ALTERED 3-D QUADRICEPS MOMENT ARMS IN PATELLOFEMORAL PAIN

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INTRODUCTION

Current literature suggests a multifactorial etiology for patellofemoral (PF) pain that is associated with abnormal patellar kinematics (maltracking) [1,2]. However, the factors that initiate the shift from healthy to pathologic knee biomechanics have yet to be determined. Since the patella can move in all six degrees-of-freedom, patellar maltracking can manifest as changes in both patellar orientation (rotation) and displacement (translation). Recent studies have shown that lateral patellar subluxation, patellar flexion, tilt, and negative spin (superior patellar pole rotates medially) are prominent markers of maltracking in PF pain [1,2]. These maltracking changes could be due to a disrupted force balance at the knee, improper muscle activation patterns, or altered PF bone shape. For example, it is commonly hypothesized that weakness and/or delayed activation in the vastus medialis (VM) muscle results in lateral patellar subluxation and tilt [3]. However, unlike PF translations, force imbalance is not necessarily the cause of rotational maltracking patterns. Changes in the quadriceps' moment arms could also result in PF rotational maltracking. Furthermore, moment arm dysfunction has been identified in other pathologies [4]. The purpose of this study was to evaluate the role of the quadriceps' moment arms in PF pain by comparing the relative moments, with respect to the patellar center of mass, of each quadriceps component in healthy knees to those in knees with PF pain and maltracking.

METHODS

Twenty two asymptomatic knees with no prior history of knee problems or pain, and 12 knees with clinically-diagnosed PF pain and maltracking were placed supine in a MR imager (1.5 T, GE Medical Systems, Milwaukee, WI, USA or 3.0 T, Philips Medical Systems, Best, NL) [5]. Kinematics were not significantly different between the two imaging systems. During cyclic knee flexion/extension, and using a 2D sagittal-oblique imaging plane (perpendicular to the femoral epicondylar line and bisecting the patella), a 3-D dynamic cine-phase contrast (PC) MR image set (x,y,z velocity and anatomic images frames) was acquired [5]. Two additional cine-PC sets (Figure 1a) were acquired using coronal-oblique imaging planes (parallel to the quadriceps tendon). Dynamic cine images were also acquired in three axial planes to establish anatomical coordinate systems (Figure 1b). The kinematics of each bone were quantified through integration of the velocity data [5]. All points of interest were visually identified in a single frame of the dynamic images and tracked through the motion

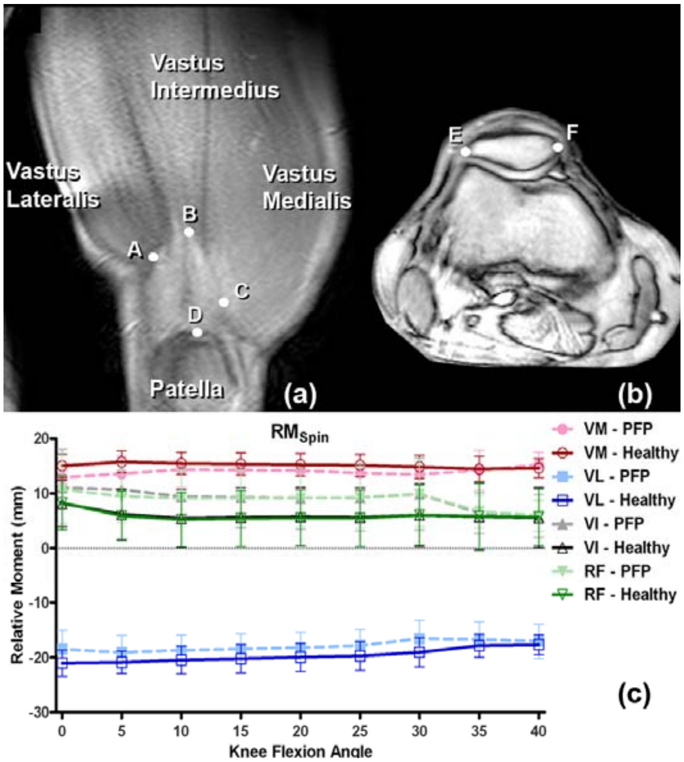

Figure 1: (a) Anatomic coronal-oblique PC image. White dots show the myotendinous junctions of the *(A)* VL; *(B)* VI; and *(C)* VM. *(D)* Represents the patellar insertion of the VI / RF tendon. **(b)** Axial dynamic image at full extension. Insertions of *(E)* VL and *(F)* VM portions of quads tendon on the patella. **(c)** Mean **Relative Moment – RM$_{Spin}$** (positive indicates superior pole rotates laterally) between 0° and 40° knee flexion. Asymptomatic mean: open symbol, solid line. PF pain mean: filled symbol, dashed line. Error bars: standard deviation.

cycle based on each bone's kinematics. For each component of the quadriceps muscle, the myotendinous junctions (MTJs) were identified in the first frame of the coronal PC series and tracked in a similar manner. The tendon insertion onto the patella was the midpoint of the most proximal edge of the patella (Figure 1a) for the rectus femoris (RF) and vastus intermedius (VI), and the most lateral and medial patellar points (Figure 1b) for the vastus lateralis (VL) and VM. Tendon lines-of-action were defined as the unit vector between the respective MTJ and the tendon insertion on the patella.

The relative moment (**RM**, 3D vector) represents the coefficients of the muscles in moment equilibrium equations. **RM** was used to assess the contribution of each quadriceps muscle in the three planes of motion. **RM** was defined as the cross product of the tendon line of action and a line connecting the line of action with the patellar center of mass and was composed of: flexion/extension ($\mathbf{RM}_{\mathbf{F/E}}$), tilt ($\mathbf{RM}_{\mathbf{Tilt}}$) and spin ($\mathbf{RM}_{\mathbf{Spin}}$). The moment of each muscle could then be calculated by multiplying scalar force by **RM**. Two-way ANOVA ($\alpha=0.05$) was used to compare **RM**s between groups and Pearson's r was used to identify associations between **RM**s and patellofemoral kinematics.

RESULTS

The VM and VL primarily control patellar spin and tilt (Table 1: both muscles have the largest magnitude **RM** in these directions). $\mathbf{RM}_{\mathbf{Spin}}$ and $\mathbf{RM}_{\mathbf{Tilt}}$ for the VM and VL are similar in magnitude, but opposite in direction. Patellar flexion is primarily controlled by the VI and RF. In PF pain, **RM**s were altered in every muscle. For example, the absolute magnitude of $\mathbf{RM}_{\mathbf{Spin}}$ decreased 9.6% and 8.4% for the VL and VM, respectively (Figure 1c). $\mathbf{RM}_{\mathbf{F/E}}$ was highly correlated with patellar extension for all muscles in knees with PF pain ($r \geq 0.90$), but only for the VI and RF in asymptomatic knees ($r \geq 0.91$). For the VL and VM, $\mathbf{RM}_{\mathbf{Tilt}}$ was highly correlated with patellar tilt in asymptomatic knees ($r = 0.85$ and 0.94, respectively), but in knees with PF pain the association was less strong ($r =$ 0.75 and 0.81, respectively). $\mathbf{RM}_{\mathbf{Spin}}$ was not correlated with patellar spin in either group.

DISCUSSION

This is the first study to characterize the relative moments of the individual quadriceps *in vivo* in both healthy subjects and subjects with PF pain. While changes in **RM** *were* seen for every muscle in subjects with PF pain, **RM** alterations were not the direct cause of rotational maltracking [1,2]. The changes in the quadriceps moment arms actually opposed maltracking patterns seen in patients with PF pain. Therefore, it is likely that a force imbalance leads to both the translational and rotational kinematic alterations seen in PF pain.

The lack of association between $\mathbf{RM}_{\mathbf{Spin}}$ and patellar spin suggests that other factors may control patellar spin (e.g. passive constraint from the femoral sulcus). Whereas, the $\mathbf{RM}_{\mathbf{F/E}}$ in patients with PF pain suggests that all muscles are recruited to create a PF extension moment.

The VM plays an important role acting as the antagonist for the VL based on the balance in $\mathbf{RM}_{\mathbf{Tilt}}$ and $\mathbf{RM}_{\mathbf{Spin}}$. The current results show that in patients with PF pain changes in the **RM** generally increase the VM's capacity to offset the VL. This suggests that kinematic alterations seen in PF pain are coupled with moment arm changes which favor normal PF kinematics. However, VM weakness will limit the ability of the VM to offset the VL (joint moment = force x moment arm) despite moment arm changes favoring normal PF kinematics. Therefore, direct knowledge of the force contributions from each quadriceps muscle is required for complete description of the etiology of patellar maltracking.

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Table 1: Mean (SD) quadriceps relative moments (**RM**) at 10° of knee flexion. Positive directions of motion are patellar flexion, medial tilt, and positive spin. * $p<0.05$, ** $p<0.01$

	VL		**VM**		**VI**		**RF**	
	Healthy	**PF Pain**	**Healthy**	**PF Pain**	**Healthy**	**PF Pain**	**Healthy**	**PF Pain**
$\mathbf{RM}_{\mathbf{F/E}}$	0.3 (0.9)	-0.2 (1.3)**	0.3 (0.9)	-0.2 (1.2)**	-5.4 (2.9)	-5.7 (2.4)*	-2.7 (2.8)	-2.5 (2.6)
$\mathbf{RM}_{\mathbf{Tilt}}$	-5.8 (2.5)	-5.9 (2.1)	5.0 (2.4)	5.3 (2.4)	0.7 (2.0)	1.9 (1.7)**	0.5 (1.2)	1.3 (1.1)**
$\mathbf{RM}_{\mathbf{Spin}}$	-20.5 (2.5)	-18.7 (2.8)**	15.5 (2.0)	14.3 (3.2)**	5.4 (5.3)	9.4 (5.4)**	5.2 (5.0)	9.1 (5.1)**