BioMechanics
January 2007

Patellofemoral pain research refocuses on hip biomechanics

Patellofemoral, biomechanists, kinematics, MRI, University of Southern California, PFPS, Journal of Orthopedic and Sports Physical Therapy, Patella, Christopher M. Powers, Musculoskeletal

By: Jordana Bieze Foster

Three years ago, a landmark MRI study called into question what most biomechanists thought they knew about patellofemoral kinematics. The impact of this finding on the biomechanics mainstream is becoming increasingly evident in the growing number of studies now analyzing hip motion in addition to lower extremity motion in order to better understand patellofemoral pain syndrome.

Prior to November 2003, most researchers and practitioners believed that patellofemoral pain resulted from abnormal lateral movement of the patella relative to the femur, which had been confirmed using kinematic MRI. However, previous MRI studies had all been performed under nonweight-bearing conditions. But when researchers from the University of Southern California borrowed the 0.5-tesla vertical MRI system used by their colleagues at Stanford to analyze the patellofemoral kinematics of six women with PFPS under both weight-bearing and nonweight-bearing conditions, they found that lateral patellar displacement and rotation were significantly greater while nonweight-bearing. In addition, they found that weight-bearing was associated with significant increases in femoral internal rotation during the end range of knee extension. That study was published in the *Journal of Orthopedic and Sports Physical Therapy*.

"The assumption that the patella moves on the femur is likely the case with nonweight-bearing activities. But under weight-bearing conditions it appears the femur is rotating up underneath the patella," said Christopher M. Powers, PhD, PT, an associate professor of biokinesiology and physical therapy at USC and director of the Musculoskeletal Biomechanics Research Laboratory, during a presentation on kinematic MRI at the annual meeting of the American Society of Biomechanics in September. "So it may be that we've been treating the wrong side of the joint all along."

Since that time, Powers and others have revised their analytical game plans to account for the potential influence of hip internal rotation, along with weakness of the muscles that work to restrain such motion, in patients with patellofemoral pain.

"It's amazing how often we see this, now that we're looking for it," Powers said.

Joint coupling

Two studies originating from the University of Delaware found evidence that femoral kinematics may help differentiate runners with patellofemoral pain from those without. In a study of 20 men with PFP and 20 without, all of whom regularly ran more than 10 miles per week, researchers analyzed joint coupling in terms of continuous relative phase during a prolonged run and found significant between-group differences. In the runners with PFP, coupling of rearfoot eversion-inversion with tibial rotation and with knee flexion-extension tended to be more out of phase during early stance, but the coupling of rearfoot eversion-inversion and knee internal-external rotation tended to be in-phase.

"The difference in knee internal rotation wasn't coming from the tibia, but from the femur," said Tracy Dierks, PhD, now an assistant professor of physical therapy at Indiana University/Purdue University at Indianapolis, who presented the group's findings at the ASB meeting. "This may lead to abnormal patellofemoral contact pressures."

The other Delaware study identified hip strength as a factor differentiating runners with PFP from those without, but found that hip weakness did not correlate strongly with running mechanics. In 12 female runners with PFP and 16 without, the researchers found that those with pain had 13% less hip external rotation strength and hip abduction strength than those who were uninjured. They also found that runners with PFP differed kinematically from those without pain-most significantly in terms of hip adduction and knee external rotation. For the group overall, the correlation between strength and kinematics was weak; however, the correlation was stronger when those with PFP were analyzed separately.

"It could be that there's a level at which the correlation becomes significant, and above that level individuals have sufficient strength to compensate for the kinematic differences," said John Willson, MPT, a doctoral student in biomechanics and movement science at the university, who presented his group's findings at the ASB meeting.

The findings suggest that, clinically, practitioners may not want to focus solely on strength in developing a rehabilitation strategy for athletes with PFP.

"It's important that clinicians be sure an athlete has sufficient strength," Willson said. "But once they have that, the best way to change their kinematics may involve something like kinesthetic or visual feedback of some kind, to maintain alignment."

More than strength

Researchers are also exploring the potential role that hip muscle weakness may play in nonathlete populations. Separate studies from New York and Kentucky published within the past year support the concept of hip strengthening as part of a rehabilitation program for patients with PFP, although both programs focused on more than just strength alone.

Investigators from the Nicholas Institute of Sports Medicine and Athletic Trauma in New York City designed a six-week exercise program that emphasized strengthening of the hip flexors, abductors, adductors, and extensors along with increasing flexibility of the iliotibial band and hip flexors. Thirty-five patients with patellofemoral pain exercised at home once daily for six weeks in addition to periodic clinic visits; strength exercises were initially performed under nonweight-bearing conditions but progressed to weight-bearing.

After six weeks, 21 patients (26 knees) had a successful outcome in terms of pain relief, defined by an improvement of at least 1.5 cm on a 10-cm visual analog scale. In addition, the researchers found that improvements in hip flexion strength and flexibility were associated with successful outcomes. Hip flexion strength improved by 35% in limbs treated successfully, but actually decreased slightly in those treated unsuccessfully; the group had had a mean hip flexion strength deficit of 14% at baseline. Of the 31 lower extremities with a positive Thomas test (indicating limited hip flexor flexibility) at baseline, the test had normalized in 20 limbs after six weeks; successful outcomes were seen in 80% of those that had normalized but only 18% of those in which the Thomas test was still positive. Similarly, successful outcomes were reported in 20 of 24 knees (83%) that had normalized from a positive Ober test (indicating limited ITB flexibility) and only four of 15 knees (27%) in which the test remained positive six weeks later. The findings were published in the April issue of the *American Journal of Sports Medicine*.

Meanwhile, researchers from the University of Kentucky found that a six-week rehabilitation

program-emphasizing quadriceps strengthening, gluteus medius strengthening, and neuromuscular control-resulted not only in patellofemoral pain reduction but also improved timing of key quadriceps muscles. Prior to the intervention, the investigators found that vastus lateralis activation preceded vastus medialis oblique activation by 36 ms in 14 subjects with PFP; by comparison, VMO activation preceded vastus lateralis activation by 59 ms in 14 control subjects. Following the intervention, however, the timing of muscle activation in the PFP subjects had essentially normalized, such that VMO activated 39 ms earlier than the vastus lateralis. In addition, mean pain scores improved from 4.85 to 1.92 on a VAS scale after four weeks of rehabilitation; function, as measured using the Functional Index Questionnaire, also improved significantly. The results were published in the November issue of the Archives of Physical Medicine and Rehabilitation.

Protonics

Long before Powers and colleagues performed their weight-bearing MRI study, Ron Hruska, PT, was a proponent of the idea that internal rotation of the femur and pelvis contributes to patellofemoral pain (see "Pelvic stability influences lower-extremity mechanics," June 1998, page 23). Hruska incorporated these biomechanical principles in designing the Protonics Rehabilitation Device, an orthosis that provides programmable resistance to flexion to allow for isolated hamstring contraction independent of the hip musculature and thus improve patellofemoral alignment.

Two 1998 studies supported this claim. Researchers from Michigan reported that 50 patients with patellofemoral pain demonstrated significant improvements in both pain and alignment, as measured on x-ray, following four weeks of Protonics-based rehabilitation; 50 patients in a control group had no changes from baseline. That study was published in the May 1998 issue of *Medicine & Science in Sports & Exercise*. Investigators from the American Sports Medicine Institute in Birmingham, AL, found that hamstring activation was significantly increased while the orthosis was worn by 18 patients with patellofemoral pain and that knee flexion angle was significantly reduced during stair climbing and level walking. Those findings were presented in August 1998 at the annual meeting of the American Society of Biomechanics. And in the March 2004 issue of the *Journal of Athletic Training*, research from Pennsylvania State University confirmed significantly decreased VMO and vastus lateralis activity in 19 healthy volunteers while wearing the Protonics device.

More recently, however, researchers have had difficulty documenting the device's effectiveness. Researchers from South Carolina reported in the April 2005 issue of JOSPT that use of the orthotic system by 17 female subjects with PFP was associated with greater gains in passive hip extension and hip external rotation than a conventional rehabilitation program undertaken by another 17 patients. But they found no significant between-group differences in iliotibial band flexibility or hip internal rotation, nor were the 2.2 fewer clinic visits needed by the Protonics group statistically significant.

Researchers from the University of Pittsburgh, analyzing the immediate residual effects of a single treatment session with the device following its removal, found in two separate studies no significant changes in terms of pain, hamstring or gluteus medius activation, anterior pelvic tilt, hip internal rotation, hip adduction, or tibial external rotation during a lateral step-up or during gait. The muscle activation study, published in the April 2004 issue of Gait & Posture, found that knee pain was 30% lower in the postbrace condition than in the prebrace condition, but also found a similar decrease in pain associated with a placebo brace condition (the Protonics orthosis set to zero resistance). The kinematic study, published in the online version of Gait & Posture in August, did find statistically significant decreases in transverse- and frontal-plane pelvic motion, although a placebo effect was also seen in the frontal plane.

The more recent studies' failure to duplicate the results of the 1998 Michigan study may be related

to the populations being analyzed. None of the subjects in the Gait & Posture studies had sought medical treatment in the previous six months, and their average patellar tilt angle (8.6 degrees plus/minus 4.8 degrees) deviated only mildly from the previously reported average in normal subjects (6.3 degrees plus/minus 3.9 degrees).

"I can't say that it was the fault of the brace that we didn't see results," said Jean L. McCrory, PhD, a research assistant professor of health and physical activity at the University of Pittsburgh. "It may have been the fault of the subject population. If the study were to be redone, the subjects should be recruited from a sports medicine clinic. They should be subjects who have come to the clinic seeking help for their anterior knee pain. This was our intent, but unfortunately, there was a drought of eligible subjects at the clinic when we were trying to recruit, so we recruited some subjects just by advertising for people with anterior knee pain."

Jordana Bieze Foster is a freelance writer based in Massachusetts and former editor of BioMechanics.