UNIVERSITÉ DE GENÈVE

Archive ouverte UNIGE
https://archive-ouverte.unige.ch

Thèse de privat-docent 2024

Open Access

This version of the publication is provided by the author(s) and made available in accordance with the copyright holder(s).

Clinical decision making and efficacy of orthopaedic surgical procedures for the restoration of locomotion

Bonnefoy, Alice

How to cite

BONNEFOY, Alice. Clinical decision making and efficacy of orthopaedic surgical procedures for the restoration of locomotion. Privat-docent Thesis, 2024. doi: 10.13097/archive-ouverte/unige:183602

This publication URL: https://archive-ouverte.unige.ch/unige:183602
Publication DOI: 10.13097/archive-ouverte/unige:183602

© This document is protected by copyright. Please refer to copyright holder(s) for terms of use.

UNIVERSITÉ DE GENÈVE

FACULTÉ DE MÉDECINE

Clinical Medicine Section
Department of Surgery

Division of Orthopaedics and Trauma Surgery
Willy Taillard Laboratory of Kinesiology

"Clinical decision making and efficacy of orthopaedic surgical procedures for the restoration of locomotion"

Thesis submitted to the Faculty of Medicine of the University of Geneva

for the degree of Privat-Docent

by Alice BONNEFOY-MAZURE

(*Geneva*)

(2023)

Acknowledgements / Remerciements

Il n’y a pas de recherche sans curiosité, questionnement, imagination, connaissances, sens critique, ouverture d’esprit, humilité, lenteur, mais il n’y a pas de recherche non plus, sans une équipe multidisciplinaire soudée, ouverte aux discussions et sans soutien humain et financier, bien sûr... J’ai la chance de travailler dans un tel environnement d’où plusieurs remerciements !

Dans un premier temps, je remercie de tout mon cœur le professeur Stéphane Armand pour sa confiance, son soutien sans faille et pour le temps qu’il a toujours accordé et trouvé pour nos discussions. Merci pour tout et surtout, merci pour notre belle amitié tissée depuis maintenant de nombreuses années. Quelle chance !

Je ne peux pas poursuivre ces remerciements, sans enchainer directement avec mon collègue et ami, le Docteur Geraldo De Coulon. Gracias de todo corazón por tu confianza, amistad, nuestras conversaciones, tus conocimientos y tu pasión por tu profesión, tus pacientes y sus familias. Aprendo mucho de ti. No cambies nada, tu inquebrantable humanidad es preciosa y tan poco frecuente, gracias.

Bien entendu, je souhaite remercier le professeur Didier Hannouche et le service de chirurgie orthopédique et traumatologie de l’appareil moteur des HUG pour leur soutien, et leur contribution précieuse dans nos projets et à notre équipe. Merci à vous.

Je remercie très chaleureusement la Prof Anne Lübbeke de m’avoir fait découvrir (entre autres) le monde des « Registres ». Merci pour ta confiance, tes conseils, tes connaissances, ta rigueur, ton temps et nos discussions. Je suis heureuse de travailler avec toi et ton équipe sur cette thématique. Merci bien évidemment au Dr Hermès Miozzarri pour sa précieuse collaboration, son suivi, son temps, ses nombreuses relectures, corrections et discussions sur nos projets « Genou » et pas que ! Merci Hermès pour ce beau travail d’équipe !

Je souhaite exprimer ma profonde gratitude envers le professeur Pierre Hoffmeyer pour l’inconditionnel soutien qu’il a toujours eu pour notre équipe, nos projets et nos postes. Merci à vous. Sans votre soutien il n’y aurait pas eu tout ça. Je tiens également à exprimer ma profonde reconnaissance au professeur Pierre Lascombes pour ses conseils et nos discussions. Nos moments d’échanges sont toujours un plaisir.

Pas de remerciements dignes de ce nom si je ne parle pas de la formidable équipe du laboratoire de Cinesiologie Willy Taillard. Merci à tous : Kevin, Mick Junior, Xavier, Marys, Gautier, Noor, Sarah, Nathalie, Anne et Floflo pour votre fabuleuse énergie (beaucoup trop pour certain 😊), motivation, soutien, fous rires, réflexion sur nos projets et la vie en générale. Je dois aussi vous remercier pour

votre motivation sans faille pour les jeudis « pâtisserie » et nos bons et beaux moments sportifs, sans oublier nos quelques soirées, ouf ! Merci à tous de tout mon cœur. Venir au labo est un plaisir grâce à vous tous. Je tiens aussi à remercier les anciens du labo qui ont été et qui sont tellement importants pour moi : Lena, Mick Senior, Annie, Jen, Katia, Yoshi, Mag. Certains sont maintenant loin, vous me manquez. Merci pour votre amitié.

Un grand Merci également notre super équipe de physios : Emmanuel, Irmi, Samuel et Jeremy sans qui les AQM ne seraient pas possibles. Vous être toujours dispos, pro, à l'écoute de nos patients et de leur famille, motivés et de bonne humeur. C'est un plaisir de partager, d'apprendre et de travailler avec vous. Je remercie également Madame Mercedes Balmer qui dans l'ombre gère beaucoup de petites choses pour la partie clinique de notre labo et nos patients.

Pour finir, un grand merci aux amis et ma famille pour tous nos bons moments de décompressions ! Une immense pensée pour mes parents qui n'ont jamais douté et ont toujours été là. Merci n'est pas suffisant, vous le savez. Cette citation de A. Einstein résume parfaitement votre façon de voir les choses et votre soutien sans faille : « Je n'ai pas échoué, j'ai trouvé dix mille moyens qui ne fonctionnent pas ».

Avec ton mon amour, les meilleurs pour la fin, Merci à mes deux hommes, Cyrille et Léo pour notre vie et toutes nos aventures.

Je dédicace cette thèse de Privat-Docent à nos patients petits et grands ainsi qu'à leurs familles.

Abstract

Human locomotion is inherently the most instinctive human movement, yet it stands as one of the most intricate. Its acquisition and development transpire across multiple stages of growth, from infancy through approximately 8 years of age. Pathological conditions have the potential to hinder walking, as exemplified in cases of cerebral palsy (CP) and total knee arthroplasty (TKA). Clinical movement analysis has long been established as a recognized methodology for quantifying human ambulation, notably walking. Consequently, it has evolved into an indispensable tool for clinical decision-making and assessing treatment outcomes in the context of restoring locomotion. The initial part of this Privat Docent thesis underscores the significance of gait and its deviations in cerebral palsy and knee osteoarthritis. Subsequently, functional gait assessment is introduced within the framework of the International Classification of Functioning, Disability and Health (ICF). The concept of Clinical Gait Analysis (CGA) is also elaborated upon, accompanied by a brief historical overview. Lastly, potential strategies for gait rehabilitation are explored, tailored to the context of CP and Knee OA. The second and third sections are parallel components, each dedicated respectively to CP and TKA. Within these sections, we present a comprehensive overview of the diverse studies conducted within these two research domains, with a primary focus on clinical decision-making and the efficacy evaluation of employed treatment modalities. The fourth and fifth sections encapsulate the core findings of the undertaken work, while simultaneously ushering in a range of prospects and potential avenues for future research endeavors.

Table of Contents

1 Introduction 6

1.1 Human locomotion: importance of walking 6

1.2 Human locomotion: alterations from different pathologies 6

1.3 Locomotion and Cerebral Palsy 7

1.4 Locomotion and Knee Osteoarthritis 11

1.5 Human locomotion: functional evaluation 13

1.5.1 ICF as framework 13

1.5.2 ICF Core sets 14

1.5.3 Core sets for CP 15

1.5.4 Core sets for Knee OA 16

1.6 Clinical gait analysis: an examination to connect “body function and structures” and walking “activity” 18

1.6.1 Quick history of gait analysis 18

1.6.2 Clinical gait analysis: a standard evaluation 19

1.7 Human locomotion: restoration 21

1.7.1 Treatment strategy 21

1.7.2 CP gait restoration 21

1.7.3 TKA gait restoration 23

1.8 Thesis objectives 25

2 Cerebral Palsy and CGA 26

2.1 Clinical issues and outcomes 26

2.2 Gait pattern and decision making 27

2.3 Efficacy of surgical procedures 28

3 TKA and CGA 30

3.1 Clinical issues and outcomes 30

3.2 Decision making 30

3.3 Efficacy of surgical procedures 31

4 Summary of our findings 33

4.1 For population with CP 33

4.2 For populations with knee OA 34

5 Perspectives, future research and general conclusion 35

5.1 The longitudinal follow-up of patients with CP 35

5.2 The determination of predictive factors of knee stability after arthroplasty 36

5.3 Implementation and validation of a fast and objective functional test for patients with total hip and knee arthroplasty 37
5.4 Geneva Arthroplasty Registry (GAR) 37
5.5 General Conclusion........ 38
6 References 40

1 Introduction

1.1 Human locomotion: importance of walking

Walking constitutes the most natural movement of the human locomotion to move from one point to another (1). The ingenuity of human walking is its amazing efficiency and adaptation to the environment. Achieving this unique movement necessitates several years of maturation, fostering the growth of bodily components (muscular and skeletal structures) and the development of the cerebral nervous system (CNS), facilitated by a learning curve that starts at approximately eleven months and continues until eleven years of age (2). Upon the culmination of this intricate developmental process, bipedal gait attains maturity, characterized by the orchestrated sequence of bodily segment motions during a cyclic activity.

However, natural walking can be influenced by a myriad of factors including: body structure, physiology, age, perception of the environment, personality, emotions, influence of others' gaze, season, culture, and fashion (3). These diverse elements collectively contribute to the modification of the human gait pattern. Thus, the ability to walk efficiently, with a keen sense of safety, optimal coordination, suitable velocity and aesthetic movement is essential for the majority of individuals granting them autonomy in their daily life (4). That is why the walking speed has been considered to be the 6th vital sign by some researchers (5). Thus, walking stands as a fundamental activity for humans with a direct impact on their social roles, activity, independence, participation, and overall health.

1.2 Human locomotion: alterations from different pathologies

For certain pathologies, structures and systems allow for good coordination and gait efficiency can be affected and/or can deteriorate. In this situation, some gait disorders can then appear and disrupt the daily life of the patient. Indeed, gait disorders are multidimensional and disabling with numerous phenotypes. Thus, several gait patterns can be described as: antalgic gait (with pain), spastic gait (with one stiff leg), crouching gait (with ankles, knees and hip flex), ataxic gait (with irregular steps), waddling gait (with exaggerated movement of the upper body), or shuffling gait (without lifting the feet completely off the ground) (https://my.clevelandclinic.org/health/symptoms/21092-gait-disorders).

Among these pathologies or causes of gait disorders, the most important are: aging (e.g., osteoarthritis), neurological disorders (e.g., Parkinson disease, stroke, multiple sclerosis…),

muscle disease (e.g., myopathy), balance disorder (e.g., inner ear, vestibular disorder), public road accident, injuries, or even depression (6, 7, 8).

This thesis will focus on two main pathologies: cerebral palsy and knee osteoarthritis.

1.3 Locomotion and Cerebral Palsy

Cerebral palsy (CP) refers to a group of permanent, non-progressive disorders which are a result of irreversible brain injury during development (pre, peri or post neonatal up to 2 years). CP is the most common cause of physical disability in children affecting 1.5-2/1000 live births in Europe (9, 10). This pathology has a direct impact on human function and affects movement (such as the gait), limiting daily activities (11). Depending on the level and type of CP, some patients are able to walk, others require external assistance, and others do not walk at all.

It appears in the literature that the CP is difficult to define and to understand due to these multifactorial and heterogeneous aspects: aetiology, presentation, functional severity, comorbidities, treatment options, individual trajectories, and outcomes (12).

However, the accepted international definition of CP is: *"Cerebral palsy describes a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing foetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication and behaviour, by epilepsy and by secondary musculoskeletal problems."* (13).

The diagnosis of CP occurs often between the age of 12 and 24 months old and is based on clinical and neurological signs. The most common risk factors for CP are: prenatal risk factors (maternal, foetal or social factors); perinatal risk factors (birth asphyxia, multiple births prematurity, genetic and metabolic disorders…) and postnatal risk factors (neonatal sepsis, respiratory distress, early onset meningitis, intraventricular haemorrhage, head injuries before 2 years) (9).

The description and classification of CP is a real challenge because of various aetiologies and manifestations (14). Indeed, CP can be divided into several subtypes based on the topography i.e., the part of the body attained, and the type of movement disorder. Thus, CP can be more

important at the level of the lower limbs (diplegia), at the level of one arm and one leg on the same side (hemiplegia), or at the level of the arms and the two legs (quadriplegia). However, these descriptions tend to be simplified by actually using a description as unilateral or bilateral CP (15) (Figure 1-A). In the literature, different publications and teams have proposed several classification systems of motor disorders observed in CP (16, 17, 18, 19).

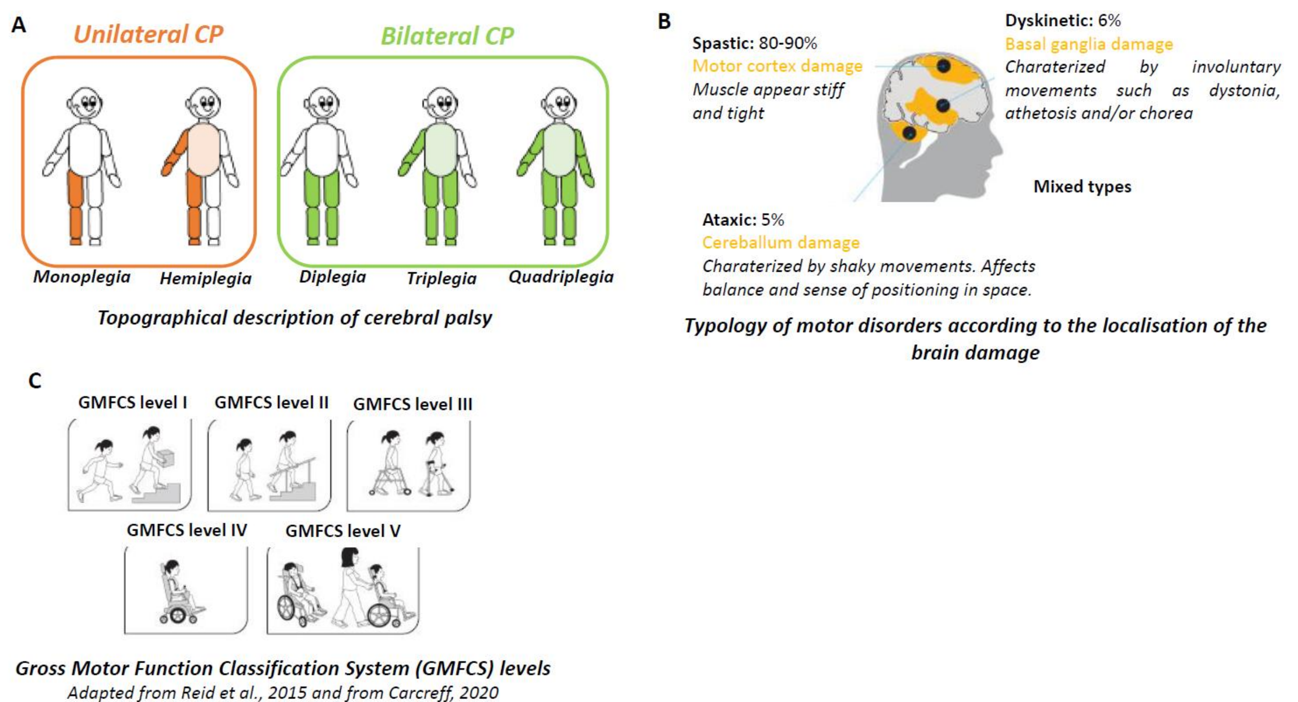


Figure 1: Presentation of several classifications in cerebral palsy. A- Topographical description of CP; B-Typology of motor disorders according to the brain damage; C-Gross Motor Function Classification System (GMFCS) (adapted from Carcreff, 2020 – Thesis (20))

Moreover, the classification of patients with CP can also be based on the typography of the disease i.e., according to the brain lesion and its location (Figure 1-B). Thus, three main categories have been proposed and defined: spastic (due to motor cortex damage representing 80-90% of CP), dyskenic (due to basal ganglia damage representing 6% of CP) and ataxic (due to cerebellum damage representing 5% of CP).

CP patients also have problems with coordination, strength, selective motor control and sensation. Moreover, spasticity and dystonia can coexist. Therefore, we understand well that classification in CP is tricky, complex, and challenging. To help clinicians to classify patients with CP, different scores and scales have been proposed such as the Manual Ability Classification System (MACS) or the Gross Motor Functional Classification System (GMFCS) (Figure 1-C) (21, 22). GMFCS is the most commonly used score to categorise children into five

levels (according to the age and of the self-initiated movement capacities): GMFCS 1 (children can walk, run, jump, climb stairs, and carry objects in all settings without limitation, but are limited in complex motor activities) to GMFCS 5 (children can move only if they are transported in a wheelchair with head and trunk support by a tertiary person) (22). It is important to note that this score is not continuous (23). Thus, it is not easy to determine the GMFCS level, especially for patients with movement capacities between two levels. In addition, CP is a non-evolutive pathology but some changing can appear over the time due to the growth. Therefore, patients can change GMFCS level from childhood to adulthood (24).

Due to the large heterogeneity of the CP described before, multiple gait deviations and patterns are observed in patients with CP. Therefore, to help clinicians to understand and analyse this disease, several classifications of the gait patterns have been proposed in the literature. These classifications are often based on kinematics curves (mainly in the sagittal plane) describing the movement of the lower limbs during gait (18, 25, 26, 27). The main gait patterns described and used in the clinical field are knee recurvatum, drop foot, true equinus with full knee extension, jump knee gait in early stance, jump knee in late stance, apparent equinus, crouch gait (25) (Figure 2). Recently, Graham et al. proposed a new tool to classify the lower limb musculoskeletal pathology (MSP) for ambulant children with CP (17). This classification proposed four-stages: hypertonia (age 4-6 years), contracture (age 4-12 years), bone and joint deformity (age 4-12 years) and decompensation (age 10 to adulthood). This classification tries to connect the gait pattern but also the type of CP and gait evolution over time. These numerous classifications and types of classification illustrate how challenging it is to classify and treat CP due to the fact that clinical manifestations vary greatly between patients in terms of movement, degree of functional ability, limitation and parts of the body affected.

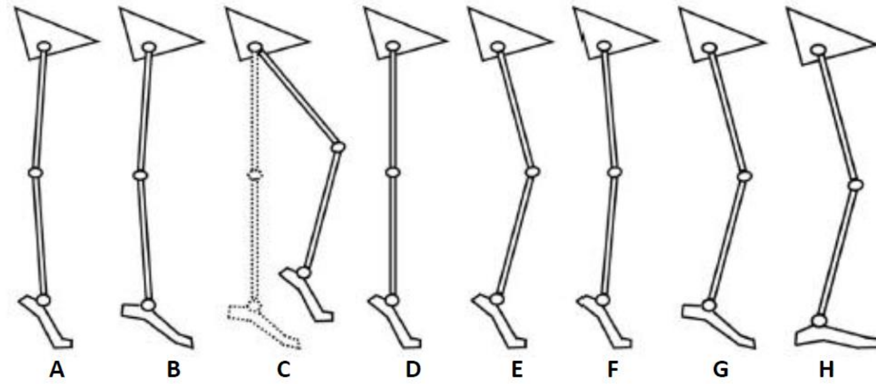


Figure 2: Classification of different gait patterns in CP (25)

In this context, the management of CP seeks to maintain and improve the functional level of the patients. The current treatments are often a combination of physiotherapy, exercise, orthosis, pharmacology, and surgery (Figure 3) (28). To have an efficient management of this disease a multidisciplinary approach is necessary.

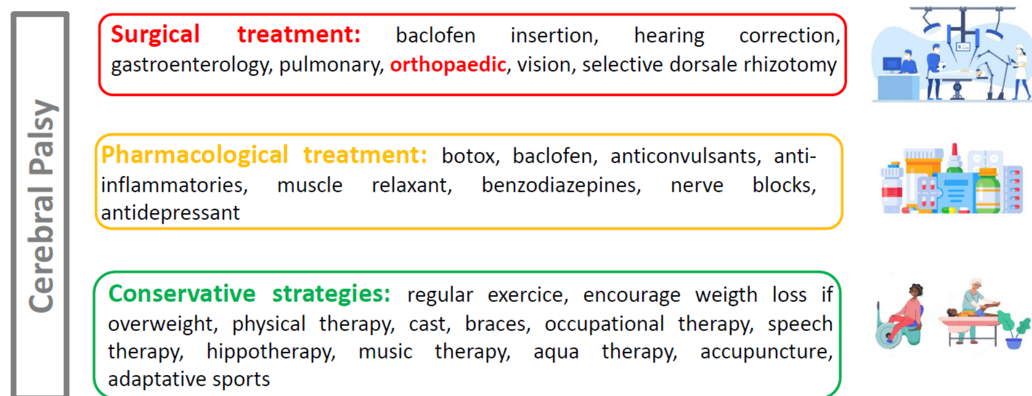


Figure 3: Illustration of the CP treatments (14)

Moreover, it appears that when there is earlier management of this disease, the treatment will be more efficient for the children (28, 29, 30). Finally, the follow-up of the evolution of children with CP during growth also has an essential role to understand the impact of the treatment on their capacity, function, quality of life, and participation over time. A large range of literature has covered this topic and particularly observed the impact of treatments on gait recovery (31,

32, 33, 34). However, longitudinal studies on this population are always lacking and still required to better understand this evolution and to refine the treatment and the follow-up of these patients.

The first chapter of this thesis will focus on the gait evolution in children with CP before treatment and after a follow-up of 10 years.

1.4 Locomotion and Knee Osteoarthritis

Knee Osteoarthritis (OA) is one of the most common joint diseases due to degenerative damage to the articular cartilage associated with changes in the biomechanics and biochemistry of the knee joints (35). Two types of knee OA can be determined: primary and secondary. Primary OA is the consequence of articular degeneration without any apparent underlying reason whereas secondary OA is the consequence of an abnormal repartition of force across the knee joint due to post-traumatic causes or abnormal articular cartilage, such as rheumatoid arthritis.

The pathophysiology of knee OA is complex and multifactorial affecting not only the cartilage but also the bones and synovial tissue (36). Knee OA disrupts the normal balance of synthesis and degradation of articular cartilage and subchondral bone. These changes result in cracking and fissuring of the cartilage and ultimately erosion of the articular surface (37).

Knee OA is the most common type of OA diagnosed with a high prevalence of Rheumatic Musculoskeletal Disorder (38). Each year, the number of cases increases in the world due to aging and obesity (39). Anyone can get knee OA, but it is more common in older people. However, as the aetiology of knee OA is multifactorial, the causes are various and could be due to: genetic factors (family history of osteoarthritis), joint injury, abnormal joint structure, overuse from repetitive movements of the joints, aging, sex (OA is more often in women than in men) (40).

The most predominant symptom of knee OA is joint pain (41). The pain tends to be worse with or after activity and particularly with weight-bearing activity. Moreover, the pain may also be worse at night and it is the first reason people visit a doctor. A second common symptom is, after a period of rest or inactivity, joint stiffness for a short period (42). The loss of movement and function in addition to a feeling of instability are also symptoms of OA. All these symptoms

can have an impact on the quality of life of the patients with a loss of independence that can be associated with depression and disturbed sleep (43). Finally, knee OA also has a considerable economic burden for society and the healthcare system.

Knee OA has a direct impact on day-to-day activities such as walking and stair climbing. The gait pattern of patients with knee OA can be classified by the level of OA severity. Thus, for patients with moderate OA, we can observe that the knee kinematic curve in the sagittal plane has a reduced peak knee flexion angle at the beginning of the stance phase. This reduction is also observed for patients with severe OA with a reduced peak knee flexion angle during the swing phase. Thus, patients with severe OA have a reduced knee kinematic amplitude during the gait. These gait patterns are inherently linked to the gait speed of the patients. Indeed, gait speed has a direct impact on the lower limb kinematic (44). However, as the disease process of knee OA has a direct impact on the gait speed of the patients, it is difficult to identify the causes of these gait modifications and patterns. Knee OA is a multifactorial disease process with various factors and interactions that produces biomechanical changes with a direct impact on the gait quality and function.

In this context, the treatment of knee OA is primordial. The objectives of the treatments are to reduce pain (and other symptoms), to improve joint function, to improve the functional capacities of the patients, to stop the evolution of the disease, to maintain a health-related quality of life to help to prevent disability (45). The choice of treatment will depend on the degree of osteoarthritis, pain and stiffness. Three main types of treatments are generally used: conservative, pharmacological and surgical (Figure 4).

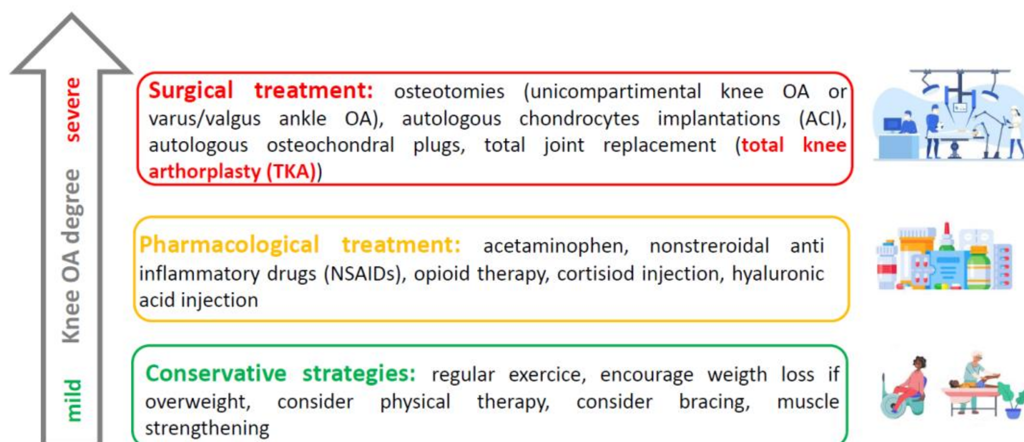


Figure 4: Illustration of the OA treatments (42)

The conservative treatments seek to maintain the level of function and to reduce short-term pain thanks to physiotherapy, muscle strengthening, ultrasound, and weight loss if necessary. These first treatments are encouraged by clinicians for patients with a mild level of OA (45).

The second category of treatment is pharmacological and is also recommended for a mild level of OA. Several pharmacological treatments are possible such as acetaminophen, nonsteroidal anti-inflammatory drugs (NSAIDs), opioids, intra-articular injections of corticosteroids or hyaluric acid (40). All these treatments could have adverse effects such as gastrointestinal bleeding, renal dysfunction, blood pressure elevation, potential dependence and constipation. Several publications have analyzed the effect of these treatments on patients (40).

The last category of treatment is surgical. These surgical solutions are recommended for end-stage of OA and for patients for whom other treatments have not worked. The most known and used surgery for lower limbs is total knee arthroplasty (TKA) (Figure 5).

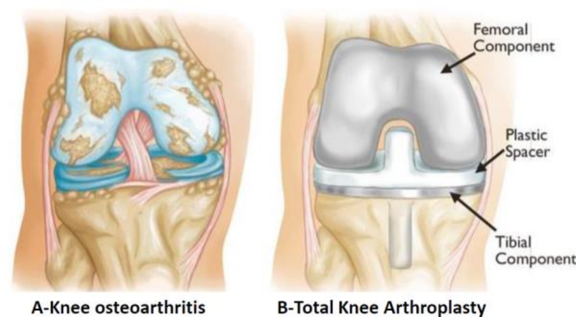


Figure 5: Illustration of the Knee osteoarthritis (A) and Total knee arthroplasty (B) (https://orthoinfo.aaos.org/en/treatment/total-knee-replacement)

1.5 Human locomotion: functional evaluation

1.5.1 ICF as framework

In order to help clinicians and to guide them in the approach and comprehension of health and of human function, a specific framework has been proposed by the World Health Organization (WHO) in 2001: the International Classification of Functioning, Disability and Health (ICF) (46). This classification is internationally recognized and describes human function in a standardized language, considering three domains: body function and structure, activities, and participation (Figure 6). These domains are influenced by the environmental and personal factors specific to each person. Thus, the ICF provides a useful framework to understand an individual's health and function in cases such as osteoarthritis and CP diseases (47, 48).

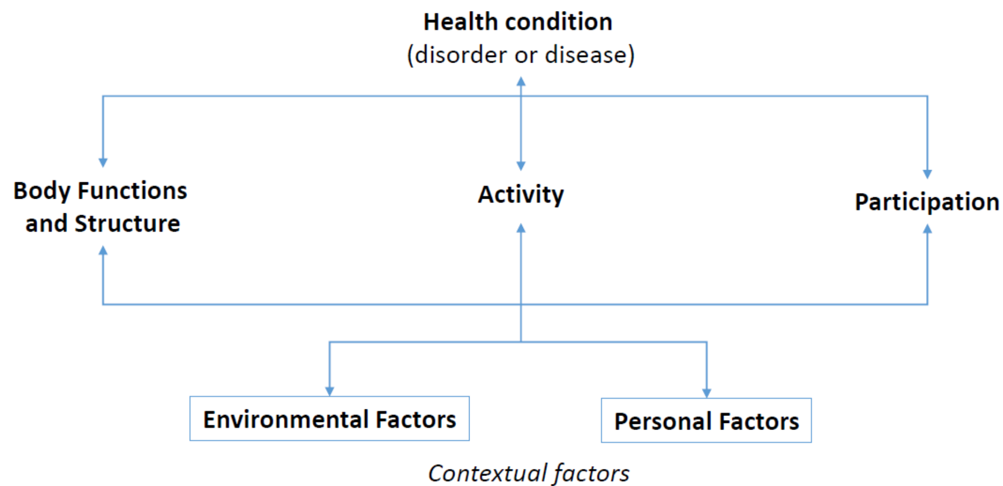


Figure 6: The ICF's model of health condition (World Health Organization, 2002)

1.5.2 ICF Core sets

The choice of the tools to evaluate the different domains of the ICF is always a delicate and important question. To facilitate the application of the ICF in daily life practice, some ICF core-sets have been proposed in the literature for several pathologies including CP and OA. These core sets provide lists of essential categories that are relevant for specific health conditions and health care contexts. Thus, to determine which category we want to analyse in the ICF core sets, several tools are available with different levels of complexity depending on the aim of the analysis, the level of accuracy, and the type of parameters that we choose to have (Table 1).

The simplest tools to assess different categories of ICF core sets are questionnaires and scale-based evaluations. Their goals are to estimate the level of difficulty in performing certain motor tasks, the impact of motor disability and gait deviations on their daily life, quality of life, pain, fatigue, body image, and self-esteem. In addition, these tools also have the potential to evaluate the patient's feelings about the effectiveness of a treatment or the evolution of their pathology. These questionnaires have become an important component of the overall evaluation of patients and their care. In this context, the patient-reported outcomes measures (PROMs) are used by the clinicians to assess and to understand patient's health status (49). The PROMs are directly linked to the patient point of view without interpretation of the clinician.

Depending on the age of the population and the pathology, different questionnaires have been developed, proposed, and validated in the literature.

1.5.3 Core sets for CP

To evaluate body function and structures, one of the most commonly used questionnaires, is the Gait Outcomes Assessment List (GOAL) (50). This questionnaire, based on 48 items, provides precious information about the child's function across several domains of ICF (environmental and personal factors) considering the priorities and patient's or parent's expectations (50).

To evaluate activity and participation, the simplest tools are based on scale-based evaluations. These evaluations can also be used to provide a global description of performance and participation. The most used in CP are the Gillette Functional Assessment Questionnaire (FAQ), the Functional Mobility Scale (FMS), and the Gross Motor Function Classification System (GMFCS) (51, 52). Thus, these tools have a preponderant place in a register as it is the case in the CP register of Switzerland (https://fr.swiss-cp-reg.ch/liens/).

To evaluate environmental and personal factors several questionnaires are also available as questionnaires concerning Quality of Life (QoL). QOL refers to an individual's perception of their wellbeing across various domains of life. In the context of CP, specific QOL questionnaires have been developed in function of the age of the patients, thus there are CP-QOL child (4-12 years old) or CP-QOL teen (13-18 years old). Other questionnaires such as Life habits questionnaire (Life H), Children's Assessment of participation and Enjoyment (CAPE) or Preferences for activities of Children (PAC) are used to measure children's participation.

Other tools are available in order to evaluate the different core-sets of CP, based on the measurement and quantification of some parameters. To evaluate body structures and functions, clinical evaluations can be done by a clinician to evaluate body function of a patient by measuring the passive range of motion of some joints (hip, knee, ankle, and foot) and the muscle strength, spasticity and selectivity. Moreover, some gait scores such as the Gait Profil Score, Gait Deviation Score, Gait Variable Score, and spatio-temporal parameters can also be calculated and used to quantify the gait function of the patients (23, 53, 54). These parameters can be computed thanks to different technologies such as an optoelectronic system in a standardized environment i.e., the lab.

Concerning the body structures, Magnetic Resonance Imaging (MRI), X-Ray, EOS-biplanar, CT scan, electromyography (EMG), electroencephalogram (EEG) are various and valuable

systems to measure information on bones deformations, muscles activities, muscles structures, and cerebral function. To evaluate the activity, participation and endurance, the Time up and Go (TUG), the 6- or 10-minutes walking tests, or actimeters are proposed (55, 56).

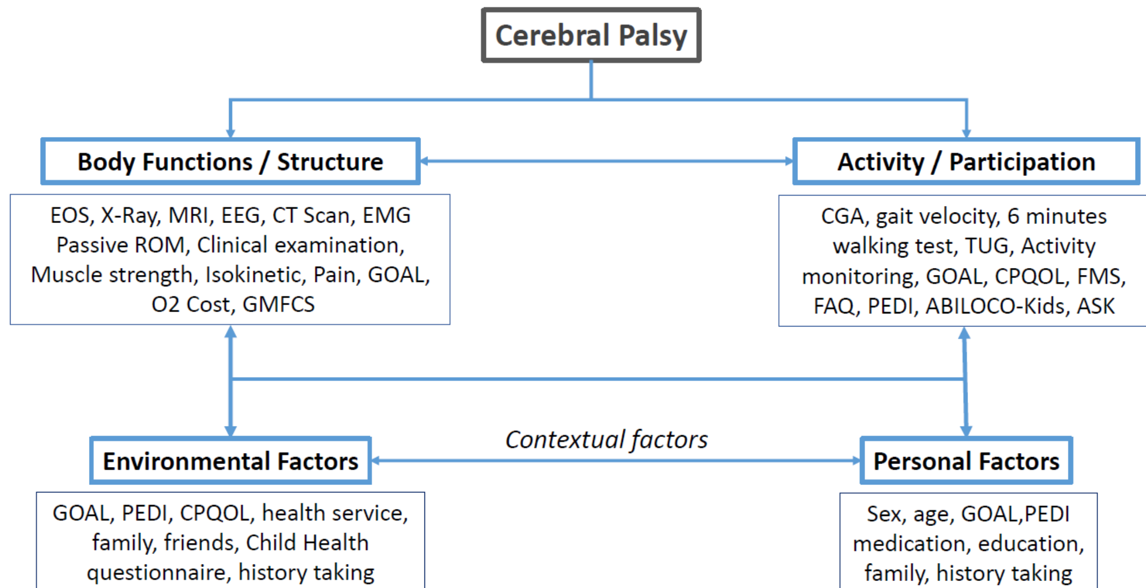


Figure 7: Illustration of possible tools available to characterize core-sets of cerebral palsy. MRI=magnetic Resonance Imaging, EEG = electroencephalogram, EMG=electromyography, TUG = Time up and Go, CGA=Clinical Gait Analysis, GOAL =Gait Outcomes Assessment List, ROM=Range of Motion, TUG=Time Up and GO, CPQOL= Cerebral Palsy Quality of Life, PEDI = Paediatric Evaluation of Disability Inventory, FMS=Functional Mobility Scale, ABILOCO = Measure of locomotion ability.

(57, 58) - (World Health Organization, 2002; https://www.icf-research-branch.org/)

1.5.4 Core sets for Knee OA

As for the CP, the simplest tools used for knee OA are based on questionnaires. To evaluate, several dimensions of the ICF, the most commonly used PROMs are the Knee Injury and Osteoarthritis Outcome Score (KOOS), the Western Ontario and McMaster Universities Arthritis Index (WOMAC) and the Oxford Knee Score (OKS) (59, 60). Indeed, these questionnaires measure several domains such as pain, symptoms, activities in daily living, sport and recreation and knee related QOL. In the same way, the Medical Outcome Study 36 or (12) Item short Form Survey (SF-36 or SF-12) are questionnaires including different scales measuring physical functioning, social activities, role activities, bodily pain, general health, vitality, social functioning, role emotional and mental health. From these scales, two scores

calculate the physical and mental scores range from 0 (worst health status) to 100 (best health status).

To evaluate body function, gait pattern and spatio-temporal parameters can be measured thanks to optoelectronic systems or inertial sensor units (IMU) systems. These data are able to quantify the gait quality of the patients.

In terms of assessing body structures, X-rays, EOS-biplanar imaging, and CT scans are employed to examine the knee and lower limb structures, including the longitudinal axis and various musculoskeletal parameters. Furthermore, it is possible to gauge joint mobility, muscle strength, muscle tone, muscle endurance, and muscle activity.

Regarding the activities and participation, certain tests can be used such as: the TUG, instrumented TUG (iTUG) able to evaluate mobility, balance, walking ability, 6 minutes walking test for endurance and long-term walking abilities.

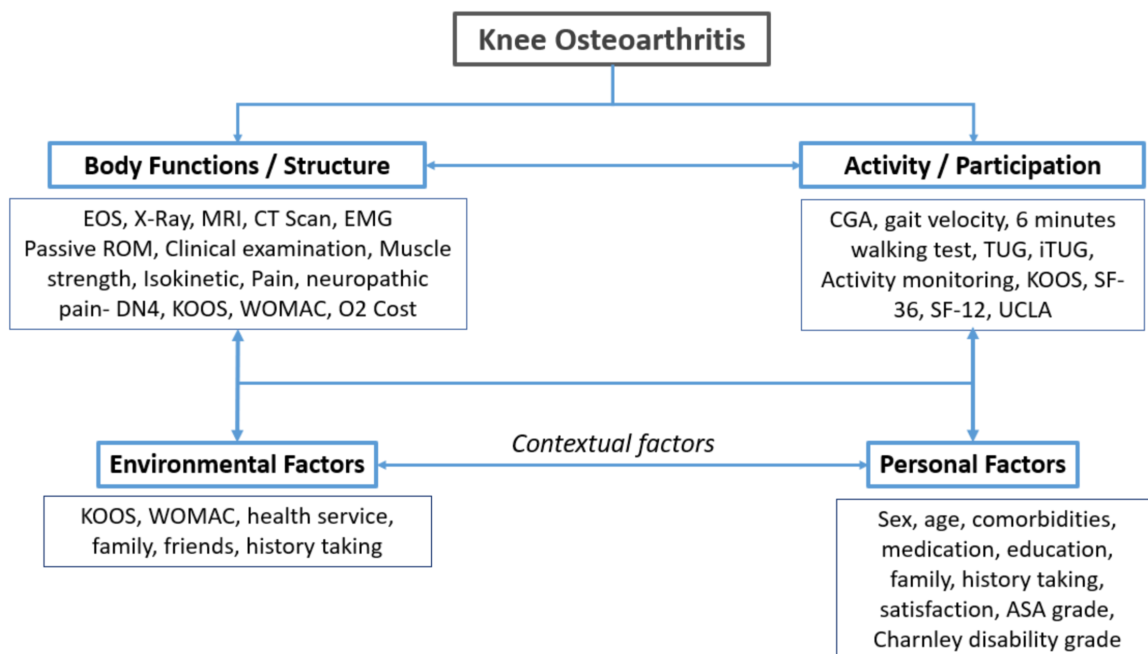


Figure 8: Illustration of possible tools available to characterize core-sets of knee arthrosis.
WOMAC = Western Ontario and McMaster Universities Osteoarthritis index, KOOS = Knee injury and Osteoarthritis Outcome Score, MRC = Medical Research Council, SF-12 or SF-36 = Item short Form Survey, ASA grade = American Society of Anaesthesiologists grade, DN4 = Douleur neuropathique en 4 questions, UCLA=University of California Los Angeles activity scale = UCLA, EMG=electromyography, TUG=Time Up and Go, iTUG= instrumented Time Up and Go

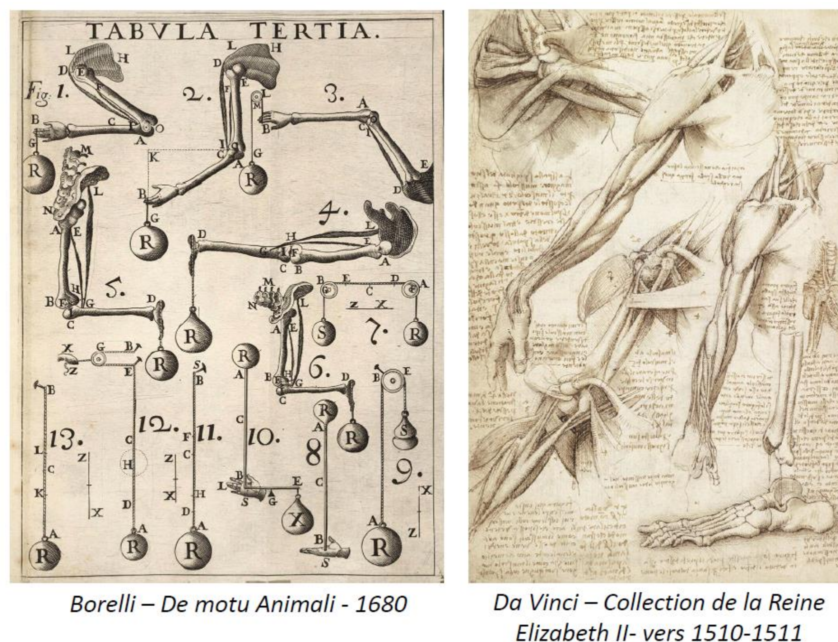
(61, 62) - (https://www.icf-research-branch.org/)

Thus, it appears that several outcomes can be used to evaluate the different domains of the ICF and that these outcomes could be complementary to have a precise overview of the patients.

1.6 Clinical gait analysis: an examination to connect “body function and structures” and walking “activity”

1.6.1 Quick history of gait analysis

The beginning of human gait observation has been done by Aristotle (384-322 BC). This first approach was, as often at this period, only based on observation. Over time, other famous scientists observed and represented the human body structure and function with amazing drawings such as those from DaVinci and Borrelli (Figure 9).



Borelli – De motu Animali - 1680

Da Vinci – Collection de la Reine Elizabeth II- vers 1510-1511

Figure 9: Pictures from Borelli and Da Vinci

(https://www.nationalgeographic.fr/photography/2019/04/les-plus-beaux-croquis-de-leonard-de-vinci)

(https://www.design-is-fine.org/post/101352180159/giovanni-alfonso-borelli-plates-from-de-motu)

In the first half of the 19th century, the Weber brothers (Wilhelm and Eduard) made the next major contribution to the history of gait analysis. Based on simple observations of stance and swing phases of the gait, they postulated in 1836 the pendulum theory of human locomotion, considering the swing phase as a purely passive movement owing to gravity and that walking is a movement of falling forward. However, it’s only since the middle of the 19th century that the first quantifications of the human gait, in two-dimensional, have been done in the same period in Paris by E.J. Marey (1830-1904) and in California by E.J. Muybridge (1830-1904) thanks to

the photographic techniques called chronophotography (63). This system used several stationary cameras to have several pictures of the movement. Thus, the analyse of the gait kinematic was based on serial pictorial images and the construction of “stick diagrams”. In 1895, Braun and Fisher (an anatomist and mathematician) realized the quantification of human gait using the first tools of three-dimensional measurement systems. Light-emitting markers were used with trigonometric measurement. Thus, Braun and Fisher were able to calculate the angular displacement of lower limb joints during gait (64). Another important step in the history of gait analysis was the development of the force plates and the understanding of kinetics. The first system has been developed by E.J Marey followed by the development of a first three-component force-plate developed by J. Amar (1879-1935) in France. Soon after the use of force-plates to analyse kinetic, the electromyography systems were developed and used in gait analysis. This new tool has been a major advancement in the characterization of muscle function during gait and provided information about muscle activities. During the 1940s and 1950s Vern Inman and colleagues, from the Medical school of the university of California, were pioneers in the fact to use these different technologies to analyse the gait (65, 66, 67). They have been the precursors of the gait analysis with the development of clinical gait analysis (CGA) driven by two surgeons: Jacquelin Perry and David Sutherland (68). Over time, thanks to the progress of computer science and the development of increasingly powerful computers, the three-dimensional analysis systems and motion analysis science, in general, have been revolutionized. Therefore, these tools and types of analysis have been used in the clinical context to evaluate and quantify the gait function of patients with walking disorders. Indeed, thanks to the pioneers and precursors of this domain, the CGA plays a crucial role and is an indispensable tool used by several specialist as neurologists, physiotherapist, orthopaedists, and rehabilitators, to observe deviations from the normal gait, to quantify these deviations, to identify injury risk factors, and to indicate an underlying abnormality or affliction. This is how CGA emerged as a potential assessment in its own regard. This tool helps clinicians to make a proper treatment plan. Furthermore, gait analysis has a wide-ranging application in diverse domains including sports, rehabilitation, medicine, and diagnosis studies (69).

1.6.2 Clinical gait analysis: a standard evaluation

CGA is a complete and complex quantification of human gait integrating joint kinematics and kinetics in three-dimension (measured thanks to 3D optoelectronic systems recording the displacement of skin markers glued on specific anatomical points of body segments (69, 70, 71, 72, 73, 74, 75, 76)), the ground reaction forces collected (measured thank to force-plates

embedded in the walkway of the lab (65, 66, 67)) and the muscular activity (recorded thanks to electromyography systems and surface electrodes glued on specific zones of the muscles during the gait) (77). In the clinical context, a physical examination is often realized to evaluate the passive range of motion, muscular strength, spasticity and selectivity (78). This examination completes the CGA to obtain precise information about the complex locomotor characteristics of a patient and help to find the possible causes of the gait deviations observed during CGA (Figure 10).

Regarding the ICF, CGA can be considered as an examination to connect the “body function and structures” to the walking “activity”.

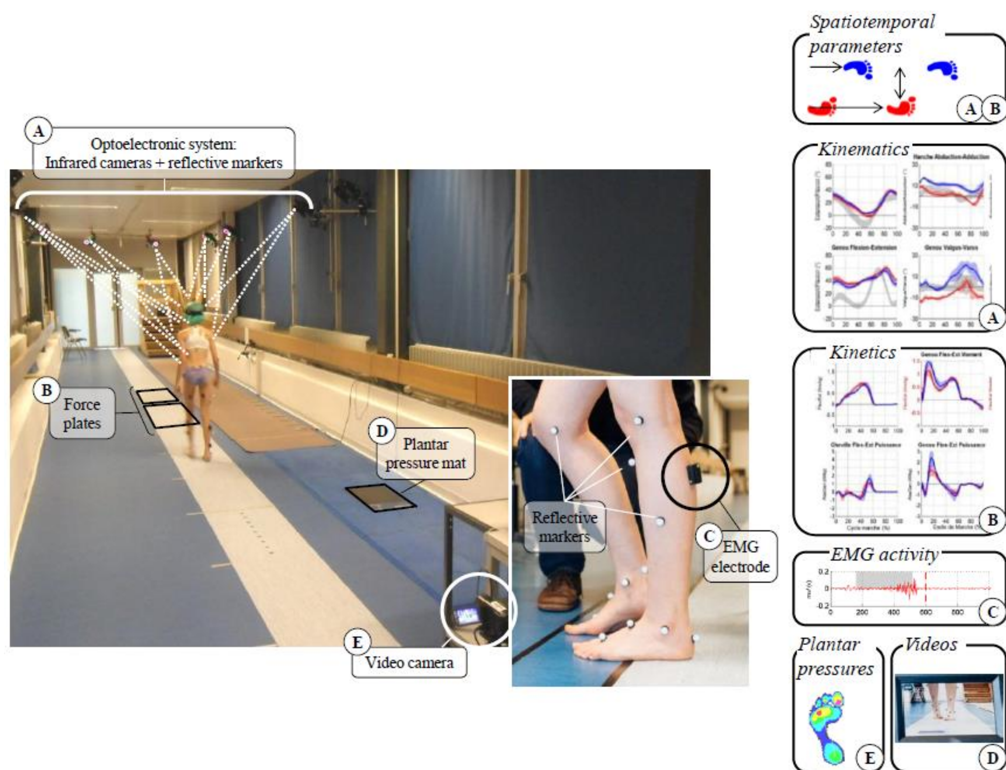


Figure 10: Tools used to perform a CGA (Carcreff, 2020 – Thesis (20))

Therefore, CGA allows to identify and understand the motor disorders and their possible causes (79, 80). It is now recognized as an effective examination used in the diagnosis, therapy and prevention of musculoskeletal disorders. It can also help clinicians in their treatment choice and reduce patients’ recovery time. As an illustration of the relevance of the CGA to help in diagnosis, the following publication is a good example. Indeed, in this work, we have shown that CGA helps to discriminate between patients with CP and patients with hereditary spastic

paraplegia. This discrimination was based on the full body gait analysis and more specifically on the movement of the pelvis and trunk in the sagittal plane (81).

However, since several years, other technologies are developed as inertial sensor units (IMU) or video cameras with artificial intelligence (82). These tools have the main interest to assess the movement of patients in their everyday life (83, 84, 85). We have published an article in the Revue Médicale Suisse about this topic in 2022 (86).

1.7 Human locomotion: restoration

1.7.1 Treatment strategy

For example, medical treatment prescribes medication, diet and lifestyle measures as well as physical therapy, speech therapy, psychiatry and physiotherapy. In certain cases and illnesses, it is necessary to have surgical treatment. Lastly, certain examinations can be either traditional treatments or surgery such as radiology, endoscopy, or phototherapy. In all cases, the treatment strategy in medicine is a very important and tricky part of this discipline. Indeed, the choice of treatment will be done by the clinical team individualized to the patient, his/her personal history, his/her anamnesis, the disease, the family, etc. In the context of the restoration of the human locomotion, the strategy treatment often includes a combination of pharmacological treatments, physical treatment, and surgical treatment. Thus, treatment strategy and management is based on multidisciplinary approaches and teams.

1.7.2 CP gait restoration

Depending on the type of CP and GMFCS level, different treatments can be proposed to the patients and their families such as rehabilitation intervention (87), Botulinum Neurotoxin-A injection to manage spasticity (88), orthoses devices such as ankle foot orthoses to restore the first ankle rocker and improve gait efficiency (89), and orthopaedic surgery to correct bone deformities, muscles contractures, joint displacement (31, 90, 91, 92). These different treatments aim to improve function, reduce pain, improve quality of live, increase daily life activities and participation. As explained by Jackman et al., in their article published in 2021 (93): *"Therapy interventions for children and young people with CP have evolved considerably over the past 20 years, in line with the World Health Organization's International Classification of Functioning, Disability and Health (ICF) framework. This evolution has seen a change of focus from primarily addressing underlying symptoms and impairments with the aspiration of*

improving function, to focusing instead on training activities and real-life tasks that are important to the person, plus directly targeting their full participation within the community."

For people with CP, orthopaedic surgery is often proposed by the clinical team after physical and medication treatments. This treatment aims to correct and improve movement and alignment in the upper and lower limbs (94). Surgery is used to relieve stiffness; correct spinal curvatures; prevent spinal deformities, correct foot deformities; improve posture, balance and coordination; relieve pain; correct fixed joints and tendons, free permanently tightened muscles, prevent hip dislocation. These procedures can be performed on the muscles, tendons, bones and nerves. The main procedures proposed are muscle lengthening, tendon lengthening, tendon transfer, tenotomy/myotomy, osteotomy and arthrodesis (see Table 1). After orthopaedic surgical treatments, medication for the pain, a period of rehabilitation, a cast, and physiotherapy are often necessary.

Table 1: Resume of the surgery used in cerebral palsy.

Surgery	Clinical Objective	Impact on movement and posture
Muscle lengthening	To relieve tightness	To help grasp objects and improve range of motion
Tendon lengthening	To reduce painful contractures	To improve gait and ability to sit upright
Tendon transfer	To ensure that the muscles are properly aligned	To improve joint extension and flexibility
Tenotomy/Myotomy	To improve muscle function	To increase control and abilities
Osteotomy	To realign joints	To improve posture and mobility
Arthrodesis	To permanently fuse bones together	To help the patient with their gait

Two other types of surgery can be performed in CP: the intrathecal baclofen therapy (ITB) and the selective dorsal rhizotomy. The baclofen is a relaxant muscle used to reduce the muscle spasticity. The baclofen medication is delivering in liquid form thank to a pump. This pump is introduced under the skin by the surgeon. The dose of baclofen must be refilled at regular

intervals (every one to six months) by a trained professional (95). The selective dorsal rhizotomy procedure aims to reduce pain and spasticity. However, this procedure is very aggressive and irreversible because surgeons cut the nerves in the spinal column responsible for muscle stiffness. It is only recommended in severe cases of spasticity (95, 96, 97).

1.7.3 TKA gait restoration

The first TKA surgery was performed in 1968 and it is one of the most successful procedures in medicine. Thus, TKA has been routinely performed for 50 years, and the number of TKA each year in the world is increasing (98). The aim of this surgery is to resurface the parts of the knee joint that have been damaged over the time (cartilage and bones), to relieve knee pain that cannot be treated and controlled by the other treatments available. For this, the surface of the damaged bones will be replaced by metal and plastic parts used to cap the ends of the bones that form the knee joint, along with the kneecap.

The standard principle of this procedure is to obtain a neutral alignment of the femoral and tibial components post-operative. The idea is thus to equalize the load on the implant to decrease wear and to improve knee stability, kinematics and clinical function. This alignment has had good long-term results with however inconsistent results concerning functional outcomes (99, 100). Indeed, there is a wide range of possible knee anatomies with a complex interplay between menisci, cruciate ligaments, collateral ligaments, knee capsule and muscles. This specificity has a direct impact on the knee biomechanics and kinematics. This complexity increases interindividual differences in knee anatomy, mobility, stability, kinematics. That is why it is difficult to replicate normal knee kinematics after TKA.

Therefore, several concepts of personalized alignments have been developed and proposed: the mechanical, kinematic, inverse kinematic, restricted kinematics, and functional (Figure 9).

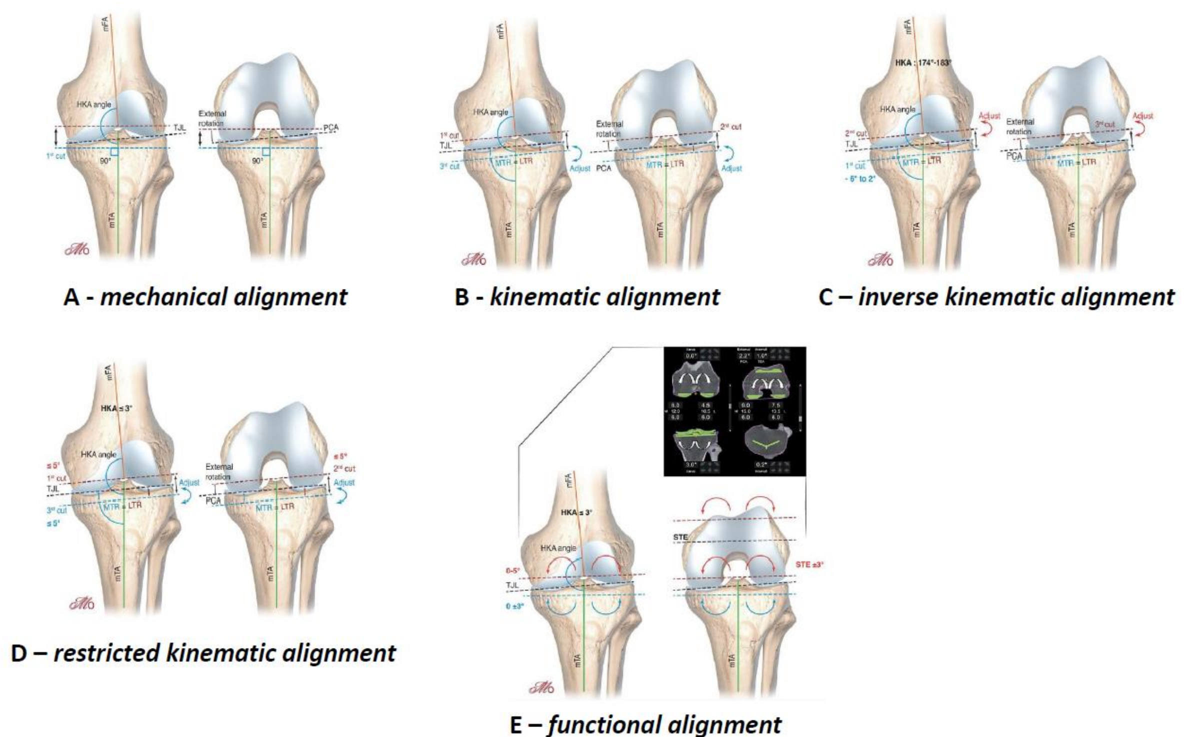


Figure 11: Illustration of the TKA alignments: kinematic alignment
From Lustig et al. – Personalized alignment in TKA: current concepts - 2021

The mechanical alignment (Figure 11 -A) consists of select neutral femoral and tibial cuts with adjusted femoral rotation and ligamentous releases to create equal rectangular flexion and extension gaps as well as a neutral mechanical axis. This procedure used only one size of implant, albeit reproducible, which does not incorporate the full range of normal knee anatomy (101).

The kinematic alignment (Figure 11-B) consists of resurfacing the femorotibial joint with restitution of the pre-arthritic anatomy and preservation of the tissue envelope. This procedure aims to co-align the axes and joint lines of implants with the kinematic axes and joint lines of the native joint (101).

The inverse kinematic alignment (Figure 11-C) consists of resurfacing the tibia with similar medial and lateral resections after corrections for wear, maintaining the pre-articular tibial joint line obliquity. The gap balancing is performed afterward to adjust the femoral posterior and distal resection. For this procedure, the robotic assisted systems can help the surgeons in their preoperative planning and gap balancing (102).

The restricted kinematic alignment (Figure 11-D) is an alternative to the kinematic alignment. This procedure aims to reconstitute native alignment within ±3° of a neutral alignment to reproduce the patient's constitutional knee anatomy within a safe range while avoiding extreme or pathological anatomies (103).

The functional alignment (Figure 11-E) is an alternative of kinematic alignment, thanks to new technology (patient specific implants, 3-dimensional printed cutting blocks, robotic-assisted system), that aims to reconstruct 3-dimensional constitutional alignment while respecting the behavior of the soft tissue envelope with the assistance of a robotic platform.

Lutzig et al., summarized the different types of alignments (104). They concluded that: *"personalized alignment aims to restore native knee alignment and improve functional outcomes after TKA"*. They also showed that the evolution of the technologies (computer navigation, patient-specific instrumentation, and robotics) can help to improve the ability to restore native knee kinematics and to individualise the alignment of knee replacement to replicate individual anatomy, independent of the approach used. Sustained, long-term monitoring is essential for assessing clinical results and the longevity of implants.

Thus, the second chapter of this thesis will focus on the knee kinematics, gait parameters and clinical characteristics before and after TKA through the exploration of different articles.

1.8 Thesis objectives

The objective of this Privat Docent thesis is to present and sum up an overview of the research that I have performed for 10 years in the Willy Taillard Laboratory of Kinesiology. The laboratory is a multidisciplinary team (biomechanicians, engineers, physiotherapists, medical staff) led by Prof Stéphane Armand. Various research projects are in progress with the aim to better identify and understand human movement disorders, and to improve the management of these disorders.

My own research is specifically oriented to better understand the impact of surgical treatments on the gait function in two population of patients: children with CP and patients with TKA thanks to data measured and calculated during a CGA.

The first chapter of this thesis will concern the gait of children with CP and the advanced knowledge that I have developed in this field. Indeed, I have participated in the publication of 15 articles (and about 20 international congresses) on this topic. I am also in charge of the execution of the research project (set up by Prof. Stéphane Armand and Dr. Geraldo De Coulon) concerning the longitudinal follow-up of these patients integrating the CGA and also conduction several questionnaires and the follow-up of their physical activity level in their daily life. Thus, about 95 patients with CP from childhood to adulthood are included in this follow-up, which makes it one of the most consequential databases currently available in the world.

The second chapter will concern functional recovery after TKA. I have participated in the publication of 15 articles on this topic and participated in many international congresses (the European Federation of National Associations of Orthopaedics and Traumatology (EFORT); American Academy of Orthopaedic surgeons (AAOS); the European Society for Movement Analysis in Adults and Children (ESMAC)) thanks to the follow-up of the project concerning the functional recovery of patients after TKA. In this database which has been developed at the lab for several years, more than 120 patients have been analysed before, three months and one year after TKA, which makes it one of the most consequential currently available in this research field.

Finally, to conclude this thesis, a final chapter will sum up the main findings of these different works and will propose some perspectives to continue these fields of research.

2 Cerebral Palsy and CGA

2.1 Clinical issues and outcomes

As shown in the introduction, CGA provides objective, accurate, and quantitative outcomes reflecting the complex biomechanics of the gait which are not necessarily observed during a standard clinical examination. This tool is now considered a gold standard to evaluate abnormal gait deviations in patients with CP (105). Thus, CGA is well-recognized to be a powerful tool to help in the clinical issues to manage gait abnormalities over time including several domains of the ICF such as body function and structures, activity and participation (106). Indeed in the literature, a very large number of studies have described, thanks to CGA, the influence of treatment on the gait function in patients with CP (107).

In addition, several outcomes specific to body movement have been used to analyse the gait function of patients with CP over time such as gait speed, gait profile scores (GPS), modified gait profile score (without hip rotation angle mGPS), Gait Deviation Index (GDI), gait variable scores (GVS) (53, 54, 108). These parameters are calculated through CGA and provide objective information concerning the gait quality and capacity of the patients. These outcomes must be reliable, valid, interpretable, and responsive (109, 110). Thus, they have the ability to describe the gait evolution and function over time even though the CP population is particularly heterogeneous and complex to describe and analyse.

Moreover, to access other dimensions of the ICF such as personal and environmental factors, several scores and questionnaires can be used for patients with CP as described before (47). Thus, thanks to the different existing tools, it is possible to have a global overview of CP at a precise instant but also over several clinical examinations (111). This knowledge acquired during a long-term follow-up is valuable to help the therapist, the patients, and the families in the understanding of the possible treatment approaches, and the possible evolutions and to discuss prognosis.

2.2 Gait pattern and decision making

In this section, one article has been selected to present how CGA could provide insight into the biomechanical components of gait and has a clear role within an interprofessional decision-making framework (81, 112, 113) .

Armand S., De Coulon G., **Bonnefoy-Mazure A**. "Gait Analysis in children with cerebral palsy". 2016. EFORT Open Rev. 1(12):448-460. DOI:10.1302/2058-5241.1.000052.

Cerebral palsy (CP) children present complex and heterogeneous motor disorders that cause gait deviations. Clinical gait analysis (CGA) is needed to identify, understand and support the management of gait deviations in CP. CGA assesses a large amount of quantitative data concerning patients' gait characteristics, such as video, kinematics, kinetics, electromyography and plantar pressure data. Common gait deviations in CP can be grouped into the gait patterns of spastic hemiplegia (drop foot, equinus with different knee positions) and spastic diplegia (true equinus, jump, apparent equinus and crouch) to facilitate communication. However, gait deviations in CP tend to be a continuum of deviations rather than well delineated groups. To interpret CGA, it is necessary to link gait deviations to clinical impairments and to distinguish primary gait deviations from compensatory strategies. CGA does not tell us how to treat a CP patient, but can provide objective identification of gait

deviations and further the understanding of gait deviations. Numerous treatment options are available to manage gait deviations in CP.
Generally, treatments strive to limit secondary deformations, re-establish the lever arm function and preserve muscle strength. Additional roles of CGA are to better understand the effects of treatments on gait deviations.

Moreover, the analysis of the upper limbs in patients with CP can also help to better characterize stabilization, compensation and different strategies. We have published articles about an analysis of the upper limb patterns and another one about trunk patterns thank to CGA during gait in individuals with cerebral palsy (114, 115) .

2.3 Efficacy of surgical procedures

In this section, two articles have been selected and present how CGA could help to understand the impact of the surgical procedures on the gait patterns over the time thank to CGA done before and after treatment but also during the period of childhood, adolescent, young adulthood and adulthood.

This follow-up over the time is essential to improve our understanding in this hetereogenous population with many types of gait patterns. That is why, our database has been divided in patients with unilateral CP and patients with bilateral CP. This choice allowed us to increase the homogeneity of our cohort and then to improve the pertinence of our statistical analysis over 10 years.

Bonnefoy-Mazure A., De Coulon G., Bregou A., Lascombes P., Armand S. "Long-term evolution of walking in unilateral cerebral palsy: a 10.5-year follow-up of 52 young adults". 2023. J Child Orthop. 17(2): 173–183. doi: 10.1177/18632521231154975

Purpose: To describe gait evolution in patients with unilateral spastic cerebral palsy (USCP) using modified Gait Profile Score (mGPS without hip rotation), Gait Variable Score (GVS), walking speed, and the observed effects of single-level surgery (SLS) after 10 years.

Methods: Fifty-two patients with USCP (Gross Motor Function Classification System I) and data from two Clinical Gait Analyses (CGAs) were included. The evolution of patients' mGPS, GVS, and walking speed were calculated. Two 'no surgery' and 'single-level surgery' patient categories were analyzed. Paired t-tests were used to compare the data between CGAs and as a function of treatment category. Pearson's correlations were used to examine relationships between baseline values and evolutions in mGPS and walking speed.

Results: Mean ages (SD) at first and last CGAs were 9.3 (3.2) and 19.7 (6.0) years old, respectively, with an average follow-up of 10.5 (5.6) years. Mean mGPS for the patients' affected side was significantly lower at the last CGA for the full cohort: baseline = 8.5° (2.1) vs. follow-up = 7.2° (1.6), effect size = 0.73, $p < 0.001$. Significant improvements in mGPS and GVS for ankle and foot progression were found for the SLS group. The mGPS change and mGPS at baseline ($r = -0.79$, $p < 0.001$) were negatively correlated.

Conclusions: SLS patients demonstrated a positive long-term change in gait pattern over time. The group that had undergone surgery had worse gait scores at baseline than the group that had not, but the SLS group's last CGA scores were relatively closer to those of the 'no surgery' group.

Bonnefoy-Mazure A., De Coulon G., Lascombes P., Armand S. "Follow-up of walking quality after end of growth in 28 children with bilateral cerebral palsy". 2020. J Child Orthop. 14(1): 41–49. doi: 10.1302/1863-2548.14.190125

Purpose: Assessment of surgical treatments on gait in patients with bilateral cerebral palsy (CP) is often performed in short-term studies. The purpose of this study was to analyze, the influence of single-event multilevel surgery (SEMLS) on long-term evolution of gait using Gait deviation index (GDI) and walking speed.

Methods: Twenty-eight patients with bilateral CP (GMFCS I-III) with two Clinical gait analysis (CGA) were included (mean age: 9.0 (2.9) years at the first CGA, 19.6 (4.1) years at the last, all of them at skeletal maturity). GDI, walking speed and their changes were calculated. Statistical analysis was performed to observe differences between baseline and follow-up CGA. Pearson's correlations were conducted to evaluate the associations between GDI and walking speed changes with: GDI at baseline and walking speed at baseline. GDI and walking speed evolution have been analyzed for two groups of patients: with and without SEMLS.

Results: Regardless the treatment, GDI was significantly higher at follow-up CGA (baseline: 73.1 (13.1) vs. follow-up: 80.1 (13.2), $p = 0.014$). Significant negative correlations were found between GDI change and GDI at baseline ($r = -0.52$, $p =0.004$) and between walking speed change and walking speed at the baseline ($r = -0.70$, $p<0.001$). Regarding the group of patients with or without SEMLS, only significant improvement of GDI was found for patients with SEMLS (at baseline: 69.0 (12.1) vs. follow-up: 77.8 (11.2), $p <0.05$).

Conclusions: Analyze at skeletal maturity showed a gait quality maintained for patients without SEMLS and an improvement for patients with SEMLS.

3 TKA and CGA

3.1 Clinical issues and outcomes

As presented in the introduction of this thesis, knee OA and the treatments of this disease are a real clinical challenge with an increase of surgeries each year and with of course, a direct impact in terms of public health-cost. In Geneva, the department of orthopaedic surgery and traumatology performed a large number of primary TKA each year. The Geneva arthroplasty registry (GAR) of HUG has followed the knee OA and surgery done in the orthopaedic department for more than 20 years (116). This valuable database and knowledge show that around 220 patients have a TKA each year. In the GAR, a lot of information is collected such as PROM's (American Knee Society Score, Oxford Knee Score, Charnley disabilities grade, WOMAC, SF-12, UCLA activity scale, level of pain, satisfaction level, neuropathic pain, co-morbidities and pain medication). However, no outcomes are collected concerning the functional recovery of the gait. Thus, the use of CGA to objectively quantify the gait function before TKA and after TKA is really challenging and relevant to complete; it also brings new knowledge thanks to the GAR. Indeed, a review of the literature by Sosdian et al. concluded that: *"The relationship between changes in gait biomechanical variables and changes in important patient factors such as pain, function, and quality of life should be investigated in order to determine the clinical relevance of changes in specific gait parameters, and whether specific gait retraining is needed following TKA."* (117).

The outcomes calculated from the CGA that were selected to observe these changes in the gait function and capacity before and after TKA were: spatio-temporal outcomes such as gait speed, cadence, stance phase, stride length and knee kinematic during gait (maximal knee flexion during gait cycle, range of motion of knee flexion and varus/valgus of the knee joint during the stance phase of the gait). These outcomes must be reliable, valid, interpretable and responsive (117, 118, 119, 120). Thus, there is the ability to describe the gait evolution and function over time.

3.2 Decision making

In this section, one article is presented and concerns how CGA can help to know from which value a change in gait outcomes reflects a perceived improvement from the patient's point of view after TKA.

Bonnefoy-Mazure A., Lübbeke A., Miozzari H., Armand S., Sagawa Y. Junior., Turcot K., Poncet A. "Walking Speed and Maximal Knee Flexion During Gait After Total Knee Arthroplasty: Minimal Clinically Important Improvement Is Not Determinable; Patient Acceptable Symptom State Is Potentially Useful ". 2020. Journal of Arthroplasty. 35(10):2865-2871 doi: 10.1016/j.arth.2020.05.038.

Background: Total knee arthroplasty (TKA) is the operation of choice in patients with end-stage knee osteoarthritis (OA). Up to 1 in 5 patients still encounter functional limitations after TKA, partly explaining patient dissatisfaction. Which gait ability to target after TKA remains unclear. To determine whether Minimal Clinical Important Improvement (MCII) or Patient Acceptable Symptom State (PASS) values could be derived from gait parameters recorded in patients with TKA. And, if so, to define those values.

Methods: In this ancillary study, we retrospectively analyzed gait parameters of patients scheduled for a unilateral TKA between 2011 and 2013. We investigated MCII and PASS values for walking speed and maximal knee flexion using anchor-based methods: 5 anchoring questions based on perceived body function and patients' satisfaction.

Results: Over the study period, 79 patients performed a clinical gait analysis the week before and 1 year after surgery, and were included in the present study. All clinical and gait parameters improved 1 year after TKA. Nevertheless, changes in gait outcomes were not associated with perceived body function or patients' satisfaction, precluding any MCII estimation in gait parameters. PASS values, however, could be determined as 1.2 m/s for walking speed and 50° for maximal knee flexion.

Conclusion: In this study, we found that MCII and PASS values are not necessarily determinable for gait parameters after TKA in patients with end-stage OA. Using anchor questions based on perceived body function and patient's satisfaction, MCII could not be defined while PASS values were potentially useful.

Another work has been completed and published, thank to CGA parameters, about the possible differences between gap balancing and measured resection technique on the gait pattern and function (121).

3.3 Efficacy of surgical procedures

In this section, one article is presented and has the objective to better understand the functional impact of the TKA on gait function. For this goal, a comparison of several gait outcomes have been performed before TKA and after three months and one year of the surgery.

Bonnefoy-Mazure A., Armand S., Sagawa Jr Y., Domizio S., Miozzari H., Turcot K. "Knee kinematic and clinical outcomes evolution before, three months and one year following total knee arthroplasty ". 2016. Journal of Arthroplasty. 32(3):793-800. doi: 10.1016/j.arth.2016.03.050.

Background: The aim of this study was to describe the evolution of kinematic and clinical outcomes of a large patient cohort with knee osteoarthritis from before surgery (V1) to 3 months (V2) and 1 year (V3) after a total knee arthroplasty (TKA).

Methods: The patients were evaluated at each visit (118 patients at V1, 93 patients at V2, and 79 patients at V3) during a clinical gait analysis and were compared with a matched control group of healthy adults (CG). The kinematic parameters, the Western Ontario and MacMaster Osteoarthritis Index (WOMAC), quality of life, and patient satisfaction were assessed. Gait velocity and knee range of motion (ROM) as well as clinical parameters were compared at each visit with CG was based on the unpaired samples t-test. To determine changes in the data at baseline, 3 months, and 1 year after surgery in the patient groups, repeated-measure analysis of variance was conducted ($P < .05$). Pearson correlation was used to examine relationships between clinical and biomechanical outcomes.

Results: One year after TKA (V3) compared to V1 and V2, the ROM of the operated knee during gait was significantly improved (V1: 44.2 ± 8.8° vs V3: 47.5 ± 7.1°, $P < .001$, and V2: 42.2 ± 9.3° vs V3: 47.5 ± 7.1°, $P = .001$), as was the gait velocity (V1: 1.0 ± 0.2 and V2: 1.1 ± 0.2 m/s vs V3: 1.3 ± 0.2 m/s, $P < .001$). The WOMAC and knee pain were significantly better 1 year after TKA. No strong relationships have been found between clinical parameters and knee kinematics.

Conclusion: This study showed that 1 year after TKA, patients exhibited improved gait velocity and ROM and experienced a significant decrease in the level of pain and an increased clinical score (although different from CG).

Additionally, two other publications have been written. The first one evaluates the long-term gait evolution of the patients seven years after TKA (122). The second publication aims to gain deeper understanding of potential difference in terms of functional recovery within our patient cohort with analyses performed as a function of the satisfaction level or of the body mass index (123).

4 Summary of our findings

Based on these different works, it appears that CGA is a powerful tool to identify, analyse and understand gait deviations due to CP or knee OA and also to follow-up the gait evolution and modifications after a treatment. The main difference between these two fields of CGA applications is that for the CP domain, CGA is used as a clinical routine of functional assessment in the management of patients with CP whereas, in the TKA domain, CGA is used as a research tool to find potential changes in gait biomechanical variables following surgery in function also of the patient's reported outcome.

Thank to these two application domains, I contributed to the increase and improvement of the knowledge and understanding of various gait deviations and the impact of the treatment on them. Thus, from these works, we found that:

4.1 For population with CP

- ✓ CGA is a useful and efficient tool to support and help the clinical team in their decisions. The essential point is that these decisions are done using a multidisciplinary approach. Indeed, thank to discussions between surgeons, neurologists, rehabilitation doctors, physiotherapists, biomechanical doctors, the CGA can help to better identify and understand gait impairments. Based on this multidisciplinary approach, the management of gait deviations in CP can be improved and better optimized for each patient. Thus, CGA now has a fundamental role in the clinical management of gait deviations.

- ✓ Thanks to a multivariate approach, data records from CGA and clinical examination can help to classify the gait deviations in four main gait profiles: an apparent equinus gait; a true equinus gait; a crouch gait and a jump knee gait (112). However, the mathematical links between clinical parameters and gait deviations are difficult to find. Indeed, we have observed that a multilinear regression model using clinical parameters in patients with CP does not provide predictions of gait patterns. This point shows that the gait is a complex movement characterized by different levels of coordination, compensation, balance, central nervous system, actions of biarticular muscles, etc.… Thus, the role and the knowledge of the clinicians that can interpret gait deviations and that can understand the link with clinical examination to choose the best therapeutic strategies cannot be replaced by a mathematical model.

- ✓ CGA can help to better understand the effects of treatments on gait deviations after a long period of follow-up. Indeed, the follow-up of patients with CP after treatment is necessary between childhood and young adulthood. This kind of knowledge allows us to better observe and refine the impact of treatment on the gait deviations and to also observe if the treatment can improve the gait and furthermore to observe if this improvement is maintained over time. Moreover, CGA provides objective data on the gait that has a role of "learning" for the clinicians that can show that some surgeries are not always the best and most appropriate way for evolution of the gait function.

4.2 For populations with knee OA

- ✓ CGA has made it possible to establish that gait parameter values one-year post-TKA were associated with perceived body function and patients' satisfaction. This Patient Acceptable Symptom State cut-off values has been defined at 1.2 m/s for walking speed and 50° for maximal knee flexion during gait. These values were the first to be established for the TKA field. These findings are important to validate two biomarkers that are both good indicators of health in the elderly regarding brain function, cognition, functionality, mobility, well-being, independence, and autonomy. In addition, CGA allows researchers to compare some technical surgery (gap balancing and measured resection technique) and then can help the surgeons in their decision. Indeed, a deeper understanding of the classifications of stability and instability in TKA, related to the surgeons' and the patients' subjective perception, is important to note, keeping in mind the technique/philosophy used. Current knee arthroplasty is not a simple resurfacing intervention. The implant's geometry and intrinsic stability are (mostly) not physiological.

- ✓ CGA allows to more precisely observe the gait function before and after TKA. The main findings of our several publications are that the improvement of the gait function and capacity are maintained even after 7 years after TKA (122). Moreover, concerning the patient's satisfaction after surgery, it has been found that a higher maximal knee flexion during gait may be associated with a higher level of patient satisfaction one year after surgery independently of age, BMI and postoperative pain level. In addition, the relation between BMI and functional performances during gait in terms of knee ROM and gait velocity recoveries before and one year after TKA have also been explored

(123). The findings confirm that all patients improved biomechanically and clinically, regardless of their BMI even though patients with obese did not achieve the same absolute postoperative level of gait speed and knee ROM as their non-obese counterparts.

- ✓ Investigating knee mobility after TKA during daily activity such as gait may provide clinicians with important additional information that could assist in the development of future interventions, to better understand and improve the dynamic recovery and knee function after surgery, to guide and better meet patient expectations, to adapt and modify rehabilitation programs after surgery and to monitor patient progression post-operatively.

Based on these various results, it appears that CGA can help to guide the thinking to find and guide better treatment and follow-up for patients. Moreover, CGA can be used to analyse other joint movements such as upper limbs with associated pathologies.

5 Perspectives, future research and general conclusion

My overall objective regarding my research work is to better understand the impact of treatments as surgical interventions on human locomotion and to more specifically:

5.1 The longitudinal follow-up of patients with CP

As explained in the introduction section, CP is a non-evolutive neurological disease. However, over time, it appears that adults with CP have a decline in their level of function and mobility (124). The gait deterioration can have several origins, such as: age, chronic pain, severity of fatigue, depressive symptoms, decrease of stability, increase of muscle contracture and spasticity, increase of weight, sedentary life, less physical activities and physiotherapy sessions and of course, type of CP (unilateral or bilateral) and level of GMFCS. This decline is thus multifactorial and implies multiple domains. Thus, the knowledge concerning this topic are difficult to understand well. Moreover, the number of adults with CP is a growing population in the world which is why it is essential to have a good overview of the evolution of the CP during adulthood. Maintaining the ability to walk efficiently and safely is of major importance in terms of social participation, quality of life, and independence.

In this context, it is essential to develop rational follow-up programs, to identify risk factors early, and to avoid fatigue and deterioration of walking ability in adulthood. Longitudinal studies following walking ability from childhood rarely extend further than 30 years and follow-up studies of walking evolution are rare. However, the understanding of gait evolution across the life of patients with CP is highly desirable to guide the development of “lifespan” models of health promotion and clinical service delivery.

Thus, to continue the longitudinal follow-up of patients with CP in collaboration with Prof. Armand and Dr. De Coulon is primordial to examine the influence of different factors such as age, treatments, function, pain, fatigue, daily life activities, subjective scores of quality of life, assistance, assistive devices, level of mobility, professional activities, education levels. Thus, this research project will be one of my priorities in future years to bring complementary pieces of knowledge to the clinicians and to help the patients and their families in their daily life and their future. Finally, I have led this work for 10 years now, and I have had a deep attachment to this topic and to our patients with CP and their families.

5.2 The determination of predictive factors of knee stability after arthroplasty

As presented in this thesis, several articles have been written about the recovery of knee function and gait abilities after TKA as a function of several factors such as BMI, patient’s satisfaction, and type of surgery. Nevertheless, we have also observed that despite many improvements in their knee function and gait abilities, a substantial proportion (about 20%) of patients continue to report pain, functional limitations including subjective knee instability, and/or dissatisfaction after TKA. Thus, a better comprehension of the factors explaining the possible dissatisfaction is very important to better manage and help patients with TKA. The knee instability can have a major impact on the patient’s level of functionality, and it is also recognized as one of the causes of TKA failure resulting in between 10-20% of prosthesis revisions (125). TKA revisions have a significant impact on the emotional level of patients due to a new operation, a new rehabilitation, with a higher mortality rate compared to primary TKA. In addition, the financial cost of TKA revision is very impactful on public health. In our department, for example, in 2021, around 13% of patients had a TKA revision (116). Therefore, it seems important to better characterize and understand knee instability in order to improve primary TKAs survival and diminish the revision burden. That is why, continuing the project concerning the determination of predictive factors of knee stability after arthroplasty is one of

the main objectives of my future research in close collaboration with Dr. Miozzari, Dr. Gasparutto, and Prof. Armand.

5.3 Implementation and validation of a fast and objective functional test for patients with total hip and knee arthroplasty

As explained in the introduction section, OA is the most prevalent joint disease and a major public health problem. The restoration of function has been reported as the most important patient expectation before surgery as TKA and THA. In this context, the evaluation of patient's function before and after surgery is a clinically relevant outcome of the surgery. Thus, the development and validation of an objective test of function, as instrumented Time-up-and-go (iTUG), for patients undergoing TKA and THA seems necessary and important in the daily clinical practice to provide a complementary approach to the current subjective evaluation of function in the arthroplasty registry. Thus, it would be possible to perform a systematic biomechanical analysis of the function of patients undergoing THA and TKA with a fast and quantified test. By doing so, large cohorts of patients could be followed and analyzed to increase the understanding of patient's functional recovery after joint arthroplasty and give more insights to clinicians and patients. Moreover, by identifying deficits in specific functional domains for a patient, such a test could contribute to better targeting the rehabilitation and more generally increase the personalization of healthcare for this growing patient population. Finally, to improve function is the declared goal of many new implants. This has so far been difficult to substantiate in large cohorts. It would thus be highly desirable to have an objective function test - reliable and easy to use. This work will be led by Dr. Gasparutto in collaboration with Dr. Miozzari, Prof Hannouche, Prof Lübbeke, Prof. Armand and myself.

5.4 Geneva Arthroplasty Registry (GAR)

Since 1996, a registry, called GAR, has been established at the Division of Orthopaedics and Trauma Surgery in the HUG (116). The GAR has been made possible thanks to the expertise and diligent work of Prof Anne Lübbeke and her team. The aim of this registry is the surveillance of safety and quality of the THA and TKA surgeries to improve the quality of life of the patients. Thus, since 1996 for THA and 1998 for TKA, all patients undergoing a surgery or revision are routinely enrolled in the GAR at the day of surgery and followed longitudinally. Several outcomes are included in the registry as: patient characteristics, co-morbidities, medication, clinical evaluation, X-ray, Patients Reported Outcomes Measures (PROMs), surgical techniques, type of implants, and surgeons. This data collection occurs before surgery,

at the time of surgery and 1,5,10,15, 20 and 25 years after the surgery. For the follow-up after surgery, only clinical evaluation, X-ray and PROMs are collected in addition to reporting possible causes of complications, revisions, reoperation and death. The immense amount of data collected over all these years makes the GAR unique in terms of detailed information. Indeed, the registry is useful and usable in-patient care, decision making, medical device monitoring, surgeon training, education, hospital care process and public health decision making. Finally, thank to this incredible database, Prof. Anne Lübbeke and her collaborators have disseminated their work in many publications and presentations at scientific meetings in the THA and TKA research field. In this context, I had the opportunity and chance to collaborate with the Prof. Lübbeke, on the database available in the registry. Our first work was about: **"Limping and patient satisfaction after primary total hip arthroplasty: a registry-based cohort study**" and was published in Acta orthopaedica in 2022 (126). This work is available in the Appendix section. In addition, another publication is in review in BMC Musculoskeletal Disorders concerning: **"Association of preoperative health status with risk of complications after primary total hip arthroplasty: How useful are the measures self-rated health, ASA classification and comorbidity count?".** My role was to perform statistical analyses (Stata, R) from the data extracted from the register, to study the literature and to write the papers. This collaboration allows me to develop new knowledge in the field of public health, epidemiology and statistics. Moreover, thanks to Prof Lübbeke and Prof Hannouche, I have had the opportunity, last year to take the course: **"Conceptual Foundations of Epidemiologic Study Design and Analysis a formation in epidemiology"** at Bergen University for four days, in order to improve my knowledge in this domain. That is why, to continue this collaboration with Prof Lübbeke and her team is another very important objective for me to learn new knowledge in a domain very different from my background, but which brings me innovative clinical research in terms of public health and statistical knowledge.

5.5 General Conclusion

This Privat Docent work aimed to present and summarize my 10 years of collaboration with the Willy Taillard Kinesiology Laboratory through my 2 main research focuses: cerebral palsy and TKA. These two areas of study have allowed me to cultivate a robust base of knowledge in clinical research. By building upon the diverse perspectives developed earlier, I aspire to further enhance my expertise in clinical decision-making and the efficacy of treatment methods to enhance and restore patient mobility and, naturally, their quality of life.

Moreover, as I lead CGA in the laboratory, I maintain constant interaction with patients, clinical colleagues, and their challenges. This connectivity provides me the opportunity to practically apply my knowledge and consistently engage in discussions concerning various issues or queries encountered by my colleagues. It also offers me the chance to contemplate the diverse approaches to best support patients and their families.

6 References

1. Perry J, Burnfield JM. Gait analysis : normal and pathological function. 2nd ed. Thorofare N.J.: Slack; 2010. 551 p. p.
2. Ivanenko YP, Dominici N, Lacquaniti F. Development of independent walking in toddlers. Exerc Sport Sci Rev. 2007;35(2):67-73.
3. Troje NF. Decomposing biological motion: a framework for analysis and synthesis of human gait patterns. J Vis. 2002;2(5):371-87.
4. Cuomo AV, Gamradt SC, Kim CO, Pirpiris M, Gates PE, McCarthy JJ, et al. Health-related quality of life outcomes improve after multilevel surgery in ambulatory children with cerebral palsy. J Pediatr Orthop. 2007;27(6):653-7.
5. Fritz S, Lusardi M. White paper: "walking speed: the sixth vital sign". J Geriatr Phys Ther. 2009;32(2):46-9.
6. Pirker W, Katzenschlager R. Gait disorders in adults and the elderly : A clinical guide. Wien Klin Wochenschr. 2017;129(3-4):81-95.
7. Beyaert C, Vasa R, Frykberg GE. Gait post-stroke: Pathophysiology and rehabilitation strategies. Neurophysiol Clin. 2015;45(4-5):335-55.
8. Cofre Lizama LE, Khan F, Lee PV, Galea MP. The use of laboratory gait analysis for understanding gait deterioration in people with multiple sclerosis. Mult Scler. 2016;22(14):1768-76.
9. McIntyre S, Goldsmith S, Webb A, Ehlinger V, Hollung SJ, McConnell K, et al. Global prevalence of cerebral palsy: A systematic analysis. Dev Med Child Neurol. 2022;64(12):1494-506.
10. Oskoui M, Coutinho F, Dykeman J, Jette N, Pringsheim T. An update on the prevalence of cerebral palsy: a systematic review and meta-analysis. Dev Med Child Neurol. 2013;55(6):509-19.
11. Beckung E, Hagberg G, Uldall P, Cans C, Surveillance of Cerebral Palsy in E. Probability of walking in children with cerebral palsy in Europe. Pediatrics. 2008;121(1):e187-92.
12. Graham D, Paget SP, Wimalasundera N. Current thinking in the health care management of children with cerebral palsy. Med J Aust. 2019;210(3):129-35.
13. Bax M, Goldstein M, Rosenbaum P, Leviton A, Paneth N, Dan B, et al. Proposed definition and classification of cerebral palsy, April 2005. Dev Med Child Neurol. 2005;47(8):571-6.
14. Bekteshi S, Monbaliu E, McIntyre S, Saloojee G, Hilberink SR, Tatishvili N, et al. Towards functional improvement of motor disorders associated with cerebral palsy. Lancet Neurol. 2023;22(3):229-43.
15. Surveillance of Cerebral Palsy in E. Surveillance of cerebral palsy in Europe: a collaboration of cerebral palsy surveys and registers. Surveillance of Cerebral Palsy in Europe (SCPE). Dev Med Child Neurol. 2000;42(12):816-24.
16. Armand S, Watelain E, Mercier M, Lensel G, Lepoutre FX. Identification and classification of toe-walkers based on ankle kinematics, using a data-mining method. Gait Posture. 2006;23(2):240-8.
17. Graham HK, Thomason P, Willoughby K, Hastings-Ison T, Stralen RV, Dala-Ali B, et al. Musculoskeletal Pathology in Cerebral Palsy: A Classification System and Reliability Study. Children (Basel). 2021;8(3).
18. Rodda J, Graham HK. Classification of gait patterns in spastic hemiplegia and spastic diplegia: a basis for a management algorithm. Eur J Neurol. 2001;8 Suppl 5:98-108.
19. Rozumalski A, Schwartz MH. Crouch gait patterns defined using k-means cluster analysis are related to underlying clinical pathology. Gait Posture. 2009;30(2):155-60.
20. Carcreff L. Gait Analysis in children with cerebral palsy: bridging the gap between the laboratory and real life: EPFL; 2020.
21. Eliasson AC, Krumlinde-Sundholm L, Rosblad B, Beckung E, Arner M, Ohrvall AM, et al. The Manual Ability Classification System (MACS) for children with cerebral palsy: scale development and evidence of validity and reliability. Dev Med Child Neurol. 2006;48(7):549-54.
22. Palisano RJ, Rosenbaum P, Bartlett D, Livingston MH. Content validity of the expanded and revised Gross Motor Function Classification System. Dev Med Child Neurol. 2008;50(10):744-50.
23. Schwartz MH, Munger ME. ESMAC BEST PAPER 2017: Using machine learning to overcome challenges in GMFCS level assignment. Gait Posture. 2018;63:290-5.

24. Hanna SE, Rosenbaum PL, Bartlett DJ, Palisano RJ, Walter SD, Avery L, et al. Stability and decline in gross motor function among children and youth with cerebral palsy aged 2 to 21 years. Dev Med Child Neurol. 2009;51(4):295-302.
25. Papageorgiou E, Nieuwenhuys A, Vandekerckhove I, Van Campenhout A, Ortibus E, Desloovere K. Systematic review on gait classifications in children with cerebral palsy: An update. Gait Posture. 2019;69:209-23.
26. Winters TF, Jr., Gage JR, Hicks R. Gait patterns in spastic hemiplegia in children and young adults. J Bone Joint Surg Am. 1987;69(3):437-41.
27. Dobson F, Morris ME, Baker R, Graham HK. Gait classification in children with cerebral palsy: a systematic review. Gait Posture. 2007;25(1):140-52.
28. Novak I, McIntyre S, Morgan C, Campbell L, Dark L, Morton N, et al. A systematic review of interventions for children with cerebral palsy: state of the evidence. Dev Med Child Neurol. 2013;55(10):885-910.
29. Novak I, Morgan C, Adde L, Blackman J, Boyd RN, Brunstrom-Hernandez J, et al. Early, Accurate Diagnosis and Early Intervention in Cerebral Palsy: Advances in Diagnosis and Treatment. JAMA Pediatr. 2017;171(9):897-907.
30. Herskind A, Greisen G, Nielsen JB. Early identification and intervention in cerebral palsy. Dev Med Child Neurol. 2015;57(1):29-36.
31. Dreher T, Thomason P, Svehlik M, Doderlein L, Wolf SI, Putz C, et al. Long-term development of gait after multilevel surgery in children with cerebral palsy: a multicentre cohort study. Dev Med Child Neurol. 2018;60(1):88-93.
32. Braatz F, Dreher T, Wolf SI, Niklasch M. Preoperative hip rotation moments do not predict long-term development after femoral derotation osteotomy in children with cerebral palsy. Gait Posture. 2018;61:215-9.
33. Schranz C, Kruse A, Kraus T, Steinwender G, Svehlik M. Does unilateral single-event multilevel surgery improve gait in children with spastic hemiplegia? A retrospective analysis of a long-term follow-up. Gait Posture. 2017;52:135-9.
34. Svehlik M, Steinwender G, Lehmann T, Kraus T. Predictors of outcome after single-event multilevel surgery in children with cerebral palsy: a retrospective ten-year follow-up study. Bone Joint J. 2016;98-B(2):278-81.
35. Sinusas K. Osteoarthritis: diagnosis and treatment. Am Fam Physician. 2012;85(1):49-56.
36. Sellam J, Berenbaum F. The role of synovitis in pathophysiology and clinical symptoms of osteoarthritis. Nat Rev Rheumatol. 2010;6(11):625-35.
37. Kisand K, Tamm AE, Lintrop M, Tamm AO. New insights into the natural course of knee osteoarthritis: early regulation of cytokines and growth factors, with emphasis on sex-dependent angiogenesis and tissue remodeling. A pilot study. Osteoarthritis Cartilage. 2018;26(8):1045-54.
38. Sebbag E, Felten R, Sagez F, Sibilia J, Devilliers H, Arnaud L. The world-wide burden of musculoskeletal diseases: a systematic analysis of the World Health Organization Burden of Diseases Database. Ann Rheum Dis. 2019;78(6):844-8.
39. Disease GBD, Injury I, Prevalence C. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet. 2018;392(10159):1789-858.
40. Kloppenburg M, Berenbaum F. Osteoarthritis year in review 2019: epidemiology and therapy. Osteoarthritis Cartilage. 2020;28(3):242-8.
41. Goldring MB, Otero M. Inflammation in osteoarthritis. Curr Opin Rheumatol. 2011;23(5):471-8.
42. Egloff C, Hugle T, Valderrabano V. Biomechanics and pathomechanisms of osteoarthritis. Swiss Med Wkly. 2012;142:w13583.
43. Zheng S, Tu L, Cicuttini F, Zhu Z, Han W, Antony B, et al. Depression in patients with knee osteoarthritis: risk factors and associations with joint symptoms. BMC Musculoskelet Disord. 2021;22(1):40.
44. Schreiber C, Armand S, Moissenet F. Influence of normative data's walking speed on the computation of conventional gait indices. J Biomech. 2018;76:68-73.

45. Holden MA, Nicolson PJA, Thomas MJ, Corp N, Hinman RS, Bennell KL. Osteoarthritis year in review 2022: rehabilitation. Osteoarthritis Cartilage. 2023;31(2):177-86.
46. Towards a Common Language for Functioning , Disability and Health : ICF The International Classification of Functioning, Disability and Health., (2002).
47. Chagas PSC, Magalhaes EDD, Sousa Junior RR, Romeros A, Palisano RJ, Leite HR, et al. Development of children, adolescents, and young adults with cerebral palsy according to the ICF: A scoping review. Dev Med Child Neurol. 2022.
48. Weigl M, Cieza A, Harder M, Geyh S, Amann E, Kostanjsek N, et al. Linking osteoarthritis-specific health-status measures to the International Classification of Functioning, Disability, and Health (ICF). Osteoarthritis Cartilage. 2003;11(7):519-23.
49. Meadows KA. Patient-reported outcome measures: an overview. Br J Community Nurs. 2011;16(3):146-51.
50. Thomason P, Tan A, Donnan A, Rodda J, Graham HK, Narayanan U. The Gait Outcomes Assessment List (GOAL): validation of a new assessment of gait function for children with cerebral palsy. Dev Med Child Neurol. 2018;60(6):618-23.
51. Graham HK, Harvey A, Rodda J, Nattrass GR, Pirpiris M. The Functional Mobility Scale (FMS). J Pediatr Orthop. 2004;24(5):514-20.
52. Schiariti V, Klassen AF, Cieza A, Sauve K, O'Donnell M, Armstrong R, et al. Comparing contents of outcome measures in cerebral palsy using the International Classification of Functioning (ICF-CY): a systematic review. Eur J Paediatr Neurol. 2014;18(1):1-12.
53. Baker R, McGinley JL, Schwartz MH, Beynon S, Rozumalski A, Graham HK, et al. The gait profile score and movement analysis profile. Gait Posture. 2009;30(3):265-9.
54. Schwartz MH, Rozumalski A. The Gait Deviation Index: a new comprehensive index of gait pathology. Gait Posture. 2008;28(3):351-7.
55. Gasparutto X, Gueugnon M, Laroche D, Martz P, Hannouche D, Armand S. Which functional tasks present the largest deficits for patients with total hip arthroplasty before and six months after surgery? A study of the timed up-and-go test phases. PLoS One. 2021;16(9):e0255037.
56. Yoon MJ, Choi H, Kim JS, Lim SH, Yoo YJ, Hong BY. Physical activity, quality of life and parenting stress in children with cerebral palsy. Pediatr Int. 2022;64(1):e15295.
57. Schiariti V, Tatla S, Sauve K, O'Donnell M. Toolbox of multiple-item measures aligning with the ICF Core Sets for children and youth with cerebral palsy. Eur J Paediatr Neurol. 2017;21(2):252-63.
58. P. T. Functional Mobility and Gait in Children and Youth with Cerebral Palsy. Cerebral Palsy. 3: Springer; 2020.
59. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol. 1988;15(12):1833-40.
60. Harris K, Dawson J, Gibbons E, Lim CR, Beard DJ, Fitzpatrick R, et al. Systematic review of measurement properties of patient-reported outcome measures used in patients undergoing hip and knee arthroplasty. Patient Relat Outcome Meas. 2016;7:101-8.
61. Ackerman IN, Kemp JL, Crossley KM, Culvenor AG, Hinman RS. Hip and Knee Osteoarthritis Affects Younger People, Too. J Orthop Sports Phys Ther. 2017;47(2):67-79.
62. Peter WF, Jansen MJ, Hurkmans EJ, Bloo H, Dekker J, Dilling RG, et al. Physiotherapy in hip and knee osteoarthritis: development of a practice guideline concerning initial assessment, treatment and evaluation. Acta Reumatol Port. 2011;36(3):268-81.
63. Marey EJ. Du mouvement dans les fonctions de la vie. Paris: Germer Bai; 1868.
64. Braune W. FO. The Human Gait: Springer Berlin, Heidelberg; 1987.
65. Sutherland DH. The evolution of clinical gait analysis part l: kinesiological EMG. Gait Posture. 2001;14(1):61-70.
66. Sutherland DH. The evolution of clinical gait analysis. Part II kinematics. Gait Posture. 2002;16(2):159-79.

67. Sutherland DH. The evolution of clinical gait analysis part III--kinetics and energy assessment. Gait Posture. 2005;21(4):447-61.
68. Baker R. The history of gait analysis before the advent of modern computers. Gait Posture. 2007;26(3):331-42.
69. Baker R. Measuring Walking: A Handbook of Clinical Gait Analysis édition MPe, editor2013.
70. Cappozzo A, Catani F, Croce UD, Leardini A. Position and orientation in space of bones during movement: anatomical frame definition and determination. Clin Biomech (Bristol, Avon). 1995;10(4):171-8.
71. Cappozzo A, Catani F, Leardini A, Benedetti MG, Croce UD. Position and orientation in space of bones during movement: experimental artefacts. Clin Biomech (Bristol, Avon). 1996;11(2):90-100.
72. Cappozzo A, Della Croce U, Catani F, Leardini A, Fioretti S, Maurizi M. Stereometric system accuracy tests. In Measurement and Data processing methodology in clinical movement analysis-preliminary. . In: Report I, editor. Models, connections with experimental apparatus and relevant DSP techniques for functional movement analysis CAMARC Internal Report1993.
73. Cappozzo A, Della Croce U, Leardini A, Chiari L. Human movement analysis using stereophotogrammetry. Part 1: theoretical background. Gait Posture. 2005;21(2):186-96.
74. Wu G, Cavanagh PR. ISB recommendations for standardization in the reporting of kinematic data. J Biomech. 1995;28(10):1257-61.
75. Wu G, Siegler S, Allard P, Kirtley C, Leardini A, Rosenbaum D, et al. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion--part I: ankle, hip, and spine. International Society of Biomechanics. J Biomech. 2002;35(4):543-8.
76. Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. J Biomech. 2005;38(5):981-92.
77. Romkes J, Brunner R. An electromyographic analysis of obligatory (hemiplegic cerebral palsy) and voluntary (normal) unilateral toe-walking. Gait Posture. 2007;26(4):577-86.
78. Viehweger E, Berard C, Berruyer A, Simeoni MC, Groupe V. [Testing range of motion in cerebral palsy]. Ann Readapt Med Phys. 2007;50(4):258-65.
79. Moissenet F, Armand S. Qualitative and quantitative methods of assessings gait disorders. Orthopeadic management of children with cerebral palsy: Nova sciences publishers; 2015.
80. Armand S, Bonnefoy-Mazure A, Hoffmeyer P, De Coulon G. [Clinical gait analysis: user guide]. Rev Med Suisse. 2015;11(490):1916-20.
81. Bonnefoy-Mazure A, Turcot K, Kaelin A, De Coulon G, Armand S. Full body gait analysis may improve diagnostic discrimination between hereditary spastic paraplegia and spastic diplegia: a preliminary study. Res Dev Disabil. 2013;34(1):495-504.
82. Carcreff L, Payen G, Grouvel G, Masse F, Armand S. Three-Dimensional Lower-Limb Kinematics from Accelerometers and Gyroscopes with Simple and Minimal Functional Calibration Tasks: Validation on Asymptomatic Participants. Sensors (Basel). 2022;22(15).
83. Carcreff L, Gerber CN, Paraschiv-Ionescu A, De Coulon G, Aminian K, Newman CJ, et al. Walking Speed of Children and Adolescents With Cerebral Palsy: Laboratory Versus Daily Life. Front Bioeng Biotechnol. 2020;8:812.
84. Carcreff L, Gerber CN, Paraschiv-Ionescu A, De Coulon G, Newman CJ, Aminian K, et al. Comparison of gait characteristics between clinical and daily life settings in children with cerebral palsy. Sci Rep. 2020;10(1):2091.
85. Carcreff L, Paraschiv-Ionescu A, Gerber CN, Newman CJ, Armand S, Aminian K. A Personalized Approach to Improve Walking Detection in Real-Life Settings: Application to Children with Cerebral Palsy. Sensors (Basel). 2019;19(23).
86. Carcreff L, Armand S, Bonnefoy-Mazure A, De Coulon G, Newman CJ. [New tools for movement assessment in children with motor disabilities]. Rev Med Suisse. 2022;18(770):336-9.
87. Moreau NG, Bodkin AW, Bjornson K, Hobbs A, Soileau M, Lahasky K. Effectiveness of Rehabilitation Interventions to Improve Gait Speed in Children With Cerebral Palsy: Systematic Review and Meta-analysis. Phys Ther. 2016;96(12):1938-54.

88. Peeters N, Papageorgiou E, Hanssen B, De Beukelaer N, Staut L, Degelaen M, et al. The Short-Term Impact of Botulinum Neurotoxin-A on Muscle Morphology and Gait in Children with Spastic Cerebral Palsy. Toxins (Basel). 2022;14(10).
89. Everaert L, Papageorgiou E, Van Campenhout A, Labey L, Desloovere K. The influence of ankle-foot orthoses on gait pathology in children with cerebral palsy: A retrospective study. Gait Posture. 2023;100:149-56.
90. Amirmudin NA, Lavelle G, Theologis T, Thompson N, Ryan JM. Multilevel Surgery for Children With Cerebral Palsy: A Meta-analysis. Pediatrics. 2019;143(4).
91. Visscher R, Hasler N, Freslier M, Singh NB, Taylor WR, Brunner R, et al. Long-term follow-up after multilevel surgery in cerebral palsy. Arch Orthop Trauma Surg. 2022;142(9):2131-8.
92. Thomason P, Baker R, Dodd K, Taylor N, Selber P, Wolfe R, et al. Single-event multilevel surgery in children with spastic diplegia: a pilot randomized controlled trial. J Bone Joint Surg Am. 2011;93(5):451-60.
93. Jackman M, Sakzewski L, Morgan C, Boyd RN, Brennan SE, Langdon K, et al. Interventions to improve physical function for children and young people with cerebral palsy: international clinical practice guideline. Dev Med Child Neurol. 2022;64(5):536-49.
94. F. M. Cerebral Palsy. Springer, editor2005. 1045 p.
95. Kudva A, Abraham ME, Gold J, Patel NA, Gendreau JL, Herschman Y, et al. Intrathecal baclofen, selective dorsal rhizotomy, and extracorporeal shockwave therapy for the treatment of spasticity in cerebral palsy: a systematic review. Neurosurg Rev. 2021;44(6):3209-28.
96. Enslin JMN, Langerak NG, Fieggen AG. The Evolution of Selective Dorsal Rhizotomy for the Management of Spasticity. Neurotherapeutics. 2019;16(1):3-8.
97. Abbott R. The selective dorsal rhizotomy technique for spasticity in 2020: a review. Childs Nerv Syst. 2020;36(9):1895-905.
98. Price AJ, Alvand A, Troelsen A, Katz JN, Hooper G, Gray A, et al. Knee replacement. Lancet. 2018;392(10158):1672-82.
99. Nashi N, Hong CC, Krishna L. Residual knee pain and functional outcome following total knee arthroplasty in osteoarthritic patients. Knee Surg Sports Traumatol Arthrosc. 2015;23(6):1841-7.
100. Riviere C, Iranpour F, Auvinet E, Aframian A, Asare K, Harris S, et al. Mechanical alignment technique for TKA: Are there intrinsic technical limitations? Orthop Traumatol Surg Res. 2017;103(7):1057-67.
101. Liu B, Feng C, Tu C. Kinematic alignment versus mechanical alignment in primary total knee arthroplasty: an updated meta-analysis of randomized controlled trials. J Orthop Surg Res. 2022;17(1):201.
102. Winnock de Grave P, Kellens J, Luyckx T, Tampere T, Lacaze F, Claeys K. Inverse Kinematic Alignment for Total Knee Arthroplasty. Orthop Traumatol Surg Res. 2022;108(5):103305.
103. Vendittoli PA, Martinov S, Blakeney WG. Restricted Kinematic Alignment, the Fundamentals, and Clinical Applications. Front Surg. 2021;8:697020.
104. Lustig S, Sappey-Marinier E, Fary C, Servien E, Parratte S, Batailler C. Personalized alignment in total knee arthroplasty: current concepts. SICOT J. 2021;7:19.
105. van der Krogt MM, Houdijk H, Wishaupt K, van Hutten K, Dekker S, Buizer AI. Development of a core set of gait features and their potential underlying impairments to assist gait data interpretation in children with cerebral palsy. Front Hum Neurosci. 2022;16:907565.
106. Hebda-Boon A, Tan XL, Tillmann R, Shortland AP, Firth GB, Morrissey D. The impact of instrumented gait analysis on decision-making in the interprofessional management of cerebral palsy: A scoping review. Eur J Paediatr Neurol. 2023;42:60-70.
107. Wren TA, Gorton GE, 3rd, Ounpuu S, Tucker CA. Efficacy of clinical gait analysis: A systematic review. Gait Posture. 2011;34(2):149-53.
108. Barton GJ, Hawken MB, Scott MA, Schwartz MH. Leaving hip rotation out of a conventional 3D gait model improves discrimination of pathological gait in cerebral palsy: A novel neural network analysis. Gait Posture. 2019;70:48-52.
109. Rasmussen HM, Nielsen DB, Pedersen NW, Overgaard S, Holsgaard-Larsen A. Gait Deviation Index, Gait Profile Score and Gait Variable Score in children with spastic cerebral palsy: Intra-rater reliability and agreement across two repeated sessions. Gait Posture. 2015;42(2):133-7.

110. Baker R, McGinley JL, Schwartz M, Thomason P, Rodda J, Graham HK. The minimal clinically important difference for the Gait Profile Score. Gait Posture. 2012;35(4):612-5.
111. Bonnefoy-Mazure A, De Coulon G, Armand S. Self-perceived gait quality in young adults with cerebral palsy. Dev Med Child Neurol. 2020;62(7):868-73.
112. Bonnefoy-Mazure A, Sagawa Y, Jr., Pomero V, Lascombes P, De Coulon G, Armand S. Are clinical parameters sufficient to model gait patterns in patients with cerebral palsy using a multilinear approach? Comput Methods Biomech Biomed Engin. 2016;19(7):800-6.
113. Bonnefoy-Mazure A, Sagawa Y, Jr., Lascombes P, De Coulon G, Armand S. Identification of gait patterns in individuals with cerebral palsy using multiple correspondence analysis. Res Dev Disabil. 2013;34(9):2684-93.
114. Bonnefoy-Mazure A, Sagawa Y, Jr., Lascombes P, De Coulon G, Armand S. A descriptive analysis of the upper limb patterns during gait in individuals with cerebral palsy. Res Dev Disabil. 2014;35(11):2756-65.
115. Attias M, Bonnefoy-Mazure A, Lempereur M, Lascombes P, De Coulon G, Armand S. Trunk movements during gait in cerebral palsy. Clin Biomech (Bristol, Avon). 2015;30(1):28-32.
116. Lubbeke A, Barea C, Miozzari H, Hannouche D. Geneva arthroplasty registry - Annual report:1996-2021. Geneva2022.
117. Sosdian L, Dobson F, Wrigley TV, Paterson K, Bennell K, Dowsey M, et al. Longitudinal changes in knee kinematics and moments following knee arthroplasty: a systematic review. Knee. 2014;21(6):994-1008.
118. McNair PJ, Boocock MG, Dominick ND, Kelly RJ, Farrington BJ, Young SW. A Comparison of Walking Gait Following Mechanical and Kinematic Alignment in Total Knee Joint Replacement. J Arthroplasty. 2018;33(2):560-4.
119. Turcot K, Armand S, Lubbeke A, Fritschy D, Hoffmeyer P, Suva D. Does knee alignment influence gait in patients with severe knee osteoarthritis? Clin Biomech (Bristol, Avon). 2013;28(1):34-9.
120. Van Essen J, Stevens J, Dowsey MM, Choong PF, Babazadeh S. Kinematic alignment results in clinically similar outcomes to mechanical alignment: Systematic review and meta-analysis. Knee. 2023;40:24-41.
121. Miozzari HH, Armand S, Turcot K, Lubbeke A, Bonnefoy-Mazure A. Gait Analysis 1 Year after Primary TKA: No Difference between Gap Balancing and Measured Resection Technique. J Knee Surg. 2021;34(8):898-905.
122. Bonnefoy-Mazure A, Attias M, Gasparutto X, Turcot K, Armand S, Miozzari HH. Clinical and objective gait outcomes remained stable seven years after total knee arthroplasty: A prospective longitudinal study of 28 patients. Knee. 2022;34:223-30.
123. Bonnefoy-Mazure A, Favre T, Praplan G, Armand S, Sagawa Junior Y, Hannouche D, et al. Associations between gait analysis parameters and patient satisfaction one year following primary total knee arthroplasty. Gait Posture. 2020;80:44-8.
124. Lundh S, Nasic S, Riad J. Fatigue, quality of life and walking ability in adults with cerebral palsy. Gait Posture. 2018;61:1-6.
125. Postler A, Lutzner C, Beyer F, Tille E, Lutzner J. Analysis of Total Knee Arthroplasty revision causes. BMC Musculoskelet Disord. 2018;19(1):55.
126. Bonnefoy-Mazure A, Poncet A, Gonzalez A, Barea C, Hannouche D, Lubbeke A. Limping and patient satisfaction after primary total hip arthroplasty: a registry-based cohort study. Acta Orthop. 2022;93:602-8.