THE ROLE OF GAIT ANALYSIS FOR FUNCTIONAL SURGERY IN BRAIN DAMAGED ADULTS: A NARRATIVE REVIEW

GAIT ANALYSIS FOR FUNCTIONAL SURGERY IN ADULTS

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Abstract

The aim of this narrative review was to summarize the use of Gait Analysis for lower extremity functional surgery in adult patients with upper motor neuron lesions. The research for articles was conducted on Medline database from 1980 to June 2020 and involved studies of adult patients with gait disorders who had undergone functional surgery on the lower limb evaluated with Gait Analysis. Selected articles were firstly classified by design and then divided into two groups according to their research question and content: decision-making for surgical treatment and assessment of outcome. 35 studies out of 1637 articles identified in our search met the eligibility criteria and were included in the review. 25 articles were considered for “decision making” group, and 14 articles for “assessment of outcomes”. The literature analyzed indicates evidence for the influence of Gait Analysis on functional orthopaedic surgery planning, whereas it is not possible to assert that the use of Gait Analysis can improve the outcome. Gait Analysis is also largely utilized to compare pre-post operative gait and has turned out to be an helpful instrument, for a quantitative and reliable assessment of activities in adult patients submitted to functional surgery.

Key words: Gait Analysis, Surgery, Decision Making, Outcome, Adult.

Introduction

Instrumented Gait Analysis (GA) is a widespread technology which is widely applied in several medical areas such as rehabilitation, biomechanics, physiology, orthopaedics and sports medicine for both clinical and research purposes. GA is defined as a process of instrumented measurement and evaluation of walking ability in patients with impairments specific to locomotion [1]. GA requires theoretical knowledge in different fields (biomechanics and neurophysiopathology of human movement), but also practical skills to apply the different techniques adopted for data recording, analysis and interpretation, as well as for assessment, preparation for data processing and representation [1]. Consequently, a large number of different health professionals usually work in a GA laboratory, namely: Physiatrists, Orthopaedists, Neurologists or Sports Medicine physicians, Physiotherapists, Psychomotor Developmental Therapists, Occupational Therapists, Biomedical Engineers, Human Movement scientists/Kinesiologists. By Clinical GA we mean the clinical evaluation of the lower-limb impairment combined with the assessment of spatial-temporal (ST) parameters, kinematics, kinetics and the recording of lower-limb muscle activity during gait. This is usually carried out through a stereophotogrammetric system together with force plates and dynamic electromyography (dEmg), which uses surface or fine-wire indwelling electrodes. Information from Clinical GA allows us to obtain a complete description of gait in relation to spatial-temporal parameters of the gait cycle, activation timing of lower limb muscles, kinematics and dynamics of different planes and joints. In Clinical GA all measurements and the process are always finalized from the beginning to support functional decision making [2]. One of the main clinical applications of GA is the assessment of gait disorders following lesions to the central nervous system in order to understand better the causes of gait abnormalities (degree of muscle activation, muscle cocontraction, exaggerated stretch-reflex, joint deformities and instabilities) and therefore to answer questions subtending clinical decisions and/or monitoring the level of activities or the outcome [3,4].

A wide range of studies describing the use of GA in cerebral palsy (CP) patients for functional diagnosis and decision making regarding functional surgery [5, 6, 7, 8, 9, 10] confirmed that GA may be useful in providing indications for surgery not previously clinically proposed, and in excluding or delaying surgery that was clinically proposed. However, the same considerations cannot be extended to adults because of the low level of evidence supporting the efficacy of clinical GA for this group of patients [11].

The role of GA for functional surgery in adult patients with disabilities resulting from acquired lesions of the central nervous system is still under debate and scientific reports in the literature are scarce and infrequent. Therefore, a deeper understanding of this topic may be useful to provide a broader view of the current state of the art. This study aims to shed light on the actual use of GA for lower extremity functional surgery in adult patients with upper motor neuron lesions through a narrative review of the literature.

Methods

The following search strategy was used:

1 - We relied on Medline database for our article search using the following key words: Rehabilitation OR Functional Surgery OR Orthopaedic Surgery OR Stroke OR Traumatic Brain Injury OR Decision making OR Equinovarus OR Spasticity. These search terms were then all combined with (Movement Analysis OR Gait Analysis) AND Surgery.

2 - Articles were considered eligible for the review if they were in English, published from 1980 to June 2020 and if the subjects of the studies were adult patients with gait disorders as a result of cerebral vascular lesions who had undergone functional surgery on the lower limb and were evaluated with GA. All records not fulfilling such eligibility criteria (e.g. different study population or grey literature) were not included in the article selection.

3 - Articles were screened for eligibility first by titles, then by abstracts and subsequently by reading the full text. Additional records were then added to the original search from relevant references in the articles selected, or from personal communications with experts in the field.

Selected articles were firstly classified by design (RCT, prospective or retrospective observational studies, case reports, editorial of experts in the field). We also included articles where Clinical GA was not the main focus of the study but where its use was considered in the context of a broader analysis in relation to functional surgery. In addition, the following data were extracted and utilized for the evaluation of every study: aim of the study, sample size and population, parameters used in GA, data analysis, results and conclusions. All selected articles were then classified into two groups according to their research question and content:

1. decision-making for surgical treatment,
2. assessment of outcome.

Article research and first title screening was extracted by one reviewer, subsequent abstract and text screening was then analysed by 3 reviewers. Data extraction was then performed independently by all reviewers.

Results

1637 articles were identified in our search. Of these, only 35 studies met the eligibility criteria and were included in the review [Figure 1].

[Figure1]

Most of the articles (25) focused on the impact of gait analysis on clinical decision-making and were included in the "decision making" group. 14 articles were categorised as "assessment of outcomes". Four of the 35 articles fit into both categories. [Table I].

[Table I]

The different parameters of GA utilized for clinical decision-making and clinical outcome are reported in Table II. As expected, different indicators of Gait analysis are utilized across the two categories. Specifically, dEmg is the most used indicator in studies focused on Decision Making and the least analysed in Outcome studies. On the other hand, ST parameters are frequently used with kinematics and kinetics to assess the results of surgery and are less common for surgical planning [Table II].

[Table II]

In Table III are summarized the papers selected and the main characteristics for each study, the papers defined as editorial have been excluded from the table considering their low utility in evidence based medicine.

[Table III]

Decision-Making

Twenty-five articles reported the impact of gait analysis on clinical decision-making and surgical planning of lower limbs in adult patients with UMN syndrome. Out of these, only five studies, two prospective observational [12, 13] and two case reports [14, 15] and one evidence based article [16] focused on the influence of gait analysis upon surgical planning and, therefore, fully matched the aim of this review. All the other studies did not have the evaluation of GA for surgical planning as their main objectives.

Regarding these five articles, Fuller et al.[12] had a three fold aims: i) the impact of gait analysis (pre vs. post) on a given patient's surgical treatment plan; ii) whether the use of gait analysis can increase the level of agreement regarding surgical planning of two surgeons with different levels of experience; iii) whether the level of competence of surgeons influences the utility of gait analysis. The results evidenced firstly, a contribution for GA (dEmg, kinematics and kinetics) in influencing surgical planning, and, secondly an increased agreement between surgeons after GA. The other observational study [13] assessed the significance of changes between pre and post GA recommendation related to clinical decision-making. The authors recorded an agreement between pre and post GA recommendation of 17% for surgery, 42% for Botulinum Toxin (BT), 63 % for orthosis, and 81% for physiotherapy. Furthermore, the total number of surgical recommendations decreased from 31 to 23. In a single case report, De Vries et al. [15] described how the use of multi-segment kinematics of foot motion during gait can influence and direct the decision during the surgery. An intraoperative review of kinematics and its deviation during gait cycle was used to help the decision regarding the possible rule of tibialis posterior in foot deviation and to guide the surgeon's decision. Consequently, the planned transfer of the Tibialis Posterior tendon to reduce the hind foot varus deformity was deemed unnecessary compared to a previous decision after a clinical assessment. In fact, a forefoot driven hindfoot varus was evident with kinematics analysis. Perviously, Forese et al [14], in three case reports underlined the use of dEmg in determining the phasic firing of the muscles during gait cycle in order to help the surgeon to plan corrective surgery for equinovarus deformity. Finally, one recent evidence based article [16] provided recommendations related to the utility of instrumented Gait Analysis to alter clinical decision-making and improve clinical outcome.

As for the remaining articles, in four observational studies [17, 18, 19, 20] the principal aim was to describe and verify the efficacy of a specific surgical approach to correct equinus, equinovarus or stiff knee gait deviations. In all these cases, preoperative gait analysis in addition to physical examination of the patients was considered useful to select surgical candidates, determine which muscles are responsible for the foot deformities and define surgical procedures.

In 10 articles, presented as editorial or reviews [21-30], the typical gait deviations in patients following stroke and/or TBI, or the different surgical approach of gait deviations were described. In these articles, the use of GA was variously considered but in any case the contribution of GA for surgical planning through alterations in dEmg, kinematics and kinetics for every kind of ankle or knee deviation was underlined. However, all the articles described as reviews do not have the features of a synthesis of published literature on a topic but tend to suggest behaviour guidelines. In four observational studies [31-34], one editorial [35] and one case report [36] the use of GA results were only mentioned in a broader context related to functional surgery. No RCT study was found in the literature investigated regarding GA use for decision making in adult patients with upper motor neuron lesions.

Outcomes

Fourteen articles reported the role of GA to assess the outcome after lower limb functional surgery in patients with UMN syndrome.

The only RCT study [37] reported the use of instrumented GA as a gold-standard method to assess and compare the outcomes between selective neurotomy versus botulinum toxin for treatment of spastic equinovarus foot. The outcomes revealed a significant improvement in two kinematic parameters (maximal dorsal flexion during the stance and swing phase) with no differences in either treatment, and no changes were recorded for the kinetic parameter related to propulsion.

In the nine observational studies, GA was applied to: 1) verify the feasibility of new surgical techniques [33, 38], 2) evaluate results of the soleus or rectus neurotomies [39, 40], 3) assess the effect of proximal or distal surgical correction on gait disability [41, 42], 4) test the efficacy of early post- surgery rehabilitation [34, 43] and 5) assess surgical efficacy with a new protocol of kinematics [44].

Four observational studies were prospective and two of them concerned the use of neurotomies. Decq et al. [39] used kinematics and ST parameters to verify the efficacy of a selective soleous neurotomy in a mixed sample of 46 patients (Stroke, TBI, PCI, MS); thanks to an adequate sample size the results are supported by a statistical analysis. Gross et al. [40] evaluated the effect of selective neurotomy of the rectus femoris nerve on unilateral spastic SKG, the study must be given credit for considering kinematics, kinetics, ST parameters and dEmg timing describing an improvement in most of the different parameters, however, the limited number of the patients described does not allow any statistical analysis. Nonnekes et al. [38] used GA to evaluate whether a tarsal fusion improved barefoot walking capacity in chronic stroke patients with an equinovarus deformity. Even if an improvement in gait capacity and ST parameters was recorded, the sample size is, however, limited. Another prospective study [34] aimed to assess the trend of changes in kinematics and ST parameters after functional surgery followed by an early rehabilitation programme. In 24 post-stroke hemiplegic patients, kinematics and ST parameters were analyzed, and a significant difference between post-surgery follow-ups and pre-surgical values was recorded; a similar observation in a retrospective study on a larger sample [43] supports the same parameters of outcome and results.

Other four retrospective studies confirm the usefulness of GA in assessing the outcome of extensor hallucis longus transfer as an alternative treatment to split transfer of the tibialis anterior tendon in patients with an equinovarus foot [33], in obtaining quantitative evidence of the effect of rectus femoris transfer surgery on improving gait following stroke or traumatic brain injury [41] as well as in evaluating whether surgical correction of fixed equinovarus foot deformity improves gait function and is safe and effective with regard to gait function and disability [42]. In this last study, 177 subjects were evaluated, and ST, kinematic and kinetic parameters showed a significant improvement.

In three case reports [14, 45, 46] the use of GA was described to verify the changes brought about by functional surgery. The main aim of one of these works [46] was to study the changes in kinetic and kinematic parameters in the gait of hemiplegic patients with an equinovarus foot deformity. Deltombe et al. [45] moreover demonstrated an improvement in ST, kinematics and kinetic parameters with follow up at 2 years after a selective tibial nerve neurotomy. Only in one editorial was there merely a citation about the possible use of GA to verify the improvement in gait after functional surgery [28].

Discussion

Decision-Making

Of Thirty-five articles selected from the literature, 25 described the use of GA for surgical decision-making. Most of the articles are editorials or reviews by experts for whom the use of GA for surgical decision-making is part of daily clinical practice; they are often useful educational articles regarding single gait deviations and their treatment, or they are discussions of the various steps in the decision-making process (from physical and instrumental evaluation up to surgical planning) [21-30]. Furthermore, most of these authors refer to a group of researchers, surgeons, bioengineers, physicians, physiotherapists [4, 47-49], who developed the use of instrumental GA and applied it in clinics and surgery from the seventies to the nineties of the last century. The same authors are quoted as references in the evidence based article by Carollo et al. [16] that provides recommendations for instrumented Gait Analysis methods that may alter clinical decision-making and improve clinical outcome. Therefore also the Carollo et al. article evidence refers to the opinion of expert authors with long experience and competence who took biomechanical principles and refined them for clinical use in stroke, spinal cord injury, TBI, CP, and congenital joint abnormalities at their respective laboratories [4, 48].

Most of the other articles are observational studies. We found only two prospective studies with a consistent sample size and statistical analysis of the results as well as a declared aim to determine the influence of gait analysis upon decision-making. In the study by Fuller et al. [12] only patients with spastic equinovarus deformity were investigated with the aim to define a surgical plan; the second study, however, [13] analyzed hemiplegic patients with various aetiologies, proximal and distal impairment of lower limbs and different therapeutic hypothesis (surgery, BT, orthosis, physiotherapy). Both studies compared the therapeutic proposals with and without the contribution of GA, and both highlighted how instrumented Gait Analysis (Kinematics, Kinetics, dEmg) has a significant impact on clinical and surgical planning and reinforces decision-making for post-stroke patients.

These results do not allow us to state that surgical treatment using GA leads to improved therapeutic outcome. Although we are unable to make such a statement, we must consider that in the decision-making process the use of further information and reliable measures can only provide additional help for the clinician to gain a better understanding of the nature and causes of the impairment and gait deviations.

The aim of other retrospective observational studies was not finalized to verify the utility of GA but to describe the instrumented assessment as a normal clinical practice used to help achieve better surgical planning. At least three of these studies [17, 18, 20] underline an exclusive or prevalent use of the dEmg, whereas Keenan [19] includes video record, ground reaction forces, dEmg, ST parameters in order to determine which muscles are responsible for the foot deformities. On the basis of previous experiences, the authors considered how the gait deviation in adult acquired hemiplegia follows an abnormal pattern of muscle firing in equinus, equinovarus and varus during walking [50] and changes with the severity of central nervous system involvement [51]. In this way, they routinely use Laboratory GA to supplement their clinical assessment of the patient and to determine which muscles are responsible for the foot deformities in order to aid the surgeon in planning corrective tendon transfer [50].

Two case report articles differ from each other regarding some gait deviations (equinovarus), while one [14] uses only the dEmg timing to plan a corrective surgery, in the more recent description de Vries et al. [15] use kinematics to guide the surgeon during an intraoperative review of data. In these articles single aspects of instrumental analysis are used with a useful contribution in both cases to surgical planning.

Therefore the most relevant evidence on the role of GA on surgical decision making comes from two studies [12, 13] proving the significant impact of GA on surgical planning for adult patients with results of stroke or TBI. Other observations are based on experts who, in the light of their experience in clinical practice and comparing single gait deviations and instrumental data, (dEmg patterns, kinematics and kinetics) have applied with efficacy the instrumental information for functional surgical planning.

Outcomes

In a lower number of articles (14) GA is used to assess surgical outcome. GA data are frequently used in conjunction with other parameters relating to impairment (spasticity, range of motion) or activities and participation (six-minute walking test, questionnaires). At the same time, the most common GA parameters are kinematics, kinetics and ST parameters that allow us to get a quantitative and available analysis of data compared to qualitative parameters which are often detected manually. Comprehensibly, dEmg data are less utilized for the surgical outcome because the dEmg timing frequently analyzed for the decision making is evaluated qualitatively. Furthermore, among the authors who compared the pre and post-operative dEmg activity, Waters et al. [17] observed, only in six out of twenty-three transferred Tibialis Anterior, a continuous activity preoperatively converted to phasic activity postoperatively, while for Keenan et al. [19] no changes in the dEmg patterns were seen postoperatively. The prevalent absence of changes in the phasic activity of the muscles could be a consequence of either the decreased or absent ability to contract individual ankle muscles selectively in most stroke and brain-injured patients, or the lack of surgical impact on muscles dependent on primitive locomotor synergies [17]. Only patients submitted to neurotomies showed a post-operative decrease in calf muscle activity [40,45]. It was interesting to notice how surgery can determine differently outcomes on GA parameters. A relevant aspect which emerged from the revision of literature using GA as a measure of post-operative outcome is the different impact that surgery may determine on the various parameters of GA. While Nonnekes et al. [38] observed that changes in ST parameters are a sign of improved gait capacity with no evident changes in kinematics, Decq et al. [39] showed how functional equinovarus surgery did not necessarily bring about significant changes in functional aspects like velocity, but rather determined a significant increase in the second rocker joint motion, which impacts on the quality of gait and energy requirement. Instrumental analysis thus allows us to identify the various ways in which surgery can influence gait: either on levels of activity with changes in ST parameters, or on gait patterns and biomechanical aspects which, in their turn, may impact other aspects like energy requirements.

Finally, in the only RCT study found, [37] the use of GA was able to confirm preservation of the triceps surae strength after surgery with the gold standard of GA. In contrast, the absence of significant differences between the two treatments compared (surgery and BT), which was revealed thanks to GA, allowed the authors to consider that BT may be a good test to predict the functional improvement achievable with surgery.

Since the use of GA in support of surgical planning was introduced in the seventies and eighties of the last century in children with CP, a larger number of observations and retrospective cohort studies compared patients with CP submitted to functional surgery with or without the support of GA. The relatively recent consensus conference of The Italian Society of Movement Analysis in Clinics [1] confirmed evidence that the use of GA combined with an expert clinical evaluation can influence the planning of functional surgery in children with CP, leading to modification of the clinical decision [6,7,9-11] and a positive influence on the outcome of functional surgery. In constrast, while evidence for the influence of functional orthopaedic surgery planning, neuromuscular blocks and/or rehabilitation programmes have been confirmed also for adult brain-damaged patients [12, 13], it is not possible to assert that the use of GA can improve the outcome.

A systematic review on the effects of surgical correction of equinovarus foot deformity [52] in patients with stroke or TBI shows that surgery improves walking capacity and diminishes the need for orthotic use, and of the 15 studies selected, 8 used the instrumental assessment for surgical planning and 3 were carried out before our observation date. However, the positive influence on the outcome is not possible to demonstrate in accordance with the results of our study.

Conclusions

GA may be considered to increase our knowledge concerning gait deviations and provide more elements for surgical decision-making in adult patients; its use allows us to learn more about the consequences of brain lesions on gait and can influence surgical planning. At the moment there are no randomized controlled trials to test whether the support of GA in the decision-making process, increases the benefits of surgery.

The main reason for this limit is about whether it is ethical to submit a control group to surgery without instrumental assessment.

GA is largely utilized to compare pre-post operative gait and has turned out to be a good tool for a quantitative and reliable assessment of activities in brain-damaged adult patients submitted to functional surgery.

To date, Campanini et al. [53] have analyzed some of the cultural, formational and technical aspects which may be limiting the routine use of instrumental analysis for surgical and clinical decision-making.

Prospective cohort studies with long-term observation and cost benefit analysis should also be planned and organised.

Authors' contributions

All authors have given substantial contributions to the conception or the design of the manuscript, Francesco Manca to literature search, Giovanni Ferraresi and Michela Cosma to analysis of literature, Mario Manca has participated to drafting and revision of the manuscript. All authors read and approved the final version of the manuscript.

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Indications of the Single Studies	Total Number of References	RCT	Observational Studies	Case Report	Evidence Based	Review Editorial
Decision Making	**25**	0	10*	3	1	11
Outcome	**14**	1	9**	3	0	1

Table I. The studies finally selected were divided for their different efficacy and their characteristics related to decision making or evaluation of post-operative outcome. In some studies both the objectives were considered (* 6 prospective and 4 retrospective ; ** 4 prospective and 5 retrospective)

Indications of the Single Studies	Dynamic Emg	Kinematics	Kinetics	Spatio-Temporal Parameters
Decision Making	24	17	17	2
Outcome	2	14	9	9

Table II. Different aspects of Gait analysis utilized for decision making or evaluation of post-operative outcome in the examined articles.

Study	O	D	Aims of the Study	S	Patients	Assessment	Role of Gait Analysis
Waters RL et al. 1982 [17]	**DM**	**Ps**	To document influence of surgery on muscle action patterns in patients	A	20 Stroke 5 TBI 2 Tumor	dEmg	Surgery of tendon transfer planned on the basis of dEmg findings.
Pinzur MS et al. 1986 [18]	**DM**	**Ps**	To evaluate the impact of correction on ankle equinus deformity in gait	A	36 Stroke 16 TBI 2 Tumor	dEmg and Kinematics	Use of preoperative dEmg and kinematics in order to assist in planning surgical procedures.
Forese L et al. 1993 [14]	**DM** **Out**	**CR**	To illustrate the principles surgical management of EV deformity	A	3 TBI	dEmg	Preoperative dEmg is helpful in determining the firing of the muscles and helps the surgeon to plan corrective surgery
Keenan MA et al. 1999 [19]	**DM**	**Ps**	To describe and evaluate a new surgical procedure of tendon transfer	A	28 TCE 22 Stroke 5 Other	video recording, dEmg, Kinematics, Kinetics, ST parameters	The decision regarding surgical procedures is based on GA (to determine which muscles are responsible for the foot deformities)
Decq P et al. 2000 [39]	**Out**	**Ps**	To evaluate the results of a soleus neurotomy for treatment of spastic equinus	A	18 Stroke 15 TBI 8 PCI 5 MS	Kinematics ST parameters	Kinematics prove the change in quality of walk with an improvement in the range of ankle motion during the stance phase of gait.
Fuller DA et al. 2002 [12]	**DM**	**Ps**	To determine the impact of instrumented GA in surgical planning	A	14 Stroke 16 TBI 5 Other	dEmg, Kinematics, Kinetics	Instrumented GA has a significant impact on surgical planning.
Buurke JH et al. 2004 [36]	**DM**	**CR**	To study the feasibility of remote consultation to determine surgery	A	12 Stroke	video recording, dEmg	Suitability for surgery is determined using GA with video recording and surface dEmg
Deltombe T et al. 2006 [45]	**Out**	**CR**	To assess improvement in gait after tibial neurotomy performed in EV	A	3 Stroke	dEmg, Kinematics, Kinetics, ST parameters	Kinematic and kinetic variables of gait are permanently improved after neurotomy
Reddy S et al. 2008 [31]	**DM**	**Rs**	To determine impact of surgery on ambulatory ability and use of nonoperative therapies.	A	26 Stroke	dEmg, Kinematics	The final decision to perform a surgical procedure is based on dEmg and clinical evaluation.
Hosalkar H et al. 2008 [32]	**DM**	**Rs**	To evaluate different techniques for SPLATT procedure	A	47 TBI	dEmg	Preoperative dEmg are part of the normal preoperative workup
de Vries G et al. 2009 [15]	**DM**	**CR**	To examine whether kinematic data aids in surgical planning for foot/ankle disorders	A	1 Stroke	Kinematics, ST parameters	Motion capture data provides clinicians with detailed information on kinematic of foot motion during gait, before and during surgery
Carda S et al. 2009 [42]	**Out**	**Rs**	To evaluate if surgery of Equinus deformity can improve gait function	A	177 Stroke	Kinematics, Kinetics, Power, ST parameters.	Significant improvement in ankle Kinematic, Kinetic and ST parameters after surgery
Namdari S et al. 2010 [20]	**DM**	**Rs**	To describe a surgical technique and report on initial outcomes.	K	29 Stroke 8 TBI	dEmg , Kinematics, Kinetics	dEmg is used preoperatively to assist in selecting surgical candidates

Carda S et al. 2010 [33]	**DM Out**	**Rs**	To assess if EHL transfer could be an alternative treatment to SPLATT	A	203 Stroke	dEmg, Kinematics, Kinetics, ST parameters	Operative plan tailored to each patient according to clinical and instrumental data. Improvement in kinematic and ST parameters and after surgery.
Benedetti MG et al. 2011 [44]	**Out**	**Rs**	To assess the clinical value of a new protocol for 3D analysis of ankle in patients with EV foot.	A	11 Stroke 2 TBI 2 SCI	Kinematics	To assess a new protocol in the specific clinical context of foot and ankle surgical treatments.
Bollens B et al. 2013 [37]	**Out**	**RCT**	To demonstrate that neurotomy is at least as effective as BTX injections in patients with EV foot	A	16 Stroke	Kinematics, Kinetics	Ankle kinematic assessment allows us to verify the improvement in two different treatments (neurotomy and btx)
Ferrarin M et al. 2015 [13]	**DM**	**Ps**	To assess the impact of GA on clinical DM	A K	49 Stroke	dEmg, Kinematics, Kinetics	GA significantly influences the therapeutic planning and reinforces decision making.
Kidate I et al. 2015 [46]	**Out**	**CR**	To discuss changes in kinetic and kinematic parameters in gait of a patient with an EV foot deformity using 3D GA.	A	1 Stroke	ST parameters, Kinetics, and Kinematics.	Measurement of ST, kinetic, and kinematic gait parameters using 3D GA systems might aid decisions regarding the optimal post-neurotomy rehabilitation strategies.
Giannotti E et al. 2016 [46]	**Out**	**Rs**	To analyze safety, adherence and gait changes after EV foot surgery and early rehabilitation treatment.	A	47 Stroke	ST parameters, Kinematics	Kinematic and ST parameters are used to evaluate safety and adherence to a specific rehabilitation protocol in the early post-surgical phase.
Gross R et al. 2017 [40]	**Out**	**Ps**	To evaluate the effect of n. rectus femoris neurotomy on SKG.	K	3 Stroke 4 SCI	dEmg, ST parameters, Kinematics, Kinetics.	Improvements in kinetic, kinematic, and ST parameters are used to verify the efficacy of neurotomy in patients with spastic SKG
Vermeiren A et al. 2019 [41]	**Out**	**Rs**	To provide evidence of the effect of RF transfer on improving SKG	K	8 Stroke 2 TBI	dEmg, ST parameters, Kinematics, Kinetics.	Significant improvements in some ST, kinematic, kinetic parameters are verified after surgery.
Nonnekes J et al. 2019 [38]	**Out**	**Ps**	To evaluate whether surgery of EV improves gait capacity.	A	10 Stroke	ST Parameters, Kinematics and Kinetics.	Improvement in ST Parameters, except kinematic and kinetic after surgery.
Giannotti E et al. 2019 [34]	**DM Out**	**Ps**	To determine the long term safety and efficacy of functional surgery followed by early rehabilitation	A	24 Stroke	Kinematics, ST parameters	Kinematic and ST parameters are used to determine the long term safety and efficacy of functional surgery followed by early rehabilitation

Table III. Selected papers and main characteristics for each study. The papers considered as editorial were excluded from the table because of their low evidence based significance. (Abbreviations: O, Objectives; D, Design; S, Site of Surgery; DM, Decision Making; Out, Outcome; Rs, Retrospective study; Ps, Prospective study; CR, Case Report; RCT, Randomized Controlled Trial; A, Ankle; K, Knee; EV, Equinovarus; SKG, Stiff Knee Gait; EHL, Extensor Hallucis Longus; SPLATT, Split Anterior Tibialis Tendon Transfer). In the articles the term GA may include all investigations (dEmg, ST parameters, Kinematics, Kinetics) or single investigations like dEmg.

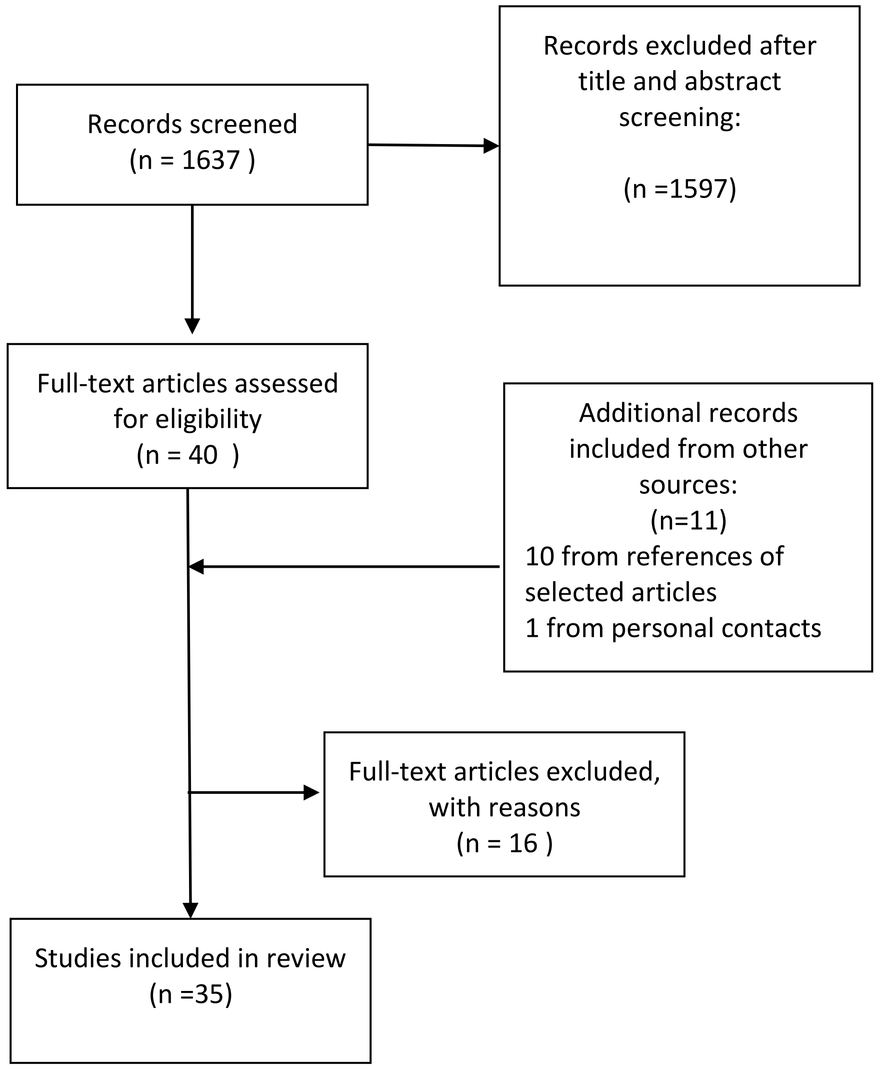

Fig. 1 - Results of Research