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Proprioception Training in ACL Rehabilitation of a Stroke Patient: A Case Report

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Abstract

Background: The ACL is the most frequently injured knee ligament and causes diminished proprioception and mechanical instability. Decreased proprioception has been shown to cause gait deviations in patients with reconstructed ACLs. Patients who have previously suffered a stroke and torn their ACL is relatively rare and not well described in the literature. The purpose of this case study is to address how a previous neurologic condition effects treatment of an orthopedic injury and how preoperative perturbation training may help patients regain normal gait sooner. **Case description:** This patient suffered a stroke at eight years old, causing decreased somatosensory and use of her right extremities. She tore her right ACL nine years later while playing soccer. Within the first few months of rehabilitation, she had difficulty gaining full knee extension which directly affected her gait pattern. She also showed decreased proprioception and believed her knee to be fully straight when she was in fact lacking between 2-5 degrees of extension. She participated in therapy that focused primarily on range of motion and strengthening. **Intervention**: Research suggests that perturbation based training before surgery may help patients regain normal gait. Individuals who participate in this therapy in addition to strengthening quadriceps show more symmetrical limb movement between the involved and uninvolved side during gait. There is also reduced co-contraction that may be related to the increased motion during gait, leading to a normalized walking pattern. **Discussion**: ACL injury and reconstruction should be viewed as a neuromuscular condition in addition to an orthopedic injury. Focus on perturbation training may have helped this patient reach her goals especially since she already had decreased proprioception due to her stroke.

Background

Anterior cruciate ligament injuries are a very common orthopedic injury seen by physical therapists. The ACL is the most frequently injured knee ligament and accounts for approximately 50% of all ligament injuries (Bonfirm et al. 2003). Every year, there are between 400,000-500,000 ACL injuries worldwide with 175,000 ACL surgeries in the United States (Williams et al. 2015). Teenage girls are two to ten times more likely than boys to tear an ACL (kidshealth.org). The cost of ACL injuries range from $7.6 to $17.7 billion per year in the United States (Grooms et al. 2017). Research has shown that despite surgical reconstruction and physical therapy, patients who have a history of an injured ACL have a dramatically higher risk for developing knee osteoarthritis (Grooms et al. 2017). Many of these patients are not able to return to their prior level of sport participation. It has been shown that athletes who attempt to return to their previous level of activity have a 30-40 times greater risk of a new ACL injury relative to those who have never had an ACL injury (Grooms et al. 2017).

In addition to the cost of surgery, rehabilitation, and potential other injuries, trauma to the ACL can lead to disturbances in everyday functioning even after patients have seemingly fully recovered. ACL injury causes diminished proprioception and mechanical instability in the knee joint (Dhillon 2011). Proprioception consists of awareness of joint position, detection of movement, and closed loop efferent activity which starts the reflex response to regulate muscles (Dhillon 2011). The ACL has a significant number of mechanoreceptors that affect an individual's proprioception. The lost mechanoreceptors alters input to the central nervous system and decrease innervation to the primary sensory cortex (Grooms et al. 2017). This may lead to absent somatosensory-evoked potentials in those with ACL injury or reconstructed ACLs even after surgery. Decreased cortical excitability after reconstruction increases the required stimulus at the motor cortex to generate a quadriceps contraction. Additionally, after ACL reconstruction individuals show decreased joint position perception, a higher threshold to detect passive knee motion, longer latency of hamstring muscles, and decreased performance in postural control (Bonfirm et al. 2003). It has been suggested that fixing the mechanical stability of the knee through surgical intervention may not be enough to lead to good outcomes (Dhillon 2011).

Because ACL injuries are known to cause decreased proprioception and altered input to the central nervous system, prior neurologic conditions, such as a stroke, pose additional problems to the rehabilitation process. A stroke is characterized by the occlusion or rupture of cerebral blood vessels and can be categorized into ischemic of hemorrhagic subtypes (Tsze 2011). While strokes are relatively rare in the pediatric population, approximately 15% of all ischemic strokes occur in individuals under 18 years old. (Singhal et al. 2013). The symptoms are more likely to be missed younger patients; children in the emergency department are often given a different diagnosis since it is "still considered a disease of the elderly" (Singhal et al. 2013). Signs to be aware of include hemiplegia (occurring in 94% of pediatric strokes), headaches, altered level of consciousness, vomiting, and seizures (Tsze 2011). The management of stroke in children has not been studied as much as managing adult stroke patients but includes monitoring for intracranial pressure, controlling systemic hypertension, normalizing serum glucose, and maintaining normal oxygenation. The use of tPA (tissue plasminogen activator) is controversial and limited to clinical trials for children under 18, although it is thought to be the gold standard for treatment of ischemic strokes in adults (American Stroke Association).

A major difference between children and adults is that pediatric stroke results in a changed ability to achieve, rather than lose, functional independence (Greenham et al. 2016). However, children usually recover better from strokes than adults because their brains are still developing (National Stroke Association, stroke.org). Studies have found motor impairments ranging from mild clumsiness to significant hemiparesis in 50% to 80% of children. Other have looked at functional independence in pediatric stroke patients and have found between 78%-94% of patients state that they have no or slight disability and are able to look after their own affairs without assistance (Singhal et al. 2013).

There are many things to consider when working with a patient who has undergone an ACL reconstruction, particularly one with a history of stroke. It is clear that an ACL injury should be regarded as a neurophysiological dysfunction and not simply a musculoskeletal injury. Thus, the purpose of this case study is to address how a previous neurologic condition may alter treatment decision-making

following ACL reconstruction in a 17-year-old female. Recommendation for additional preoperative rehabilitation focused on perturbation training in patients with neurologic deficits will also be considered.

Case description

This patient was selected for a case study because while she had an otherwise very common orthopedic injury, her previous stroke made treatment more difficult due to the associated impairment of decreased somatosensory inputs in her right lower extremity. This case allows us to see how proprioception deficits after ACL were amplified in this patient.

When the patient was 8 years old, she was admitted to a local hospital for acute renal insufficiency associated with presumed hemolytic uremic syndrome (HUS). Labs were conducted which confirmed a diagnosis of E. Coli. The patient was transferred to a larger hospital for treatment and was discharged nine days later. Her parents report that on the day following discharge, she began developing right hemiparesis which began as weakness of right upper extremity followed by weakness of right lower extremity and face. The patient became nonverbal, restless, and agitated. She was brought into the Emergency Department and underwent a head CT. The physician reported that the patient had hemolytic uremic syndrome now with secondary cortical infarction involving the left cerebral cortex (due to cerebral vasculitis linked to HUS). A neurologist was brought in for consultation and he diagnosed the patient with a left middle cerebral artery stroke with consequent edema. Stroke precautions were followed (head of bed lowered, maintain blood pressure 110-120/70-80, etc.) to minimize further complications and she was discharged one week later. She initially required physical and occupational therapy to assist with decreased endurance, decreased ability to ambulate, and decreased use of her right upper and lower extremities. She had difficulties grasping objects with her right hand and tended to rest with her right upper extremity in a flexed posture typical of a stroke patient. She required physical therapy intervention, although the time frame of this therapy was unknown due to patient report. Nine years later, her function had improved and she had no major deficits other than decreased right sided sensation (per patient report). She was able to participate in competitive soccer as a high school student. Her other past medical history includes a right ankle sprain at age sixteen.

In May of 2017, the patient (now seventeen years old) was playing in a soccer game when she collided with another player. She reports that she did not remember if there was a direct blow to her knee or not, but she heard a crack/pop and felt a sudden onset of right lateral knee pain. Upon examination in the Emergency Department, she presented with a positive Lachman's, negative anterior drawer, negative posterior drawer, and negative varus/valgus stress testing. An MRI was ordered which revealed a right ACL rupture with potential meniscal involvement. She was seen by physical therapy the following week for pre-operative consultation and crutch training. She was also given a home exercise program that consisted of quadriceps and hip strengthening exercises (straight leg raises in four directions, bridges). She underwent ACL reconstruction the following month. They opted to use a bone-tendon-bone reconstruction (autograft) with lateral meniscal debridement.

Her primary co-morbidity was decreased sensation and proprioception caused by her stroke. She had difficulty knowing the position of her right sided joints and had trouble knowing if her knee was flexed or extended. She also showed upper motor lesion signs with clonus in her right ankle. Since the patient tore her ACL at the end of her senior year soccer season, she had made a deal with her soccer coach that they would run a 5k together in November. Other goals included being able to fully participate in her job as a youth soccer coach.

Clinical Impression

The patient was seen for her post-operative physical therapy evaluation two days after surgery**.** The patient ambulated into the clinic with a single crutch using her left upper extremity for balance with full weight bearing through her involved right lower extremity. Given her prior stroke and recent surgery, she was ambulating fairly well and did not appear to be in any distress. Minimal oozing was noted upon removal of her wound dressings, in addition to moderate effusion with a ballotable patella. She showed

a fairly good quad set with only 10 degrees of extensor lag during a straight leg raise. This was better than expected based on her previous stroke and patient reported decreased sensation in her right lower extremity. In fact, she did not appear to have any significant limitations that would be attributed to her prior stroke other than her self-reported decreased sensation. She also demonstrated improved quadriceps function and range throughout the session, which indicated that she would benefit from future physical therapy to increase strength, range of motion, and function. Based upon her surgery and presentation, the clinician developed the following three goals for the patient: to demonstrate symmetrical knee range to maximize functional and sport based activity; to participate in school, work, and recreational activity without pain or instability; and to ambulate with symmetrical gait on levels and stairs.

Intervention

The patient was seen 2x/week after surgery. This intervention schedule lasted for approximately 9 weeks until she ran out of visits covered by insurance. After petitioning the insurance company for more visits (incurred 1 week off to receive approval), she resumed therapy at 2x/week. However, the physical therapist planned on decreasing her frequency to 1x/week to save visits for when the patient was able to do higher level exercises such as with return to running and return to sport.

The patient began with range of motion exercises immediately after her surgery. This consisted of supine knee extension with bolster and ankle weights, progressing to NMES to help activate quadriceps to achieve full knee extension. She eventually progressed to biking for dynamic range of motion. Research suggests that non-symmetrical knee range of motion (comparing the involved side to the uninvolved side) can lead to long term arthritic changes in the joint (Shelbourne 2009). Maintaining full range of motion during gait is advantageous because it allows joint loads to be distributed over a larger contact area. Active and passive range of motion were one of the primary measurements used with this patient. Loss of full knee extension is one of the three most common complications after ACL reconstruction (in addition to patellofemoral pain and quadriceps weakness). In fact, losing 5 degrees of extension can lead to increased joint loading, patellofemoral pain, and quadriceps weakness (Noll 2015). One study found that patients with normal extension scored significantly better in the International Knee Documentation Committee form (Shelbourne and Gray, 2000). Loss of knee extension has also been associated with osteoarthritic knee changes. Noll found that knee extension should be within 3-5 degrees of the uninvolved knee at 4 weeks (Noll, 2015). The M.O.O.N. group state that patients should achieve full and symmetrical knee extension range of motion and should achieve 110 degrees of active knee flexion by approximately two weeks post-operatively (Wright et al. 2015).

Active range of motion measurements were taken using a goniometer, with the patient positioned in supine (using the greater trochanter for the stationary arm and the lateral malleolus for the moving arm). The patient initially achieved 86 degrees active knee flexion and lacked 6 degrees of knee extension. Goniometric measurements at the knee have been shown to be valid and reliable (Gogia et al. 1987) however some suggest that differences in range of motion of less than eight degrees cannot be distinguished from measurement error (Lenssen et al. 2007). See Figure 1 and 2 for measurements.

The patient's primary deficit was knee range of motion during gait, so it was important to look at this more closely. The patient was recorded walking on different occasions with video recording on an iPhone (with patient's written consent to being videotaped). Screen shots were captured at various points in the gait cycle and knee range of motion measurements were taken.

Extensor lag was measured during a straight leg raise. The straight leg raise was performed with the patient in supine with the contralateral leg in hooklying. Extensor lag shows activation of the quadriceps muscles. As previously mentioned, quadriceps weakness is one of the most common complications after ACLR which is why it is closely monitored after surgery. The Multicenter Orthopaedics Outcome Network (M.O.O.N.) has found that patients should be able to perform a straight leg raise with no more than five degrees of active extension lag by approximately 2 weeks (Wright et al. 2015). Overall, the patient could perform a "fair quad set" (with muscle definition easily seen during contraction) with 10 degrees extensor lag during the straight leg raise at 2 days post-operatively.

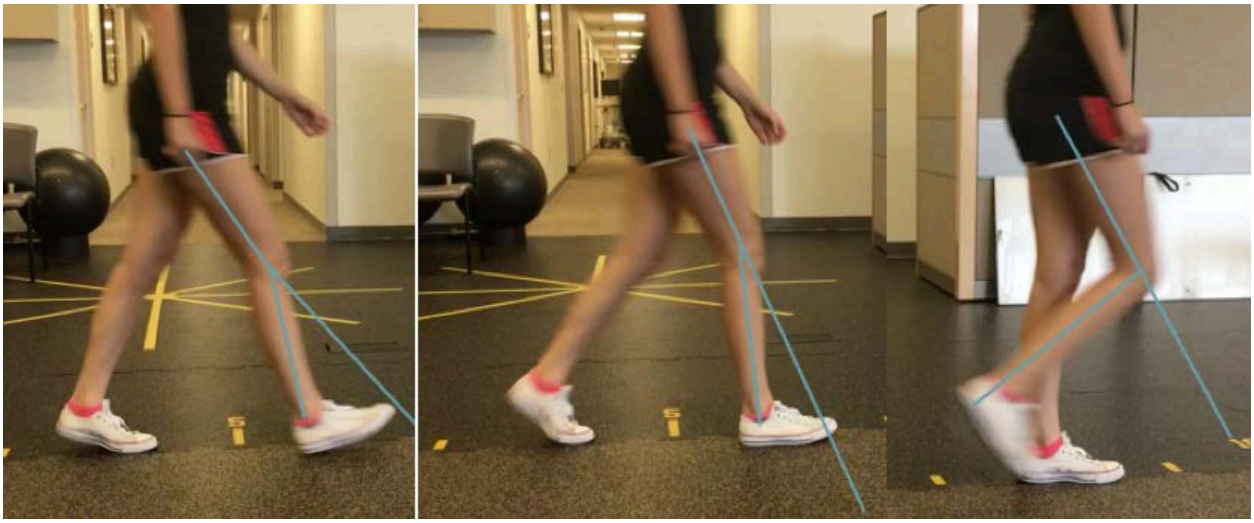

Figure 1. Screen shots were captured from videos of patient during ambulation 46 days after surgery, before the patient began wearing the knee brace at night. Makers were placed on the knee joint axis, lateral malleoli, and greater trochanter with lines drawn to take goniometer measures of knee range of motion at various points of gait (from left to right: initial contact 27 degrees knee flexion, mid-stance 22 degrees of flexion, initial swing 75 degrees of flexion).

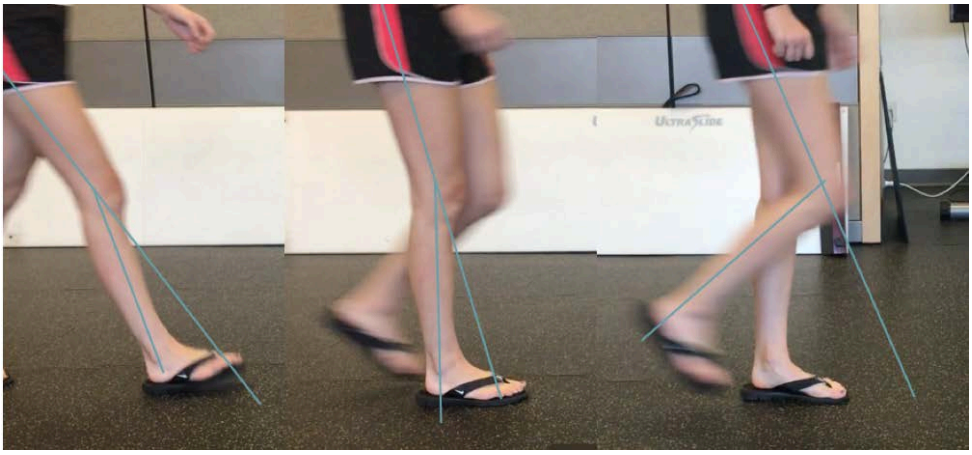

Figure 2. The patient was once again recorded walking 64 days post-op. The same technique was utilized to measure knee range during gait (from left to right: initial contact 18 degrees knee flexion, mid-stance 15 degrees of flexion, initial swing 70 degrees of flexion)

The patient also began with simple strengthening exercises, including quad sets and straight leg raise in all four directions. She progressed to ball squats, unilateral leg press, heel raises, hamstring curl, and step-downs to increase her lower extremity strength. Aquatic therapy was also incorporated into treatment because research has shown that rehabilitation in water may decrease joint effusion and lead to greater self-reports of functional improvement in subjects with intra-articular ACL reconstructions (Tovin et al. 1994). It allowed her to work on increased loading and impact training at less than body weight due to the water's buoyancy. Aquatic therapy consisted of running, squats, lunges, double leg jumps, single leg jumps, and side-sets. Some manual therapy was included in treatment to work on gaining knee range of motion including patellar mobilizations, fat pad mobilization, and soft tissue massage to the hamstrings and IT band.

Since the patient had difficulty gaining full knee extension, the physical therapist and her surgeon opted to use a dynamic knee extensor brace to be worn at night. Due to difficulties with getting insurance to cover the price of the brace, she did not begin to wear it until 45 days after surgery. This splint allowed the patient to change the positioning of her knee over the course of a few weeks. After approximately two weeks, her knee passive range of motion improved to consistently lacking two degrees of knee extension. However, it should be noted that the patient felt like she lost active knee flexion range of motion using this brace.

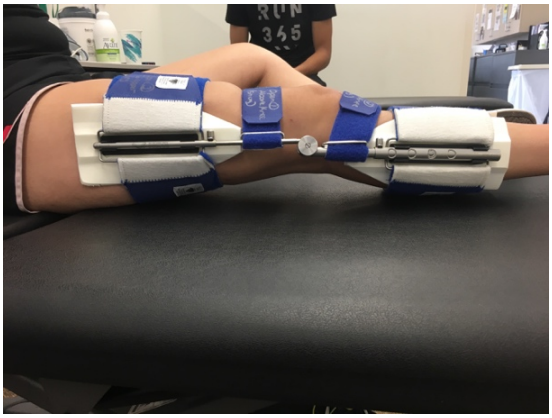

Figure 3. The patient used this dynamic knee brace at night to help her gain knee extension range of motion

While proprioception and gait training were addressed in this patient's plan of care, there may not have been emphasis in these areas considering the patient's already decreased sensation. As discussed in the introduction, patients lose sense of joint position after injury to their ACL and after reconstruction. This patient showed decrease awareness of her joint position before her injury and the decreased proprioception after ACL injury was possibly magnified due to her stroke. The only proprioception exercises included in her plan of care were weight shifts, lateral tilt board for weight shifting and use of video feedback for hip positioning and proper form with step downs from a 12" box.

Gait training was focused on initially and consisted of stepping over hurdles for knee flexion and extension using a single tip cane, standing marches, long stepping, side stepping as well as pool-based running for reasons discussed above. Gait disturbances have been shown to be an indicator of poor performance with return to sport testing. Researchers have found that individuals who fail on return to sport testing at 6 months post-operative (using quadriceps strength index, four single-legged hop tests, and scores from the Knee Outcome Survey–Activities of Daily Living Scale 22 and the Global Rating Scale for Perceived Function) also showed abnormal gait patterns (White et al. 2013). Subjects in the study were instructed to walk at a self-selected speed over an embedded force plate and those who failed the testing showed smaller peak knee flexion angle at peak knee flexion on the involved limb, lower extensor moments on the involved knee, altered contralateral hip strategy while limiting motion and attenuating forces on the involved knee and increased flexion of the uninvolved knee during weight acceptance. This is relevant to our patient, since she wanted to return to running and soccer. Her gait deviations (such as increased flexion at initial contact) may be an indicator that she would have more difficulty passing return to sport testing.

This patient would likely have benefited from more proprioception training before and after surgery in an effort restore normal gait and improve her outcomes. Lynn Snyder-Mackler and her research team looked at the effects of pre-operative perturbation training on ACL patients who complain of knee instability ("non-copers"). In this study, patients were divided into a perturbation group (PERT) or a strengthening group (STR) (Snyder-Mackler et al. 2012). The PERT group received neuromuscular training and progressive quadriceps strength training before surgery while the STR group only did strengthening exercises before surgery. Both groups had ten therapy sessions over three weeks. The leg press and leg extension machines were utilized for strengthening; subjects performed three sets of six repetitions at 75% of their one repetition maximum weight in order to maximize quadriceps force

output (at high intensity, low repetition). Subjects also performed lateral and forward step downs starting at a 4-inch step and progressing in step height when they demonstrated proper technique.

The PERT group followed the University of Delaware guidelines for perturbation training using three techniques (Snyder-Mackler et al. 2012). First, translational perturbations were applied to patients by placing the involved limb on a roller board. Next, patients stood on top of a tilt board with their involved limb and anterior/posterior and medial/lateral perturbations were applied depending on the position of the tilt board. The third technique involved patients standing on a roller board with their involved limb and a stationary platform with their opposite limb. The patient is instructed to maintain a steady position on the roller board while the therapist applies perturbations.

Quadriceps strength was found to be improved in both groups. The PERT group had better ability to utilize their quads to move the involved limb through a more similar range of motion compared to the uninvolved limb. Non-copers in the PERT group had no differences in knee excursions between their limbs at 6 months during mid-stance of gait. The STR group showed smaller knee excursions during mid-stance. Perturbation training increased motion and decreased muscle co-contraction in involved limb during weight acceptance. The authors of this study suggested that reduction in co-contraction may be related to findings of increased motion during gait, leading to a normalized walking pattern. Relating this research back to the patient in this case study, it would seem like our patient may have benefited from increased work on proprioception in order to improve her gait following surgery especially considering that she already had decreased proprioception due to her stroke (as well as increased co-contraction due to upper motor neuron lesions seen when the patient had clonus in her lower extremities).

Additional studies support extended preoperative rehabilitation to improve outcomes after ACL reconstruction. Failla and his team found that those who had therapy consisting of progressive strengthening and neuromuscular training had greater functional outcomes and return to sport at two years postoperative (Failla et al. 2017). They echo the previous study and emphasize that perturbation based training should be used in order to improve International Knee Documentation Committee form (IKDC) score as well as the Knee Injury and Osteoarthritis Outcome (KOOS) score, both of which have been found to be valid and reliable in the ACL population (Failla et al. 2017).

Outcomes

Knee range of motion was measured many times throughout treatment. Knee extension was recorded in terms of degrees lacking from full extension. Photographs were also taken to depict the patient's standing knee posture.

Figure 4. (From left to right) The patient standing at 46 days after surgery and the patient standing at 64 days after surgery. The patient's right knee appears to be more flexed in her resting posture at the earlier date.

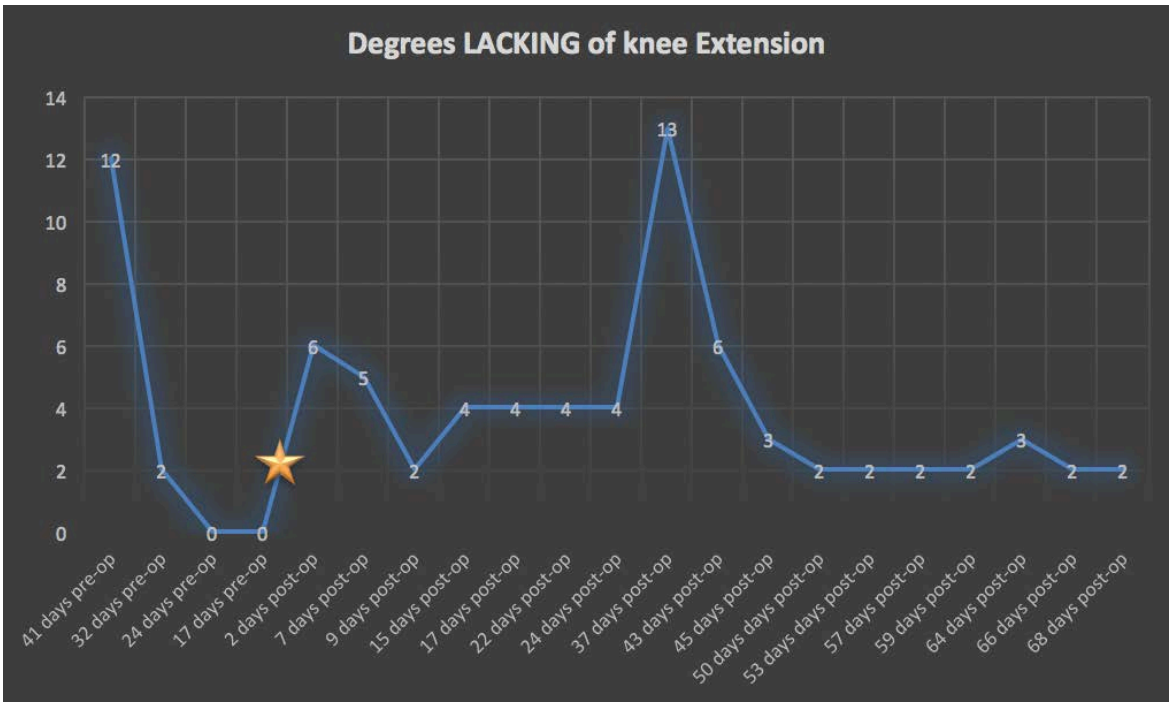

Figure 5. This graph represents the number of degrees that the patient was lacking from full extension (0 degrees extension). The star represents the date of the surgery.

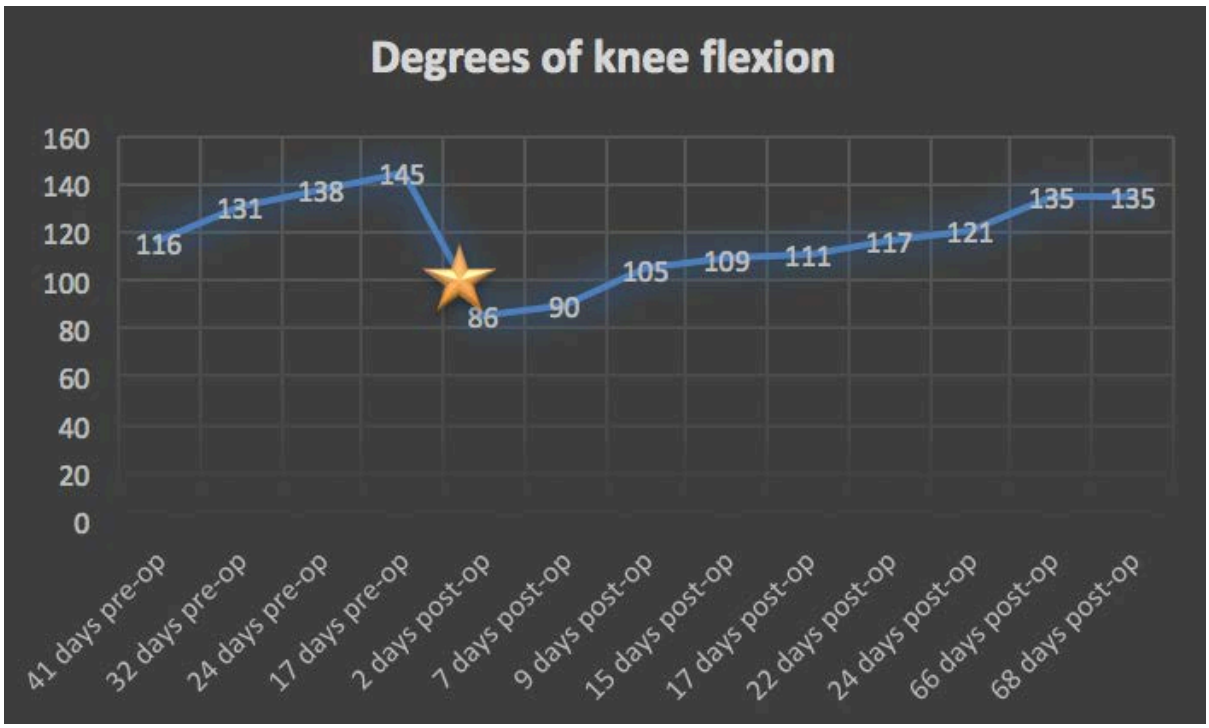

Figure 6. This graph represents that patient's knee flexion degrees. The star represents the date of the surgery.

The chart below (Table 1) outlines knee range of motion during gait, measured in the technique described previously. For reference, normal knee range motion at initial contact is 0-5 degrees flexion. At mid-stance, the knee should flex to 5 degrees. The knee flexes to 60 degrees at initial swing and the knee moves into 25 degrees of flexion at mid-swing (Sass, 2015).

Table 1. Degrees of knee flexion at three different points of gait at 46 and 64 days after surgery.

	46 days post-op	64 days post-op
Initial contact	27	18
Mid-stance	22	15
Initial Swing	75	70

Since the patient in this case was followed by this author for only three months post-operatively, return-to-sport testing was not indicated. It is anticipated that she will continue to make gains in her range, strength, and balance however there is a strong chance that due to her deficits she would not return to running as quickly as other patients might (the M.O.O.N protocol outlines pain free running as a goal in the 7-12 week timeframe). The patient would need to demonstrate normal walking patterns prior to starting to run, which may affect the patient's goal to return to running by November.

As indicated previously, clinical outcome reporting in pediatric ACL reconstructions are variable but there are some other outcomes that could have been used in this case. The Short Form-36 has been used in some patients to measure general quality of life divided into a physical component summary and a mental component summary. Research has shown that large improvements in the physical component score are seen at two years after surgery and are maintained at six years (Dunn et al. 2015). Return to sport testing will be an important outcome measure to look at (including single leg hop distances and quad:hamstring radio) however since the patient is still in the early phases of rehabilitation, these measurements would not have been appropriate to use at the time. These outcome measurements would be very important later in the therapy process to maximize the patient's goals to return to running and coaching soccer. Other outcomes typically reported include rate of re-rupture, however this would not be relevant in our case since the patient has not returned to sport or full activity participation.

Discussion

Injury to the ACL is known to cause decreased proprioception. This case study amplifies this deficit since the patient had decreased proprioception prior to ACL injury due to her stroke. She clearly showed decreased sense of joint positioning that has been reported in ACLR patients because she would state that she felt like her knee was straight when she was laying supine with her knee in two to five degrees of flexion. No research publications specifically discussing ACL rehabilitation in the stroke patient population were found, thus supporting the need for case reports to begin considering specialized evaluation and/or interventions for this unique patient population. Future studies are needed to examine how co-morbidities such as stroke could affect the typical rehabilitation process and outcome of ligamentous reconstruction. However, it is important to remember that the ACL injury should not be confined to only an orthopedic condition whether or not a patient has had a previous neurologic condition.

It is possible that the decreased proprioception may lead to gait disturbances. Gait has been found to be altered in sagittal, frontal and transverse planes after ACL reconstruction (ACLR) and may take months or years to normalize (and may never normalize). However, altered gait has been shown to improve through specialized gait retraining programs. Patients who receive perturbation training and

quad strengthening for 6 months had no difference in knee excursion between legs compared to control who only received quad strengthening and showed decreased knee excursion.

Clinical outcome reporting in youth who have undergone ACLR is widely variable (Brusalis et al 2017). A systematic review of 17 studies (772 subjects, mean age 14.3 years) found that range of motion was only reported 65% of the time, leg-length discrepancy and angular deformity were reported in 76% of studies, 82% of studies reported rate of re-rupture, and 71% of studies reported rate of revision surgery. Clearly there is no standardized, pediatric-specific outcome measure currently used however, there are several outcome measures for adults in return to sport criteria. Other studies have looked at outcome measures for adult in return to sport criteria. Some commonly used exams include the 90-degree cut to the right and to the left, drop landing test, single leg squat, three-star excursion balance test, and the tuck jump. Research suggests that using the single leg squat, drop-landing off 18 inches, and the star excursion balance test for outcome measures in this patient population (Iturbide et al. 2015). Those at the American Orthopaedic Society for Sports Medicine 2017 meeting state that achieving 96% symmetry on 6-meter timed hop test 6 months after ACLR was associated with 2x probability of successful outcome (Failla et al 2017). Logerstedt et al. (2012) showed the 6-meter timed hop was the strongest independent predictor and had the highest discriminatory accuracy for self-reported knee function one year following ACLR (90% specificity for identifying patients with self-reported knee function below normal ranges). This research shows that even in the adult population, there is varying opinions on what outcome measures are best to use in ACLR patients in regard to return to sport, which is why many physical therapists choose to use many different measures to ensure that they are not missing any deficits.

One limitation to the techniques that was used in this case was the lack of three-dimensional markers due to cost and availability of technology. Many researches use markers on the joint to more accurately measure motion, however we did not have access to markers. Davis and his research team have concluded that using these marks show the instantaneous joint center locations, joint angles, and the orientation of segmentally-embedded coordinate systems. Another limitation was that the range of motion was not always recorded in her chart as active or passive range. Additionally, it was not always recorded whether the measurement was taken before or after treatment; in general, the patient tended to gain range after warming up through exercise. Since knee extension appeared to be the primary deficit, knee flexion was not measured as frequently however the patient still shows decreased range later in her treatment. She consistently lacked two degrees of extension but flexion range was less closely monitored in this case.

The research discussed in this case study suggest that focusing on perturbation training before surgery may help patients regain normal gait patterns and normal gait patterns have been shown to be an indicator of better return to sport outcomes. Since the patient only received basic strengthening exercises prior to surgery and there was minimal perturbation training in the first two months after surgery, we do not know if her gait deviations are due to her previous stroke or the lack of proprioception training. More evidence is warranted to look at specific proprioceptive or perturbation training in the post-operative phase and how this may affect a person’s return to normal gait and return to sport.

References

1. American Stroke Association. Pediatric Stroke. Website accessed 11/1/2017. https://www.strokeassociation.org/STROKEORG/AboutStroke/StrokeInChildren/Stroke-In-Children_UCM_308543_SubHomePage.jsp

2. Bonfim TR, Jansen Paccola CA, Barela JA. Proprioceptive and behavior impairments in individuals with anterior cruciate ligament reconstructed knees. *Archives of Physical Medicine and Rehabilitation*. 2003;84:1217–23

3. Brusalis CM, Lakomkin N, Suryavanshi JR, et al. Clinical Outcome Reporting in Youth ACL Literature Is Widely Variable. *Orthopaedic Journal of Sports Medicine.* 2017;5(8):2325967117724431.

4. Dhillon MS, Bali K, Prabhakar S. Proprioception in anterior cruciate ligament deficient knees and its relevance in anterior cruciate ligament reconstruction. *Indian Journal of Orthopaedics*. 2011;45(4):294-300

5. Dunn WR, Wolf BR, Harrell FE, et al. Baseline Predictors of Health-Related Quality of Life After Anterior Cruciate Ligament Reconstruction: A Longitudinal Analysis of a Multicenter Cohort at Two and Six Years. *The Journal of Bone and Joint Surgery American*. 2015;97(7):551-557.

6. Failla et al. Hop Test Symmetry Scores Early after Rehab predict Successful 2 year outcomes of ACLR. AOSSM 2017 Annual Meeting.

7. Gogia PP, Braatz JH, Rose SJ, Norton BJ. Reliability and validity of goniometric measurements at the knee. *Phys Ther*. 1987 Feb;67(2):192-5.

8. Greenham M, Gordon A, Anderson V, Mackay MT. Outcome in Childhood Stroke. *Stroke*. 2016;47:1159-1164

9. Grooms DR, Page SJ, Nichols-Larsen DS, Chaudhari AMW, White SE, Onate JA. Neuroplasticity Associated With Anterior Cruciate Ligament Reconstruction. *Journal of Orthopaedic & Sports Physical Therapy*. 2017 47:3, 180-189

10. Iturbide PA, Guelich DR. 2015. Objective Tests after Anterior Cruciate Ligament Reconstruction Surgery: a review summary. *Ann Sports Med Res* 2(8): 1046

11. Kids Health. Anterior Cruciate Ligament (ACL) Injuries. Website accessed 11/1/2017. http://kidshealth.org/en/parents/acl-injuries.html

12. Lenssen AF, van Dam EM, Crijns YH, et al. Reproducibility of goniometric measurement of the knee in the in-hospital phase following total knee arthroplasty. *BMC Musculoskeletal Disorders*. 2007;8:83

13. Logerstedt D, Grindem H, Lynch A, et al. Single-legged Hop Tests as Predictors of Self-reported Knee Function After Anterior Cruciate Ligament Reconstruction: The Delaware-Oslo ACL Cohort Study. *The American Journal of Sports Medicine*. 2012;40(10):2348-2356.

14. National Stroke Association. Pediatric Stroke. Website accessed 11/1/2017. http://www.stroke.org/understand-stroke/impact-stroke/pediatric-stroke

15. Noll S, Garrison JC, Bothwell J, Conway JE. Knee Extension Range of Motion at 4 Weeks Is Related to Knee Extension Loss at 12 Weeks After Anterior Cruciate Ligament Reconstruction. *Orthopaedic Journal of Sports Medicine*. 2015;3(5):2325967115583632.

16. Sass, K. Functional Tasks of Gait – ROM. Lecture presented at Principles of Physical Therapy II, University of Iowa; November 17, 2015; Iowa City, IA.

17. Shelbourne, KD, Gray, T. Results of anterior cruciate ligament reconstruction based on the meniscal and articular cartilage status at the time of surgery: five- to fifteen-year evaluations. *Am J Sports Med*. 2000;28:446-452.

18. Shelbourne, KD, Gray, T. Minimum 10-Year Results After Anterior Cruciate Ligament Reconstruction. In *The American Journal of Sports Medicine*. March 2009;37(3):471-480.

19. Singhal AB, Biller J, Elkind MS, et al. Recognition and management of stroke in young adults and adolescents. *Neurology*. 2013;81(12):1089-1097.

20. Synder-Mackler L, Adam D, Logerstedt D, Hunter A, Axe MJ,. Current Concepts for Anterior Cruciate Ligament Reconstruction: A Criterion–Based Rehabilitation Progression. *The Journal of Orthopaedic and Sports Physical Therapy*. 2012;42(7):601-614.

21. Tovin BJ, Wolf SL, Greenfield BH, Crouse J, Woodfin BA. Comparison of the effects of exercise in water and on land on the rehabilitation of patients with intra-articular anterior cruciate ligament reconstructions. *Phys Ther* 1994 Dec;74(12):1165.

22. Tsze DS, Valente JH. Pediatric Stroke: A Review. *Emergency Medicine International*. 2011;2011:734506

23. White K, Logerstedt D, Snyder-Mackler L. Gait Asymmetries Persist 1 Year After Anterior Cruciate Ligament Reconstruction. *Orthopaedic Journal of Sports Medicine.* 2013;1(2):2325967113496967. doi:10.1177/2325967113496967.

24. Williams D, Heidloff D, Haglage E, Schumacher K, Cole B, Campbell KA. Anterior Cruciate Ligament Functional Sports Assessment. *Operative Techniques in Sports Medicine*. 2015;24(1):59-64.

25. Wright RW, Haas AK, Anderson J, et al. Anterior Cruciate Ligament Reconstruction Rehabilitation: MOON Guidelines. *Sports Health*. 2015;7(3):239-243.