Bachelor's thesis

Yngvil Melhuus Johansen

3D motion analysis as a tool in pre- and postoperative evaluation of patients with CP

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1 ABSTRACT

Bakgrunn: Cerebral parese (CP) er en bevegelsesforstyrrelse forårsaket av hjerneskade eller unormal hjerneutvikling i den motoriske korteks før eller kort tid etter fødsel. 3D motion capture-systemer brukes ofte for ganganalyse og blir rapportert som et pålitelig verktøy i preoperativ planlegging og postoperativ evaluering av pasienter med CP. Denne litteraturoversikten hadde følgende spørsmål: *På hvilke måter kan 3D bevegelsesanalyse brukes, både pre- og postoperativt, for å evaluere pasienter med CP?* **Metode:** Søkemotorer brukt inkluderte Google Scholar, PubMed, og Oria. Søkeord brukt var "3D motion capture", "3D gait analysis", "gait analysis", "femoral neck anteversion", "femoral anteversion", "femoral torsion", "torsion", "femoral derotational osteotomy", "cerebral palsy", og "accuracy." Artikler ble inkludert/ekskludert basert på abstrakt, nøkkelord, og titler. Totalt 7 artikler ble inkludert i litteraturoversikten. **Resultater:** Resultatene viser at 3D motion capture er et allsidig verktøy som kan brukes både for preoperativ planlegging og postoperativ evaluering. 3D motion capture-systemene brukt på sykehus, dog dyre, rapporteres å være nøyaktige og pålitelige. **Konklusjon:** 3D motion capture er et pålitelig og nyttig verktøy som kan brukes både for å vurdere operasjonsbehov og evaluering av operasjonseffektivitet hos pasienter med CP.

Background: Cerebral palsy (CP) is a movement disorder caused by a brain lesion or abnormal brain development in the motor cortex before or early after birth. 3D motion capture systems are often used for gait analysis in clinical settings, and has been reported as a reliable tool in preoperative planning and postoperative evaluation for patients with CP. This literature review had the following question: *In what ways can 3D motion analysis be used, both pre- and postoperatively, to evaluate patients with CP?* **Method:** Search engines included Google Scholar, PubMed, and Oria. Search words used were "3D motion capture", "3D gait analysis", "gait analysis", "femoral neck anteversion", "femoral anteversion", "femoral torsion", "torsion", "femoral derotational osteotomy", "cerebral palsy", and "accuracy." Articles were included/excluded based on the abstract, keywords, and titles. 7 articles were included in the literature review. **Results:** Results show 3D motion capture as a versatile tool that can be used both for preoperative planning and postoperative evaluation. The 3D motion capture systems used in hospitals are expensive, but reported to be accurate and reliable.

Conclusion: 3D motion analysis is a reliable and useful tool that can be used for assessing surgery needs and evaluating surgery efficacy in patients with CP.

Key words: cerebral palsy, 3D motion capture, femoral anteversion, gait analysis

2 INTRODUCTION

Cerebral palsy (CP) is a movement disorder caused by brain lesion or abnormal brain development in the motor cortex during pregnancy, birth, or infancy, and the lesion and subsequent movement issues are permanent (1). The level of impairment differs, depending on the size and localization of the lesion (1). The lesion is non-progressive, but results in progressive musculoskeletal pathologies, such as bony torsion and spasticity of muscles (2). Damage to the motor cortex affects signals sent to the muscles, meaning muscles sometimes not moving as the individual intends to, if at all. In addition, a loss of descending inhibitory input increases the excitability of gamma and alpha neurons. This produces spasticity, defined as excessive, inappropriate, and involuntary muscle activity. Spasticity in CP may cause contractures, pain, and subluxation (3). In developed countries, CP is the most common cause of physical disability affecting children (1,2). An important part of diagnosing a child with CP is assessing which areas of the musculoskeletal system impair the motor skills.

When assessing patients with CP and their gait patterns, 3D motion capture is often used to gain and assess kinematic and kinetic data. Biomechanical 3D motion capture analysis techniques are used both in clinical, sporting, and industry settings (4). A 3D motion capture system typically uses 8-12 infra-red cameras and reflective markers (4). The cameras surround the patient, and the reflective markers are attached to body key-points close to the joint centres where their positions define the segment’s 3D orientation. 3D motion capture is considered the gold standard in measuring human movement, as it has high precision and allows for analysis of motion in multiple planes (4). 3D motion analysis provides quantitative kinematic and kinetic data, and has both pre- and post-operative applications (2). This literature review will focus on using 3D motion capture for 3D gait analysis. Objective data has been reported to be a reliable tool for planning and evaluating surgery plans for patients with CP, and can be used to determine deformities causing disturbances in the gait cycle (5,6).

A typical orthopaedic surgery for patients with CP is to correct femoral anteversion (FAV). FAV indicates the “twist” of the femur, measured in degrees. While FAV varies within the population, children with CP have an FAV that is typically 10% higher than unaffected children of the same age (7). FAV is frequently associated with in-toeing during gait and internal hip rotation. Femoral torsion deformities have also been associated with increased risk of hip subluxation and instability and, to a limited degree, degenerative osteoarthritis of the hip (2). Consequences of a higher FAV for health includes changes in moment arms of muscle groups in the hip and thigh, changed muscle activity, and several orthopaedic pathologies, such as an increased risk of anterior cruciate ligament injury and osteoarthritis. The shorter hip extension moment arm together with the longer hip flexion moment arm that we see with increased FAV are consistent with the gait pattern in individuals with cerebral palsy (7).

There is an increased prevalence of lower-limb deformities in people with CP, and children with CP often have large kinematic and kinetic deviations in gait. Gait disturbances are often a combination of torsional deformity and neuromuscular control. Untreated CP often results in a decrease of functional and walking ability. Treatment including surgery has been found to improve both gait pathology, gait efficiency, and functional walking ability (8). Most children with CP go through surgery to improve quality of life. The majority of corrective surgeries are so-called single-event multilevel surgery (SEMLS), where surgeons perform several corrective surgeries during just one procedure (9). This is because patients with CP typically need several corrective surgeries. Performing them in a single event rather than over several sessions saves rehabilitation time for patients and resources for the hospital (10).

A FAV that indicates torsional deformities in the bone structure requires bony surgery. Femoral derotational osteotomy (FDO) is used to correct bony torsion and is a part of most SEMLs performed. FDO can be performed on both the proximal and distal part of the femur (2). Proximal FDO is performed in either the subtrochanteric or the intertrochanteric region, while distal FDO is performed at the supracondylar region. Distal FDO is quicker and less invasive, as it does not require dissection of hip musculature (2). Soft tissue surgeries are also part of SEMLS and include surgeries such as lengthening of tendons to correct muscle contractions and tendon transfers for imbalance between muscles (10).

Whether or not surgery is required depends on whether an anatomical deformity is present, and its functional impairment of gait. The anatomical deformity can be confirmed using medical imaging, for instance a computed tomography (CT) scan. The functional impairment on gait is often assessed both visually, with a clinician assessing video footage of the gait cycle, and through 3D gait analysis. (2). Gait analysis and kinematic and kinetic data from 3D gait analysis is not an accurate method in assessing anatomical deformities. However, a study has shown 3D gait analysis to be a very useful tool for surgeons when deciding if the patient may need bony or soft tissue surgeries, and in that case which surgeries should be performed (5). After surgery, 3D gait analysis is frequently used to assess the efficacy of the corrective surgery, for example how much the FAV is corrected after an FDO (11).

Through a literature search, this review will examine how 3D motion capture could be used in preoperative and postoperative evaluations in patients with CP. The research question of this review is: *In what ways can 3D motion analysis be used, both pre- and postoperatively, to evaluate patients with CP?*

3 METHODS

The literature search was done mainly on the databases of Pubmed and Oria. In addition, more general searches were done on Google Scholar for an overview of the subject. Search words used included “3D motion capture”, “3D gait analysis”, “gait analysis”, “femoral neck anteversion”, “femoral anteversion”, “femoral torsion”, “torsion”, “femoral derotational osteotomy”, “cerebral palsy”, and “accuracy.” Articles with titles that concerns the use of 3D gait analysis on patients with CP were picked out. The abstract of each article was read, and the articles with low relevance were excluded. The articles used are briefly described in appendix A.

Table 1: overview of the search terms used when searching for relevant articles to review.

Database	**Search words**	**Total no. of articles found**	**Total no. of articles assessed**	**No. of articles included after reading abstract**
Google Scholar	femoral anteversion 3D gait analysis accuracy	5700	1	1
Google Scholar	Using 3D gait analysis cerebral palsy	28700	3	1
Oria	“3D gait analysis”, “cerebral palsy”, “femoral torsion” OR “femoral neck anteversion” OR “femoral anteversion”	438	4	1

Oria	"cerebral palsy" AND "gait analysis" AND "femoral derotation osteotomy"	150	2	1
PubMed	"3D gait analysis" OR "3D motion capture" AND "cerebral palsy" AND "kinematics"	122	3	1
PubMed	"cerebral palsy" AND "kinematics" AND "torsion"	34	3	2

4 RESULTS

Most of the studies had different research questions; see appendix A for a summary of each study's research question. However, all the chosen studies use or include 3D motion capture systems to assess their study's aim. The studies' respective results are described in the paragraphs below, with the source number for the study following each subheading. Articles 1 through 5 detail results relevant for 3D motion analysis in preoperative considerations, while article 6 and 7 detail postoperative uses for 3D motion analysis.

4.1 ARTICLE 1 AND 2, (5,12)

Both articles assessed changes made in surgery plans after consulting computerized gait analysis. In article 1, changes were made in 52% of the patients, while article 2 found a mean agreement of 62% between primary clinical proposals and the subsequent surgery done. In addition, article 2 reviewed improvement of measured parameters related to the surgeries, this was not considered in this review. In article 1, more surgery was recommended in 21 cases, less surgery in 24, and changes in surgical without changing the number of surgeries was recommended in two cases. There was a net decrease in the number of procedures of 22 after consulting 3D gait analysis data. Changes in recommendations happened most frequently in rectus femoris transfer (17%), hamstring lengthening (15%), gastrocnemius lengthening (12%), femoral derotational osteotomy (12%), and tibial derotational osteotomy (8%). The most increase in surgical recommendations was found for the gastrocnemius and rectus femoris (59% and 65%, respectively). A decrease in surgical recommendations was found for the hamstrings (61%), psoas (78%), adductors (83%), femur (86%), and tibia (64%).

4.2 ARTICLE 3, (6)

There was slight agreement between observational and quantitative gait analysis for ankle dorsiflexion at initial contact and hip adduction at loading response, with kappa score (*k*) at 0.01–0.10 and 0.15–0.12, respectively. There was slight to fair agreement for hip rotation at mid stance (*k* = 0.13–0.36), and fair for hip extension at terminal stance (*k* = 0.31-0.24), knee position at initial swing (*k* = 0.35–0.21), pelvic rotation (*k* = 0.22), and knee position at terminal stance (*k* = 0.35–0.33). A slight to moderate agreement was found on hip rotation at mid stance (*k* = 0.13–0.49), moderate agreement for pelvic obliquity (*k* = 0.51), and moderate to substantial agreement for knee position at initial contact (*k* = 0.65–0.47). The overall agreement was highest for knee position at initial contact with 96.08 – 88.24% agreement, and smallest for ankle dorsiflexion at initial contact with 33.33 – 35.29% agreement.

4.3 ARTICLE 4, (13)

A low correlation between torsion angle measured by CT (FAV and tibial torsion) and gait kinematics on the femur (FAV and hip rotation), the correlation coefficient being 0.30. A high correlation regarding the tibia was found (tibial torsion and knee rotation on kinematic results), with a correlation coefficient of 0.62. The kinematic data showed high correlation with physical examination (hip rotation and external rotation), showing a correlation coefficient of 0.72 between knee rotation and thigh-foot angle, and 0.80 between FAV and hip external rotation.

4.4 ARTICLE 5, (14)

The results identified two different pathological groups; group 1, who had patients with FAV higher than normal values and normal rectus femoris (RF) spasticity; and group 2, who had normal FAV and high RF spasticity. Data on the hip joint revealed limited flexion at initial contact with the ground, in addition to reduced capacity of extension during midstance in both groups. Both groups had excessive knee flexion at contact and reduced capacity of the knee flexion during swing (KFSw) index. There was found a significant difference in (KFSw); group 1's KFSw timing were close to normative data, while group 2 showed a delay in their KFSw timing. Analysing ankle kinematics revealed that both groups were similar; they both had a normal ankle position at initial contact, good dorsal flexion when standing, and reduced plantar flexion at toe-off. All patients showed normal foot orientation.

4.5 Article 6, (11)

Both groups showed 50% of the surgical derotation in foot progression angle post-surgery. Foot rotation was not affected by FDO in any group, and neither was pelvic rotation.

In the unilateral group, there was found a mean decrease of 22.8° on internal hip rotation after derotational correction of 25°. For external hip rotation, there was a mean increase of 27.1°, almost equal to the surgical derotation (25°). The hip joint was externally rotated by 14.8% after surgery. FDO had no effect on knee rotation in the unilateral group. The total pelvic rotation range was not significantly altered (16.0°-15,7°).

In the bilateral group, the internal hip rotation had a mean decrease of 24.4°, which was almost the same as the mean correction of 24.6°. The external hip rotation had a mean increase of 16.6°, almost two-thirds of the surgical derotation (24.6°). The hip joint was externally rotated by 6.7% after surgery. FDO changed the knee rotation by 9.6% in the bilateral group. There was a significant change in the total range of pelvic rotation (21.2°-15.4°).

4.6 Article 7, (15)

For the factor TIME there was found no significant changes. Both sides had smaller mean internal hip rotation, 16.5 ± 14.9° across all legs. The change in the more involved side was 23.0 ± 12.4° while the less involved side had a mean change of 9.9 ± 14.4°. Mean improvement for all legs was 3,3 ± 13.6°, with the more involved legs getting better (10.8 ± 13.0°) and the less involved legs getting worse (-4.2 ± 9.5°).

For the less involved side, 41% were classified as good, 44% as overcorrected, and 15% as undercorrected. For the more involved side, 87% were classified as good and 13% were classified as either over- or undercorrected.

Across all legs the midpoint between passive internal and external rotation of the hip was 21 ± 8° internal rotation. Average change of midpoint was found to be 14 ± 10° for the less involved legs and 16 ± 11° for the more involved legs. Improvement in the midpoint was 12 ± 9° for the less involved side and 14 ± 10° for the more involved side.

5 Discussion

Although the studies had a wide variety of research questions, they all demonstrated a way to utilise 3D motion analysis in the treatment of patients with CP. The studies regarding preoperative and postoperative results were considered separate, but 3D motion capture had high usability in both groups.

Five of the seven studies evaluated use of 3D motion analysis pre-operatively. Three of the studies specifically evaluated the agreement between visual analysis and 3D gait analysis, whereas two of these also assessed how the kinematic data affected what procedures were recommended for the patients. In both of these studies there were incidences of both more and less surgery being recommended, in addition to changes in what surgical procedures should be part of the SEMLS (5,12). This could indicate that patients evaluated without consulting kinematic data could risk having too many, too few or not the right surgeries done, meaning a larger risk of re-operation. A specific and tailored surgery plan means the patient runs a smaller risk of needing additional surgery, which increases lying-in time and need for an additional rehabilitation, which both has substantial costs as well as being taxing for the patient (5,16). The third study, from Kawamura et al., evaluated agreement between visual and 3D gait analysis. The study found that only two points of the gait cycle could reliably be evaluated by visual assessment alone. Most clinical evaluations include a visual gait analysis, which lacks agreeability to the kinematic data presented (6). Observational analysis is often used over 3D motion analysis because of cost and accessibility concerns, but accurate assessment of treatment cannot be achieved by video alone (6). The results show the importance of an objective measure when assessing gait cycles, as the subjective assessment of video is not reliable enough to base a treatment plan on (5,6,12).

Another pre-operative focused study evaluated the correlation between rotational profile, kinematics, and CT. The study found low correlation between CT and kinematics on the femur, but high correlation on the tibia. In addition, a high correlation between the physical examination and kinematic data was found (13). These results indicate that physical examination and gait analysis often agree. Adding 3D gait analysis in the pre-operative stage, together with physical examination and visual gait analysis, could as such further concretize the planned surgeries in the SEMLS. The last pre-operative study showed how 3D gait analysis can be used to analyse how a high FAV and spasticity gives the patient different pathologies regarding gait and abnormal kinematics in the hip, knee, and ankle. By dividing the study group into two groups with different pathologies, the study found that a higher FAV led to only reduced KFSw, while rectus femoris spasticity led to both reduced KFSw and delayed timing of KFSw (14). Dividing patients into different pathological groups could make it faster and easier to assess the kinematics, as this study suggests there are distinct differences in the kinematic data between the pathological groups. The data might be faster to assess when grouped beforehand, as the physicians will know the most likely pathologies the grouped data will have.

Two of the seven studies chosen used 3D gait analysis post-operatively. The reason for this skewness might be a greater focus on usability of 3D gait analysis pre-operatively, or that post-operative uses lack research. Both studies also evaluated FDO in some way, meaning data on postoperative use compared to preoperative use. One of the two studies used 3D gait analysis to evaluate the mean correction after an FDO. Both foot progression angle and hip rotation were corrected, the amount of correction was about 50% of the surgical derotation angle (11). FDO is very often a part of SEMLS, even though studies argue that this surgical procedure may not always be necessary for the patient (5,12). In the other post-operative study, 3D gait analysis was used to confirm degree of change in the more and less involved leg. For the less involved side, only 41% of corrections were classified as good, while the remaining 59% were either over- or undercorrected. On the more involved side, however, 87% were classified as good (15). These findings illustrate that the less involved side of patients with spastic diplegia does not improve as often as the more involved side. The mean improvement of the more and less involved legs show that the less involved leg did in fact get worse over time after FDO, indicating that using the leg more after surgery may improve the efficiency of the FDO (15). A post-operative evaluation can help determine the effectiveness of the SEMLS, and whether the patient needs more corrective surgery (15). Long-term outcomes show that most patients have lasting improvements, although with some decline, such as decline in peak knee flexion (17).

Depending on the surgeries considered, the use of 3D gait analysis has a significant impact on the pre-operative planning (5,12). Access to objective data from 3D gait analysis helped tailor the surgery plan, both by eliminating, adding, or changing the surgeries that were planned before assessing the kinematic data from 3D gait analysis (5,12). The study from DeLuca et al. noted that rectus femoris transfer was most changed on the surgery plan, as it was added as another surgery in 82% of the cases. Less surgery than was originally intended was mostly recommended for gastrocnemius, psoas, hip adductors, and the femur (5). Visual assessment often fails to recognize the actual reason for perceived torsions and deformities, and after consulting kinematic data, FDO was often removed from the plan (5). Adduction and internal hip rotation may exaggerate the FAV perceived from visual observation when the real issue lies in the abnormality of certain muscle groups surrounding the femur. This removes the need to perform an FDO on the patient (5). 3D gait analysis has been proven useful in the preoperative planning for both psoas tenotomy and rectus femoris transfer, while it was less reliable for hamstring lengthening, gastrocnemius lengthening, and FDO (12). The surgery plan thus seems to benefit from adding kinematic data to the preoperative planning stage, but other means of patient evaluation is needed for precise decision making in choosing surgeries to perform in the SEMLS. Kinematic data can help more accurately pinpoint what is the cause of the patient's symptoms, reducing the risk of a patient needing several corrective surgeries in the case that the first SEMLS caused over- or undercorrection of FAV, or possibly neglected soft tissue surgeries, such as adduction and internal hip rotation surgery replacing an FDO, as previously mentioned.

Postoperatively, 3D gait analysis seems useful for determining how effective an FDO is at correcting the FAV of the patient. However, as patients with CP often have issues with spasticity in addition to abnormal FAV, soft tissue surgery would also be necessary for properly correcting gait (3). The very narrow look on surgery effectiveness of the two postoperative studies could mean that other surgeries' contribution to the total improvement of gait is, at least partially, erroneously credited to FDO alone.

Both pre- and post-operative uses of 3D motion analysis has been illustrated, and the overall results show that 3D motion analysis technology is a reliable tool when used in several different clinical settings. However, some limitations of the studies do appear, the most significant being the small size of the studies (range 19 – 91, mean 37). Larger samples contribute to ensure validity of the results and the reliability of 3D motion capture as a clinical tool (18). The participants of the study are also often restricted to patients at the hospital where the study is conducted, reducing the external validity the studies have. This is a common problem when using 3D motion capture systems, as researchers must sacrifice external validity in return for proper accuracy of measurements (19). Another limitation is the year of publication of some of the studies, particularly the study from Deluca et al. (1997). With all the technological progress made in the last 20 years, the validity of this study depends on the applicability of the results. However, a study from Lofterød et al. in 2008 demonstrates the same tendencies shown in the 1997 study. Thus, the article was deemed reliable for this review (5,12).

Several positives to the use of 3D motion capture technology in clinical settings have been highlighted, but there are also several limitations: First, the cost of the equipment is a rather large limitation, making it inaccessible for many clinics (6). This also poses a challenge for continued studies using 3D motion capture technology, as repeatability of studies using 3D gait analysis will be limited to larger hospitals with access to 3D motion capture systems (6). Studies on different 3D motion capture systems show that, although promising, low-cost alternatives to today's expensive clinical systems lack the accuracy, reliability and support of force platform and electromyography data, which makes them less viable for use in a clinical setting (16). The more expensive systems used in hospitals were made specifically for clinical 3D gait analysis and clinical use, and the high cost reflects both the research and development effort laid into these 3D motion analysis systems (16). Commercial use of 3D motion capture systems contributes to developing better systems at a lower cost for the consumer (19). For the same to happen to the more clinically focused systems, the use of 3D motion capture would likely have to become a standard addition in clinical evaluation of patients. This would in turn make further development easier for the developers and less expensive for the hospitals. Second, and related to the first issue; treatment possibilities for patients may differ depending on how close the patient lives to a hospital with 3D motion capture (6). This could mean that patients must travel far for the most optimal treatment options, which is both time-consuming, expensive, and tiring for the patient. Further development on clinical motion capture systems to make them both more affordable and accessible to smaller hospitals would prevent the travel-time needed for patients. Third, the need for proficient technicians to operate the equipment. Imprecise marker placement and insufficient joint centre localization is the most important error source in 3D gait analysis (15). Properly defining the anatomical coordinate systems for gait analysis is challenging, but methods and equations have been developed to best define the proper anatomical coordinates to use (2). To minimise risk of user error and maintain reliability and validity of the kinematic data gained, trained personnel using a standard protocol for marker placement is needed. Lastly, the amount of soft tissue can affect the accuracy of marker placements, meaning individual differences in terms of soft tissue on the body may be a source of error in the kinematic data (2). This usually happens when capturing dynamic activities, such as gait, and introduces both systemic and random errors (19). To reduce the frequency of such errors, the markers could be more strategically positioned to reduce risk of error due to soft tissue. Refined pose-estimation algorithms and joint angle definitions contribute to the accuracy of marker-based gait analysis (19).

3D motion capture is considered the gold standard when measuring biomechanical parameters (4), but the reflective markers pose a limitation, prone to placement error and soft tissue movement (2). The systems most used in clinical settings, as well as in entertainment and engineering, are the Vicon and Optitrack systems, most commonly the type that uses reflective markers (20,21). A possible future approach features video-based 3D motion capture without the need for reflective markers, thus eliminating the limitations today's systems encounter. Current marker-less systems are not widespread yet, and the accuracy of these systems needs to be studied more to ensure proper validity and accuracy (19). Error ranges tend to be larger with the marker-less solutions (20). Marker-less systems are prone to blur motion because of relative low resolution and frame rate (22). Marker-based motion capture could prove more viable in clinical settings, especially in cases where detailed kinematic analyses are required (22). Physicians typically review video of their patient as a qualitative analysis, in addition to the objective kinematic data provided by the 3D motion capture and the physical examination (2). As such, it is possible for the video-based, marker-less systems to provide quantitative data in addition to the qualitative analysis made by physicians. As marker-less options continue to be developed with greater accuracy and reliability, researchers could possibly design studies without having to choose between the accuracy from laboratory-based systems and the external validity of field-based analyses (19).

6 CONCLUSION

3D motion analysis is both reliable and useful in a clinical setting, and can be used both for assessing surgery needs and evaluating efficiency of especially FDO in patients with CP. However, no data apart from evaluation of FDO efficiency was found for postoperative assessment. More research is needed, especially on the postoperative applications of 3D motion analysis.

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8 APPENDICES

APPENDIX A

Table 1: details about chosen articles, starting with the source no., as placed in the reference list. Author, year, keywords from the study's abstract, and purpose of study is described.

Source no.	Article no.	Author	Year	Keywords	Purpose of study
(5)	1	DeLuca, P. et al.	1997	Cerebral palsy, clinical decision making, gait analysis	Comparing surgical recommendations made before and after adding kinematic, kinetic, and electromyographic (EMG) data.

(12)	2	Lofterød, B. & Terjesen, T.	2008	N/A	Assessing the recommendation changes made to the surgery plan, as well as outcome of surgery in children with CP that are ambulant when the orthopaedic surgeons followed the recommendations from preoperative 3D gait analysis.
(6)	3	Kawamura, C. M. et al.	2007	Cerebral palsy, spastic diplegia, gait analysis, gait laboratory, visual gait assessment	On a population of patients with spastic diplegic CP, the inter-observer reliability in observational gait analysis was tested, determining its correlation to a method of quantitative gait analysis, and to identify existent correlations between studied parameters. Lastly, transposing the result to clinical practice, determining which aspects of the gait points of interest require a quantitative method for appraisal.
(13)	4	Kim, H. Y. et al.	2017	Torsion, rotational profiles, kinematics, cerebral palsy, gait	Analyzing the correlation between bony torsion measured by Staheli’s rotation profile, CT, and gait analysis in patients with CP.
(14)	5	Cimolin, V. et al.	2010	Cerebral palsy, femoral anteversion, gait analysis, rectus femoris spasticity, rehabilitation	A quantitative comparison of gait strategy used with stiff knee gait, caused by rectus femoris spasticity versus caused by femoral anteversion.
(11)	6	Kim, H. Y. et al.	2018	Cerebral palsy, femoral derotational osteotomy, medial femoral torsion	Quantifying the change in different gait parameters after FDO.

(15)	7	Dreher, T. et al.	2006	Cerebral palsy, gait analysis, femoral derotation osteotomy, overcorrection, undercorrection, asymmetry	Assessing under- and overcorrection following FDO in spastic diplegic children with internally rotated gait that is compromising to function, especially considering asymmetry.