TOE SLIDE VERSUS FLAT-FOOT SLIDE: WHAT'S BEST FOR THE ATHLETE?

THE TECHNICAL COACH SERIES

GLENN PAULLEY, ONTARIO CURLING COUNCIL

JOHN NEWHOOK, DALHOUSIE UNIVERSITY

6 DECEMBER 2024 **NO. 20**

The dynamics and movements of different sports impose a variety of different stresses on the body, along with different characteristic injuries. For example, we term tendonitis in the elbow as "tennis elbow" because it is a commonplace injury with tennis athletes. Baseball players, on the other hand, tend to suffer from wrist, elbow, and shoulder issues, such as rotator cuff or tendon injuries, with their throwing arm. For pitchers, certainly in the Major Leagues, the frequency of injury from the strain on the throwing arm from delivering 90 mph sliders and 100 mph fastballs imposes constraints on team rosters, and a great deal of effort is dedicated to injury management. Surgeries, such as Tommy John surgery to repair the medial elbow ligament in a pitcher's throwing arm, while initially rare has now become routine in the major leagues [23], and throwing injuries are the main focus of injury prevention programs in youth fastball and softball [10,27].

However, perhaps there is no other sport that causes unilateral, repetitive strain injuries more than curling. A 2004 study [24] of competitive players competing in two USA National events found a high incidence of back, knee, hip, wrist, and shoulder injuries amongst competitors of both genders:

> "Sweeping the stone (55%) and delivering the stone (50%) were the skills most provocative of symptoms (fig 2A–C). Collectively, symptoms of knee (54%), back (33%), and shoulder pain (20%) were most prevalent (table 2). Knee pain was most often reported in the “tuck” knee, which is typically flexed well beyond 90° during stone delivery. Sixty-two per cent of those with knee pain were symptomatic in their tuck [slide foot] knee, while 31% complained of bilateral discomfort." [24]

The catalyst for this article is that over the past few seasons one of the authors (Paulley) has coached several female players who suffer from chronic anterior knee pain:

- Athlete #1, who suffers continuously from anterior (frontal) knee pain in both knees, due to a combination of problems including ankle issues and a prior injury, a sprained Medial Collateral Ligament (MCL), with her hack leg;
- Athlete #2, who suffers from Plica Syndrome, which is chronic swelling in the middle of the knee, with her slide leg;
- Athlete #3, diagnosed with chronic patellar tendonitis in her slide leg; and
- Athlete #4, who suffers from Patellofemoral Pain Syndrome (PFPS) and Iliotibia (IT) band tightness with her slide leg.

All of these young women are in their late teens or early 20's. Moreover, they aren't the only young athletes of which we are aware, over our respective coaching careers, who have suffered from chronic knee pain as curlers. A number of these young athletes have had their curling careers cut short due to chronic knee pain.

WHAT CAUSES ANTERIOR KNEE PAIN?

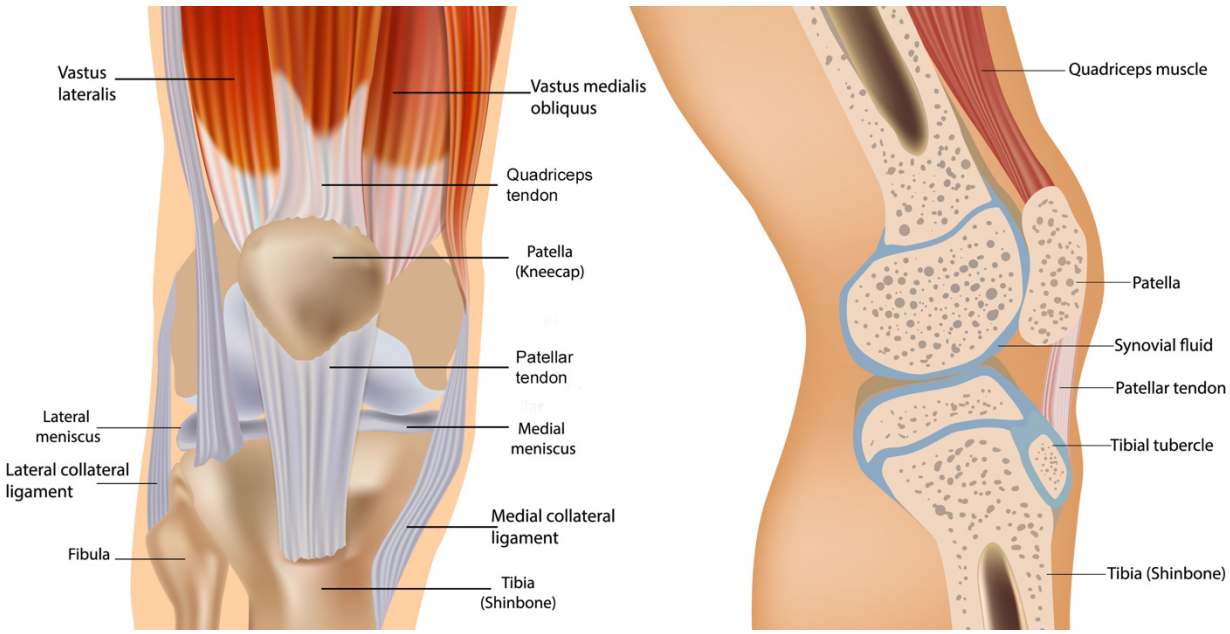

Figure 1 - Anatomy of a right knee.

Anterior knee pain is an umbrella term used to describe a variety of different pathologies that lead to anterior (frontal) knee pain occurring around or behind the patella (kneecap) that occurs when, or is aggravated by, an activity that applies a weight-bearing load on a flexed knee [6,12,13]. These pathologies include Patellofemoral Pain Syndrome, or PFPS, patellar tendinopathy, Plica Syndrome, and a set of other but more infrequently-occurring causes. Patellofemoral Pain Syndrome is itself another umbrella term that encompasses a number of pathologies that result in anterior knee pain with quite similar symptoms. To many, PFPS is known as "Runner's Knee" as PFPS is frequently suffered by recreational runners [6]. Some of the pathologies that cause PFPS include: prior surgery(ies); patellar instability, possibly due to ligamentous laxity; patellofemoral osteoarthritis; quadricep and/or patellar tendonitis (inflammation); Iliotibial (IT) band tightness and/or inflammation; along with a host of other pathologies [6,31,32]. Common symptoms include stiffness and/or pain with prolonged inactivity, or pain when performing activities that impose a load on the knee, such as squatting, running, jumping, or negotiating a staircase [18]. Researchers indicate that PFPS is a condition of either the malalignment of the knee structure or muscular dysfunction [6,32] usually accompanied with overuse of the joint, and is disproportionally more common in female athletes than in males [25]. PFPS is the most common cause of knee pain in female athletes; however, men can also suffer from PFPS. Two other common causes of anterior knee pain are Plica Syndrome and patellar tendinopathy. The former involves pain, swelling, and/or inflammation in the knee due to an irritated fold in the knee’s synovial membrane. The latter, commonly termed "Jumper's Knee", describes structural damage to the patellar tendon rather than inflammation (tendonitis).

There are many possible pathologies that can cause similar symptoms, and so a clinical assessment by a physician or physiotherapist is necessary to ensure the correct set of treatments are applied when a patient presents with anterior knee pain. There are a variety of tests that clinicians can use with a patient to determine a precise diagnosis [1,11,13]. While short-term treatments, such as physiotherapy, exercise therapy, bracing, and taping, can be effective in the short-term [7,9,21,28], long-term issues with anterior knee pain are frequent and, unfortunately, can sometimes lead to patellar osteoarthritis [5,7,18]. Surgery is usually a last resort.

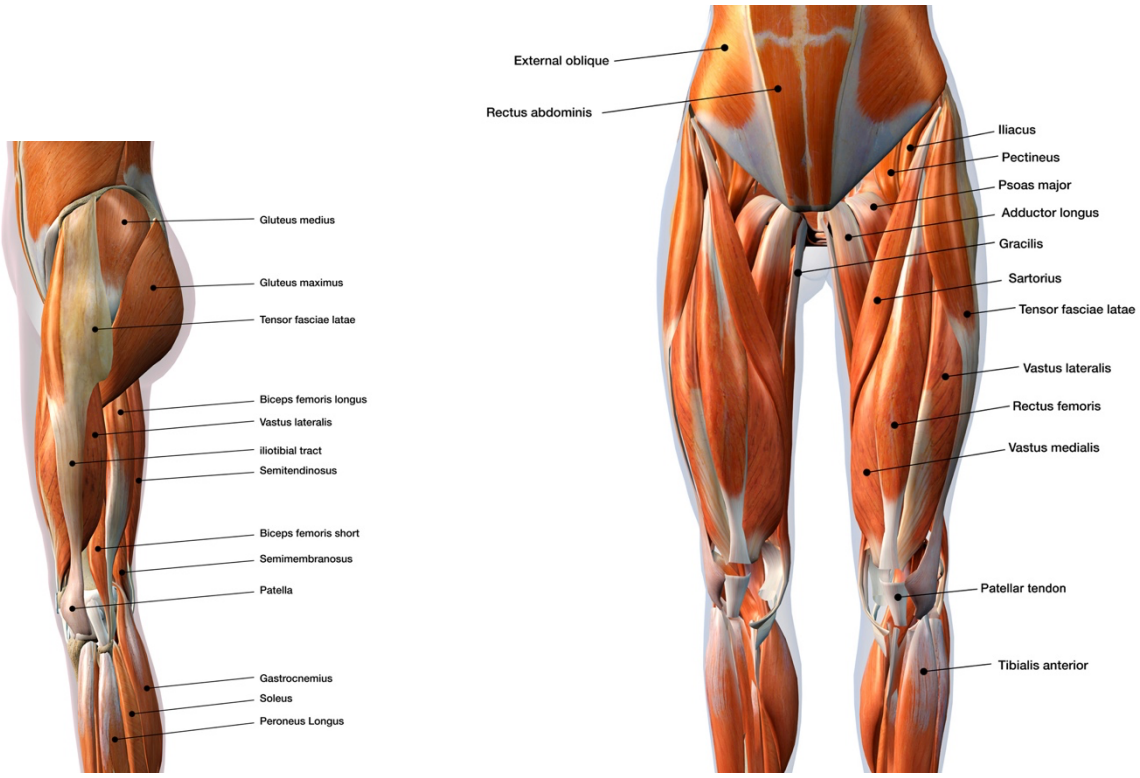

Figure 2 - Muscles of the (female) leg. Note that the Iliotibial Band is not a muscle per se, but a thickened band of deep fascia. Tightness in either the tensor fascia latae or the gluteus maximus can result in tightness of the IT band and, in turn, can cause issues with patellar function.

There are a multitude of potential risk factors for anterior knee pain and there is a great deal of analysis in the available literature about potential causes, particularly in female athletes [1,5,6,9,13,23]. These risk factors include: weaker knee extension strength (i.e., quadriceps); muscle tightness or poor flexibility of the calf, hamstring, or IT band; generalized ligamentous laxity; hip/glute muscle weakness; excessive Q-angle (quadricep angle); patellar compression or tilting; and a delayed/improper VMO/VL reflex timing (these are quadriceps muscles), amongst others.

So the next question to be asked is: just how common is anterior knee pain in youth curling?

INJURY STUDIES IN THE SPORT OF CURLING

There are a limited number of studies that have looked at injuries in the sport of curling, and their focus tends to be of one of two subject cohorts: recreational players [15,29] or elite athletes [3,4,24,34]. Studies of recreational players in the sport, unsurprisingly, consider a

typical cohort of participants of at least middle age and who typically play (only) once per week, and for whom falling and concussions are of paramount importance even though they, too, can suffer from other types of injuries (wrist, shoulder, knee, hip). Conversely, injury evidence of studies that consider elite athletes find varying degrees of injury frequency, but these are athletes who have already played a great many games through several competitive seasons and do not necessarily reflect the physiology or athleticism of adolescent or junior-aged athletes.

Unfortunately, studies of the fitness and athleticism of curling athletes of any LTCD stage are rare. Kivi, Auld et al. [16] study the fitness of a small sample of Junior-aged males from Thunder Bay, and found their fitness to be low in general, and specifically poor given the demands of the sport, particularly in brushing. Nonetheless this was a small study, and female athletes were not included in the set of participants. The work by Behm [2] is cited frequently but his subject, again, are elite athletes in Canada's National Training Program and Behm doesn't directly address injury frequency. In our own coaching experience, the participation rates of competitive female curling athletes in fitness and weight training programs presents a wide spectrum, even when there exists a funded post-secondary curling program with specific fitness expectations and organized gym sessions.

Hence, we have an information gap. To our knowledge, there exists no survey data specific to curling that considers the cohort of competitive adolescent or junior-aged athletes, specifically women, with which to get an idea of the rates of injury, particularly to the knee. Moreover, we lack a longer-term, longitudinal study that looks at a broad cohort of both male and female participants to determine the attrition rate of youth curlers should they develop knee pathologies at earlier ages and leave the sport altogether. Our feeling is that knee injuries amongst female competitive curlers are a widespread problem, but the literature provides very little curling-specific data to support that claim.

So our next question is: can we estimate the prevalence of knee injuries in youth and competitive curling based on other populations?

KNEE INJURY STUDIES FROM OTHER SPORTS

Figure 3 - Example of a flat-foot delivery

There are many studies of PFPS and other forms of anterior knee pain available in the literature; our list of references (below) contains several but our list is far from exhaustive. Most studies find that the incidence of anterior knee pain is higher in females than in males, but precisely what percentages exist depend on the demographics of the sample and, in terms of injuries or injury management, on the sport. For example, many of the studies pertaining to male and female volleyball and basketball players look at patellar tendinopathy rates (as high as 1 in 3) and test athletes with smaller (< 30 degrees) of knee flexion, since jumping is a common occurrence during play in both sports (cf. [33]). Similarly, studies of cohorts of track or cross-country runners look at PFPS as largely an overuse injury. But none of the common movements in those sports are anything like the characteristic skills required in a curling delivery. A textbook, flat-foot curling delivery will typically involve slide knee flexion of at least 120-130 degrees, and possibly more (see Figure 3 above). One sporting activity that also involves deep knee flexion is that of a catcher in baseball or softball [22,23,27]. Unfortunately, to date little academic research has focused on the biomechanics of a catcher (in contrast, for example, with pitchers or infielders) and unsurprisingly most of the surveys in baseball involve (only) men.

There are a number of studies that look at more general populations that can provide some useful context, though again few sporting activities involve repetitive loads of deep knee flexion in the way that a curling delivery does. The Q-angle of an athlete's leg is frequently mentioned as a potential risk factor for PFPS but studies have found mixed, if not contradictory, results [18]. In [14], Hikawa and his Japanese colleagues looked at over 31,000 elite athletes (17,420 men with average age 26.5 $\pm$ 5.0, and 13,623 women with average age 22.5 $\pm$ 4.9) and recorded their Q-angle in a supine position. Overall, their study showed the expected result that, overall, women had larger Q-angles than men. The results were stratified by sport, and for women, the curling athletes tested presented a Q-angle of 15.1 $\pm$ 3.3 degrees, middle of the range across all of the sports represented in their study.

In [5], Boling et al. surveyed 1727 female and 2816 male cadets at US military academies. Together, the female participants in the study (18.6 ± 0.9 years, 165.7 ± 6.6cm, and 63.0 ± 7.9 kg) along with the males (18.9 ± 0.8 years, 178.1 ± 7.2cm, and 77.5 ± 12.3 kg) included 607 individuals (13.4%) that already had some history of PFPS. These individuals were eliminated from analysis over their subsequent academic terms. The remaining cohort of 3,893 cadets were then periodically evaluated over a number of tests, including box jumps, isometric strength tests, and structural alignment measures, including Q-angle, to determine a set of gender-specific risk factors. These subsequent tests identified a further 4% of men and 7% of women who were initially healthy but developed PFPS over their time at an Academy.

Taken altogether, this landmark longitudinal study would indicate that PFPS exists in approximately 20% of active young people aged 18-22. While the aim of the study was to determine the biomechanical risk factors for PFPS specific to males and females of training age, activities involving deep knee flexion were not included in any assessments, and deep flexion results in significantly different loads than ordinary movements [20].

In another large cohort study, this time in Denmark and published in 2011, Rathleff et al. [25] looked at a cohort of 2200 adolescents aged 15 to 19 years. They quote an anterior knee pain incidence rate of 33% in adolescents in general, and in their cohort of 2200 athletes found that 504 reported knee pain (25%) and, two years later, 55.9% of those individuals still reported knee pain. They also found that adolescents with PFPS were more likely to reduce or stop sports participation compared to adolescents who suffered from other forms of knee pain. Furthermore, an additional 12.8% of participants reported knee pain two years later, when they did not report knee pain initially.

Finally, in our literature review we found that a number of North American collegiate sports, particularly volleyball, basketball, rugby, baseball, soccer, and (American) football, had developed injury prevention strategies for their specific sports to reduce occurrences of PFPS and other forms of knee injury [21]. In addition, universities and sports organizations have created detailed treatment regimens involving a combination of physiotherapy and exercise therapy for when injuries occur, such as those described in [7,9,11,19,28,30]. Regrettably, we are aware of no published injury prevention strategies for knee pathologies in the sport of curling in Canada, though we are aware of one curling-specific program developed by the Norwegian School of Sports Sciences whose exercises have been included in an app for both iPhone and Android devices, which was developed by the International Olympic Committee.

In summary, there is some evidence that the occurrence of anterior knee pain in young adults is approximately 1 in 5, or perhaps as high as 1 in 3 – significant enough that injury mitigation and injury prevention programs should exist in many sports, and certainly should in curling.

BIOMECHANICAL STUDIES OF THE CURLING DELIVERY

At the time of writing, formal biomechanical studies of the curling delivery do exist, but there are very few in the published literature. In her Master's thesis, Kraemer [17] measured the alignment of back, hips, and knee flexion of the trailing leg in a flat-foot slide, but did not measure the flexion of the sliding leg nor measure the load placed on the sliding knee during the delivery. Yoo et al. [35] found differences between elite and non-elite curlers in their leg/ankle position, and in the dorsiflexion of their sliding ankle – which may constitute a risk factor for PFPS, though the authors did not address those differences with respect to injury risk. A very recent paper by Wu, Zhao, and Li [34] documented the Rating of Perceived Exertion (RPE) of 8 athletes during their preparations for the last Olympic Games and determined correlations between practice workload and injury risk during periodization, noting that the time lag between workload increase and injury occurrence is important.

By far the most interesting article is one by Robertson et al. [26] of the University of Dundee who looked at the difference in knee loading between toe-slide and flat-foot slide deliveries. Their biomechanical assessment of toe and flat-foot deliveries found that the total load on the knee during a toe slide was roughly **double** of the force when sliding flat-foot, because of the increase in the moment arm of the knee when a toe slide is being used. The authors suggest two reasons why toe-slide athletes may suffer from more injuries than those that deliver flat-foot: (a) increased knee joint force and (b) the increased moment arm of the ground reaction force (see Figures 4 and 5 on the following pages).

BMJ Open Sport & Exercise Medicine

A pilot biomechanical assessment of curling deliveries: is toe sliding more likely to cause knee injury than flatfoot sliding?

Iona Robertson, Graham P Arnold, Weijie Wang, Tim S Drew, Sadiq Nasir, Calum MacDonald, Rami J Abboud

To cite: Robertson I, Arnold GP, Wang W, *et al*. A pilot biomechanical assessment of curling deliveries: is toe sliding more likely to cause knee injury than flatfoot sliding?. *BMJ Open Sport Exerc Med* 2017;3:e000221. doi:10.1136/bmjsem-2017-000221

Accepted 26 May 2017

Department of Orthopaedic & Trauma Surgery, Institute of Motion Analysis & Research (IMAR), TORT Centre, Ninewells Hospital & Medical School, University of Dundee, Dundee, UK

Correspondence to
Professor Rami J Abboud, Institute of Motion Analysis & Research (IMAR), Department of Orthopaedic & Trauma Surgery, TORT Centre, Ninewells Hospital & Medical School, University of Dundee, Dundee DD1 9SY, UK; r.j.abboud@dundee.ac.uk

ABSTRACT

Background The aim of this study was to determine whether toe sliding is more likely to cause knee injuries than flatfoot sliding in curling.

Methods Twelve curlers participated in the study, each delivering 12 stones. Six stones per volunteer were delivered using a flatfoot slide and six were delivered using a toe slide. The Pedar-X in-shoe pressure system recorded the plantar pressure during each of the slides, while a sagittal plane digital video recorded the body position of the curler. Measurements were taken from the video recordings using a software overlay program (MB Ruler), and this, combined with the Pedar-X data, gave the overall joint force in the tuck knee.

Results The knee joint force for toe sliding was more than double that of flatfoot sliding ($p<0.05$). There was a strong correlation between the increase in knee joint force and the increase in the moment arm of the ground reaction force. Images produced using the three-dimensional Vicon system confirm that toe sliding produces a larger moment arm than flatfoot sliding.

Conclusion Injuries are more likely to occur in toe sliding, compared with flatfoot sliding, due to the increase in force and moment, pushing the weight of the curler forward over the knee, which could make the adopted position less stable. Curlers might consider avoiding toe sliding to reduce the risk of knee injuries if the two types of delivery could be performed equally well.

What are the new findings?

- Toe sliding causes higher joint forces in the tuck knee than flatfoot sliding.
- The greater the extent of the toe slide, the greater the knee joint force.
- Increased moment arm in the toe slide makes the curler's position less stable and so more prone to injury.

INTRODUCTION

The aim of this study was to analyse the joint forces about the tuck knee during curling, in flatfoot and toe slide stone deliveries (figure 1A,B), and to assess whether one is more likely to subject the curler to injury than the other.

Curling is a sport played on ice between two teams of four players. To deliver a stone, players gain momentum by pulling the stone back while lifting their hips, followed by a drive forward from the foot on the hack (a foothold on the ice). The delivery position, involving significant hip and knee flexion, is sustained for a short period after the curler releases their stone, creating potential for injury to the player.

Only three papers have been published regarding the epidemiology of curling-related injuries. A retrospective study carried out in the USA analysed injury patterns among competitive curlers, showing that over 54% of injuries were to the knee.[1] Berry *et al*.[2] surveyed participants at the 2008 World Men's Curling Championships and reported five musculoskeletal injuries, all of which were pain on curling-related movements, were sustained throughout the championships.

The third paper claimed to find results similar to those reported by Berry *et al*.[2] Beere *et al*.[3] reported 216 injuries over a 10-year period in high-performance curlers. They declared that most injuries occurred in the back; however, this turns out to be only 39 of 216 injures (18%), very closely followed by injuries to the knee at 33 of 216 (15%). Furthermore, their study failed to account for the nature of 63 injuries, the total value of injuries to the back increases from 39 to 56 without any explanation, and they misquote the findings from Reeser and Berg.[1] Altogether, this questions the

Figure 4 - Robertson et al. [26], published in 2017.

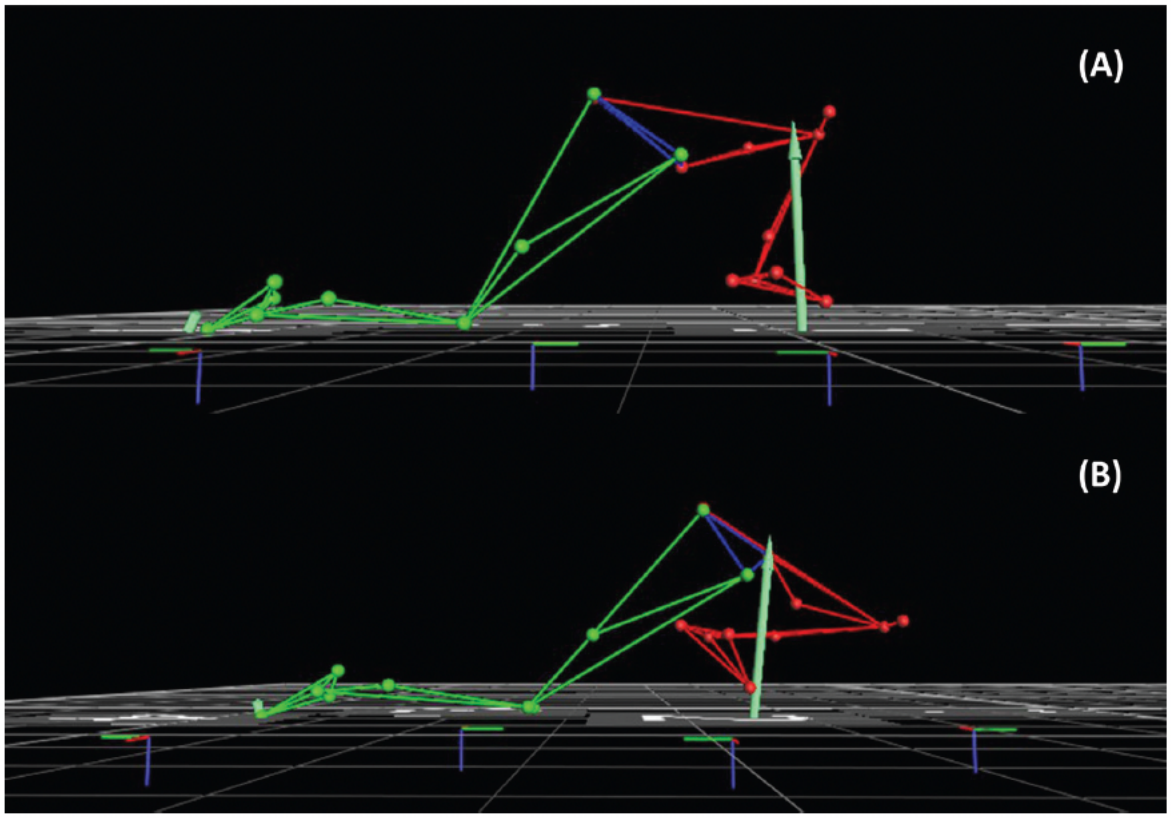

Figure 5 - Arrows indicating the direction of ground reaction forces in (A) a flat-foot slide and (B) a toe slide. Taken from [26], pp. 7.

Robertson and his co-authors did not directly consider a classical Manitoba-style "tuck" slide. However, they determined that the greater the angle of the toe slide, the greater the knee joint force. While some athletes who toe-slide have their slide foot very close to their pelvis, approximating a "tuck" delivery, we are unaware of any biomechanical research that specifically addresses a Manitoba-tuck style of curling delivery.

DELIVERY MODIFICATION AND PAIN MITIGATION FOR CURLING ATHLETES

As mentioned in the introduction, in recent seasons four athletes coached by one of us (Paulley) suffer from anterior knee pain. While Athletes #1 and #2 deliver stones with a flat-foot delivery, Athlete #3 threw with a self-taught, Manitoba-style "tuck" delivery with near-full deep flexion, and Athlete #4 threw with a "toe" slide that includes deep flexion, with the ball of her slide foot almost directly underneath her pelvis. Both Athletes #3 and #4 complained of chronic knee pain.

Figure 6 - Practicing a flat-foot delivery on a slide board.

Taking into account Robertson's research on toe vs. flat-foot slides in [26], it was decided with both these athletes that a change to a flat-foot slide would help to reduce knee loading, mitigate pain, and permit the athlete to play more tournament games in succession. Athlete #3 undertook a leg-strengthening program through the summer months, and in addition practiced a flat-foot delivery using a slide board (see Figure 6) to learn the mechanics and balance of the flat-foot slide. With Athlete #4, the conversion from a toe slide to a flat-foot delivery was initiated at the beginning of the curling season, in late August. In both cases the athletes adjusted well to the change, mastering the flat-foot slide within a few weeks of dedicated practice. In both cases their knee pain has been reduced, though not eliminated.

Other pain mitigation strategies have been implemented with all four athletes, including physiotherapy, exercise therapy, taping, and bracing to address weakness and/or flexibility as required. In response to a question from one of the authors (Paulley), Estelle Haines, BMR PT, a recently-retired clinical rehabilitation physiotherapist in Winnipeg, commented that:

> "I would agree with a recommendation that these young athletes try the flat foot position on their slide leg to decrease the knee joint forces. The difference in knee joint position and the transfer of body weight further onto the knee with a tuck or toe position would put them more at risk of patellofemoral (and tibiofemoral) knee problems.

As to why young females are more prone to patellar issues (as, outside of the realm of curling, I can vouch for the fact that I saw many more young females for patellar issues than males), it can be due to a number of factors. Anatomy (wider pelvis causing increased Q-angle between upper and lower leg, propensity towards joint hypermobilities, relatively increased internal rotation and decreased external rotation at the hip in females as compared to males, etc.) as well as hip- and knee-muscle strength/flexibility, and imbalance in strength between medial and lateral quadriceps, are often significant factors in patellofemoral pain development. Other issues like hormonal fluctuations of progesterone and relaxin with monthly cycles can increase joint hypermobility as well.

Hopefully the young athletes that you speak of have had a chance to be assessed regarding medial and lateral quadriceps strength and flexibility, knee and ankle mobility, hip strength and mobility, hypo/hypermobility and alignment of the patellofemoral joint, gait, Q-angle, etc. and have had appropriate treatment of any issues. Their patellofemoral issues may definitely be exacerbated by knee loading, since it is their slide leg that is problematic, but mechanics of gait, and how their knee functions once ambulatory, may perpetuate the irritation. I would definitely have them assessed by a qualified physiotherapist, preferably one who deals with gait and lower limb issues, footwear, orthotics, etc. to assess the young athlete's lower body mechanics – both in and out of the slide position – to be able to make the best treatment recommendations: stretches, strengthening, patellofemoral taping, orthotics if indicated, etc."

SUMMARY

Our intent in writing this article was two-fold: one, to make other coaches aware of the prevalence of anterior knee pain in youth curling, particularly with young women, and two, to recommend that athletes who suffer from PFPS or other knee pathologies see a qualified physiotherapist for recommendations for exercise, stretching, taping, or other therapies. That therapy may include changes to an athlete's curling delivery to mitigate their individual issues. Hopefully such adjustments are helpful and can assist an athlete to navigate the rigors of a competitive curling season with reduced pain and an improved prognosis. Our experience with Athletes #3 and #4 has been quite positive, and the change to a flat-foot delivery was accomplished within a single season.

We are well aware that there are many successful athletes who utilize a toe slide in their deliveries (Kerri Einarson, John Epping, Chelsea Carey, and Rachel Homan to name but four)

and many "tuck" sliders from the Prairies who are, or have been, extremely successful (Jeff Stoughton, Matt Dunstone, Kate Cameron, Mike McEwen, Colton Flasch, Pat Ryan, Jacques Gauthier). We are not saying that a flat-foot technique is definitively better than toe- or tuck-sliding. What we are saying, however, is that if an athlete presents with chronic anterior knee pain it may be appropriate to change their delivery technique to flat-foot to reduce knee loading and, hopefully, mitigate their pain issues. That, along with the help of an assessment by a clinical physiotherapist and recommendations for specific therapies, may help to make the athlete more successful and keep them in the game.

Finally. we would like to list a number of action items that we feel are important:

- Coaches should become more aware of the possibility that their athletes may present with anterior knee pain, and it is our hope that they could steer the athlete towards getting a formal clinical assessment of their injury so that the correct therapies can be prescribed and implemented.
- More biomechanical research is required to understand the loads and biomechanics of curling deliveries that involve deep knee flexion, particularly when an athlete performs a "tuck" delivery.
- We believe that a longitudinal study, perhaps more than one, should be undertaken to understand the prevalence of knee injuries in youth curling in Canada and its impact.
- We also believe that Curling Canada should sponsor a project to develop injury prevention programs and injury treatment programs for youth athletes, not only for knee injuries but other common injuries in the sport.

ACKNOWLEDGEMENTS

We would like to gratefully thank Melissa Hay, who holds a Ph.D in Health and Rehabilitation Sciences: Physical Therapy from the University of Western Ontario and is currently a practicing clinical physiotherapist, located in Waterloo, Ontario, for her tremendous help in navigating the literature, explaining terms and knee biomechanics, and providing some very helpful references and useful feedback. We would also like to thank Estelle Haines, BMR PT, of Winnipeg, Manitoba for her analysis and helpful feedback during the development of this article.

REFERENCES

Regrettably we note that several of the articles below are available only through a paywall. However, the majority of the articles below are either freely available or can be accessed by the general public under a Creative Commons license.

[1] C. J. Barton, S. Lack, S. Hemmings, S. Tufail, and D. Morrissey (February 2015). The 'Best Practice Guide to Conservative Management of Patellofemoral Pain': incorporating level 1 evidence with expert clinical reasoning. British Journal of Sports Medicine 49, pp. 923-934. URL: https://pubmed.ncbi.nlm.nih.gov/25716151/ DOI: https://doi.org/10.1136/bjsports-2014-093637.

[2] D. G. Behm (June 2007). Periodized Training Program of the Canadian Olympic Curling Team. Strength and Conditioning Journal 29(3), pp. 24-31. DOI:https://doi.org/10.1519/1533-4295(2007)29[24:PTPOTC]2.0.CO;2.

[3] L. P. Beere, A. Murray, M. Belch, and B. Walker (May 2014). Injury patterns in high-performance curlers. British Journal of Sports Medicine online blog. Available at: https://blogs.bmj.com/bjsm/2014/05/14/injury-patterns-in-high-performance-curlers-the-sport-has-2-million-players-worldwide-although-has-200x-less-publications-than-aussie-rules-football/

[4] J. W. Berry, M. A. Romanick, and S. M. Koerber (March 2013). Injury Type and Incidence Among Elite Level Curlers During World Championship Competition. Research in Sports Medicine 21(2), pp. 159-163. DOI: https://doi.org/10.1080/15438627.2012.757229.

[5] M. C. Boling, A.-D. Nguyen, D. A. Padua, K. L. Cameron, A. Beutler, and S. W. Marshall (January 2021). Gender-Specific Risk Factor Profiles for Patellofemoral Pain. Clinical Journal of Sports Medicine 31(1), pp. 49-56. DOI: http://dx.doi.org/10.1097/JSM.0000000000000719

[6] H. Collado and M. Fredericson (July 2010). Patellofemoral pain syndrome. Clinics in sports medicine, 29(3), pp. 379-398. DOI: https://doi.org/10.1016/j.csm.2010.03.012.

[7] N. J. Collins, C. J. Barton, M. van Middelkoop, M. J. Callaghan, M. S. Rathleff et al. (June 2018). 2018 Consensus statement on exercise therapy and physical interventions (orthoses, taping and manual therapy) to treat patellofemoral pain: recommendations from the 5th International Patellofemoral Pain Research Retreat, Gold Coast, Australia, 2017. In British

Journal of Sports Medicine 52, pp. 1170–1178. DOI: https://doi.org/10.1136/bjsports-2018-099397

[8] K. M. Crossley, J. J. Stefanik, J. Selfe, N. J. Collins, I. S. Davis, C. M. Powers et al. (June 2016). 2016 Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 1: Terminology, definitions, clinical examination, natural history, patellofemoral osteoarthritis and patient-reported outcome measures. In British Journal of Sports Medicine 50, pp. 839–843. DOI: https://doi.org/10.1136/bjsports-2016-096384.

[9] S. Dixit, J. P. DiFiori, M. Burton, and B.Mines (2007). Management of Patellofemoral Pain Syndrome. American Family Physician 75(2), pp. 194-202. Available at https://www.aafp.org/pubs/afp/issues/2007/0115/p194.html.

[10] B. T. Feeley, S. E. Feeley, and C. C. Chambers (January 2024). Fastpitch Softball Injuries: Epidemiology, Biomechanics, and Injury Prevention. Current Reviews in Musculoskeletal Medicine 17, pp. 110–116. DOI: https://doi.org/10.1007/s12178-024-09886-y.

[11] D. Figueroa, F. Figueroa, and R. Calvo (2016). Patellar Tendinopathy: Diagnosis and Treatment. Journal of the American Academy of Orthopaedic Surgeons 24(12), pp. e184-e192. DOI: https://dx.doi.org/10.5435/JAAOS-D-15-00703.

[12] A. J. S. Fox, F. Wanivenhaus, and S. A. Rodeo (May 2012). The basic science of the patella: structure, composition, and function. Journal of Knee Surgery 25(2), pp. 127-141. DOI: https://doi.org/10.1055/s-0032-1313741.

[13] D. Y. Gaitonde, A. Ericksen, and R. C. Robbins (2019). Patellofemoral Pain Syndrome. American Family Physician 99(2), pp. 88-94. Available at https://www.aafp.org/pubs/afp/issues/2019/0115/p88.html.

[14] K. Hikawa, S. Takahashi, R. Shimizu, et al (February 2024). EP106 - Characteristics of the Q-Angle in elite athletes. British Journal of Sports Medicine 58, pp.A125. DOI: https://doi.org/10.1136/bjsports-2024-IOC.221

[15] M. A. Kanters, J. A. Hipp, K. Bunds, J. Casper, and R. Nelson (2024). Adult Sports Participation and Physical Activity: How About Curling? Journal of Healthy Eating and Active Living 4(2), pp. 107-117. Available at https://pubmed.ncbi.nlm.nih.gov/39372064/.

[16] D. Kivi, T. Auld, C. Leon-Carlyle, and D. Witluk (2013). Physical and Physiological Assessment of Competitive Junior Curlers. Thunder Bay, ON: Northern Ontario Curling Association. Available online at: https://curlnoca.ca/wp-content/uploads/2013/06/Curling-Fitness-Assessment-Study.pdf.

[17] E. F. Kraemer (July 2009). Hip and Knee Positions During the Curling Delivery. Master's Thesis, University of Wisconsin-La Crosse College of Science and Health, Human Performance. 49 pages. Available at: https://minds.wisconsin.edu/bitstream/handle/1793/46662/KraemerEllanora2009.pdf.

[18] N. E. Lankhorst, S. M. Bierma-Zeinstra, and M. van Middelkoop (February 2012). Risk factors for patellofemoral pain syndrome: a systematic review. Journal of Orthopaedic & Sports Physical Therapy, 42(2), pp. 81-94. DOI: https://doi.org/10.2519/jospt.2012.3803.

[19] Massachusetts General Hospital, Brigham Sports Medicine (June 2021). Rehabilitation Protocol for Patellofemoral Pain Syndrome. Available at https://www.massgeneral.org/assets/mgh/pdf/orthopaedics/sports-medicine/physical-therapy/rehabilitation-protocol-for-patellofemoral-pain-syndrome.pdf.

[20] T. Nagura, C. O. Dyrby, E. J. Alexander, and T. P. Andriacchi (2002). Mechanical loads at the knee joint during deep flexion. Journal of Orthopaedic Research 20, pp. 881-886. DOI: https://doi.org/10.1016/S0736-0266(01)00178-4.

[21] J. Peña, D. Moreno-Doutres, X. Borràs, A. Altarriba, E. Baiget, A. Caparrós, and B. Buscà (June 2017). Patellar Tendinopathy in Team Sports: Preventive Exercises. Strength and Conditioning Journal 39(3), pp. 20-30. DOI: https://doi.org/10.1519/SSC.0000000000000303.

[22] Y.-C. Peng, K.-C. Lo, and L.-H. Wang (August 2015). Lower Extremity Muscle Activation and Kinematics of Catchers When Throwing Using Various Squatting and Throwing Postures. Journal of Sports Science and Medicine 14(3), pp. 484-493. Available at https://pmc.ncbi.nlm.nih.gov/articles/PMC4541110/.

[23] M. Posner, K. L. Cameron, J. M. Wolf, P. J. Belmont Jr, and B. D. Owens (August 2011). Epidemiology of Major League Baseball injuries. American Journal of Sports Medicine 39(8), pp. 1676-1680. DOI: https://doi.org/10.1177/0363546511411700.

[24] J. C. Reeser and R. L. Berg (September 2004). Self reported injury patterns among competitive curlers in the United States: a preliminary investigation into the epidemiology of curling injuries. British Journal of Sports Medicine 38(5). DOI: https://doi.org/10.1136/bjsm.2003.010298

[25] M. S. Rathleff, C. R. Rathleff, J. L. Olesen, S. Rasmussen, and E. M. Roos (2016). Is Knee Pain During Adolescence a Self-limiting Condition? Prognosis of Patellofemoral Pain and Other Types of Knee Pain. American Journal of Sports Medicine 44(5), pp. 1165-1171. DOI: https://doi.org/10.1177/0363546515622456.

[26] I. Robertson, G.P. Arnold GP, W. Wang W, et al. (August 2017). A pilot biomechanical assessment of curling deliveries: is toe sliding more likely to cause knee injury than flatfoot sliding?. British Medical Journal of Open Sport Exercise Medicine 3(1). Available at https://bmjopensem.bmj.com/content/3/1/e000221. DOI: https://doi.org/10.1136/bmjsem-2017-000221.

[27] E. Shanley, M. J. Rauh, L. A. Michener, and T. S. Ellenbecker (November 2011). Incidence of injuries in high school softball and baseball players. Journal of Athletic Training 46(6), pp. 648-654. DOI: https://doi.org/10.4085/1062-6050-46.6.648.

[28] D. Sisk and M. Fredericson (June 2020). Taping, Bracing, and Injection Treatment for Ptallofemoral Pain and Patellar Tendinopathy. Current Reviews in Musculoskeletal Medicine 13, pp. 537-544. DOI: https://doi.org/10.1007/s12178-020-09646-8.

[29] D. K. Ting and R. J. Brison (April 2015). Injuries in recreational curling include head injuries and may be prevented by using proper footwear. Health Promotion and Chronic Disease Prevention in Canada: Research, Policy, and Practice 35(2), pp. 29-34. DOI: https://doi.org/10.24095/hpcdp.35.2.01.

[30] University Hospitals Bristol (May 2018). Exercises for patellofemoral pain syndrome (PFPS). Available at https://bpfsoc.com/wp-content/uploads/exercises-for-patellofemoral-pain-syndrome.pdf.

[31] M. Vora, E. Curry, A. Chipman, E. Matzkin, and X. Li (February 2018). Patellofemoral pain syndrome in female athletes: A review of diagnoses, etiology and treatment options. Orthopedic Reviews (Pavia), 9(4), pp. 7281. DOI: https://doi.org/10.4081/or.2017.7281. PMID: 29564075; PMCID: PMC5850065. Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC5850065/.

[32] G. R. Waryasz and A. Y. McDermott (June 2008). Patellofemoral pain syndrome (PFPS): a systematic review of anatomy and potential risk factors. Dynamic Medicine 7:9. Available at https://dynamic-med.biomedcentral.com/articles/10.1186/1476-5918-7-9. DOI: https://doi.org/10.1186/1476-5918-7-9.

[33] K. Weiss and C. Whatman (July 2015). Biomechanics Associated with Patellofemoral Pain and ACL Injuries in Sports. Sports Medicine 45(9), pp. 1325-1337. Available at https://pubmed.ncbi.nlm.nih.gov/26130304/. DOI: https://doi.org/10.1007/s40279-015-0353-4.

[34] J. Wu, F. Zhao, and C. Li (August 2024). Analyzing activity and injury risk in elite curling athletes: seven workload monitoring metrics from session-RPE. Frontiers in Public Health 12:1409198. DOI: https://doi.org/10.3389/fpubh.2024.1409198

[35] Kyoung-Seok Yoo, Hyun-Kyung Kim, and Jin-Hoon Park (2012). A Biomechanical Assessment of the Sliding Motion of Curling Delivery in Elite and Subelite Curlers. Journal of Applied Biomechanics 28(6), pp. 694-700. DOI: https://doi.org/10.1123/jab.28.6.694.

[36] E. Zacharias, N. Robak, and S. Passmore (February 2024). An examination of studies related to the sport of curling: a scoping review. Frontiers in Sport and Active Learning 6, 1291241. DOI: https://doi.org/10.3389/fspor.2024.1291241.

QUESTIONS

We are pleased to provide whatever assistance we can to coaches and athletes. Our contact information is below.

John Newhook, Ph.D., P.Eng.
Professor, Dept. of Civil and Resource Engineering
Room D215, Sexton Campus
Dalhousie University
Halifax NS B3H 4R2
Phone: (902) 494-5160
e-mail: john.newhook@dal.ca

Glenn Paulley, Ph.D.
Competition Development Coach
194 Pinegrove Crescent
Waterloo, ON N2L 4V1
Phone: (519) 725-4921
e-mail: glennpaulley@gmail.com