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Original Article

Clinical study of modified patellar tendon shortening for the treatment of knee deformity in children with spastic cerebral palsy

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Abstract: Objective: This study aims to explore the effect of modified patellar tendon shortening in treating knee deformity among children diagnosed with spastic cerebral palsy. Methods: A total of 39 children (51 knees) with cerebral palsy received modified patellar tendon shortening between June 2021 and June 2023. Knee HSS score, Lysholm score, passive knee extension angle, quadriceps muscle strength, patellar height, Q-angle passive knee range of motion, and knee motor function were compared before and after the operation. Results: The average follow-up period for all 39 children (51 knees) with cerebral palsy was 17.36±4.43 months. One child suffered internal fixation loosening and another developed a superficial skin infection. There were no notable complications in the remaining patients at the end of follow-up. The mean HSS score after operation was 90.53±2.64. The average Lysholm score was 89.65±2.92. The patella returned to its normal anatomical position. Postoperative knee movement significantly improved. The difference before and after the operation was statistically significant ($P<0.05$). Conclusion: In summary, modified patellar tendon shortening can effectively correct high patellar and flexion malformation among children with cerebral palsy. This significantly improves knee joint motor function, with few operation-related complications. Moreover, it has little effect on the growth and development of children. This operation is simple and can be popularized in hospitals at all levels.

Keywords: Cerebral palsy, patella alta, gait kinematics

Introduction

Cerebral palsy (CP) is a collection of non-progressive brain injuries caused by various factors affecting an infant's brain; movement disorders are the major clinical manifestations. Cerebral palsy affects 1.4-3.2‰ individuals globally, with a prevalence of 2.46% among 1-6-year-olds in China [1]. Special pathological gaits often occur due to hamstring and iliopsoas spasms and quadriceps weakness. Knee flexion gait is one of the most common forms, primarily characterized by excessive knee flexion during the whole standing stage [2]. This process involves excessive traction of the quadriceps muscle, leading to elongation of the patellar tendon and subsequent upward displacement of the patella. As a result, the mechanical advantage of the patellar lever arm is diminished, compromising the efficiency of the knee extensor mechanism [3].

Orthopedic surgery is the primary intervention for treating flexion knee gait among children with cerebral palsy. A recent systematic review reported that hamstring lengthening surgery is the only well-supported intervention for knee flexion gait [4]. Therefore, solely relying on distal hamstring extension to treat cursory gait in patients with spastic cerebral palsy may cause incomplete or over-correction in several patients, as well as early recurrence and increased pelvic tilt [5]. Additionally, the status quo of the high patella has not been improved, accelerated degeneration of the patella joint caused by high patella, dislocation rate of the patella and the delayed activity of the knee extension remain unresolved. As such, surgery

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Table 1. General information on the children before surgery

Age at surgery (y)	12.1±2.6
Gender (male/female)	23/16
BMI (kg/m^2)	18.32±1.42
follow-up time (months)	17.36±4.43
Affected side (left/right)	24/27

aims to improve the efficiency of the knee extensor mechanism, rather than extending tight knee flexor muscle.

Knee extensor mechanism correction in these children conventionally includes lowering the patella by distal osteotomy of the tibial tubercle. Complications including injury of the epiphysis, necrosis of the tibial tubercle, or bone nonunion may occur during this operation, interfering with the growth and development of children [6]. Alternative surgical methods have been developed to shorten patellar tendons, keeping the tibial tubercle intact to prevent these complications. Most of these surgeries reduce the patellar tendon and conduct overlapping repairs [7-9]. These procedures caused limited displacement of patella descent and higher complications, including patellar tendon rupture and knee extensor device failure.

Herein, patellar tendon shortening (PTS) was performed using a titanium cable across the patella and tibial tubercle, similar to the tension band technique. This implies that internal fixation is more reliable, and reduces the risk of failure of the knee extensor mechanism, allowing a faster and more gradual rehabilitation process. This study investigated the improvement of high patella and knee function as well as gait changes among children.

Materials and methods

A retrospective analysis was performed on children diagnosed with cerebral palsy admitted to the Second Hospital of Shijiazhuang City between June 2021 and June 2023. These children underwent surgery to treat high patella of unilateral or bilateral knee joint or as part of multi-stage surgery. A total of 39 patients (51 knees) were enrolled, i.e., 16 female patients (41.0%) and 23 male patients (59.0%). Age of left 24 knees (47.1%) and right 27 knees (52.9%) ranged from 9 to 17 years, with a mean age of 12.1±2.6 years. The duration of follow-up was at least 12 months, with a mean follow-up of 17.36±4.43 months. **Table 1** shows a comprehensive information.

The inclusion criteria for surgery included: (1) diagnosis of spastic cerebral palsy [10]; (2) knee flexion deformity greater than 10° and less than 30°; (3) diagnosis of high patella using the Koshino-Sugimoto technique. On the other hand, exclusion criteria included: (1) history of other lower extremity orthopedic surgery or Botox injection within 6 months; (2) inability to complete follow-up or rehabilitation training; (3) patients with other severe diseases and cannot tolerate surgery.

This clinical study was conducted in full compliance with the Declaration of Helsinki and was approved by the Ethics Committee of the Second Hospital of Shijiazhuang (Ethics Approval No.: SEY-KYLL-202467; Approval Date: 2024-12-06). Written informed consent was obtained from all legal guardians of minor participants prior to study enrollment, with the consent process completed by June 2023.

The authors declare that there are no conflicts of interest regarding the research and writing of this article.

Data collection and analysis

The preoperative and postoperative clinical data obtained included age, height, weight, and patellar height. Passive knee extension (ROM) was measured in the supine position, and quadriceps lag and knee extensor strength was assessed using the manual muscle strength test (MMT). X-ray was used to measure patellar height and Q angle.

Gait motion data through four embedded force boards (BTS Bioengineering, in Italy). Participants walked barefoot until they had performed at least five kinematic tests. The spatio-temporal parameters (stride speed, stride frequency, stride length, and gait period) of all patients were computed from the three-dimensional gait data.

Surgical technical instructions

All procedures were conducted by the same surgical team, led by a single operating surgeon. The patient was positioned supine on the operating table. A midline longitudinal incision was made, extending from 3 cm proximal to the

Figure 1. Preoperative evaluation clearly showed patella alta in the affected limbs of the children.

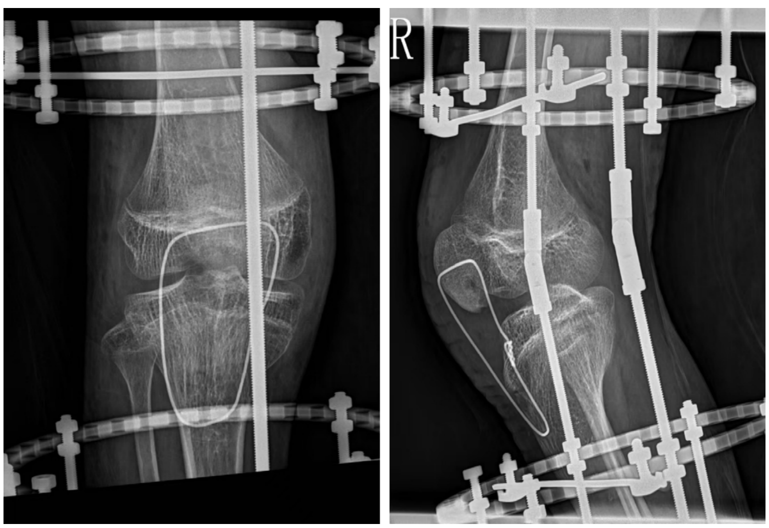

Figure 2. Postoperatively, the patella was restored to normal position in the children's affected limbs.

patella to 2-3 cm below the tibial tubercle. Distal V-shaped release of the quadriceps. The patellar tendon was cut in the middle of the patellar tendon. A transverse hole in the middle of the patella was made using a 2 mm drill bit, taking care not to penetrate the articular surface. The second distal transverse foramen was located near the tibia near the distal tubercle. Titanium cables were passed through the patella and tibial tubercles to secure the construct. During the procedure, the knee was maintained at 90° flexion while applying distal pressure on the patella to facilitate its downward repositioning. The distal quadriceps muscle was then sutured in a Y pattern. Patellar tendons were folded, shortened, and sutured together.

Tendon release or tendon transfer was performed if the child was accompanied by a varus foot or other malformation.

Postoperative rehabilitation program

After surgery, the affected limb was fixed with an adjustable knee brace, and fixed flexion at 30° for 3 weeks. Subsequently, the knee brace was adjusted and the angle increased by 15° per week; the brace was removed after 6 weeks. Isometric muscle training was performed during brace fixation. Active and passive joint function exercise was carried out a day after brace removal. Brace fixation was continued at night for 3 months after surgery to reduce the risk of recurrence of postoperative flexion deformity. The tension band was removed 6 months following the surgery (**Figures 1**, **2**).

Statistical analysis

SPSS22.0 statistical software was used for statistical analyses. The measurement data conforming to normal distribution were expressed as mean ± standard deviation. Count data were compared using the sum test. Measurement data were compared by t-test. Counting data were expressed as frequency (percentage), and the Wilcoxon signed-rank test was used for statistical analysis. P<0.05 was considered statistically significant.

Results

Complications

One child experienced internal fixation loosening, whereas another developed a superficial

Table 2. Comparison of knee HSS score, Lysholm score, passive knee extension angle, patellar height, and Q angle before and after surgery

	HSS score		Lysholm score		Passive knee extension angle (°)		Patellar height Koshino-Sugimoto method		Q angle (°)	
	Pre OP	Post OP	Pre OP	Post OP	Pre OP	Post OP	Pre OP	Post OP	Pre OP	Post OP
	63.43±3.88	90.53±2.64	61.73±4.28	89.65±2.92	13.45±4.53	3.47±2.14	1.44±0.63	1.21±0.32	18.86±3.45	15.26±2.89
t-Value	-46.17		-47.06		-21.21		23.48		13.89	
p-Value	0.021		0.017		0.013		0.02		0.034	

Table 3. Lower limb muscle strength (MTT 0-5)

	3	4	Z	p
Pre	51	0	-3.16	0.02
Post	10	41		

MMT = manual muscle test.

skin infection. At the end of the follow-up, no significant complications occurred in the remaining patients.

Before and after surgery in patients with knee joint American hospital for special surgery (HospitalforSpecialSurgery, HSS) score, Lysholm knee pain score, the passive knee Angle, patellar height, and Q Angle of comparison

Unlike the last postoperative follow-up, the average HSS score of patients before surgery increased from 63.43±3.88 to 90.53±2.64, with a statistically significant difference (P<0.05). The Lysholm score increased from 61.73±4.28 preoperative to 89.65±2.92 postoperative, with a statistically significant difference (P<0.05). Passive knee motion of the patient improved from -3.45±4.53° preoperative to -3.47±2.14° postoperative, with a statistically significant difference (P<0.05). On imaging, the patellar height improved from preoperative (1.44±0.63) to postoperative (1.21±0.32), with a statistically significant difference (P<0.05). The Q angle improved from 18.86±3.45° before surgery to 15.26±2.89 during the last follow-up, with a statistically significant difference (P<0.05) (**Table 2**).

Comparison of lower limb muscle strength before and after surgery

The muscle strength of the quadriceps femoris in 51 knees before surgery was grade 3 (100%). The muscle strength of the quadriceps femoris in 41 knees increased to grade 4 (80.39%) and grade 3 (19.61%) following surgery, with statistical significance (P<0.05). **Table 3** lists specific data.

Gait analysis of children before and after an operation

The walking speed of the patients increased from preoperative (0.44±0.13) (m/s) to postoperative (0.67±0.18) (m/s), with a statistically significant difference (P<0.05). The stride length of the patients improved from preoperative (0.42±0.17) m to postoperative (0.64±0.21) m, with a statistically significant difference (P<0.05). The gait period of children was shortened from (1.16±0.31) s before the operation to (1.03±0.27) s after the operation, with a statistically significant difference (P<0.05). We found no significant difference in the step frequency index (P>0.05). **Table 4** presents specific data.

Discussion

A high patella is the most prevalent knee deformity among children with cerebral palsy. High patella targets knee extensor muscle strength, knee range of motion, and knee extensor muscle hysteresis among children. It also causes patellar dislocation and accelerated degeneration of the patellofemoral joint. Through surgical treatment to correct excessive patella, surgery optimizes muscle performance, restores the normal shape of the knee joint and patella position in the trochlea, and improves the leverage of quadriceps muscle in an upright posture. The quadriceps can effectively extend the knee joint [11]. Proper knee extension is a prerequisite for effective gait. Many surgical options exist for different indications. Surgical outcomes are difficult to compare with each other, particularly in multilevel interventions. Treatment options include Botox injections, hamstring lengthening or transfer procedures,

Table 4. Temporal and spatial parameters of patients' gait before and after surgery

	Pace (m/s)		Step frequency (steps/min)		Stride length (m)	
	Pro	Post	Pro	Post	Pro	Post
	0.44±0.13	0.67±0.18	61.23±16.31	60.31±18.43	0.42±0.17	0.64±0.21
t-Value	-37.13		5.09		-56.2	
p-Value	0.018		0.37		0.014	

growth plate modulation, and patellar tendon shortening surgery. Knee extension depends on the length of functional hamstring muscles, the strength of knee extensor muscles, and the capacity for passive knee extension, as well as ankle-knee activity combination. Therefore, any functional analysis should include these factors, and treatment should be tailored to each component. Knee flexion, with or without plantar flexor dysfunction, is a prevalent factor limiting gait efficiency in patients with spastic diplegia. Single-event multilevel surgery (SEMLS) is considered the standard treatment for improving gait and function in patients with spastic diplegia. However, its efficacy varies. While distal hamstring lengthening can enhance knee extension, it fails to correct patella alta, resulting in limited improvements in knee morphology, function, and overall gait. Surgery in the past focused on hamstring lengthening and has been linked to several complications, such as pelvic forward tilt immediately following surgery. This can worsen to varying degrees in subsequent years and the risk of sciatic nerve damage and hip sublxation [5, 12].

Our modified patellar tendon shortening was used to treat pathologically high patella and knee flexion deformity instead of lengthening the hamstrings in the back of the thigh. Knee function improved by targeting the patellar position. Our experimental findings revealed that the knee function score (HSS score) and knee pain score (Lysholm score) of the children were significantly improved, with statistical significance. This is because knee joint function is closer to normal in children by directly improving the patella position. The passive knee extension angle of the child before and after surgery improved from the preoperative average of -13.45±4.53 to the average of -3.47± 2.14; this confirmed significant improvements in knee flexion deformity among children. Patellar cartilage pressure would be significantly reduced when the knee joint is extended. Moreover, compensatory hyperextension of the hip joint and compensatory rotation of the pelvis can be properly corrected when the knee flexion deformity is improved [13]. A few patients in this study underwent additional tendon release, which may also help improve knee extension. Patellar height greatly varies from individual to individual. The Koshino-Sugimoto method was used to measure patellar height. This method has good reliability, repeatability, and similarity between and within observers [14]. Q angle is a good outcome variable for evaluating lower limb musculoskeletal problems. The contributing factors of the Q angle primarily include lower limb force line and patellar height. Q angle is a predictor of lateral patellar dislocation and a high-risk factor for patellar dislocation or subluxation. Q angle reduction through patellar displacement can effectively reduce the incidence of patellar dislocation.

Knee extensor strength and quadriceps lag significantly improve after operation. Knee extensor strength and quadriceps lag significantly improve following surgery. Studies have previously reported improvements in knee extensor strength and quadriceps lag after PTS surgery [15]. Mohammad used femoral osteotomy and/or patellar propulsion to treat knee flexion deformities among children; the results revealed that femoral osteotomy could correct knee flexion deformities. However, patellar propulsion is a factor that could improve quadriceps walking lag [16]. Overall, 83.3% of children with CP had improved knee extensor strength after pts surgery and could resist gravity movement to some extent.

In a separate study, Patrick reported long-term follow-up outcomes following hamstring muscle transfer for knee range of motion improvement. While initial gains in passive knee mobility were observed, these improvements gradually declined over time [17]. For children with severe flexion deformity with knee flexion angle greater than 30°, soft tissue surgery alone hardly achieves the expected effect. The one-stage correction of flexion deformity will damage nerves and blood vessels to a large extent, as well as skin necrosis. Xu introduced an Ilizarov technique combined with hamstring muscle extension to correct severe flexion deformity of cerebral palsy with satisfactory outcomes [18].

This study found that the step speed and length of children with cerebral palsy increased following surgery. Furthermore, we found no significant change in step frequency, indicating that children can walk more efficiently. These improvements in strength and gait parameters indicate that surgical intervention combined with progressive rehabilitation enhances knee extensor efficiency and walking performance in children with cerebral palsy. However, Sossai et al. observed no change in walking speed during short-term follow-up [13]. Based on Rutz et al., an increase in walking speed can sometimes be observed in the medium term [19].

At the time of their surgery, most study participants were in their pre-adolescence or middle adolescence. Therefore, the flexion knee gait is likely to worsen if surgery is not performed. Unlike the conventional patellar tendon shortening that requires osteotomy of the tibial tubercle, the modified patellar tendon shortening is safer and has little effect on the metaphyseal. Unlike normal children, research has shown that children with cerebral palsy take longer and more energy to walk the same distance, increasing knee flexion angle [20]. As such, we believe that it is important to promptly correct the deformed knee patellar position via surgical intervention. This is to improve muscle strength and range of motion of the knee joint, as well as reduce the abnormal gait and the high energy consumption linked to abnormal gait. Moreover, patellar tendon shortening improves the motor function of the sagittal knee over a follow-up period of at least 9 years without further deterioration [15].

Henrik Greaves used Tycron non-absorbable sutures to assist patellar shortening, preventing a second surgery for internal fixation removal. Improvement in joint function is in line with our findings. However, he did not use X-rays before and after surgery to compare changes in patellar height [21].

Nonetheless, this study has limitations. First, we recruited relatively few subjects and the follow-up time was short. There is therefore no guarantee that the patellar position will change in the long term. However, mixing additional procedures, including a release of the adductor muscle or the lengthening of the Achilles tendon may influence the results.

In conclusion, this study indicates that the described patellar downshifting patellar tendon shortening surgery effectively improves the efficiency of knee extensor muscle, and knee extensor strength. It also reduces the probability of patellar dislocation, and prevents osteotomy of tibial tuberosity through soft tissue surgery, greatly reducing the risk of physeal injury among children. This has little effect on the growth and development of children with cerebral palsy. Therefore, patellar downshifting patellar tendon shortening surgery is a reliable surgical technique.

Disclosure of conflict of interest

None.

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