Patellar tendon shortening surgery restores the knee extensor mechanism in flexed knee gait in children with cerebral palsy

Abstract

Background

This study evaluated a patellar tendon shortening (PTS) surgical procedure that uses an overlapping repair combined with an additional Tycron non-absorbable suture to support the shortening in children with Cerebral Palsy (CP). This study aimed to outline this surgical technique and to evaluate its effectiveness in restoring the knee extensor mechanism.

Methods

The sagittal plane lower limb kinematics, peak knee extensor moment, gait deviation index (GDI), localised movement deviation profiles (MDP), temporospatial parameters, passive knee extension ROM, quadriceps lag, and knee extensor strength were calculated pre- and postoperatively. To determine significant differences a robust linear regression model with high breakdown point and high efficiency was fitted to the data.

Results

In this retrospective cohort study, a total of 41 patients with CP who were treated with unilateral or bilateral PTS in isolation or as part of single event multilevel surgery (SEMLS), with a mean age of 11.1 years were included. The knee extension angle improved at initial contact ($p<0.0001$), and during stance phase ($p<0.0001$). The peak internal knee extensor moment decreased during early ($p=0.0014$) and late stance phase ($p<0.0001$). The quadriceps lag decreased ($p<0.0001$) and knee extensor strength increased ($p<0.0001$). The GDI improved ($p<0.0001$), as well as the localised MDP for sagittal angles ($p<0.0001$) and moments ($p=0.0001$). Walking speed ($p=1.0$) remained unchanged, but the cadence decreased ($p=0.024$) and step length increased ($p=0.0001$).

Conclusions

The knee extension angle and moment during stance phase improved significantly. The children with CP in this study showed improvements in knee extensor strength and quadriceps lag. Thereby it can be concluded that the PTS procedure was able to restore the knee extensor mechanism effectively.

Key words: patella tendon shortening, gait analysis, cerebral palsy, flexed knee gait, crouch gait

1. Introduction

Cerebral palsy (CP) describes a group of disorders of the development of movement that are attributed to disturbances to the infant brain(1). One of the most common forms of pathological gait is flexed-knee gait, which is predominantly defined by excessive knee flexion throughout stance phase (2) requiring excessive effort of the quadriceps muscle (3, 4). This can lead to an elongation of the patella tendon and subsequently to patella alta resulting in a lever arm dysfunction and decreased efficiency of the knee extensor mechanism (5).

Orthopaedic surgery remains the dominant intervention to treat flexed-knee gait in children with CP(6). A recent systematic review reported that hamstrings lengthening surgeries were the only well-supported intervention for flexed-knee gait in the literature(6). However, there is a risk that hamstrings lengthening can weaken the hamstrings leading to increased anterior pelvic tilt(7) and back pain (6). This has caused a shift in surgical procedures towards surgeries that aim to improve the efficiency of the knee extensor mechanism instead of lengthening tight knee flexors (8-10).

Traditionally the correction of the knee extensor mechanism in these children involves lowering the patella by a distalisation osteotomy of the tibial tuberosity. This procedure has an overall complication rate ranging from 4.6% to 10.7% (11) and to avoid these complications alternative surgical procedures evolved that aimed to shorten the patella tendon and leaving the tibial tuberosity intact. Most of these surgeries shorten the patella tendon with an overlapping repair (12-14). To reinforce the position of the lowered patella some studies described an additional procedure using a steel wire which passed through tunnels drilled through the patella and the tibia (15). The disadvantage is that it requires further surgery to remove the metal work at a later stage.

The patella tendon shortening (PTS) procedure in this study used an additional Tycron suture, which meant that no further surgery was required at a later stage. The additional suture reduces the risk of knee extensor mechanism failure and allows a faster and more progressive rehabilitation process.

Thereby, this surgery is unique in its form and combines the benefits of a solely soft-tissue surgery with an additional suture to support the shortening procedure.

To our knowledge, clinical outcomes of this technique have not previously been reported. In addition, this study aimed to investigate not only sagittal gait kinematics, clinical and functional outcome measures but also the knee extensor moment to understand the functional impact on the knee extensor mechanism after PTS.

2. Materials and Methods:

A retrospective cohort study was conducted using a gait laboratory database of patients with CP who were treated with unilateral or bilateral PTS in isolation or as part of single event multilevel surgery (SEMLS) between 2011 and 2021 to correct flexed-knee gait. The inclusion criteria for PTS surgery was: 1) flexed knee gait with a mean knee flexion throughout stance phase of more than 20° and 2) knee extensor lag of more than 10°.

An isolated PTS was performed in patients with CP with no knee flexion deformity. Patients with a knee flexion deformity over 10 degrees received additionally a distal femoral extension osteotomy (DFEO). Skeletally immature patients with mild knee flexion deformities received additionally an anterior distal femoral hemiepiphysiodesis (ADFH).

In 22 of the 41 participants additional hamstrings lengthening was carried out. The indication for hamstrings lengthening were: 1) excessive knee flexion at late swing phase/ initial contact with 2) increased unilateral and bilateral popliteal angles (<55degrees).

Further SEMLS procedures in children with CP were:

Femoral derotation osteotomy surgery for patients with increased femoral anteversion and consequently clearance problems. Calf recession/ lengthening surgery for patients with established calf contractures leading to reduced stance stability, altered foot preposition at IC and/or clearance problems in swing phase. Lateral column lengthening surgery for patients with planovalgus deformity which became symptomatic and/or leading to lever arm dysfunction. Adductor release for patients with adductor contractures leading to clearance problems resulting from a scissoring gait. Rectus femoris transfer/ release for patients with stiff knee gait defined by reduced peak knee flexion/velocity in conjunction with rectus spasticity in swing phase (table 1).

The study was approved in form of a local clinical audit and written informed consent was obtained from the legal guardian of each participant.

2.1 Data collection and data analysis

All the data were collected during routine hospital appointments pre- and post-PTS surgery.

The inclusion criteria for this study were: 1) diagnosis of CP, 2) ability to cope with the demands of a 3D gait analysis. Patients with previous surgeries at the lower limbs and previous interventions like Botulinum Toxin injections within the last six months were not included in this study.

The following pre-and postoperative clinical data were collected: age, height, mass, Gross Motor Function Classification System (GMFCS) level. Passive knee extension ROM was measured in supine position. Quadriceps spasticity was assessed using the Duncan Ely's sign and the Tardieu scale, and quadriceps lag and knee extensor strength using the manual muscle test (MMT) (scale: 0-5).

Three-dimensional motion data and ground reaction forces were collected using a 12-camera-optical motion capture system and four embedded force plates (BTS Bioengineering, Milan, Italy). Participants walked barefoot until at least five kinematic trials were conducted. From the 3D gait data the following parameters were calculated for all patients both pre- and postoperatively: the gait deviation index (GDI), the mean movement deviation profile (MDP_{mean}), cadence, walking speed, step length, the maximum angle of pelvic tilt and hip flexion during the gait cycle, the mean knee flexion angle during initial contact (IC), the minimum knee flexion angle during stance and maximum knee flexion angle during swing phase. Internal maximum knee extensor moments were calculated during early and late stance phase if they were acquired both pre- and postoperatively.

Joint angles and moments were calculated using the modified Davis marker-set and the BTS SMART-Clinic software. The MDP_{mean} was calculated from the pelvis, hip, knee and ankle angles in the sagittal plane and the hip, knee and ankle moments in the sagittal plane (16).

2.2 Surgical technique description

The patient was placed supine on the operating table. A midline longitudinal incision was made from the top of the patella to 2-3cm below the tibial tubercle. The patellar tendon was split in the sagittal plane similar to the technique described by Sossai et al. (2015) (17). The ventral portion was detached from the lower pole of the patella and the dorsal portion remained intact. Using a 2mm drill bit, a proximal transverse hole was made at the midpole of the patella being careful not to penetrate the articular surface. A second distal transverse hole was made in the proximal tibia just distal to the tubercle. Two strands of size 5 Tycron were passed through the holes to make two loops. The Tycron sutures were then tied individually which distalises the patella. After each suture was tied, the knee was flexed to ensure 90 degrees of flexion was possible. The patella was distalised during surgery as much as it allowed while ensuring that the knee could still achieve 90 degrees flexion. The ventral portion of the tendon was then folded in on itself and sutured together in this shortened position similar to the technique described by Sossai et al. (2015) (17). The dorsal portion was then sutured to the anterior surface of the patella.

By keeping the dorsal portion intact, failure of the tendon sutures would not result in a complete rupture of the extensor mechanism. The addition of the Tycron suture allows early movement whilst protecting the suture repair of the patellar tendon.

2.3 Rehabilitative post-surgery protocol

Postoperative knee immobiliser/ gaiter was used during walking for 6-12 weeks until quadriceps control was regained. The children were allowed to weight-bear as tolerated starting on the first day after surgery. Knee flexion was facilitated on a continuous passive motion (CPM) device for the range of 0-90° for 3 weeks. The early physiotherapy rehabilitation target was an active knee flexion ROM of at least 90° and a straight leg raise by 6 weeks post op.

2.4 Statistical analysis

To reduce the impact of small sizes of sub-samples and potential outliers, a robust linear regression model with high breakdown point and high efficiency (18) was fitted to the data. Robust clustered covariance estimators were used to account for intra-subject correlations due to repeated observations (19). The contrast statistics were reported, and the Holm correction was applied to control the family-wise error rate of the test statistics. All analyses were implemented using the R language (v.4.2.2)(20) and the *rms, MASS,* and *emmeans* libraries. The p-value was amended with a Bonferroni correction to p=0.0025.

3. Results

In total 41 patients, 16 females and 25 males, with a mean age of 11.1 years were included. Four patients were GMFCS level 1, 21 patients were GMFCS level 2, and 16 patients were GMFCS level 3. The mean follow-up time was 17.7 months postoperatively (Table 1 and 2).

3.1. Complications

According to the Clavien-Dindo system in 20% of the children eight complications were recorded (Table 2). Three of these complications were grade 1 complications: two being superficial wound healing problems, one being the development of a plaster allergy. Grade 2 complications occurred in 5 patients: four patients developed neuralgic pain or spasms and were treated with Gabapentin. One patient experienced pain around the 8-plates and required additional pain medication for this.

3.2. Gait biomechanics

Knee flexion at IC decreased from 35.5° to 21.4° ($p<0.0001$). Minimal knee flexion during stance phase improved from 25.2° to an average of 11.1° ($p<0.0001$). Swing phase knee flexion decreased from 59.7° to 51.9° ($p<0.0001$). The maximum anterior pelvic tilt did not change ($p=0.15$) (Table 3, Figure 1).

The estimated marginal (EM) of the internal knee extensor moment was -0.36Nm/kg ($p<0.0014$) and in late stance phase -0.27Nm/kg ($p<0.0001$) (Table 3, Figure 2).

The GDI improved from 74.61 to 83.08 ($p<0.0001$). The MDP_{mean} of the sagittal kinematics improved with an EM of -4.28° ($p<0.0001$) and the MDP_{mean} of sagittal moments -0.1Nm/kg ($p=0.0001$) (Table 3).

There were no significant changes in walking speed ($p=1.0$). However, the cadence decreased from 125.1 to 107.6 steps/min ($p=0.024$) with an increase of step length by 0.064m ($p=0.0001$) (Table 3).

3.3. Clinical examination and function

Passive knee extension ROM improved from -3.5° to -0.3° ($p=0.002$) and the quadriceps lag improved from 17.7° to 5.5° ($p<0.0001$) (Table 3).

Knee extensor strength improved post-PTS surgery ($p<0.0001$) and 40.5% patients achieved knee extensor strength of at least 4- post-PTS surgery (Table 3).

Rectus femoris spasticity and function did not change after post-PTS surgery (spasticity: $p=0.026$, function: $p=0.0038$) (Table 3).

Discussion

Patellar tendon shortening procedures are believed to be safe and effective to treat flexed knee gait and correct patella alta. However, there remains a risk of patellar tendon rupture after the surgery, which is commonly addressed by immobilisation (15, 17, 21) or limited knee flexion (12, 13). The rehabilitation protocol after this surgery allowed an early active knee flexion and immediate weight-bearing, with the advantage of avoiding a post-surgery knee joint stiffening and reduced the risk of muscle atrophy (22). The knee extensor strength and quadriceps lag improved significantly after the PTS-surgery. Knee extensor strength and quadriceps lag improved significantly in this study after surgery. An improvement in knee extensor strength/ quadriceps lag after PTS procedures has previously been reported by some authors (13, 14), whereas other authors did not report any changes in knee extensor strength (12, 15, 21). In total 47.9% of the children with CP improved in knee extensor strength post-PTS surgery and were able to move against gravity with some resistance.

The sagittal gait kinematics showed excellent results: the minimal knee flexion improved by 16° in stance phase and fell within the normal range post-PTS surgery. The minimal knee flexion in stance phase post-PTS surgery was 11.1°, which is better compared to previous studies that reported results between 15° and 21°(17, 23-26). It should be noted that 46% of patients in this study had additional hamstrings releases and 52% of patients had additional calf lengthening surgery which might have also contributed to an improved knee extension in stance phase.

The internal knee extensor moment decreased significantly during early and late stance phase and fell within normal range post-PTS surgery. The knee extensor moment was only reported in the study by Hyer et al. (2021) who showed a similar reduction of 0.4 Nm/kg post-PTS surgery(13). However, the postoperative knee extensor moment in Hyer's et al. study was much higher compared to this study(13). These findings are interesting as their sagittal knee kinematics were similar to the results in this study, which indicates that although they achieved almost normal knee flexion angles during stance phase the knee extensor moment remained increased. Therefore, the knee extensor mechanism appeared to be more effectively restored in this study. Although it was not formally evaluated the additionally reinforcement of the lowered patella in this study might have resulted in better kinetic results. Another explanation could be the early progressive rehabilitation in this study, whereas in Hyer's study the extremity was placed in a knee immobilizer for 6 weeks.

A frequent complication after PTS surgery is an increased anterior pelvic tilt with compensatory lumbar lordosis that might lead to back pain (26). The maximal anterior pelvic tilt in this study did not significantly increase and changed with an EM by 3.0° which is similar to some previous studies (12, 23, 26), but is significantly lower than described in other studies (13, 17, 21, 24). A change of 5° falls within marker placement variability and thereby it is questionable whether this would be a true meaningful change (27). Spasticity of the rectus femoris and psoas muscle are believed to lead to an increased anterior pelvic tilt (26). This study showed a significant reduction of rectus femoris spasticity from 52.1% of patients before to only 33.3% post-PTS surgery which might have led to a less severe anterior pelvic tilt compared to previously published results. Also, equinus posture can result in an anterior position of the ground reaction force vector that requires advancing the centre of mass by tilting the pelvis and trunk anteriorly (26). In this study calf lengthening procedures were carried out in 55.4% of the children, which might have also resulted in less severe anterior pelvic tilt post-surgery.

A second frequent complication study after PTS surgery is a loss of knee flexion in swing phase. This study showed a loss of 9.6° knee flexion in swing phase which is comparable to previously published studies (13, 15, 26). However, most PTS studies reported a loss of knee flexion of more than 14° post-PTS surgery (17, 21, 23, 24). Interestingly, the knee flexion graph showed an improved rate of knee flexion during early swing phase. One explanation for this might be that in 17% of patients in this study a rectus femoris transfer/ release surgery was also carried out as part of the SEMLS surgery. Another explanation might be the slower walking speed of children with CP in this study compared to typically developed children (28). However, the reduced knee flexion did not appear to cause any clearance issues as no increased hip flexion to aid clearance was noted. In addition, dorsiflexion was improved after the SEMLS surgery which aided further clearance.

The GDI improved significantly by 8.86. However, each 10-point change corresponds to a clinically meaningful change, indicating that this might not be clinically meaningful (29). The study of Min et al. (2020) emphasised that specific procedures in SEMLS influence the GDI more than others, and therefore changes in the GDI always need to be set into the context of the specific surgical procedures (29). Most of the children with CP in this study underwent SEMLS procedures which might have influenced the GDI in other than the sagittal planes (Table 1). In contrast to the GDI, the MDP calculates the deviation of an individual's movement curve from the distribution of normality exclusively in the sagittal plane (16) and showed significant improvements in the sagittal angles and moments.

Although there were no significant changes in speed, the patients walked with reduced cadence and increased step length postoperatively, which can be regarded as a positive change towards a more efficient gait. Previous studies showed no changes in speed but also no changes in step or stride length or cadence (13, 17, 21).

These improvement in strength and gait parameters indicate that this surgery and a progressive rehabilitation were able to improve the efficiency of the knee extensor mechanism in children with CP.

However, this study has several limitations. Firstly, the retrospective nature of this review, a relatively small cohort and a short-term follow-up time. Another limitation is caused by the heterogeneous mixture of SEMLS procedures and additional surgeries in the sagittal plane, such as calf and hamstrings lengthening's might have influenced the results in this study.

In this study no x-rays were used to measure the patella height prior or post-surgery. Thereby, the precise amount of distalisation was not captured, neither whether the patella might result in a long-term baja position (4). It would be advisable to investigate this in a future study.

In conclusion this study showed that the described PTS surgery restored the knee extensor mechanism effectively. Our results demonstrate significantly improved knee extension with a decreased internal knee extensor moment during stance phase, and improved knee extensor strength.

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Figure legends:

Figure 1: Sagittal plane pelvic, hip, knee, and ankle mean angles pre- (dotted line) and post-surgery (solid line) in children with CP who underwent PTS surgery. The shaded area represents ±1SD of a typically developed group

Figure 2:Mean internal knee extensor moment pre-PTS surgery (dotted line) and post-PTS surgery (solid line) in children with CP. The shaded area represents ±1SD of a typically developed group.