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Review article

Orthopedic treatment of the lower limbs in spastic paralysis

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ABSTRACT

Spastic paralysis of the limb mainly results from the central lesion, in which spastic cerebral palsy is the common cause. Due to durative muscle spasm in spastic cerebral palsy, it is often accompanied by the formation of secondary musculoskeletal deformities, resulting in limb motor disability. Based on its pathogenesis, surgical treatment is currently applied: selective posterior rhizotomy (SPR) or orthopedic surgery. The primary purpose of early orthopedic surgery was simply to correct limb deformities, which usually led to the recurrence of deformity as a result of the presence of spasticity. With the application of SPR, high muscle tone was successfully relieved, but limb deformity was still present postoperatively. Therefore, this study aimed to elaborate on the management of orthopedic surgery, common deformities of the lower limb, and orthopedic operative methods; discuss the relationship between SPR and orthopedic procedure for limb deformity; and focus on the indications, timing of intervention, and postoperative outcome of different surgical methods.

1 Introduction

Spasticity is one component of upper motor neuron syndrome. It is a motor disability, which is the characteristic of velocity-dependent increase in the tonic stretch reflex to tendon jerks, resulting from the stretch reflex with hyperexcitability [1]. Pandyan et al. suggested that spasticity should be redefined as disordered sensorimotor control, which is caused by the upper motor neuron lesion and characterized by intermittent or continuous involuntary activation of muscles [2]. Spasticity not only limits mobility but also leads to various deformities (torsional deformities of the bone, muscle contractures of joints or muscles, and joint instability or deformity) [3]. The principal lesion sites associated with spasticity are the cerebral cortex, cerebral white matter, brainstem, and spinal cord. Spastic limb paralysis is often caused by cerebral palsy (CP), hereditary spastic paraplegia, brain trauma, multiple sclerosis, spinal cord injury, and stroke, among which CP is the most common cause [4–9].

CP is a group of permanent disorders of move-

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ment and posture resulting in activity limitations, attributed to nonprogressive disturbances within the brain occurring early in development [10]. It is a common motor disorder in childhood with a prevalence of 1.8–2.9 per 1000 live births [11, 12]. Spastic CP is one of the most common types of CP, accounting for 85%–89% [13, 14], which can be further classified as unilateral (hemiplegic) and bilateral (diplegic and quadriplegic) spastic CP [15]. Treatment methods for spasm include administration of oral drugs, intrathecal baclofen, and botulinum toxin type A; physical therapy; orthoses; selective posterior rhizotomy (SPR), and orthopedic surgery. Orthopedic surgery should be considered an important adjunct to other interventions [16]. Moreover, any operative intervention must be implemented in coordination with other spasticity management specialists and suitable postoperative therapy [17]. Presently, there is no unified consensus and standard on the indication, intervention time, surgical program, and multidisciplinary care of orthopedic surgery for spastic limb paralysis.

This review aimed to introduce the common deformities of the lower extremities in spastic CP and discuss the indication, operational strategy, and efficacy assessment of different orthopedic procedures. We hoped that a detailed introduction to orthopedic surgery can help us promote a more standardized surgical treatment of spastic paralyzed limbs, organically integrate spasticity management with orthopedic surgery, and promote multidisciplinary cooperation in the treatment of spastic paralysis.

2 Surgical management

Orthopedic surgery can roughly be divided into tendon lengthening, tendon transfer, osteotomy, and arthrodesis. The indications include fixed contracture, joint deformity, joint dislocation, and subluxation that affect function or cause pain [18–22]. Furthermore, the purpose of surgery is to improve motor function, prevent deformity, relieve pain, and modify the appearance of patients [23, 24]. Among these, orthopedic surgery can correct skeletal deformities and restore their functional position. Soft tissue release surgery aims to correct the asymmetrical load on muscle tendons [25]. Thus, the goals of orthopedic surgery should be built on the severity of the disease, functional impairment, and level of ambulation [Gross Motor Function Classification System (GMFCS) level] and goals of the person with CP, family, and multidisciplinary team. In patients with CP with GMFCS levels I–III, the goal of treatment is to optimize gait efficiency, improve gait appearance, and increase participation in sports and daily activities. While, for the cerebral palsy patients with CP with GMFCS levels IV and V, the goal is to relieve symptoms such as pain, facilitate care, and improve health and quality of life [26, 27]. However, the ultimate result is to improve overall motor function, functional independence of the patient, and health-related quality of life [17].

The intervention of orthopedic surgery should be implemented at an appropriate time. Children under 5 years old can obtain a better clinical outcome through standardized rehabilitation training and even be exempted from orthopedic surgery [28–30]. Orthopedic procedures should be best considered after gait has matured, generally between the ages of 6 and 10 years [17, 31]. Meanwhile, to prevent effects on growth and development of the limbs, it is recommended to perform orthopedic surgery at the age of > 12 years [32–34]. Single-event multilevel surgery (SEMLS) is considered the gold standard treatment for ambulatory CP patients with GMFCS levels I–III [35, 36]. It has been defined as a combination of two or more soft-tissue or bony operative procedures at two or more anatomical levels and addresses the correction of all fixed musculoskeletal pathology in one surgical procedure to improve both gait and gross motor function [37, 38]. The superiorities in SEMLS involve decreased need for repeated anesthetics and single stay in inpatient rehabilitation, as well as the prevention of secondary deformities from delay in sequential "birthday syndrome" [39]. Some studies suggested that the older the child was at the time of the surgery, the better the long-term result [40]. Nevertheless, there are points of controversy common to these studies in analyzing outcomes of SEMLS, which are patient selection, optimal time of intervention, standardized indications, and long-term follow-up and durability of gait function at skeletal maturity [39, 41].

When performing a comprehensive preoperative assessment, the reasonable goals and needs should be set according to appropriate expectations of the patient and family, and also the preoperative motor function level [42]. The GMFCS has commonly intended to assess the functional level and motor development of patients. In 1997, it was initially found to provide a standardized method to classify CP in patients aged between 1 and 12 years based on functional abilities and limitations in gross motor function [43]. Furthermore, the main objective of the GMFCS is to promote communication between families and professionals while presenting a child's gross motor function, setting goals, and assisting in making management decisions. Currently, the GMFCS has become an internationally recognized classification standard that could provide a determination of the gross motor function and severity of disability [44]. However, the GMFCS can only evaluate and predict functions of mobility, and remains relatively stable over time, regardless of whether it applies interventions [45]. The researchers found that patients with CP who underwent SEMLS had improved mobility, to some extent, by applying the Functional Mobility Scale, but many patients had stable GMFCS levels throughout the postoperative period [46]. Consequently, different evaluation scales have their limitations. The clinically feasible tool for quantifying change after orthopedic surgery in CP should be selected based on the characteristics of distinct evaluation scales [47, 48].

One of the purposes of orthopedic surgery is to correct the patient's abnormal movement pattern and improve gait. Due to the complexity of the human walking trajectory, it is difficult for surgeons to observe the instantaneous change in gait movement and accurately evaluate gait by clinical examination, static imaging data, and scales [49, 50]. However, three-dimensional gait analysis (3DGA) can accurately identify the key points that lead to dyskinesia, quantify the extent to which gait abnormalities deviate from the normal range, and assist physicians to better understand pathophysiologic and biomechanical processes associated with an abnormal gait. 3DGA has become the gold standard for the assessment of pathological gait, guiding clinicians in formulating treatment plans and clarifying outcome assessment [51, 52]. A randomized controlled trial of ambulatory patients with spastic CP associated with excessive hip internal rotation found that gait analysis could provide marked improvements in the outcome when its suggestions are incorporated in femoral derotation osteotomy [53]. The orthopedic procedure, founded on preoperative gait analysis, had a remarkable benefit in gait quality and increased parents' satisfaction, which remained stable over a 5-year period [54]. Additionally, gait analysis aided in differentiating ambulatory patients with spastic CP who would benefit from the operation and who did not need surgery because of the better natural history of the disease [55]. Putz et al. reported that the Gillette Gait Index and Gait Profile Score of adults with bilateral spastic CP after SEMLS were significantly decreased [56]. The study also revealed that SEMLS is an effective and safe procedure to improve gait disorders of adults with CP [56]. Saglam et al. reported that Edinburgh Visual Gait Analysis was applied to evaluate the postoperative outcome after femoral derotational osteotomy with multilevel soft-tissue procedures [57]. The results showed that the Foot Progression Angle (FPA) and hip rotation angle in gait parameters were considerably improved. Simultaneously, stance time was improved, and swing time was reduced. The most significant effects were on transverse plane hip rotation and FPA [57].

3 Surgical treatment

3.1 Selective posterior rhizotomy

Posterior rhizotomy has been applied for > 100 years. In the 1980s, Peacock and Staudt [58], based on Fasano's study, improved the procedure, which descended the plane of operation from the conus level to cauda equina, and reduced the risk of intraoperative injury to the spinal cord. After consulting Peacock, Park modified the procedure back to the original conus-level exposure and applied ultrasound localization and electromyography intraoperative monitoring to prevent severe complications [59]. Due to the definite curative result of the two procedures for relieving spasm and improving motor function, SPR has been accepted in the mainstream academic circles and gradually developed in North America. Thus, there is the formation of the two prevailing surgical methods: the "Peacock school" and the "Park school" [59].

In the early 1990s, Xu et al. [60] pioneered SPR in the Asian region for the treatment of spastic CP based on the study on anatomy, histochemistry, and electrophysiology of lumbosacral nerve roots in the Asian population. His team independently developed a new type of nerve threshold measuring instrument and the "limb-movement method" intraoperatively monitoring mode to distinguish pathological nerve rootlet. Simultaneously, he proposed the big loop theory of "periphery-cortex-periphery" and the large one associated with the γ-loop, which provided the basis for the mechanism of SPR [60, 61]. Since then, SPR has been gradually promoted and developed in China.

Although surgery is a well-recognized treatment for spastic CP, it still has been the focus of academic attention for the long-term postoperative outcomes, improvement of motor function, and whether it can reduce the frequency of other therapeutic interventions. Several studies reported significant short-term efficacy after SPR, and the overall outcomes of the postoperative Gross Motor Function Measure, Modified Ashworth Scale, Pediatric Evaluation of Disability Inventory, Activities of Daily Living, and International Classification of Functioning, Disability and Health were satisfactory [62–67]. The relevant meta-analysis also found that SPR could effectively relieve extremity tone and increase the range of motion under strict surgical selection criteria [68, 69]. Most scholars found that the long-term benefit of improvement of muscle tone after SPR has been persistent in CP with GMFCS levels I–III through adolescence and into early adulthood [65, 70–72]. However, the evaluation of long-term functional outcome postoperatively had conflicting results. Some scholars pointed out that SPR had a definite effect in improving the quality of life of patients and increasing the range of joint motion, even improving walking ability and abnormal gait [65, 71, 73–75]. Tedroff et al. found that surgery did not improve the long-term motor function of patients, and did not prevent contracture of limb muscles in a follow-up of > 10 years after SPR [76, 77]. Consequently, most studies suggest that the decline in functional movement ability during the long-term follow-up may be associated with the natural growth and development curve of CP [78, 79], weak muscle strength [80], sensory feedback [81, 82], percentage of intraoperative nerve root resection, and number of rootlets [72].

Presently, whether it could decrease the need for adjunct orthopedic procedures after SPR is always controversial. There is no outstanding evidence that the demand for orthopedic surgery after SPR is reduced. Most long-term follow-up literature reported that orthopedic surgeries after SPR were common and most of them were soft-tissue surgeries [70, 71, 74, 83–85]. Despite this, it is meaningless to blindly pursue the maximization of the benefits of a single operation or simply compare the costs of two operations due to the different indications. It is wrong to perform various orthopedic surgeries [86]. In principle, SPR and orthopedic surgery should be performed in stages. Orthopedic surgery should follow SPR [87]. Similarly, Baker and Graham [88] revealed that the selection and sequence of orthopedic surgery or SPR should be based on the surgical indications and natural growth and development curve of children with CP. In preschool, limb deformities of children are mainly caused by spasticity and primarily characterized by weak muscle strength and secondary skeletal dysplasia from school age to adolescent stage. Therefore, the choice of surgical methods should strictly adhere to indications of various types of surgery and screen cases critically. All surgeons must design overall surgical treatment and rehabilitation programs according to the principle of individualization, and conduct multidisciplinary cross-evaluation and management to achieve optimal postoperative results.

3.2 Orthopedic surgery

3.2.1 Hip surgery

Hip deformity is one of the common symptoms of secondary malformation in patients with CP [89, 90]. Due to persistent muscle spasm of the adductor, flexor, and internal rotation muscle group, it leads to imbalance in antagonism and coordination among different muscle groups, causing flexion, adduction, or internal rotation deformity of the hip joint, followed by increased femur anteversion, proximal femoral osteoporosis, and dysplasia of femoral head and acetabulum [91–93]. The continuous progression of hip flexion and adduction deformity tends to increase the risk of hip subluxation and progression to dislocation of the hip joint without any intervention [94].

The major goal of the treatment of hip deformity is to restore normal lower limb alignment and prevent the development of deformity. Some scholars made progress toward the prevention and treatment of deformity by injecting botulinum A toxin into the flexor and adductor muscles around the hip [95–97]. The follow-up studies showed that, although the migration percentage (MP) of the femoral head had a downward trend, the efficacy was not widely accepted due to the interference and uncertainty of multiple factors. Therefore, surgical intervention is essential. Hip deformity is often accompanied by knee and ankle deformity. Its principle of management should assess the development of each joint deformity relationship between the primary and secondary malformation severity. Surgery is performed in accordance with the sequence of the hip, knee, and ankle. Meanwhile, a single fixed deformity in any of the three joints that seriously affects the patient’s mobility should be corrected [94].

Adduction deformity of the hip, the earliest sign of hip subluxation, is a common type of hip deformity in spastic CP. This is usually rectified by soft-tissue surgeries, which mainly include adductor tenotomy, adductor transfer, resection of the anterior branch of the obturator nerve, and iliopsoas tendon release [98–100]. The indications are mild hip dislocation (MP > 30%) without skeletal deformity or high risk of dislocation of the hip (passive abduction < 20°–45°, MP > 25%) [94, 98]. Presently, academic to soft-tissue surgery is recommended as a preventative procedure, and its efficacy has been proven to be correlated to the degree of preoperative movement ability. The postoperative outcome (postoperative follow-up measurement of MP, MP < 30%) in patients with GMFCS levels I–III was maintained between 50% and 94%, while the proportion of patients with GMFCS levels IV and V was < 30% [101]. Some studies indicated that patients aged < 4 years with or without risk of hip dislocation should adopt SEMLS as early as possible to correct the deformity, which was usually performed by bilateral rather than unilateral tendon release to avoid secondary malformations, such as pelvic tilt caused by imbalance of muscle strength around the pelvis [98, 100, 102, 103]. Currently, the application of resection of the anterior branch of the obturator nerve, which may only be suitable for patients with spastic CP compared with athetoid CP, is still controversial because it would result in a high risk of secondary hip adduction and external rotation deformity after surgery [98, 104].

Hip deformity may develop in inseparable association with hip dislocation. Generally, hip dislocation may appear in children with CP from the age of 2 years [105–107], most of which progress to unilateral or bilateral hip progressive subluxation, even the Wind-Swept deformity, namely, the side hip adduction, on the other side of hip abduction [108, 109]. There was a linear affiliation between the incidence rate and motor movement ability; that is, the higher the GMFCS level, the higher the risk [89, 107, 110]. Moreover, it has been reported in relevant literatures that femoral anteversion and femoral neck-shaft angle were also correlated to incidence [93], while pelvic tilt and scoliosis were weakly correlated to incidence [110]. Currently, there is evidence of some advantages that early intervention could effectively delay or prevent the progression of hip dislocation. Based on this, most studies advocate the establishment of early screening, diagnosis, and treatment of hip deformity [111, 112]. The early diagnosis of dislocation is usually evaluated by the measurement of the hip MP (MP > 30%–33% with hip subluxation, MP > 100% with hip dislocation). When the MP is close to 33%–40%, timely surgical intervention is necessary [110, 113–115]. Some scholars have proposed that a more detailed morphological classification should be developed to guide treatment based on the MP assessment [116]. The main goal of surgical treatment for hip subluxation or dislocation is to restore the normal mechanic structure of the hip and improve limb movement ability and nursing quality. Thus, the choice of surgery depends on the stage of pathological progression [94, 117]. Hip reconstruction is mainly recommended in patients with soft-tissue surgery failure or those who have undergone progressive hip subluxation or dislocation with or without femoral valgus and acetabular dysplasia. Moreover, femoral head deformity or degenerative changes are contraindications to reconstructive surgery. This procedure usually involves soft-tissue release, followed by femoral derotation osteotomy (FDO) or open reduction [91, 118]. FDO is primarily conducted for correction of the excessive internal hip rotation to improve internal rotation gait and increased femoral anteversion [119, 120]. Due to the differences in the degree of correction of rotational deformity and the difficulty of the intraoperative operation, the selection of osteotomy segment of the FDO, which should be performed either proximally or distally, has always been controversial [121–123]. Although some literature noted that kinematic and kinetic parameters of gait in most patients undergoing FDO were effectively maintained during the follow-up of 5 to 10 years postoperatively [19, 124, 125], the adverse effect of postoperative complications has been incessantly reported, such as pelvic tilt and recurrence of internal hip rotation and hip subluxation [126–129]. For symptomatic patients with subluxation or dislocation, which were associated with deformity of the femoral head or degenerative changes for blocking hip reconstruction, salvage treatment, including pelvic osteotomy, arthrodesis, and arthroplasty, should be considered [130, 131]. Pelvic osteotomy is performed using various methods, including Pemberton osteotomy, Chiari pelvic osteotomy, Salter innominate osteotomy, and Dega osteotomy [91, 132, 133], among which the Dega osteotomy has been widely adopted for the treatment of hip dislocation of CP [134, 135]. Currently, most studies report that multilevel surgery (FDO or open reduction associated with pelvic osteotomy), better than single-level surgery in a therapeutic outcome, can be available to reduce the recurrence rate of hip dislocation. However, serious complications have led to more concerns, such as heterotopic ossification and avascular necrosis of the femoral head [130, 131, 136, 137]. Arthrodesis and prosthetic interposition arthroplasty have been gradually applied to the treatment of hip dislocation of the patients with CP. Some studies indicated that the improvement of painful symptoms and motor function for nonambulatory patients with end-stage spastic hip deformity could benefit from arthroplasty in the short-term follow-up. Nevertheless, the long-term follow-up results remain to be proven, as well as the indications [138–140].

3.2.2 *Knee surgery*

The incidence of knee deformity in patients with spastic CP is second only to that of ankle and foot deformity. Common deformities of the knee include knee flexion contracture, genu recurvatum, and lower limb rotation deformities. Currently, the Ilizarov external fixator is available for non-surgical treatment of knee deformity in patients with CP [141]. Due to the difficulty to achieve an ideal therapeutic target by applying external fixator alone, it is often combined with soft-tissue surgery. Thus, orthopedic surgery is still a reliable intervention in the treatment of knee deformity in patients with spastic CP.

These patients often suffer from hamstring muscle spasm and contracture, which is the main cause of crouch gait. Additionally, weakness of quadriceps and triceps surae muscles can lead to excessive flexion of the knee. Flexion contracture of the knee and crouch gait can be satisfactorily improved by distal hamstring elongation [18], which is a simple surgical procedure involving the release of the semitendinosus, semimembranosus, gracilis, and biceps femoris. As the development of severe contracture deformity (fixed knee flexion deformity angle < 40°) or bony deformity, patients could benefit from multilevel surgery (distal femoral extension osteotomy combined with soft tissue surgery) [142]. However, postoperative complications, especially increased anterior pelvic tilt, deformity recurrence, and requirement for walking aids, have made the application of this surgery controversial [143].

Genu recurvatum could result from weakness of the muscles that maintain knee stabilization, with secondary bony deformity of the proximal tibia [144]. It can also be caused by failed surgeries of hamstring transfer or tendon lengthening and gastrocnemius proximal release [145, 146]. Currently, knee orthosis has been a common therapeutic method, even becoming a postoperative remedy of failed surgeries that is applied to correct abnormal joint movement by preventing and reducing resumption of forwarding movement of the proximal tibia. Simon et al. reported that, based on the gait analysis date, the fixed ankle below the knee brace could eliminate genu recurvatum and result in more normal moments of all joint movements, especially the knee [144].

As the natural growth and development of children with CP, severe muscle contractures and muscle strength imbalance in the lower extremities generally lead to abnormal rotation of the femur and tibia. Rotation deformities, by strongly affecting the normal limb alignment and axis of movement in the lower limbs, result in limitation of motor movement ability and cause joint pain and secondary development of the "lever arm dysfunction" [147, 148]. Thus, osteotomy of the femur or tibia can be performed according to the region of rotation deformity. The favorable surgical treatment to remove the middle rotation deformity of the femur is FDO [121, 149]. Nevertheless, there was concern that the high incidences of overcorrection and recurrence of femur internal rotation were reported after this surgery [119, 127, 150]. Additionally, distal tibial rotational osteotomy, with or without a concomitant fibular osteotomy, is also an accepted treatment for correcting excessive internal or external tibial torsion in patients with CP. The postoperative outcome of this procedure in short-term observation was favorable [151]. Compared with distal tibial rotational osteotomy, proximal tibial osteotomy is abandoned due to high rates of neurovascular complications [152, 153]. Furthermore, whether fibula osteotomy is associated with distal tibia rotation osteotomy is still unclear. Some studies indicated that isolated distal tibia rotation osteotomy could maintain leg stability and reduce the risk of cross-union complication, preventing ankle valgus during growth [151, 154]. Considering the plastic deformation of the ankle joint and fibula to accommodate acute torsional correction, there is also no need to perform fibula osteotomy [155]. On the contrary, combined surgery could be a facility to achieve better magnitude of torsional correction and correction of stress-free rotation, even little risk of recurrence [156, 157].

3.2.3 Ankle surgery

In patients with spastic CP, the muscle tension on the part of leg muscles is increased. Most patients have spastic muscle, which leads to secondary ankle deformities [158]. Talipes equinovarus, talipes valgus, high-arched foot, and tibial rotation are the most common malformations in patients with spastic CP. Talipes valgus is the most common global deformity of deformed feet in spastic CP, which consists of foot-drop deformity and hindfoot inversion [159, 160]. The important cause of this is insufficient muscle strength or muscle contracture, while another reason is excessive muscle strength of the tibialis anterior muscle. There are several types of operative methods: Achilles tendon lengthening, neurotomy of the muscular branch of the tibial nerve, tibialis anterior tendon shortening or transfer, and tibialis posterior lengthening. The etiology of this deformity is complex, and the individualization greatly varies. The surgeon ought to determine the involvement of each muscle carefully so that the operative method should be selected based on gait and imaging data. Related studies have shown that surgical treatment of varus of the foot in patients with spastic CP can significantly improve the gait of patients [161, 162]. In severe cases, the age receiving surgery can be advanced appropriately, and it is not necessary to restrict the age limit of conventional operation.

Valgus deformity is a typical secondary deformity. There are several causes of valgus deformity, such as fibula contracture, posterior tibialis muscle weakness, and calf triceps contracture and combination of the abovementioned causes in spastic CP. In imaging, there will be stenosis and shortening of the distal fibula. During the treatment process, the patient's muscle contracture should be carefully evaluated, and it should be determined whether it is associated with other deformities. The surgical methods include Grice extra-articular subtalar arthrodesis, lateral column lengthening, calcaneal osteotomy, and three-joint fusion. Three-joint fusion is suitable for patients with severe deformity and joint stiffness, which may affect the adjacent joints. Consequently, it is more suitable for nonambulatory patients [163–166]. The Grice extra-articular subtalar arthrodesis can effectively correct valgus without affecting the normal growth of tarsal bone [167, 168]. However, there are risks of postoperative complications, including graft delayed healing, dissolution, dislocation, and fracture of the surgical site in this type of surgery. Indications should be strictly controlled in clinical application, and it should not be used as a substitute for three-joint fusion [169]. The aim of lateral column lengthening is to correct the excessive movement of the talus. It is better in patients who have mild deformity. Patients with severe deformities often need to be treated with other surgeries. Preoperative evaluation of gross motor function needs to be carefully performed. Patients who cannot walk are unsuitable for this surgery [170].

Talipes cavus is an abnormal deformity caused by metatarsophalangeal joint overextension, interphalangeal joint flexion, and abnormal longitudinal arch. This type of deformity can often cause muscle strength of crus and sufficient internal muscle imbalances and even result in compound deformity. Clinically, it is believed that the Coleman block test is not the only way to determine the treatment of talipes cavus, and the key lies in the position of the apex of arch deformity [171, 172].

Through orthopedic and rehabilitation treatment, joint flexibility could be effectively maintained, and aggravation of deformity could be prevented. However, the natural course of foot deformities is not entirely predictable, and they tend to develop with age. There may even be joint stiffness. Surgical intervention is necessary in this situation. The prognosis of foot deformities varies greatly depending on the severity, treatment, age, and joint function in the deformities.

4 Conclusion

Orthopedic surgery is a traditional therapeutic method for limb deformity in patients with CP. It is still insufficient for evidence-based support on the feasibility of SEMLS protocol and various procedures of orthopedics, which benefit the improvement in movement ability, range of motion and gait in patients with CP. There are also limitations to be addressed in current studies: inadequate randomized controlled trials and heterogeneity across trials, and clinical variability. However, orthopedic surgery still plays a critical role in the treatment of CP. It ought to be an additional measure to SPR, especially if significant fixed contracture and bony deformity of limb have already developed. With the deepening research on the neuropathophysiology of movement disorders in CP, the observation on the long-term result of orthopedic surgery, and widespread application of SPR, many scholars have begun to reevaluate the timing of surgical intervention, selection of surgery type, therapeutic strategy, and other issues of orthopedic surgery.

Conflict of interests

The authors declare no conflict of interests in this work.

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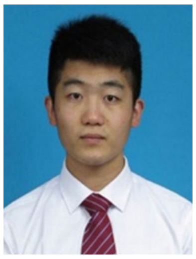

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