femoris transfer surgery is performed to improve knee flexion in persons with cerebral palsy who walk with a stiff-knee gait (Gage et al., 1987; Perry, 1987). In this surgery, the rectus femoris muscle is separated from the quadriceps tendon, tunneled through the subcutaneous tissue on the medial aspect of the thigh and sutured to one of the knee flexors – such as sartorius or semitendinosus. Sutherland (1990) showed knee flexion improved when rectus femoris transfer alone was performed. Other investigators have shown that knee flexion improves when rectus femoris transfer is performed in conjunction with other surgeries (Miller et al. 1997). The conceptual basis for these improvements after rectus femoris transfer is (i) removal of the rectus femoris as a knee extensor and (ii) conversion of the rectus femoris to a knee flexor.

Two recent observations have challenged the assumption that the rectus femoris is converted to a knee flexor after transfer. First, stimulation of the rectus femoris in subjects after transfer did not generate knee flexion moment, but instead generated knee extension moment (Riewald and Delp, 1997). Second, measurements of rectus femoris motion after surgery using dynamic magnetic resonance imaging showed that the muscle moves in the direction of the knee extensors after transfer (Asakawa et al., 2002). These studies suggest that the transferred rectus femoris may be tethered to the underlying vasti by connective tissue. To better understand the role of this muscle in production of knee motion post-operatively, the three-dimensional muscle path needs to be assessed. Computer models and anatomical studies have been used to characterize muscle-tendon geometry after surgery, but *in vivo* geometry of the transferred rectus femoris has not been investigated. The purpose of this study, therefore, was to evaluate the muscle-tendon geometry of the rectus femoris after transfer using magnetic resonance images.

Statement of Clinical Significance

Characterizing the *in vivo* geometry of the rectus femoris after transfer will aid in understanding the mechanism by which rectus femoris transfer improves knee flexion.

Methodology

Magnetic resonance images (MRI) of the lower limbs were acquired from five subjects with cerebral palsy who had undergone bilateral rectus femoris transfer surgery (Table 1). Each subject had a diagnosis of spastic diplegia and had concomitant surgeries including hamstrings lengthenings, adductor myotomy, and psoas tenotomy at the time of rectus femoris transfer. No subject had undergone bone surgery. Four different surgeons performed the rectus femoris (RF) transfers to either the sartorius (SAR) or the semitendinosus (ST). The subjects were imaged between 10 months and 9 years after rectus femoris transfer. Each subject's lower limb was imaged in both the axial and sagittal planes using conventional MRI. Subjects were imaged in a 1.5T GE MR scanner. Proton density images (TR=4000ms, TE= 11.3ms) were acquired with a 24cm x 24cm field of view and a 256x 256 pixel matrix at 10-cm intervals from the inferior iliac spine to below the knee. A computer model of the musculoskeletal geometry of each subject was created by outlining the muscle and bone boundaries in the MR images. Three-dimensional polygonal surfaces were generated for each structure from the two-dimensional outlines. The subjects had pre- and post-operative gait analysis using an eight-camera motion measurement system (Motion Analysis, Santa Rosa, CA). Each subject's kinematic gait data were used to compute the peak knee flexion during swing phase and the knee range of motion before and after rectus femoris transfer.

Results

The three-dimensional geometry of the rectus femoris muscle in 5 subjects (10 limbs) indicates that the transferred muscle does not follow a straight course from its origin to its new surgical insertion (e.g., Fig. 1). An angular deviation was observed to some extent in all 10 limbs studied. In some cases there was a sharp deviation, with preservation of muscle mass proximal to the deviation and apparent atrophy distal to it. MR images showed evidence of scar tissue and thickened connective tissue near the location of the angular deviation. Despite these angular deviations, several subjects demonstrated postoperative improvements in peak knee flexion and knee range of motion (ROM) during walking (Table 1).

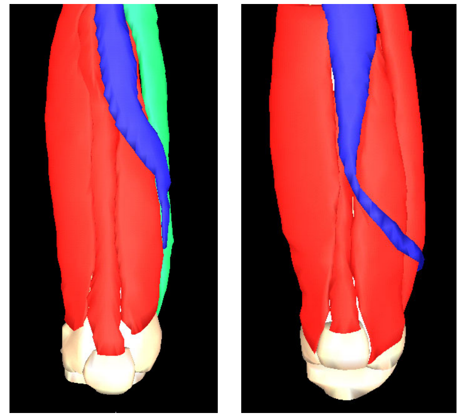

Fig. 1. Reconstruction of muscle-tendon geometry from MRI. Anterior view of the transferred rectus femoris (blue), vasti (red), sartorius (green) and bones (white) of the right lower limbs are shown for Subject 1 (left panel) and Subject 4 (right panel).

Table 1. Subject Characteristics and Gait Analysis Data.

Subject	Age (yrs)	Time since RF Transfer (yrs)	Limb	Transfer Site	Surgeon	Peak Knee Flexion Pre/Post (deg)	Knee ROM Pre/Post (deg)
1	12.9	0.8	L	SAR	A	46/66	27/69
			R	SAR	A	43/65	29/70
2	15.6	1.6	L	SAR	A	67/44	27/31
			R	SAR	C	63/51	26/28
3	8.8	3.0	L	ST	B	✞/52	✞/57
			R	ST	B	✞/63	✞/59
4	14.8	3.2	L	ST	B	40/42	19/41
			R	ST	B	51/51	28/51
5	16.6	9.0	L	SAR	D	✞/37	✞/27
			R	SAR	D	✞/45	✞/30

✞ preoperative gait analysis data not available

Discussion

Muscle configuration after rectus femoris transfer does not conform to the geometry expected in a traditional muscle or tendon transfer. The rapid change in the direction of the transferred rectus femoris suggests that the muscle may be constrained by connective tissue or the subcutaneous tissue through which the tendon is routed during surgery. Based on the angular deviation observed in the muscle path, we postulate that force is not effectively transmitted through the transferred rectus femoris in these subjects. Therefore, we believe the beneficial effects of rectus femoris transfer derive from reducing the effects of the rectus femoris as a knee extensor, rather than converting the muscle to a knee flexor. These findings clarify our understanding of the mechanism by which rectus femoris transfer improves knee flexion.

References

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