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Long-term effects after conversion of biarticular to monoarticular muscles compared with musculotendinous lengthening in children with spastic diplegia

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ABSTRACT

Adverse effects such as increased anterior pelvic tilt (APT) are reported after muscle-tendon lengthening (MTL) for the correction of flexed knee gait in cerebral palsy. The conversion of biarticular muscles (CBM) to monoarticular muscles represents an alternative treatment, but only few short-term results have been published, without comparison with MTL. The long-term outcome of 21 diplegic patients treated with CBM in a prospective study was compared with the results in MTL patients in a matched-pair analysis. Standardized clinical examination and three-dimensional gait analysis were done before surgery, 1 year thereafter, and at long-term follow-up a mean of 9.2 years postoperatively. Mean APT increased one year after surgery in both groups. This increase was higher in MTL patients and statistically significant only for this group. Knee flexion at initial contact and minimum knee flexion in stance were significantly decreased in both groups, while in swing the CBM group tended to show more of a decrease in knee flexion but at the cost of reduced peak flexion. Both groups showed deterioration of kinematic knee parameters through to long-term follow-up; the favourable effects of CBM disappeared, and the two groups displayed comparable average pelvic and knee kinematics. Considering individual patterns the prevalence of increased APT was lower in the CBM group 1 year after surgery, indicating that sparing the semitendinosus may have a positive effect on pelvic stability. However, after 9 years 30% of the patients in both groups showed increased APT indicative of persistent hamstring insufficiency. These results demonstrate that CBM, a significantly more extensive procedure, has no long-term advantage over MTL.

1. Introduction

Patients with diplegic cerebral palsy show a variety of gait disorders, of which flexed knee gait is one of the most frequent [1–3]. These gait problems are commonly treated by single-event multilevel surgery (SEMLS) [4–7]. Various surgical strategies have been employed for the correction of flexed knee gait. Lengthening of the hamstring muscles is widely accepted as the standard treatment [6,8–13]. Encouraging short- and mid-term results have been reported after hamstring lengthening [6,8–13]. However, a number of authors reported adverse effects after hamstring lengthening, such as genu recurvatum and increased anterior pelvic tilt (APT) [9–11,13]. The occurrence of these unintended effects can be partially explained by the influence of the lengthening of biarticular muscles on both adjacent joints [14]. Patients with cerebral palsy show more difficulties in controlling biarticular muscles than monoarticular muscles [15,16]. Elongation of the muscle-tendon unit by surgical means may add to muscle weakness after surgery [17]. As weakness of specific muscle groups due to primary brain damage is commonly found in patients with cerebral palsy, this surgical elongation aggravates the weakness of these muscles [18].

To avoid these adverse effects in the treatment of flexed knee gait, conversion of biarticular muscles to monoarticular muscles has been introduced [19–22]. In an early report, Silfverskiöld described conversion of the gastrocnemius, the hamstrings and the rectus femoris into monoarticular muscles [19,20]. Using a modified technique, Eggers transplanted the medial and lateral hamstring tendons to the femoral condyles [21]. Satisfactory initial results after transfer of the semitendinosus tendon to the adductor magnus tendon were published by Ma et al. [22]. Metaxiotis et al. found significant improvements after conversion of the semitendinosus and gastrocnemius muscles to monoarticular muscles [16].

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Interest in the conversion of biarticular to monoarticular muscles (CBM) has diminished, probably because of the lack of long-term reports comparing its results with those of conventional muscle tendon lengthening surgery (MTL) by means of three-dimensional gait analysis. The purpose of this study was therefore to evaluate the long-term effects of CBM in comparison with those of MTL. The hypothesis of the present investigation was that CBM and MTL lead to comparable outcomes concerning knee kinematics, but that CBM carries less risk than MTL for increased APT and recurrence of flexed knee gait.

2. Methods

2.1. Subjects

Before 1998, the standard approach for correction of flexed knee gait in spastic diplegia at our institution was MTL. Due to the frequent occurrence of increased APT and genu recurvatum, a prospective cohort study was conducted to evaluate the outcome of CBM. Between 1998 and 2004 one cohort of 25 diplegic children underwent CBM during SEMLS. These children met the following inclusion criteria: spastic diplegia, ambulatory (GMFCS I–III), age at surgery 6–16 years, flexed knee gait, scheduled for SEMLS. The exclusion criteria were athetosis, previous lower limb orthopaedic surgery, and botulinum toxin injections less than 6 months before surgery. The study was approved by the institutional ethics committee. All the subjects were evaluated according to a standardized protocol before operation and 1 year thereafter. The results were published [16]. For the present investigation, the same patients were invited to attend for a long-term follow-up examination at least 6 years after their multilevel surgery. Twenty-one of the 25 patients could be re-evaluated 6–14 years after surgery. The remaining patients had moved ($n = 2$), were not able to attend ($n = 1$) or preferred not to participate ($n = 1$). For the sake of comparison, the CBM patients were matched to 21 diplegic patients with flexed knee gait from our gait laboratory database who had received MTL during SEMLS. The patients were selected according to the following preoperative parameters: knee flexion and ankle dorsiflexion in stance (primary matching parameters), together with pelvic tilt, hip flexion, age at surgery, body mass index (BMI), Gillette Gait Index (GGI) and GMFCS level (secondary matching parameters). No significant differences in all these preoperative parameters were detected between the two groups (one-way ANOVA, $p < 0.05$). The selected MTL patients were evaluated following the same study protocol.

2.2. Examinations

Forty-two patients (21 CBM, 21 MTL) were examined before the intervention (E0) and 1 year (E1) (CBM: $1.3y \pm 0.6y$; MTL: $1.2y \pm 0.7y$) and 6–14 years (E2) (CBM: $9.2y \pm 2.5y$; MTL: $9.1y \pm 2.6y$) thereafter using the same protocol. Demographic data are summarized in Table 1. Standardized clinical examination including range of motion and special tests (Thomas test, popliteal angle, Silfverskiöld test) as well as instrumented three-dimensional gait analysis, carried out with a 50-Hz six-camera Vicon® 370 system (Oxford Metrics, Oxford, UK) and two force-plates (Kistler Instruments, Winterthur, Switzerland) until 2002. Subsequently a 120-Hz 12-camera Vicon® 612 system (Oxford Metrics) was used and the equivalence of the two systems was tested. Kinematics and kinetics were calculated according to Kabada et al. [23]. Each patient was asked to walk along a 7-m walkway barefoot at a self-selected speed, and at least five representative strides were averaged for further analysis.

2.3. Surgery

All patients received standardized SEMLS (Table 1). All procedures were performed according to specific clinical and gait analysis criteria under the supervision of one of the authors (L.D.). Treatment of the two groups differed with regard to the following biarticular muscles: semitendinosus, gastrocnemius and rectus femoris. In the CBM group, the semitendinosus tendon was released from its insertion with the patient in prone position. The medial tendon origin of the gastrocnemius was released at the femoral condyle, leaving a stump of 3–4 cm. The lateral part of the gastrocnemius was also released, and both heads were transferred to the tibial condyles. The released semitendinosus tendon was subsequently sutured to the medial gastrocnemius tendon stump at the medial femoral condyle under slight tension. The rectus femoris was released from its proximal origin at the anterior inferior iliac spine in all CBM patients and sutured to the anterior hip joint capsule, while the reflected head of the rectus femoris muscle was released.

In contrast, in the MTL group the semitendinosus was lengthened by intramuscular tenotomy (middle thigh, supine position) or *Z*-lengthening (popliteal, prone position), and the gastrocnemius muscle was lengthened by intramuscular aponeurotic lengthening. Proximal rectus femoris release was performed only in cases with a double-bump pattern of the pelvis and a positive Duncan-Ely test in the MTL group.

2.4. Postsurgical management

Epidural anaesthesia was used for the first days after surgery, and passive range of motion treatment was started early. All the patients wore lower leg weight-bearing casts for 4 weeks and long-leg night orthoses for 6 months to maintain knee extension. After 4 weeks ankle-foot orthoses with dorsiflexion stop were fitted to assist passive extension of the knee. In cases with additional bony foot surgery (derotation osteotomy or bony foot reconstruction) short-leg non-weight-bearing casts were fitted for 4 weeks after surgery.

2.5. Statistical analysis

Both limbs of each patient were used for further analysis. The GGI [24] was calculated for all subjects at all examinations. Descriptive statistics were used for basic statistical analysis. To show time and group effects, two-way repeated-measures analyses of variance (ANOVA) were applied. *p*-Values of less than 0.05 were considered to show significant differences, and Bonferroni correction was employed to adjust for multiple comparisons. Statistical analysis was done using PASW® Statistics 18.

2.6. Funding

There was no external source of funding for this investigation.

3. Results

The results of three-dimensional gait analysis and clinical examination are summarized in Table 2 and Figs. 1–3.

3.1. Kinematics

APT increased significantly ($p < 0.01$) in the MTL group directly after surgery, while there was only a moderate, non-significant increase in the CBM group. At E2 both groups showed a decrease: APT values were similar and there was no significant difference between the groups. However, the APT in the MTL group was still