

The Use of Diagnostic Gait Analysis in the Treatment of Cerebral Palsy

Diagnosis: Gait abnormalities (ICD 781.2) secondary to cerebral palsy (ICD 343), static encephalopathy (ICD 437), congenital syndrome (ICD 344), childhood stroke (ICD 767, 335, 436, 767, 850) and other neurological impairments that cause permanent motor disability impacting gait.

Definition: Diagnostic gait analysis is a well established method of measuring the abnormalities of gait in individuals with the above diagnoses. Comprehensive gait analysis testing for this purpose should include an appropriate physical examination, recording static joint range of motion, muscle strength and tone, kinematic measurement of major joint and segment motions in the lower extremity and trunk in three dimensions, measurement of ground reaction forces with a force plate, combining this data with kinematics to report joint moments and powers during gait and surface electromyography to record the activity of principle muscles used during gait. Dynamic finewire electromyography is included when indicated. Pedobarograph, which measures the surface pressure under the foot may be obtained and ambulatory oxygen consumption may be measured. This full evaluation requires two to three staff members between two and four hours to complete. All of the data is then processed, analyzed, integrated, and reviewed by a clinician or team of clinicians with expertise in the treatment of gait abnormalities. Specific gait abnormalities and their etiology are defined, and treatment options are suggested for the referring physician. This is the definition used by the Commission for Gait Laboratory Accreditation (CMLA) {CMLAinc.org}, which is an independent non-profit organization whose board is appointed by Gait and Clinical Motion Analysis Society (GCMAS), American Academy of Physical Medicine and Rehabilitation (AAPM&R), American Academy of Orthopaedic Surgeons (AAOS) and American Physical Therapy Association (APTA). The CMLA offers gait laboratory accreditation.

Current Practice: The treatment of gait abnormalities in individuals with cerebral palsy varies widely across North America with many children receiving very little or no expert orthopedic treatment. There are also centers of specialization and focused interest in providing the best care possible. The current **Standard of Expert Care** for children with gait abnormalities secondary to cerebral palsy is to obtain a full gait analysis prior to treatment interventions to improve a child's walking ability or concern over a major decline in the child's function. Treatment interventions include surgery for muscle lengthening and/or correction of bone deformities, reduction in spasticity and bracing options. It is also the **Standard of Expert Care** to evaluate the child with a follow up analysis after treatment and rehabilitation is completed to assess the changes from the intervention and determine what additional treatment is needed to maximize the outcome of the intervention. The follow up gait analysis test is also useful as a reference point against which to assess the child when future major gait changes occur either secondary to growth, neurologic change, or musculoskeletal change.

The current **Standard of Expert Care** for the person with cerebral palsy is a multilevel surgical approach for the correction of gait abnormalities. A multilevel surgical approach includes correction of both bone and soft tissue deformities at multiple levels

simultaneously. Therefore it is critical to have comprehensive measurements and assessments prior to treatment so a better understanding of the pathomechanics is possible.

Literature Review: There is very extensive literature on the use of gait analysis in the management of cerebral palsy with Pub Med listing 430 papers published from 1975 to 2007. All current textbooks on the orthopedic management of cerebral palsy (B1, B2) Base recommended treatments for gait impairment on the results of comprehensive gait analysis testing. The current major textbooks on pediatric orthopedics also base recommendations for gait treatment on gait analysis results (B3, B4). Excellent clinical review papers have been published in peer-reviewed publications with recommendations on the treatment of cerebral palsy gait using comprehensive gait analysis testing. (7,14,16,19,24). The indications for some operative procedures have evolved directly from the use of comprehensive gait analysis testing pre- and post-operatively. Some specific procedures include rectus femoris transfer to improve swing phase knee flexion, (8,22) hamstring lengthening to improve knee extension at foot contact and midstance knee extension, (1,3) gastrocnemius lengthening to improve ankle dorsiflexion, (4,21,25) gastrocnemius lengthening to create a plantigrade foot position and decrease a premature plantarflexion moment, (9,12,18) and torsional corrections. (2,5,11,13,15) There are also multiple papers demonstrating that gait analysis alters the surgical plan with most of the papers finding that surgeons recommend different procedures or fewer procedures when they utilize the results of comprehensive gait analysis testing. (6,17,20,23)

Alternatives to Gait Analysis: The only alternative to quantitative assessment with Gait analysis for the surgical planning of problems related to gait abnormalities in cerebral palsy is physician observation and static physical examination. It is well documented in the literature that this consistently leads to repeated encounters with surgeries and often recurrence of deformities necessitating repeat surgery (Fabry, Liu, & Molenaers, 1999; J. Gage, 1994). It has also been established that the informal visual analysis of gait abnormalities is not acceptable. It has been well documented that there is considerable variation in observer agreement for the most common clinical assessment measures (Keenan et al., 2004; Saleh & Murdoch, 1985). Evaluations based on clinical assessment of joint range of motion, measure of spasticity, strength, x-rays and visual observation frequently do not correlate with the dynamic findings during a gait analysis (P. DeLuca, Öunpuu, Davis, & Walsh, 1998; McMulkin, Gulliford, Williamson, & Ferguson, 2000; Orendurff, Chung, & Pierce, 1998). There are also many peer-reviewed publications that include long-term patient outcome data that demonstrates its efficacy beyond informal visual analysis of gait abnormalities routinely performed by clinicians. Studies demonstrate long-term patient outcome data at both 5 and 10 years is clearly far superior to the old results (S Öunpuu, DeLuca, Davis, & Romness, 2002; Sylvia Öunpuu, Keggi, Davis, Bell, & DeLuca, 1996). In fact, the need for repeat surgery has been found to be less than 10% in patients followed out over 10 years. The ability to evaluate a patient with complex walking problems at multiple levels including pelvis, hip, knee, ankle and foot is possible only with three-dimensional gait assessments. The ability to package surgeries at multiple levels at a single sitting necessitates an appropriate pre operative assessment so that the correct surgical plan can be delivered.

References: Textbooks:

- B1. Gage, J., The Treatment of Gait Problems in Cerebral Palsy, MacKeith Press, London, UK, 2004, 448 pp
B2. Miller, F. Cerebral Palsy, Springer, New York City, New York. 2004, 1055 pp
B3. Morrissy, RT, S. Weinstein, Lovell and Winter's Pediatric Orthopaedics, Sixth Edition, Lippincott, Philadelphia, PA, 2005, 2682 pp
B4. Herring, J. Tachdjian's Pediatric Orthopaedics, Elsevier, London, UK, 2001, 2950 pp

References: Peer Reviewed Papers

1. Reference Type: Journal Article

Author: Lovejoy, S. A.; Tylkowski, C.; Oeffinger, D.; Sander, L.

Year: 2007

Title: The effects of hamstring lengthening on hip rotation

Journal: J Pediatr Orthop

Volume: 27

Issue: 2

Pages: 142-6

Date: Mar

Accession Number: 17314637

Abstract: The purpose of this study is to determine the effect on hip rotation of hamstring lengthening as measured by preoperative and postoperative motion analysis. Thirty-eight patients/76 hips in children with cerebral palsy spastic diplegia were retrospectively reviewed using presurgical and postsurgical gait analysis. Physical examination and gait analysis showed an increase in knee extension and decreased popliteal angles postoperatively. Kinematic analysis showed an increase in knee extension and decreased hip internal rotation throughout the gait cycle postoperatively as well. No difference was seen between those with internal and external rotation pattern at the hip preoperatively. As a group, the patients did not improve enough to change from internal to external rotation at the hip, suggesting that children with cerebral palsy spastic diplegia with significant internal rotation gait should have other surgical options besides hamstring lengthening when internal rotation gait of the hip is to be treated.

Notes: 0271-6798 (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17314637

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2. Reference Type: Journal Article

Author: Hicks, J.; Arnold, A.; Anderson, F.; Schwartz, M.; Delp, S.

Year: 2007

Title: The effect of excessive tibial torsion on the capacity of muscles to extend the hip and knee during single-limb stance

Journal: Gait Posture

Date: Jan 15

Accession Number: 17229573

Abstract: Excessive tibial torsion, a rotational deformity about the long axis of the tibia, is common in patients with cerebral palsy who walk with a crouch gait. Previous research suggests that this deformity may contribute to crouch gait by reducing the capacity of soleus to extend the knee; however, the effects of excess external torsion on the capacity of other muscles to extend the stance limb during walking are unknown. A computer model of the musculoskeletal system was developed to simulate a range of tibial torsion deformities. A dynamic analysis was then performed to determine the effect of these deformities on the capacity of lower limb muscles to extend the hip and knee at body positions corresponding to the single-limb stance phase of a normal gait cycle. Analysis of the model confirmed that excessive external torsion reduces the extension capacity of soleus. In addition, our analysis revealed that several important muscles crossing the hip and knee are also adversely affected by excessive tibial torsion. With a tibial torsion deformity of 30 degrees, the capacities of soleus, posterior gluteus medius, and gluteus maximus to extend both the hip and knee were all reduced by over 10%. Since a tibial torsion deformity reduces the capacity of muscles to extend the hip and knee, it may be a significant contributor to crouch gait, especially when greater than 30 degrees from normal, and thus should be considered by clinicians when making treatment decisions.

Notes: 0966-6362 (Print)

Journal article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17229573

Author Address: Department of Mechanical Engineering, Stanford University, Stanford, CA, USA

3. Reference Type: Journal Article

Author: Rodda, J. M.; Graham, H. K.; Nattrass, G. R.; Galea, M. P.; Baker, R.; Wolfe, R.
Year: 2006

Title: Correction of severe crouch gait in patients with spastic diplegia with use of multilevel orthopaedic surgery

Journal: J Bone Joint Surg Am

Volume: 88

Issue: 12

Pages: 2653-64

Date: Dec

Accession Number: 17142416

Abstract: **BACKGROUND:** Severe crouch gait in patients with spastic diplegia causes excessive loading of the patellofemoral joint and may result in anterior knee pain, gait deterioration, and progressive loss of function. Multilevel orthopaedic surgery has been used to correct severe crouch gait, but no cohort studies or long-term results have been reported, to our knowledge. **METHODS:** In order to be eligible for the present retrospective cohort study, a patient had to have a severe crouch gait, as defined by sagittal plane kinematic data, that had been treated with multilevel orthopaedic surgery as well as a complete clinical, radiographic, and instrumented gait analysis assessment. The surgical intervention consisted of lengthening of contracted muscle-tendon units and correction of osseous deformities, followed by the use of ground-reaction ankle-foot

orthoses until stable biomechanical realignment of the lower limbs during gait was achieved. Outcome at one and five years after surgery was determined with use of selected sagittal plane kinematic and kinetic parameters and valid and reliable scales of functional mobility. Knee pain was recorded with use of a Likert scale, and all patients had radiographic examination of the knees. RESULTS: Ten subjects with severe crouch gait and a mean age of 12.0 years at the time of surgery were studied. After surgery, the patients walked in a more extended posture, with increased extension at the hip and knee and reduced dorsiflexion at the ankle. Pelvic tilt increased, and normalized walking speed was unaltered. Knee pain was diminished, and patellar fractures and avulsion injuries healed. Improvements in functional mobility were found, and, at the time of the five-year follow-up, fewer patients required the use of wheelchairs or crutches in the community than had been the case prior to intervention.

CONCLUSIONS: Multilevel orthopaedic surgery for older children and adolescents with severe crouch gait is effective for relieving stress on the knee extensor mechanism, reducing knee pain, and improving function and independence.

Notes: 0021-9355 (Print)

Journal Article

Research Support, Non-U.S. Gov't

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17142416

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4. Reference Type: Journal Article

Author: Park, C. I.; Park, E. S.; Kim, H. W.; Rha, D. W.

Year: 2006

Title: Soft tissue surgery for equinus deformity in spastic hemiplegic cerebral palsy: effects on kinematic and kinetic parameters

Journal: Yonsei Med J

Volume: 47 Issue: 5 Pages: 657-66

Date: Oct 31

Abstract: The purpose of this study was to evaluate how soft tissue surgery for correcting equinus deformity affects the kinematic and kinetic parameters of the ankle and proximal joints. Sixteen children with spastic hemiplegic cerebral palsy and equinus deformities (age range 3-16 years) were included. Soft tissue surgeries were performed exclusively on the ankle joint area in all subjects. Using computerized gait analysis (Vicon 370 Motion Analysis System), the kinematic and kinetic parameters during barefoot ambulation were collected preoperatively and postoperatively. In all 16 children, the abnormally increased ankle plantar flexion and pelvis anterior tilting on the sagittal plane were significantly improved without a weakening of push-off ($p < 0.05$). In a group of 8 subjects with a recurvatum knee gait pattern before operation, the postoperative kinematic and kinetic parameters of the knee joint were significantly improved ($p < 0.05$). In a group of 8 subjects with ipsilateral pelvic external rotation before operation, the postoperative pelvic deviations on the transverse plane were significantly decreased

($p < 0.05$). These findings suggest that the soft tissue surgery for correcting equinus deformity improves not only the abnormal gait pattern of the ankle, but also that of the knee and pelvis.

Notes: 0513-5796 (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17066509

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5. Reference Type: Journal Article

Author: Rethlefsen, S. A.; Healy, B. S.; Wren, T. A.; Skaggs, D. L.; Kay, R. M.

Year: 2006

Title: Causes of intoeing gait in children with cerebral palsy

Journal: J Bone Joint Surg Am

Volume: 88 Issue: 10 Pages: 2175-80

Date: Oct

Abstract: **BACKGROUND:** Intoeing is a frequent gait problem in children with cerebral palsy. It is essential to determine the cause(s) of intoeing when surgical intervention is being planned. The purpose of this study was to evaluate the prevalence of various causes of intoeing in children with cerebral palsy and to determine whether the causes differ between children with bilateral and those with unilateral involvement. **METHODS:** The cause of intoeing gait was examined retrospectively, with use of gait analysis, in 412 children with cerebral palsy (587 involved sides). The causes were evaluated separately for the children with bilateral involvement (diplegia or quadriplegia) and those with hemiplegia. **RESULTS:** Overall, the most common causes of intoeing were internal hip rotation (322 of 587 sides) and internal tibial torsion (296 of 587 sides). Pes varus contributed to intoeing of thirty-five of the eighty-two involved limbs of the patients with hemiplegia and of forty-two of the 505 limbs of the patients with diplegia or quadriplegia. Multiple causes of intoeing were noted in 215 of the 587 involved limbs, including 176 of the 505 limbs of the patients with bilateral involvement and thirty-nine of the eighty-two involved limbs of the patients with hemiplegia. The most common causes of intoeing in the subjects with bilateral involvement were internal hip rotation (288 of 505), internal tibial torsion (261 of 505), and internal pelvic rotation (ninety-two of 505). The most common causes in the hemiplegic children were internal tibial torsion (thirty-five of eighty-two), pes varus (thirty-five of eighty-two), internal hip rotation (thirty-four of eighty-two), and metatarsus adductus (twenty of eighty-two).

CONCLUSIONS: More than one-third of children with cerebral palsy have multiple causes of intoeing. Pes varus commonly contributes to intoeing by children with hemiplegic cerebral palsy but rarely contributes to intoeing by those with diplegia or quadriplegia. These findings should be carefully considered prior to surgical correction of the intoeing gait of these patients.

Notes: 0021-9355 (Print)

Journal Article

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http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17015594

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6. Reference Type: Journal Article

Author: Chang, F. M.; Seidl, A. J.; Muthusamy, K.; Meininger, A. K.; Carollo, J. J.

Year: 2006

Title: Effectiveness of instrumented gait analysis in children with cerebral palsy-- comparison of outcomes

Journal: J Pediatr Orthop

Volume: 26 Issue: 5 Pages: 612-6

Date: Sep-Oct

Abstract: The aim of this study was to evaluate the impact of instrumented gait analysis on the walking performance of children with cerebral palsy at The Children's Hospital, Denver. The study population consisted of 2 groups of 10 children; an experimental group (X) and a recommendation matched control group (C). All subjects had 2 instrumented gait analyses at least 1 year apart. Group X was composed of patients who abided by the gait analysis recommendations and completed all surgical interventions. Group C included patients who chose not to follow surgical recommendations from the initial gait analysis but instead pursued alternative nonsurgical treatments. Sagittal and coronal plane kinematic outcomes for each surgical procedure were obtained from comparing sequential instrumented gait analyses, and analyzed using logistic regression. Group X was found to experience a significantly higher percentage of positive outcomes (44%) than Group C (26%). The calculated odds ratio using the Wald test indicated that patients who complied with gait analysis surgical recommendations were 3.68 times more likely to experience a positive outcome than recommendation matched patients who chose not to follow gait analysis recommendations.

Notes: 0271-6798 (Print)

Comparative Study

Journal Article

Research Support, Non-U.S. Gov't

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16932100

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7. Reference Type: Journal Article

Author: Davids, J. R.

Year: 2006

Title: Quantitative gait analysis in the treatment of children with cerebral palsy

Journal: J Pediatr Orthop

Volume: 26 Issue: 4 Pages: 557-9

Date: Jul-Aug

Review

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16791080

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8. Reference Type: Journal Article

Author: Moreau, N.; Tinsley, S.; Li, L.

Year: 2005

Title: Progression of knee joint kinematics in children with cerebral palsy with and without rectus femoris transfers: a long-term follow up

Journal: Gait Posture

Volume: 22 Issue: 2 Pages: 132-7

Date: Oct

Abstract: The purpose of this study was to compare long-term outcomes of multi-level surgery with and without rectus femoris transfer (RFT) in a group of children with cerebral palsy. Forty-one subjects with a diagnosis of cerebral palsy were divided into a RFT group (28 subjects with 50 sides) and non-RFT group (13 subjects with 22 sides). The study protocol included pre-operative gait analysis, multi-level orthopedic surgical intervention, one year post-operative gait analysis, and three year or greater post-operative gait analysis. All participants received inpatient physical therapy for 2-12 weeks either following surgery or following a period of immobilization, depending on surgical procedures performed. Results showed improved peak knee flexion during swing phase (PKFS) for the RFT group one year after surgery. The deviation from normal in PKFS in the RFT group improved, on average, from seven to five degrees. The deviation from normal in PKFS in the non-RFT group increased approximately four degrees in the same period of time. The knee flexion swing range (KFSR) of the RFT group increased dramatically by 11 degrees after surgery, where no significant KFSR changes observed in the non-RFT group. Those parameters maintained relatively stable from one to three years post surgery for both groups. These observations support our hypothesis that improvements after RFT surgery persist over time, counteracting the negative effects of growth and time.

Notes: 0966-6362 (Print)

Comparative Study

Journal Article

Research Support, Non-U.S. Gov't

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16139748

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9. Reference Type: Journal Article

Author: Lyon, R.; Liu, X.; Schwab, J.; Harris, G.

Year: 2005

Title: Kinematic and kinetic evaluation of the ankle joint before and after tendo achilles lengthening in patients with spastic diplegia

Journal: J Pediatr Orthop

Volume: 25 Issue: 4 Pages: 479-83

Date: Jul-Aug

Abstract: Fourteen patients, at a mean age of 9.1 years (range 4.1-16.6 years), who had spastic diplegic cerebral palsy were evaluated before and after tendo Achilles lengthening (TAL). Follow-up (by gait analysis) after TAL ranged from 8 to 30 months. A Vicon motion analysis system with six CCD cameras and two AMTI force plates provided three-dimensional measurements of joint motion and moments. The TAL procedure resulted in normal passive dorsiflexion of the ankle joint with the knee at 0 degrees of extension and 90 degrees of flexion, reduced plantarflexion during swing phase, and reduced premature plantarflexor moment. However, 10 degrees greater than normal dorsiflexion of the ankle joint during mid-stance phase was indicative of a mild calcaneal gait pattern. The TAL procedure improved lower extremity function as documented by both kinematic and kinetic analysis in cerebral palsy.

Notes: 0271-6798 (Print)

Comparative Study

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15958899

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10. Reference Type: Journal Article

Author: Maathuis, K. G.; van der Schans, C. P.; van Iperen, A.; Rietman, H. S.; Geertzen, J. H.

Year: 2005

Title: Gait in children with cerebral palsy: observer reliability of Physician Rating Scale and Edinburgh Visual Gait Analysis Interval

Testing scale

Journal: J Pediatr Orthop

Volume: 25 Issue: 3 Pages: 268-72

Date: May-Jun

Abstract: The aim of this study was to test the inter- and intraobserver reliability of the Physician Rating Scale (PRS) and the Edinburgh Visual Gait Analysis Interval Testing (GAIT) scale for use in children with cerebral palsy (CP). Both assessment scales are quantitative observational scales, evaluating gait. The study involved 24 patients ages 3 to 10 years (mean age 6.7 years) with an abnormal gait caused by CP. They were all able to walk independently with or without walking aids. Of the children 15 had spastic diplegia and 9 had spastic hemiplegia. With a minimum time interval of 6 weeks, video recordings of the gait of these 24 patients were scored twice by three independent observers using the PRS and the GAIT scale. The study showed that both the GAIT scale and the PRS had excellent intraobserver reliability but poor interobserver reliability for children with CP. In the total scores of the GAIT scale and the PRS, the three observers showed systematic differences. Consequently, the authors recommend that longitudinal assessments of a patient should be done by one observer only.

Notes: 0271-6798 (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15832135

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11. Reference Type: Journal Article

Author: Graham, H. K.; Baker, R.; Dobson, F.; Morris, M. E.

Year: 2005

Title: Multilevel orthopaedic surgery in group IV spastic hemiplegia

Journal: J Bone Joint Surg Br

Volume: 87 Issue: 4 Pages: 548-55

Date: Apr

Abstract: Most children with spastic hemiplegia have high levels of function and independence but fixed deformities and gait abnormalities are common. The classification proposed by Winters et al is widely used to interpret hemiplegic gait patterns and plan intervention. However, this classification is based on sagittal kinematics and fails to consider important abnormalities in the transverse plane. Using three-dimensional gait analysis, we studied the incidence of transverse-plane deformity and gait abnormality in 17 children with group IV hemiplegia according to Winters et al before and after multilevel orthopaedic surgery. We found that internal rotation of the hip and pelvic retraction were consistent abnormalities of gait in group-IV hemiplegia. A programme of multilevel surgery resulted in predictable improvement in gait and posture, including pelvic retraction. In group IV hemiplegia pelvic retraction appeared in part to be a compensating mechanism to control foot progression in the presence of medial femoral torsion. Correction of this torsion can improve gait symmetry and function.

Notes: 0301-620X (Print)

Evaluation Studies

Journal Article

Research Support, Non-U.S. Gov't

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15795209

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12. Reference Type: Journal Article

Author: Wren, T. A.; Rethlefsen, S.; Kay, R. M.

Year: 2005

Title: Prevalence of specific gait abnormalities in children with cerebral palsy: influence of cerebral palsy subtype, age, and previous surgery

Journal: J Pediatr Orthop

Volume: 25 Issue: 1 Pages: 79-83

Date: Jan-Feb

Abstract: The authors retrospectively reviewed a series of 492 consecutive cerebral palsy patients undergoing computerized motion analysis. The prevalence of 14 specific gait abnormalities was evaluated and compared based on involvement (hemiplegia, diplegia, or quadriplegia), age, and history of previous surgery (lower extremity orthopaedic surgery or rhizotomy). Stiff knee in swing, equinus, and intoeing were all seen in more than 50% of the subjects in each of the hemiplegic, diplegic, and quadriplegic groups. Increased hip flexion and crouch were also present in more than 50% of the subjects in the diplegic and quadriplegic groups, and hip adduction occurred in more than 50% of the quadriplegic subjects. The likelihood of having stiff knee in swing, out-toeing, calcaneus deformity, and crouch increased with prior surgery. The likelihood of having rotational malalignment of the leg (internal hip rotation with outtoeing), calcaneus, out-toeing, varus and valgus foot deformities, and hip internal rotation increased with age. These findings provide important information for counseling ambulatory children with cerebral palsy and their families.

Notes: 0271-6798 (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15614065

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13. Reference Type: Journal Article

Author: Karol, L. A.

Year: 2004

Title: Surgical management of the lower extremity in ambulatory children with cerebral palsy

Journal: J Am Acad Orthop Surg

Volume: 12 Issue: 3 Pages: 196-203

Date: May-Jun

Abstract: Despite the increasing popularity of nonorthopaedic treatment alternatives for children with cerebral palsy, bony and softtissue surgery remains a common component in the management of ambulatory patients. Multisite simultaneous tendon surgery provides improvement in gait by addressing hip, knee, and ankle contractures together. Careful preoperative physical examination is required; computerized gait analysis can be useful in confirming a plan for multiple tendon surgeries. Rotational osteotomies can improve transverse-plane malalignment. Shorter periods of immobilization and aggressive postoperative gait training and strengthening may optimize improvements in gait.

Notes: 1067-151X (Print)

Journal Article

Review

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15161173

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14. Reference Type: Journal Article

Author: Davids, J. R.; Ounpuu, S.; DeLuca, P. A.; Davis, R. B., 3rd

Year: 2004

Title: Optimization of walking ability of children with cerebral palsy

Journal: Instr Course Lect

Volume: 53

Pages: 511-22

Abstract: A new paradigm based on an appreciation of the biomechanics of normal and pathologic gait and a better understanding of muscle-tendon unit anatomy and physiology has emerged for orthopaedic clinical decision making to optimize the ambulatory abilities of children with cerebral palsy. This quantitative, biomechanically based approach has been accepted as a research and teaching tool and as an instrument of outcome assessment; however, controversy remains concerning the expense of using this approach and about its accuracy and repeatability. This paradigm is used within a diagnostic matrix consisting of five data sources. Members of the clinical and technical teams from the motion analysis laboratory interpret data from the clinical history, physical examination, diagnostic imaging, quantitative gait analysis, and examination under anesthesia. The certainty of intervention selection is proportional to the consistency of the data within the diagnostic matrix. When inconsistencies in the data exist, input from both the clinical and

technical teams is needed to resolve discrepancies. Working within the framework of the diagnostic matrix, it is possible to identify the indications used in the selection and recommendation of musculoskeletal surgical interventions to optimize gait in children with cerebral palsy. It is important to examine indications and controversies for surgical intervention related to iliopsoas recession, femoral rotational osteotomy, medial hamstring lengthening, rectus femoris transfer, and gastrocnemius recession.

Journal Article

Review

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15116640

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15. Reference Type: Journal Article

Author: Kay, R. M.; Rethlefsen, S.; Reed, M.; Do, K. P.; Skaggs, D. L.; Wren, T. A.

Year: 2004

Title: Changes in pelvic rotation after soft tissue and bony surgery in ambulatory children with cerebral palsy

Journal: J Pediatr Orthop

Volume: 24 Issue: 3 Pages: 278-82

Date: May-Jun

Abstract: The authors performed a retrospective review of pelvic rotation in 59 children with cerebral palsy who underwent lower extremity surgery and pre- and postoperative gait analysis. Two groups were studied: a femoral derotation osteotomy (FDRO) group and a soft tissue surgery only (no FDRO) group. Both groups exhibited abnormal pelvic rotation preoperatively and normalization of this abnormal pelvic rotation postoperatively. Though the mean change in pelvic rotation was small (3.3 degrees +/- 6.0 degrees), some patients demonstrated postoperative changes as large as 21 degrees. Variability in pelvic rotation was greater in the no FDRO group than in the FDRO group. Improvement in pelvic rotation occurred both in children with unilateral (hemiplegic) involvement and in those with bilateral (diplegic or quadriplegic) involvement. Surgeons planning lower extremity surgery in children with cerebral palsy should expect improvement in abnormal pelvic rotation in both hemiplegic and diplegic patients, whether or not bony surgery is planned in addition to soft tissue surgery.

Notes: 0271-6798 (Print)

Comparative Study

Journal Article

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Author Address: Children's Orthopaedic Center, Children's Hospital Los Angeles, Los Angeles, California 90027, USA.

16. Reference Type: Journal Article

Author: Aiona, M. D.; Sussman, M. D.

Year: 2004

Title: Treatment of spastic diplegia in patients with cerebral palsy: Part II

Journal: J Pediatr Orthop B

Volume: 13 Issue: 3 Pages: S13-38

Date: May

Abstract: This review article describes the evaluation, treatment options, and expected outcomes for many of the common deformities of the lower extremities in patients with cerebral palsy. The evaluation tools including gait analysis will be applied to each specific deformity. Dynamic components are addressed with spasticity management and appropriate muscle and tendon procedures. The static components are treated with bony procedures, including various osteotomies and arthrodesis, incorporating biomechanical principles.

Notes: 1060-152X (Print)

Journal Article

Research Support, Non-U.S. Gov't

Review

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15083127

Author Address: Shriners Hospitals for Children, 3101 SW Sam Jackson Park Road, Portland, OR 97239, USA.

17. Reference Type: Journal Article

Author: Cook, R. E.; Schneider, I.; Hazlewood, M. E.; Hillman, S. J.; Robb, J. E.

Year: 2003

Title: Gait analysis alters decision-making in cerebral palsy

Journal: J Pediatr Orthop

Volume: 23 Issue: 3 Pages: 292-5

Date: May-Jun

Abstract: This study was designed to assess the impact of gait analysis on the treatment of patients with cerebral palsy. One hundred two ambulant patients with cerebral palsy were assessed clinically and with gait analysis. Separate treatment proposals for each patient were recorded after clinical examination and after gait analysis. The results of the two methods of assessment were compared. After clinical assessment, 71 of the 102 patients evaluated were recommended for a surgical procedure and 31 for nonoperative treatment. After gait analysis, the indications for treatment were confirmed in 91 cases (89%). Clinical assessment by the same orthopedic surgeon was in close agreement with gait analysis in identifying an indication for surgery. There was less agreement in the type or level of operation recommended. Gait analysis altered the decision in 106 of 267 operations (40%). There was good agreement for bone surgery, suggesting that clinical evaluation of torsional problems was fairly reliable. The poorer agreement seen for soft tissue operations probably reflects the difficulties in assessing tone-related problems in these patients clinically. This study confirms the value of gait analysis for decision-making in cerebral palsy.

Notes: 0271-6798 (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12724589

Author Address: Anderson Gait Analysis Laboratory, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED, Scotland, UK.

18. Reference Type: Journal Article

Author: Saraph, V.; Zwick, E. B.; Zwick, G.; Steinwender, C.; Steinwender, G.; Linhart, W.

Year: 2002

Title: Multilevel surgery in spastic diplegia: evaluation by physical examination and gait analysis in 25 children

Journal: J Pediatr Orthop

Volume: 22 Issue: 2 Pages: 150-7

Date: Mar-Apr

Abstract: Gait improvement surgery was performed on 25 ambulatory children with the diplegic type of cerebral palsy. Multiple soft tissue and bony procedures were performed (mean 8.2 procedures) according to criteria defined on the basis of physical examination and gait analysis. Relevant physical examination findings and kinematic and kinetic data in the sagittal plane were evaluated before surgery and at least 3 years after surgery. Physical examination showed a reduction in the ankle plantar-flexor power and in the range of hip flexion and ankle plantarflexion after surgery. Analysis of gait data showed significant improvements in the sagittal plane kinematics and the power generation at the hip and the ankle. At the knee joint there was maintenance of power of the flexor and extensor group of muscles on physical examination, with significant improvements in the kinematics after surgery. The authors conclude that well-selected surgery improves function of the spastic muscle. The importance of assessing clinical, kinematic, and kinetic data together for proper evaluation of gait is stressed.

Notes: 0271-6798 (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11856920

Author Address: Department of Pediatric Surgery, Karl Franzens University, Graz, Austria. vinay.saraph@kfunigraz.ac.at

19. Reference Type: Journal Article

Author: Gage, J. R.; Novacheck, T. F.

Year: 2001

Title: An update on the treatment of gait problems in cerebral palsy

Journal: J Pediatr Orthop B

Volume: 10 Issue: 4 Pages: 265-74

Date: Oct

Abstract: This article summarizes our experience with cerebral palsy over the past 20 years. The primary and secondary deformities that occur with cerebral palsy are described. Following this, there is a brief overview of the nature and role of gait analysis in the treatment of gait problems in cerebral palsy. The concept of lever-arm dysfunction is introduced. Our current treatment algorithm is then presented along with a brief discussion of our current treatment program, which is illustrated by a case example. Finally, a brief study of a group of patients with spastic diplegia or quadriplegia is presented to illustrate our current method of evaluating treatment outcomes and the need for team management in the treatment of this complex condition.

Notes: 1060-152X (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11727367

Author Address: Department of Orthopaedics, University of Minnesota, USA.

20. Reference Type: Journal Article

Author: Kay, R. M.; Dennis, S.; Rethlefsen, S.; Skaggs, D. L.; Tolo, V. T.

Year: 2000

Title: Impact of postoperative gait analysis on orthopaedic care

Journal: Clin Orthop Relat Res Issue: 374 Pages: 259-64

Date: May

Abstract: The impact of postoperative gait analysis on the ongoing orthopaedic care of 38 consecutive patients with a static encephalopathy was evaluated. Of the 38 postoperative gait analyses, 32 (84%) resulted in recommendations of a change in patient care. Surgery was recommended in 16 of 38 (42%) cases, bracing in 20 (53%) cases, and specific physical therapy regimens in eight (21%) cases. Eleven of the 38 (29%) patients had changes recommended in at least two of the three areas (surgery, bracing, and therapy). The results of this study suggest that postoperative gait analysis serves not only as a measure of treatment outcome, but also as a useful tool in planning ongoing care for these patients.

Notes: 0009-921X (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=10818985

Author Address: Childrens Hospital Los Angeles, CA 90027, USA.

21. Reference Type: Journal Article

Author: Fabry, G.; Liu, X. C.; Molenaers, G.

Year: 1999

Title: Gait pattern in patients with spastic diplegic cerebral palsy who underwent staged operations

Journal: J Pediatr Orthop B

Volume: 8 Issue: 1 Pages: 33-8

Date: Jan

Abstract: Fifteen patients with spastic diplegic cerebral palsy (CP) were monitored for a mean length of 9.5 years after they underwent staged operations and were evaluated by gait analysis, including joint motion in the sagittal plane and the ground reaction force (GRF) in three dimensions. Results showed an increased hip flexion (132%) at midstance, a reduction of peak knee flexion (PKF) during swing (45%) accompanied by an augmented time of PKF during swing (50%), and an increased dorsiflexion of the ankle during swing (293%) as well as its time during the gait cycle, in comparison with normal values. Moreover, significant decreases of the vertical GRF at the terminal stance and the forward and backward GRF were present. Additionally, it was found that a bilateral popliteal angle < 20 degrees is acceptable in spastic CP. Staged operations gave unpredictable results in the correction of contracture of the hamstrings, the Achilles tendon, and the iliopsoas. The authors are convinced that gait analysis is useful in evaluating these patients and enhances the results of operative treatment, and they have since changed their approach toward multilevel simultaneous corrections.

Notes: 1060-152X (Print)

Clinical Trial

Controlled Clinical Trial

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=10709595

Author Address: Department of Orthopaedic Surgery, University Hospital Pellenberg, Katholieke Universiteit Leuven, Belgium.

22. Reference Type: Journal Article

Author: Chambers, H.; Lauer, A.; Kaufman, K.; Cardelia, J. M.; Sutherland, D.

Year: 1998

Title: Prediction of outcome after rectus femoris surgery in cerebral palsy: the role of cocontraction of the rectus femoris and vastus lateralis

Journal: J Pediatr Orthop

Volume: 18 Issue: 6 Pages: 703-11

Date: Nov-Dec

Abstract: Rectus femoris surgery was performed on 70 patients with cerebral palsy and stiff-knee gait. Fifty-three patients underwent distal rectus transfer, and 17 patients had distal rectus release with complete muscle mobilization. Gait analysis was performed preoperatively and postoperatively at a minimum of 1 year. Swing-phase peak knee flexion (PKF) was improved in the transfer group, allowing improved foot clearance and more efficient gait ($p = 0.04$). PKF in swing deteriorated slightly in the release group ($p = 0.04$). The presence of abnormal swing-phase electromyogram (EMG) activity in the rectus alone or abnormal combined rectus and vastus lateralis activity did not influence the PKF results in either surgery ($p < 0.05$). The Ely test had no predictive value in identifying patients with abnormal EMG activity ($p > 0.05$). Preoperative knee range of motion was not a significant variable in determining relative success of rectus surgery. No deleterious effects were observed in stance phase in either group ($p > 0.05$).

Notes: 0271-6798 (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9821123

Author Address: Motion Analysis Laboratory, Children's Hospital, San Diego, CA 92123, USA.

23. Reference Type: Journal Article

Author: DeLuca, P. A.; Davis, R. B., 3rd; Ounpuu, S.; Rose, S.; Sirkin, R.

Year: 1997

Title: Alterations in surgical decision making in patients with cerebral palsy based on three-dimensional gait analysis

Journal: J Pediatr Orthop

Volume: 17 Issue: 5 Pages: 608-14

Date: Sep-Oct

Abstract: The purpose of this study was to compare surgical recommendations made by clinicians experienced in gait analysis when using information provided from the clinical examination and videotape, with recommendations made after the addition of kinematic, kinetic, and electromyographic (EMG) data. Ninety-one patients with a diagnosis of cerebral palsy were seen in the gait laboratory as part of the surgical decision-making process. Experienced clinicians reviewed video and clinical examination data for each patient and made surgical recommendations. Joint kinematics and kinetics and EMG data were then reviewed, and a second set of surgical recommendations was made.

Comparisons between these recommendations showed that the addition of gait-analysis data resulted in changes in surgical recommendations in 52% of the patients, with an associated reduction in cost of surgery, not to mention the human impact of an inappropriate surgical decision, which is more likely without gait analysis. When changes in recommendations were made, an increase in surgical recommendations was observed for the gastrocnemius (59%) and rectus femoris (65%), whereas decreases were observed for the hamstrings (61%), psoas (78%), hip adductors (83%), femur (86%), and tibia (64%).

Notes: 0271-6798 (Print)

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9591998

Author Address: Connecticut Children's Medical Center, Hartford 06106, USA.

24. Reference Type: Journal Article

Author: Gage, J. R.; DeLuca, P. A.; Renshaw, T. S.

Year: 1996

Title: Gait analysis: principle and applications with emphasis on its use in cerebral palsy

Journal: Instr Course Lect

Volume: 45 Pages: 491-507

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8727765

Author Address: University of Minnesota, Minneapolis, USA.

25. Reference Type: Journal Article

Author: Ounpuu, S.; Muik, E.; Davis, R. B., 3rd; Gage, J. R.; DeLuca, P. A.

Year: 1993

Title: Rectus femoris surgery in children with cerebral palsy. Part I: The effect of rectus femoris transfer location on knee motion

Journal: *J Pediatr Orthop*

Volume: 13 Issue: 3 Pages: 325-30

Date: May-Jun

Abstract: Rectus femoris transfer was performed in 78 children (105 sides) with cerebral palsy (CP) at the same time as other surgical procedures as appropriate. The transfer was either medial to the sartorius (62 sides), semitendinosus (19 sides), or the gracilis (14 sides) muscles, or laterally to the iliotibial band (10 sides). Gait analysis performed before and 1 year after operation demonstrated increased knee range of motion (ROM) with increased extension at initial contact and in midstance and maintained knee flexion in swing. There were no statistically significant differences between the four transfer sites in the effect on those variables. Therefore, the choice of rectus femoris transfer site can be dictated by surgical preference or by the nature of other simultaneous procedures.

There was no consistent change in transverse plane motion of the hip or foot progression angles between the two gait analyses, suggesting that rectus femoris transfer does not affect gait abnormalities observed in the transverse plane.

Notes: 0271-6798 (Print)

Comparative Study

Journal Article

URL:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8496366

Author Address: Gait Laboratory, Newington Children's Hospital, Connecticut 06111.

Additional references

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McMulkin, M. L., Gulliford, J. J., Williamson, R. V., & Ferguson, R. L. (2000). Correlation of static to dynamic measures of lower extremity range of motion in cerebral palsy and control populations. *J Pediatr Orthop*, 20(3), 366-369.

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This position statement was approved by the Gait and Clinical Motion Analysis Society (GCMAS) at the annual meeting in March 2009.