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STUDY OF THE CORRELATIONS BETWEEN MALOCCLUSION, MASTICATORY FUNCTION AND SPINAL POSTURE IN UNILATERAL POSTERIOR CROSSBITES VERSUS NORMAL CONDITION BEFORE AND AFTER ORTHODONTIC THERAPY

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A mio fratello Raffaele,

alla sua preziosa postura isometrica con una mano sempre tesa verso di me, volta ad aiutarmi.

A Giulia e Giorgia,

ai passi, ai salti e alle corse che faranno, alle strade entusiasmanti che riserverà loro il futuro.

Alla mia famiglia,

baricentro di ogni mio movimento.

“Le emozioni che lo tormentavano erano le stesse che lo sostenevano;

senza l’uragano, la vela sarebbe uno straccio.”

Victor Hugo

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1. INTRODUCTION

In the last years, a growing interest in the evaluation of the relationship between dental occlusion and general body posture has prompted specialists from various medical branches to produce numerous scientific studies about this topic [Mannion AF. et al., 2004 , Ciancaglini R. et al., 2007, Kim P. et al. 2014].

In 2009, a *Consensus Conference* about the relationship between posture and dental occlusion was held in Milan, with the aim of analyzing the different stances on the subject emerging from scientific research. The final document highlighted the insufficiency of existing studies in terms of scientific rigor and impact, therefore dismissing the possibility of a univocal thesis regarding the existence of a correlation or a recognized set of cause-effect relationships between malocclusions and posture and underscoring the need for further research [Ciancaglini R. et al., 2007]. In fact, the human being is a psycho-physical unity constituted by an interconnection of locomotor, sensory, cognitive and emotional systems, which influence each other during normal daily activities. Deepening knowledge of the effects that good mastication has not only on teeth and circum-dental structures (bones, muscles, temporo-mandibular joint) but also on the rest of the rachis and soma is crucially important to acquiring a global vision of adults as well as growing individuals, in order to ultimately promote a status of general well-being of patients (Fig. 1.a).

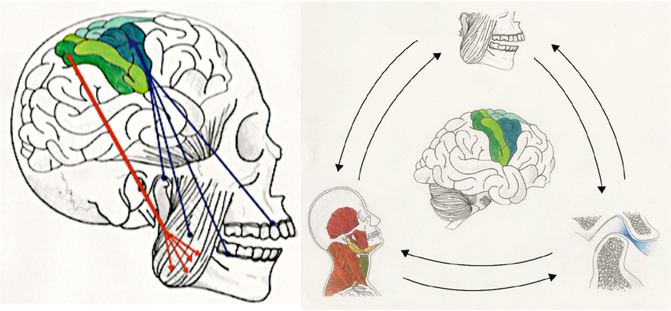


Fig. 1.a: The stomatognathic system: relationships between dental occlusion, temporo-mandibular joint and neuromuscular control. Source: Piancino MG. et al. 2016. Understanding Masticatory Function in Unilateral Crossbites.

1.1. THE CONCEPT OF POSTURE

Posture can be defined as a macroscopic space-time phenomenon of synergic responses directed to maintain the balance of the body during dynamic movements or while in a static position. These responses are always adapted to changing internal and extra-corporeal conditions, thanks to a fine ability to organize different subsystems and to integrate neurophysiological, biomechanical and psycho-emotional factors [Lazzari E., 2006; Scoppa F., 2002]. The term posture, then, refers to a dynamic event in continuous evolution, manifested as an automatic and unconscious bodily position determined by the contraction of skeletal muscles and maintained for a certain time under the constant control of the Central Nervous System (CNS). Its aim is to keep body balance with maximum stability, minimum energy consumption, and minimum stress to anatomic structures [Carini F. et al., 2017].

According to Ciancaglini et al. [2007] and as previously stated, the most acceptable definition of posture is "the way of staying in balance in various positions". From this standpoint, posture can be conceived as the upkeep of the right relationship among forces internal to the body, determined by a correct body alignment and the structural and dynamic symmetry it creates, as well as the upkeep of the right relationship among environmental external forces, which translates into a correct static balance.

The meaning of posture is strictly linked to the concept of balance. Maintaining balance in a stationary upright position is a function based on intact sensory pathways, sensorimotor integration centers and motor pathways (Fig.1.1.a).

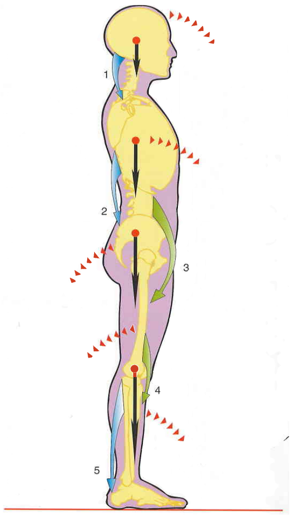


Fig. 1.1.a: Balance in a stationary upright position needs a simultaneous isometric contraction of some muscle groups: head erectors (1), lumbar masses (2), ileo-psoas (3), femoral quadriceps (4), sural triceps (5). Source: Lentini S. (2003). Ortodonzia e postura. Percorsi e atlante del sistema dento-cranio-vertebrale. Book. Ed. Martina.

Balance can be:

- Static, i.e. the ability of the body to maintain the static position: in this condition the spinal column is upright from the cervical to the sacrum in the median plane, with the four physiological curves.
- Dynamic, i.e. the ability of the body to keep a stable condition during daily activities.

Lastly, it is worth noting that posture is defined as functional if characterized by: absence of pain; a normal muscular tone; a harmonious relation between skeletal segments in the three spatial planes. On the contrary, it is nonfunctional when these characteristics are not maintained [Scoppa F. et al., 2002].

1.1.1. THE UPRIGHT PHYSIOLOGICAL POSTURE

The term physiological posture does not refer to a single and well-determined position of the soma, rather it relates to an infinite number of positions that allow the body to maintain balance. The ideal posture is described by the position assumed by corporal segments, in correlation with the presence of internal and external forces acting in a specific moment on the subject, which is able to maintain balance with minimal energetic effort and maximum stability.

On the grounds of such premises, it is useful to analyze the peculiar features of a physiological posture in upright position, i.e. in a static condition. In order for the erect posture to be efficient and economic, the body must be correctly aligned in the three spatial planes to avoid an excessive movement of the center of gravity, which would force the creation of a myofascial compensation with a permanent tension needed to contrast the incremented pressure of the gravitational force.

The physiological standing upright posture in the three spatial planes (Fig. 1.1.1.a) is as follows [Lentini S., 2003]:

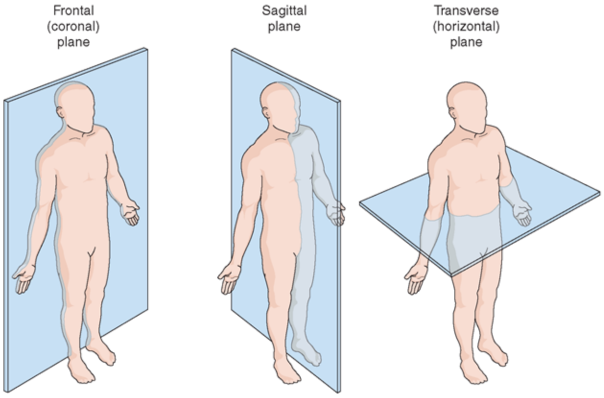
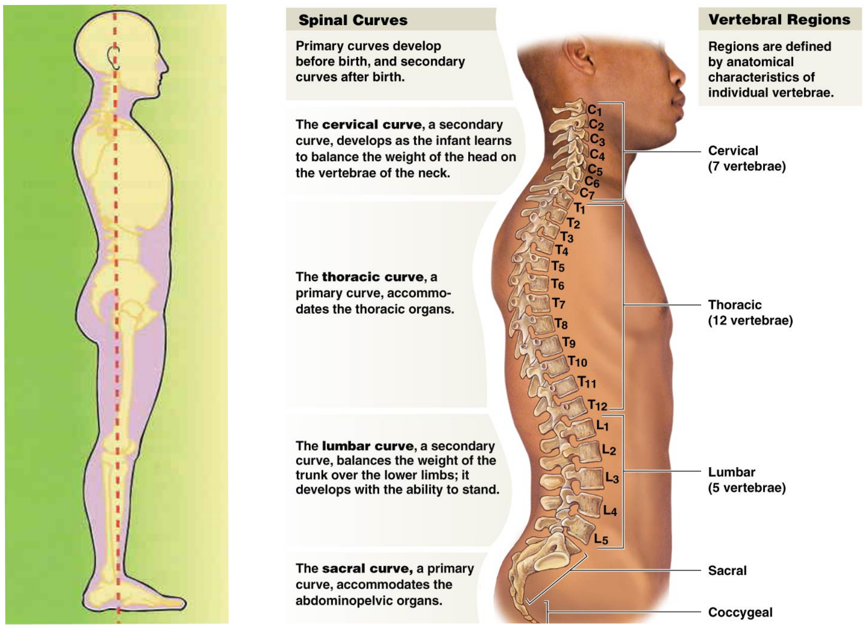


Fig. 1.1.1.a: The physiological standing upright posture in the three spatial planes.

- <u>Sagittal plane</u>: the vertical axis of the body, easily reproducible with a plumb line, passes through the mastoid process in the center of shoulders, through the coxofemoral joint and through the back portion of the lateral malleolus (Fig. 1.1.1.b). The scapular and gluteal planes are aligned, and the four physiological curves of the spinal column – two with anterior convexity and two with posterior convexity – are visible. The anterior curves are in the cervical and lumbar regions: they are called lordosis and their main characteristic is mobility. Instead, the curves with posterior convexity are called kyphosis: located in the dorsal and sacral regions, their characteristic is rigidity. The alternation between more mobile and more rigid curves enables the individual to stand in the upright position and, concurrently, provide flexibility associated with a correct distribution of mechanical inputs (Fig. 1.1.1.c).



Spinal Curves

Primary curves develop before birth, and secondary curves after birth.

The **cervical curve**, a secondary curve, develops as the infant learns to balance the weight of the head on the vertebrae of the neck.

The **thoracic curve**, a primary curve, accommodates the thoracic organs.

The **lumbar curve**, a secondary curve, balances the weight of the trunk over the lower limbs; it develops with the ability to stand.

The **sacral curve**, a primary curve, accommodates the abdominopelvic organs.

Vertebral Regions

Regions are defined by anatomical characteristics of individual vertebrae.

Fig. 1.1.1.b, Fig. 1.1.1.c: The physiological standing upright posture and the spinal curves in the sagittal plane.

- <u>Frontal (coronal) plane</u>: the spinal column is straight and divides the body into two symmetrical portions. In the frontal plane, furthermore, six horizontal parallel reference lines can be highlighted (Fig. 1.1.1. d):

  1. Bi-pupilar line
  2. Bi-tragalic line
  3. Bi-scapular line
  4. Bi-mammillary line
  5. Bi-styloid line
  6. Bi-iliac line

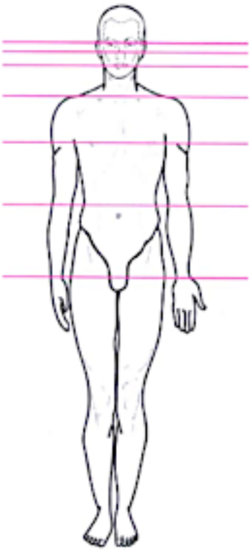


Fig. 1.1.1.d: Postural horizontal parallel reference lines in the frontal plane.

- Horizontal (transverse) plane: the subject with a physiological erect posture shows no rotation in the shoulder and pelvic girdles. For this reason, when arms are stretched fingers lay on the same line.

Hence, physiological or normal posture can be summarized by the following key concepts:

- In orthostatic position, the body is aligned to the gravity force vector; in every other position, the force of gravity exerts non-deforming action [Carini F. et al., 2017];
- Alignment follows the correct postural mechanical patterns of the body [Scoppa F., 2002];
- Adequate cognitive, sensory and motor functions are in balance with each other [Zimmermann M. et al., 2013].

Ultimately, the physiological reference is represented by a morphogenetically determined model, which adapts to external environmental stimuli over time [Bressan P. et al. 2019, Zimmermann M. et al., 2013]

1.1.2. THE NEUROMUSCULAR CONTROL OVER POSTURE

Posture is mainly regulated by the extra-pyramidal system, which includes nuclei, cerebral cortex, basal ganglia, bulb and spinal cord. The extra-pyramidal mechanisms involved in maintaining postural are integrated at various levels, from the spinal cord to the cerebral cortex.

The mechanical model of bodily posture control is constituted by a static-dynamic system composed of osteoarticular, ligament, fascial and muscle-tendon apparatuses. These structures are organized in cinematic chains, represented by head, thorax and pelvis, in alternation with elastic-dynamic systems, that is, cervical rachis, lumbar rachis and lower limbs.

From a structural point of view, posture maintenance is granted by the integrations of closed systems that can be divided into three large categories [Lazzari E., 2006]:

1. Inelastic systems: constituted by bones, which are connected to one another by joints. These systems provide structural support.
2. Elastic systems: resulting from the association of rigid elements (bones) and elastic elements (muscles and tendons), which defines the dynamic structure of the body.

3. Plastic system: represented by the fascial and muscular casing of the body, it constitutes the dynamic component of posture maintenance. From a locomotor point of view, indeed, muscular fascia not only plays a role of support and passive transmission of tensions, but also represents a real receptor *network*, continuously providing information to the nervous system regarding body position and movements.

The association between agonistic and antagonistic tensions determined by the miofascial components on the cinematic chains is the result of a continuous action of adaptation carried out by the tonic-postural system. This receives information from the complex and redundant receptor system, which is sensitive to both exogenous and endogenous determinants.

The set of information deriving from the receptor system is integrated and elaborated under the cortical control of the Central Nervous System (CNS) at the level of superior centers, such as vestibular nuclei, cerebellum, and reticular substance. These centers allow for the elaboration of responses which are then translated into body movements through the effectors, i.e. nuclei related to ocular motility as well as both pyramidal and extrapyramidal tracts that regulate the contraction of skeletal muscles [Takakusaki et al., 2017]. The tonic postural system is of the cybernetic type, because it is subservient to *regulation*. Therefore, it is provided with:

- inputs that inform about the state of equilibrium;
- the central nervous system that processes, manages and integrates the information received;
- outputs that maintain balance by changing the tone of the postural muscles (postural reflexes) (Fig. 1.1.2.a).

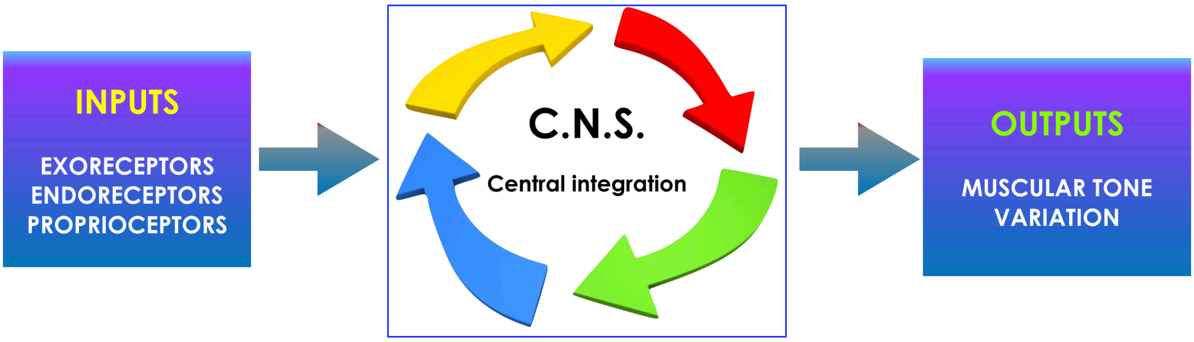


Fig. 1.1.2.a: The regulation of the tonic postural system.

The inputs of the postural system can be divided into:

- Exoinputs: visual system, podalic system and vestibular system (labyrinth in the inner ear)
- Endoinputs: proprioception (muscle, skin, tendon, joint, oculomotor, stomatognathic, podalic), visceroception and psychoception.

Therefore visual, oculomotor and podalic systems function both as endo- and as exoreceptors. All exo and endo-entrances then require a correct integration by the CNS (Fig. 1.1.2.b).

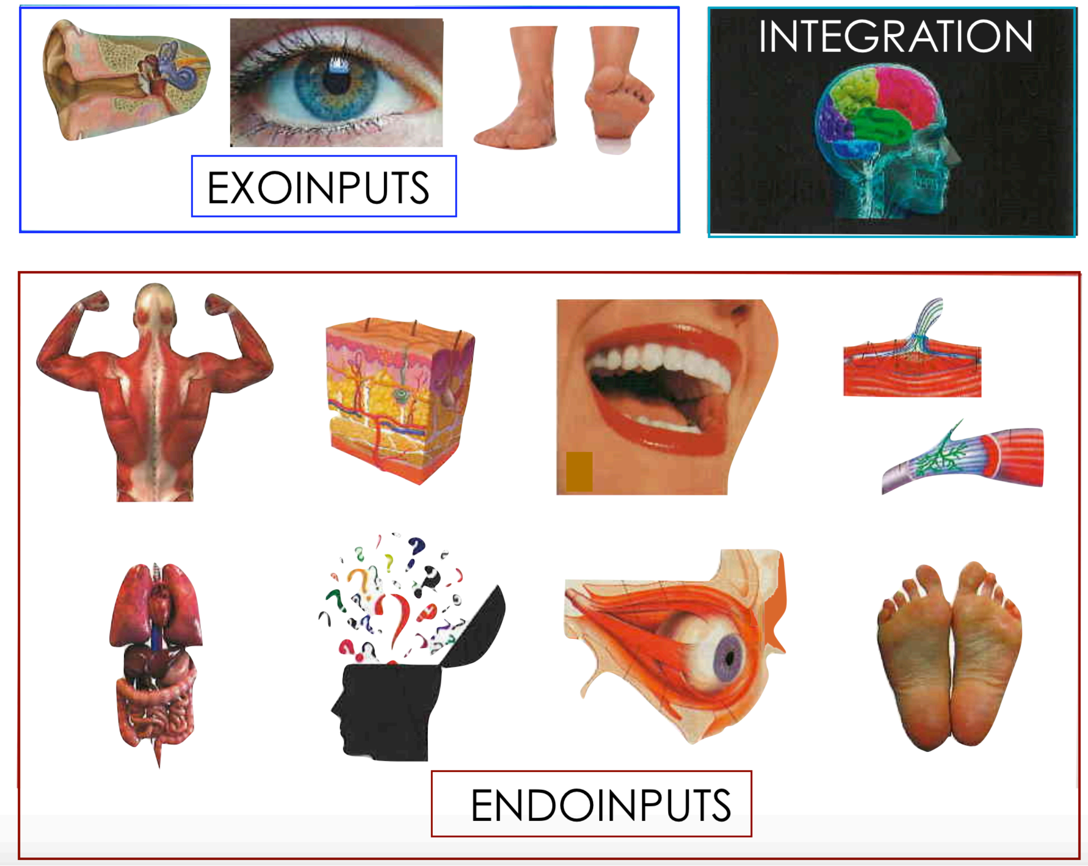


Fig. 1.1.2.b: The inputs of the postural system.

The *adjustment* of postural control is primarily entrusted to the pyramidal and extrapyramidal systems. The first is responsible for the execution of precise and specific movements of voluntary muscles; while the latter, phylogenetically older, is responsible for postural movements, stereotyped and repetitive, which are mainly located at the level of the brain stem [Kapandji AI, 2020].

The *primum movens* of such a system of adaptation is found in the receptor system, which carries out the primary task of adjusting the tonic activity of limbs and back muscles as well as the amplitude of movement of the various joints, on the basis of external and internal information detected. The model of postural control and adjustment is based on three principal systems of receptor afferents [Bressan P. et al. 2019, Ciancaglini R. et al., 2007].

- Visual system (Fig.1.1.2.c): exteroceptors sending information derived from the external environment to the cortex. The crucial contribution of the visual system in adjusting and maintaining postural tone is made empirically evident by means of Romberg's test, which illustrates a significant difference in the position of the center of gravity and body balance when keeping the eyes open and closed.

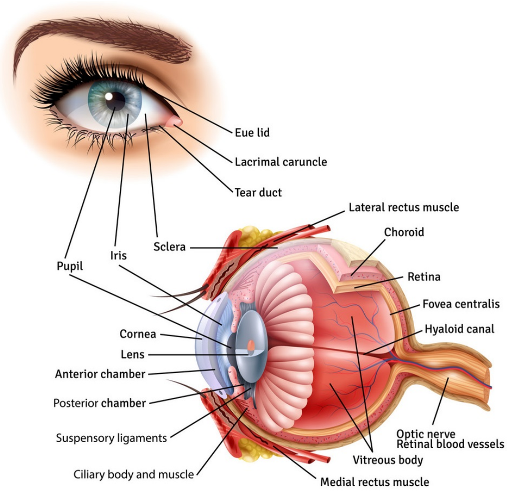


Fig. 1.1.2.c: The visual system.

- Proprioceptive system (Fig.1.1.2.d): it is responsible for the kinesthetic phenomenon, i.e. the capacity to perceive and recognize the position of one's own body in space as well as the state of muscular contractions. These receptors work thanks to the interplay of several elements: neuromuscular spindles, which allow for the detection of the variation in length, and therefore the state of contraction, of the muscles over time; Golgi tendon organs, which are sensitive to the variation in tension at the level of the muscle-tendon junctions; cutaneous proprioceptors, i.e. Pacinian and Ruffini's corpuscles, which allow for the perception of, respectively, pressure stimuli and vibrations; lastly, articular receptors, which enable the detection of bone segments' movements and positions.

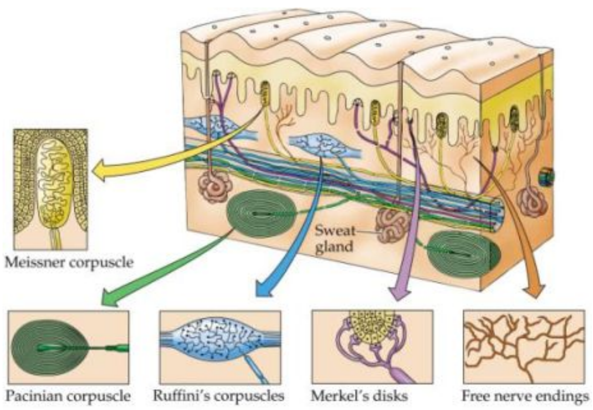


Fig. 1.1.2.d: The proprioceptive system.

- <u>Vestibular system</u> (Fig.1.1.2.e): it provides information regarding the position and movements of the head and its spatial orientation with respect to the force of gravity. Thanks to the presence of specific mechanoreceptors in the otolithic membrane, vertical and horizontal head movements can be perceived due to phenomena of variation of membrane potential in such cells as a consequence of angular acceleration.

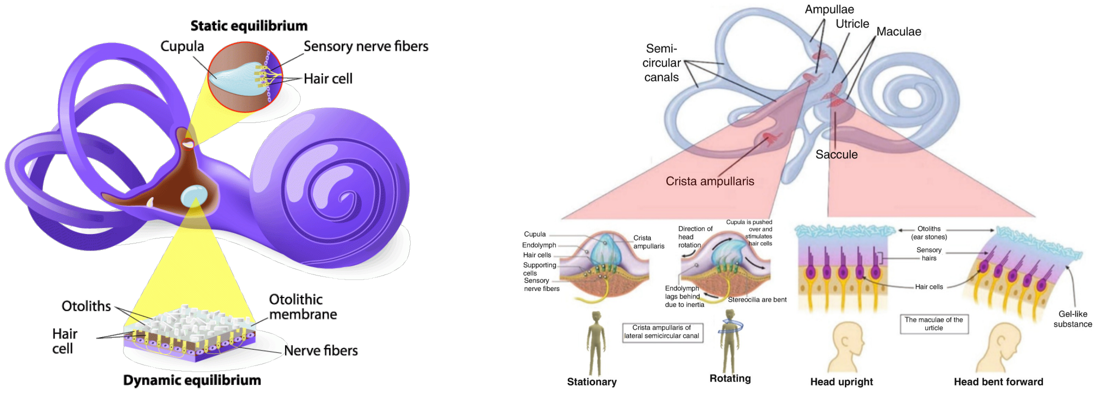


Fig. 1.1.2.e: The vestibular system.

Within this framework, the morpho-functional characteristics of the individual – both congenital and acquired – appear to be fundamental in determining the quality of motor and postural responses. Every gesture is a communication action unique to the subject, whereby subject and environment represent two open systems that condition each other.

The system of sensory receptors determines the postural adjustments that occur at any moment to guarantee the upkeep of a balance position. With the term *balance* we refer to a position taken by the body wherein all the forces applied have null resultant and momentum. The human body is never in such a situation when standing upright, because oscillatory anteroposterior and lateral micro-movements are always present. According to a notable model called ‘inverted pendulum’ (Fig.1.1.2.f), the upright standing man (orthostasis) is compared to an inverse pendulum that oscillates around its ankles’ axis with oscillations on the frontal plane less than 4° and with oscillations on the sagittal plane greater than 4° [Chen KF. 2008, Loram ID. et al. 2002, Macpherson JM. et al. 2007]. These movements are mostly caused by the limbs’ effectors. The ensemble of postural adjustments is the mean the body employs in its constant search for balance, which allows for the creation of postural stability.

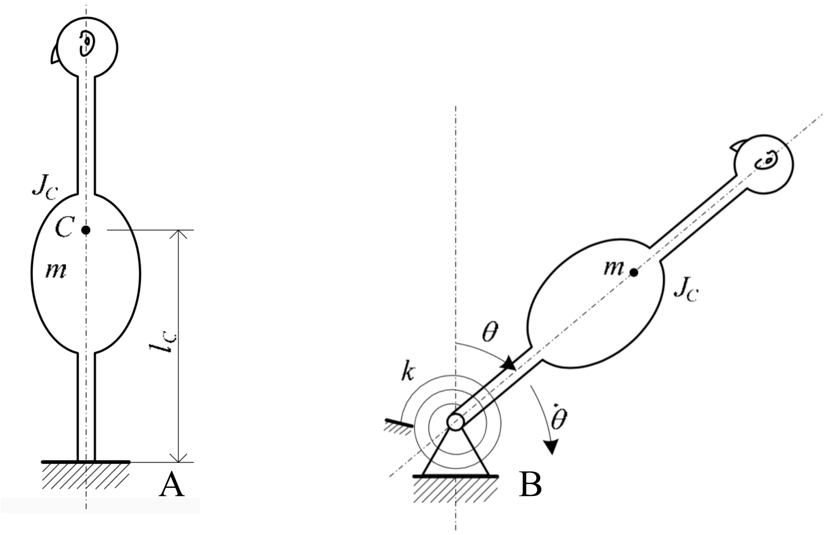


Fig. 1.1.2.f: The model of a standing human (A) and the inverted pendulum model with a coiled spring (B).

The role of postural adjustments is to sustain the head and the body against the external forces that act upon them – primarily the force of gravity – and maintain the center of mass aligned and in balance within the perimeter of the support base on the ground. This mechanism of continuous adaptation of the tonic-postural system works along two signal pathways [Ting et al., 2007]:

- Feedforward: it allows for the generation of responses planned upon potential disturbances that may occur while executing certain movements. It is also known as the anticipatory mechanism.
- Feedback: it enables the body to adapt to environmental conditions affecting the movement while or after it is realized. It is therefore a compensatory mechanism.

Postural fatigue originates precisely from this control system; in fact, as the availability of conditions for balance decreases, the energy demand to maintain a correct postural stability increases.

Pathological manifestations of the postural system – recognizable as cases of overload, wear and tear, degeneration and nonfunction – result from the failure to comply with excessive functional requirements, or to keep up, for various reasons, with normal functional demands [Ciancaglini R. et al., 2007]. These occurrences lead to postural compensations, i.e. reactions of the neuromuscular control system to a pathological stimulus – whether endogenous or exogenous – which prevent the system from staying within a physiological range, thus generating a pathological postural condition. Therefore, every postural failure causes progressive structural alterations, compensations, overloads and tensions that, in turn, lead to a nonphysiological adaptative model showing signs of tissue wear and tear, which are assessable through clinical and/or instrumental analyses.

1.2. THE CORRELATION BETWEEN POSTURE AND OCCLUSION

A great number of anatomical, clinical and experimental observations testify to the existence of morphofunctional and pathophysiological correlations between the occlusal-cranio-mandibular district, the spine and postural adjustments.

From a biological point of view, many analogies between posture and occlusion exist: the first, in fact, is defined by the interplay between skeletal segments in the organism, while the second is shaped by the relation between antagonist dental arches [Carini F. et al. 2017, Khan MT et al., 2013]. Functionally, while posture serves the purpose of maintaining body balance in static and dynamic conditions, the task of occlusion is to stabilize the position of the jaw both at rest and during the execution of motor, masticatory and extra-masticatory activities (i.e swallowing, phonation, breathing).

The analysis of such a correlation cannot be limited to addressing the relation between the two dental arches, whether dynamic or static. Rather, it must scrutinize the whole stomatognathic apparatus, that is, the interplay between dental elements, masticatory muscles (especially elevator mandibular muscles, i.e. masseter, temporalis, medial and lateral pterygoids), the temporomandibular joint (TMJ) (Fig. 1.2.a), cephalometric characteristics and craniomandibular morphology [Piancino MG et al. 2019].

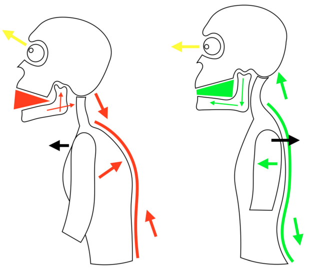


Fig. 1.2.a: Influence of TMJ dysfunction on postural assessment.

1.2.1. POSTURE AND STOMATOGNATHIC SYSTEM: ANATOMICAL CORRELATIONS

The various cranio-cervical bodily segments were closely related to each other by muscles, fascias, ligaments and joints, establishing a precise balance between head, spine, shoulder girdle, mandible and hyoid bone. One positional (i.e. postural) imbalance involves the other structures, creating tensions and structural overloads. For example, the hyoid bone is linked to the mandible (suprahyoid muscles), the sternum (sternohyoid muscle), the clavicle (omohyoid muscle) and the thyroid cartilage (thyroid muscle), and from this back to the sternum (sternothyroid muscle) (Fig. 1.2.1. a). The hyoid bone is also connected to the skull by the posterior belly of the digastic and by the stylohyoid, as well as to the tongue by the ioglossus.

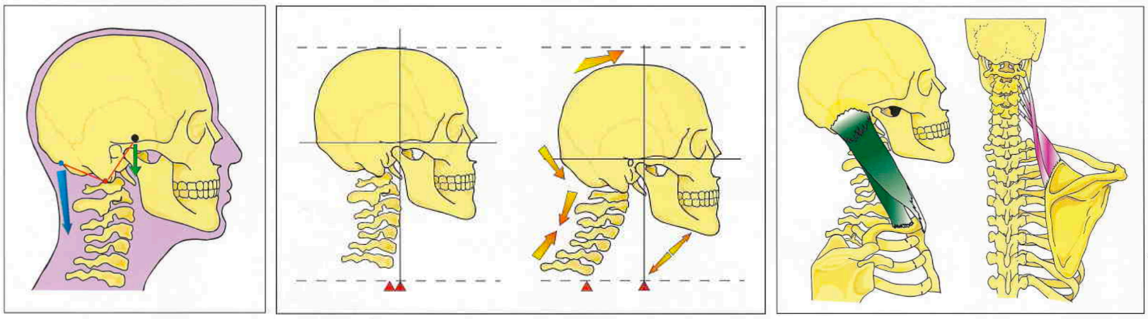


Fig. 1.2.1.a: Anatomical correlations between cranio-cervical bodily segments

Mohl [Mohl N, 1976], Darling [Darling DW et al., 1984] and Gross [Gross MD et al., 1994], also demonstrated how the resting position of the jaw was influenced by head posture. Neck fascias and the superficial muscular aponeurotic system play a fundamental role in this correlation.

1.2.2. POSTURAL AND OCCLUSAL NEUROLOGICAL CONTROL: MEETING POINTS

The functional basis of the correlation between occlusion and posture can be found in their common neuromuscular control. The stomatognathic apparatus features highly specialized receptors that are connected to the Central Nervous System through electrical synapses that are particularly fast in transmitting sensory inputs. Such receptors are located in the oral mucosa, on the tongue, inside the teeth and their supporting tissue, within muscles and within the temporomandibular joint. They are therefore numerous, yet they possess other important features, such as their sensitivity and specialization: they are able to activate even with very weak stimuli and discriminate the direction and orientation of the force vector applied.

In order to understand which meeting points exist within the neuromuscular control system, between tonic-postural and stomatognathic systems, it is possible to analyze the kinesthetic receptors involved in the control of the masticatory function. In this sense, the principal systems of sensory afferents relate to muscular receptors, temporomandibular joint receptors, and periodontal mechanoreceptors:

- <u>Temporomandibular joint (TMJ) receptors</u>: these are low-threshold receptors innervated by the auriculotemporal nerve and mainly concentrated in the back portion of the joint capsule (Fig. 1.2.2.a).

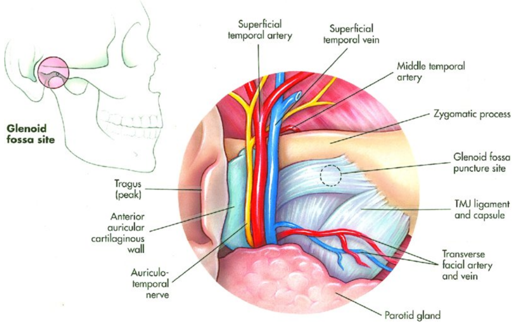


Fig. 1.2.2.a: Temporomandibular joint anatomy.

These receptors allow for the transmission of jaw placement in space, coding the position, displacement and speed of the condylar movement of the condyle, especially during the opening movement of the mouth [Morquette et al., 2012]. This function involves various types of TMJ receptors, each featuring different peculiarities. Firstly, Pacini's corpuscles signal the beginning and the end of the movement executed by the jaw. Then, Ruffini's organs send information about the position of the condyle and the posture of the jaw, thanks to their high sensitivity that allows each receptor to activate at a certain degree of the opening of the mouth. Next, Golgi's corpuscles oversee the protection of the joint structure by activating only in case of strong pressure. Lastly, free nerve endings, concentrated in the posterior region, deliver nociceptive information (Fig.1.2.2.b).

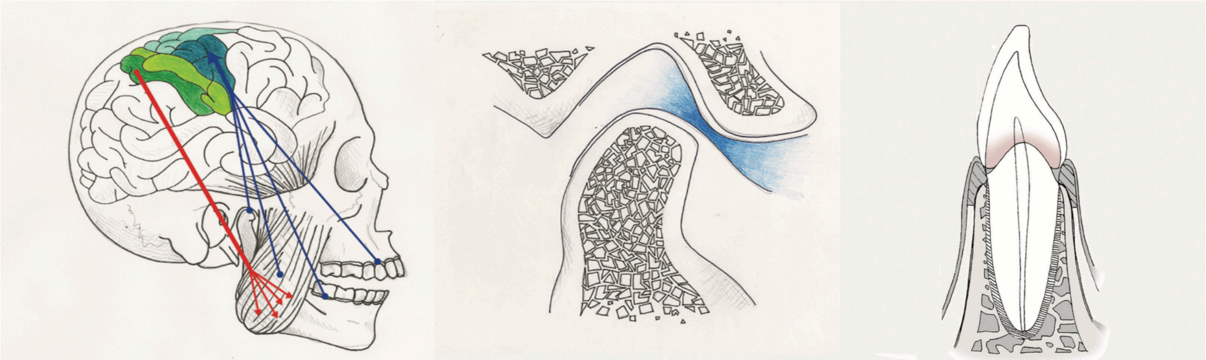


Fig. 1.2.2.b: Peripheral receptors of the stomatognathic system.

- Periodontal mechanoreceptors: these receptors are located within the supporting tissues of teeth and are highly sensitive. In fact, they are able to respond to forces applied to the teeth surface even weaker than 1 N. They are able to create a fine sensory system needed for somatosensory physiological reflexes and to perceive external forces exerted on teeth. A series of histological studies have identified different categories of sensory receptors in the area of the supporting tissue of teeth, the main of which is undoubtedly represented by endings of a Ruffini type: these are classified as stretching mechanoreceptors, of a slow adaptation kind, sensitive to force directions and low thresholds [Piancino MG and Kyrkanides S, 2016]. Being stretching receptors, they are concentrated in the alveolar region of the ligament, and are susceptible to stretching during tooth function, even though their location can vary according to development and aging. Periodontal receptors are directly involved in the response to occlusal load, which in turn can vary depending on the presence of quick and slow adaptation units. Quick adaptation units generate a transitory discharge in response to a sustained stimulus. In this case, the number of impulses depends on the frequency of the applied stimulus. Slow adaptation units, instead, keep generating nervous impulses for longer periods through dental displacement, even if the load is no longer applied to the tooth (Fig. 1.2.2.c) [Tabata et al., 2006, Trulsson M and Essick GK, 2010].

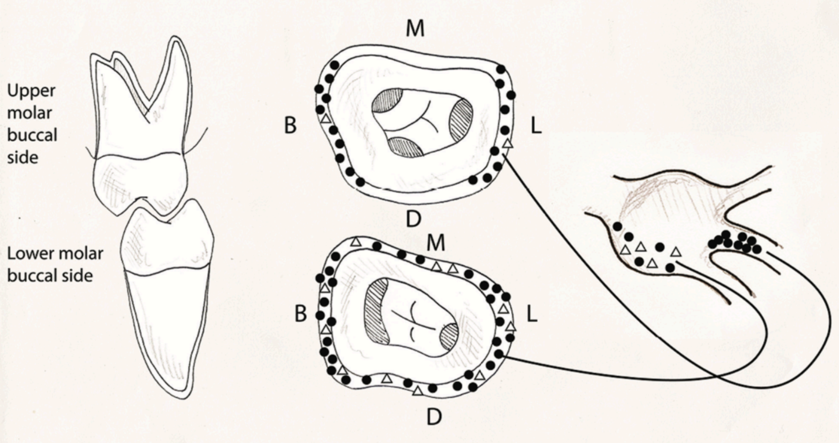


Fig. 1.2.2.c:Different characteristics of the upper and lower molar periodontal mechanoreceptors in experimental studies in rats. Interestingly, the rapid-adapting receptors (black triangles) are more concentrated in the lower molars, which convey information from the moving bone, and the slow-adapting receptors are more concentrated in the maxillary molars. B: buccal; M: mesial; L: lingual; D: distal. Source: Tabata et al. (2006). Reproduced with permission from Elsevier.

- <u>Muscular receptors</u>: they include neuromuscular spindles (narrow bundle-shaped encapsulated receptors located in the muscle, able to provide information about the length of the muscle and particularly diffused in the masseter muscle), Golgi's tendon organs, located at the junction between muscle and tendon fibers and able to provide information about muscular tension variations, and extra-spindle receptors that deliver nociceptive information (Fig. 1.2.2.d).

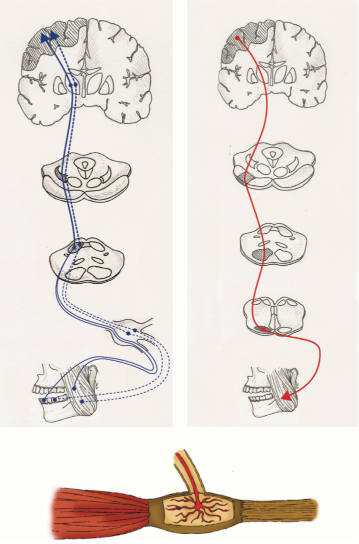


Fig. 1.2.2.d:Muscular receptors and motor control.

This complex system of sensory afferents converges on the sensory nuclei of the facial, trigeminal and hypoglossal nerves, from which afferents directed to the cerebellum, locus coeruleus and lateral vestibular nucleus branch off. A study performed in 1999 on 10 rats by Pinganaud et al. highlighted, through injection of a tracing fluorescent substance in the vestibular nuclei, the existence of projections departing from the mesencephalic trigeminal nucleus directed towards the same vestibular nuclei. Furthermore, the authors detected the presence of some axonal collateral projections to the cerebellum of a series of neurons from the caudal portion of the trigeminal nucleus [Pinganaud G et al., 1999]. In addition, a 2002 study by Gangloff and Perrin demonstrated, by employing a stabilometric platform, that a unilateral anesthesia of the trigeminal nerve causes a significant variation in analyzed subjects' postural control, thus highlighting the important influences exerted by the system of afferents deriving from cranial nerve V [Gangloff P and Perrin PP, 2002].

Hence, the convergence of such proprioceptive information on the Central Nervous System enables a series of reflex control mechanisms to determine the posture of the stomatognathic apparatus, thus exerting an influence on the neuromuscular control of the posture of the whole body. The two systems, indeed, influence each other: for instance, a forward flexion of the head determines an increase in activity of masseter and digastric muscles, whereas backward flexion increases the activity of temporal muscles [Fujimoto M et al., 2001; Lund JP et al., 1970]. Such an interconnection is also observable between masticatory and neck muscles, because alterations in the first can cause significant variations in head posture [Ciancaglini R. et al. 1994, Ciancaglini R. et al, 2007, Khan MT et al., 2013]. The common embryological origin is also worth remembering, which involves Meckel's cartilage, the TMJ disk and the malleus – i.e., the outermost of the chain of middle ear ossicles – and supports a possible explanation to the relation between TMJ pathology and ENT diseases, especially balance and/or spatial orientation disorders (Fig. 1.2.2.e).

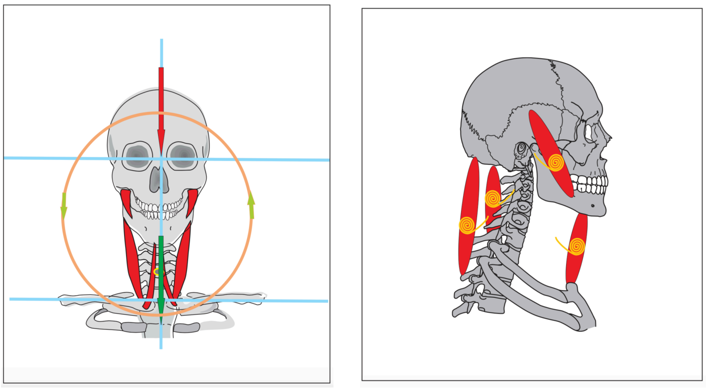


Fig. 1.2.2.e:Interconnection between head posture, TMJ, masticatory and neck muscles.

1.2.3. POSTURE AND STOMATOGNATHIC SYSTEM: BIOMECHANICAL CORRELATIONS

Besides this wide and complex neurophysiological framework, which lays the groundwork for finding a plausible correlation between occlusion and posture, there is also a biomechanical rationale to be taken into account. This is because the muscle-connective system creates a continuity between the cranio-mandibular structure and the cervical spine, shoulder girdle and internal organs through the interposition of the hyoid bone.

Postural biomechanics, indeed, act upon three fundamental segments (Fig. 1.2.3.a):

- Cranio-mandibular system
- Acromio-scapular complex
- Pelvic girdle

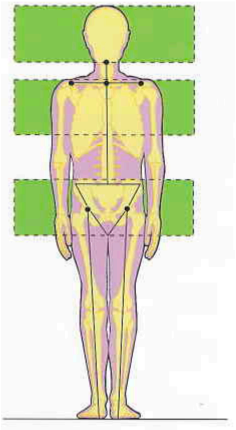


Fig. 1.2.3.a: Three segments of the postural biomechanics.

The cervical and thoracolumbar tracts work as junctions connecting, respectively, the cranio-mandibular system to the acromio-scapular complex, and the latter to the pelvic girdle. This strong interconnection explains why the stimulation of a muscle generates the contraction, either tonic or phasic, of functionally-related muscle components, therefore justifying hypotheses of the influence of the cranio-mandibular complex on spinal diseases. Many scientific studies, in fact, have demonstrated that a variation in the position of the jaw, i.e. of the cranio-mandibular region, can induce modifications of the position and posture of the soma; while at the same time global posture changes can affect the position of the cranio-mandibular complex [Chessa and Capobianco, 2002].

Tight connections between the jaw, suprahyoid muscles and cervical vertebrae have also been described. These structures compose an anatomo-functional unit that finds in the hyoid bone its key junction point, rendering the latter therefore responsible for head position variations as a consequence of mandibular position modifications (Fig. 1.2.3.b).

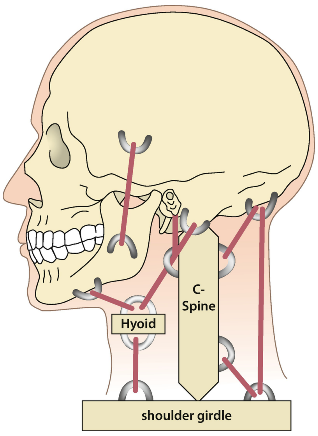


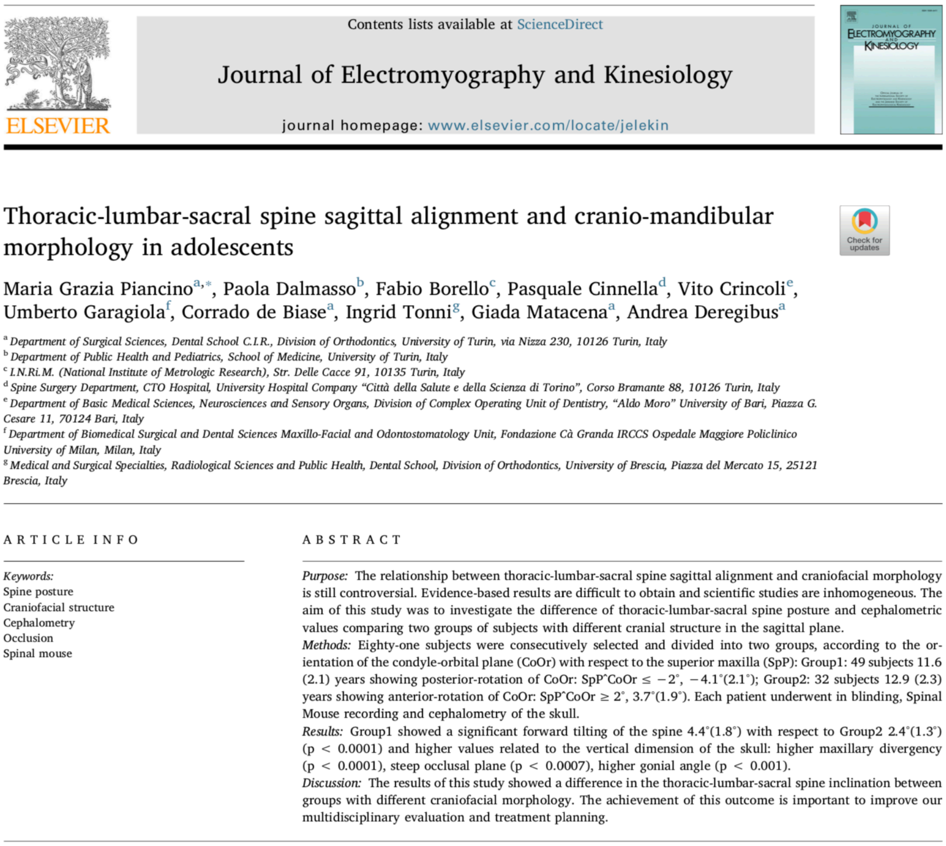
Fig. 1.2.3.b: key junction point of hyoid bone for anatomo-functional posture

In fact, Chapman [Chapman RJ et al., 1991] demonstrated that during the extension of the head the occlusal contacts in the posterior sectors (molars) are higher and, reversely, the flexion of the head accentuates the anterior contacts (incisors-canines).

1.2.4. POSTURE AND CRANIO-FACIAL MORPHOLOGY

As already mentioned, research about the correlation between occlusion and posture cannot limit itself to the evaluation of the relation among dental elements in the two arches. Rather, it must take on a wider analysis of the cranial characteristics of the subject, standing by the principle that the organism is a complex psychophysical entity composed of different apparatuses that are deeply interconnected and able to exert bidirectional influence. Indeed, when evaluating such a complex system it is difficult to obtain evidence-based results, due to the large amount of involved elements and the high degree of individual variability [Gomes LdC et al., 2014]. A deeper knowledge of the influence exerted by cranio-mandibular morphology on spinal alignment on the sagittal plane, and on posture in general, is crucial to preventing postural problems, which can become disabling for the subject and difficult to keep under control [Lima M et al., 2018; Piancino MG et al., 2019, Lippold C et al., 2006].

Towards this aim, many efforts have been extended, and some scientific studies are beginning to offer stimulating responses, spurring increasing interest about such topics. In particular, a study conducted in 2019 by Piancino and colleagues attempted to investigate the differences among subjects with different cranial morphology in the alignment and flexion on the sagittal plane of the thoracic-lumbar-sacral spinal column (Fig. 1.2.4.a).



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Thoracic-lumbar-sacral spine sagittal alignment and cranio-mandibular morphology in adolescents

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ABSTRACT

Purpose: The relationship between thoracic-lumbar-sacral spine sagittal alignment and craniofacial morphology is still controversial. Evidence-based results are difficult to obtain and scientific studies are inhomogeneous. The aim of this study was to investigate the difference of thoracic-lumbar-sacral spine posture and cephalometric values comparing two groups of subjects with different cranial structure in the sagittal plane.
Methods: Eighty-one subjects were consecutively selected and divided into two groups, according to the orientation of the condyle-orbital plane (CoOr) with respect to the superior maxilla (SpP): Group1: 49 subjects 11.6 (2.1) years showing posterior-rotation of CoOr: SpP^CoOr ≤ −2°, −4.1°(2.1°); Group2: 32 subjects 12.9 (2.3) years showing anterior-rotation of CoOr: SpP^CoOr ≥ 2°, 3.7°(1.9°). Each patient underwent in blinding, Spinal Mouse recording and cephalometry of the skull.
Results: Group1 showed a significant forward tilting of the spine 4.4°(1.8°) with respect to Group2 2.4°(1.3°) ($p < 0.0001$) and higher values related to the vertical dimension of the skull: higher maxillary divergency ($p < 0.0001$), steep occlusal plane ($p < 0.0007$), higher gonial angle ($p < 0.001$).
Discussion: The results of this study showed a difference in the thoracic-lumbar-sacral spine inclination between groups with different craniofacial morphology. The achievement of this outcome is important to improve our multidisciplinary evaluation and treatment planning.

Fig. 1.2.4.a: Paper published in 2019 by Piancino and colleagues. Abstract.

In the study, measuring parameters were derived from a cephalometric analysis of latero-lateral teleradiographes realized for orthodontic reasons. A sample of n=81 subjects was divided into two groups on the basis of their cephalometric features, specifically according to the orientation of the condyle-orbital plane (CoOr) with respect to the superior maxilla (SpP):

- Group 1: 49 subjects with posterior-rotation of the condyle-orbital plane (SpP^CoOr ≤ --2°)
- Group 2: 32 subjects with anterior-rotation of the condyle-orbital plane (SpP^CoOr ≥ 2°)

Subjects were then examined in a non-invasive way, using a *Spinal Mouse* to evaluate their spinal posture on the sagittal plane. Results highlighted a statistically significant difference in spine mobility on the sagittal plane between the two groups. Subjects with posterior-rotation of the condyle-orbital plane showed a significantly greater tendency to flex the spine forward, which was not observable among members of the second group. Hence, this study confirms the hypothesis of the influence of vertical cranial structure on sagittal alignment and mobility and postural balance. It also underlines the need to perform a comprehensive analysis of the cranio-mandibular complex, minding the influence it can exert on the postural system, in order to pursue a truly multidisciplinary approach in treating patients. The orientation of the condyle-orbital plane with respect to the upper maxilla may be considered a reliable cranial reference in the sagittal plane. Furthermore, this type of knowledge can enable the implementation of primary prevention strategies, especially in the case of patients evidently more inclined to kiphotic posture, therefore preventing abnormal postures of the soma and associated painful conditions (Fig. 1.2.4.b).

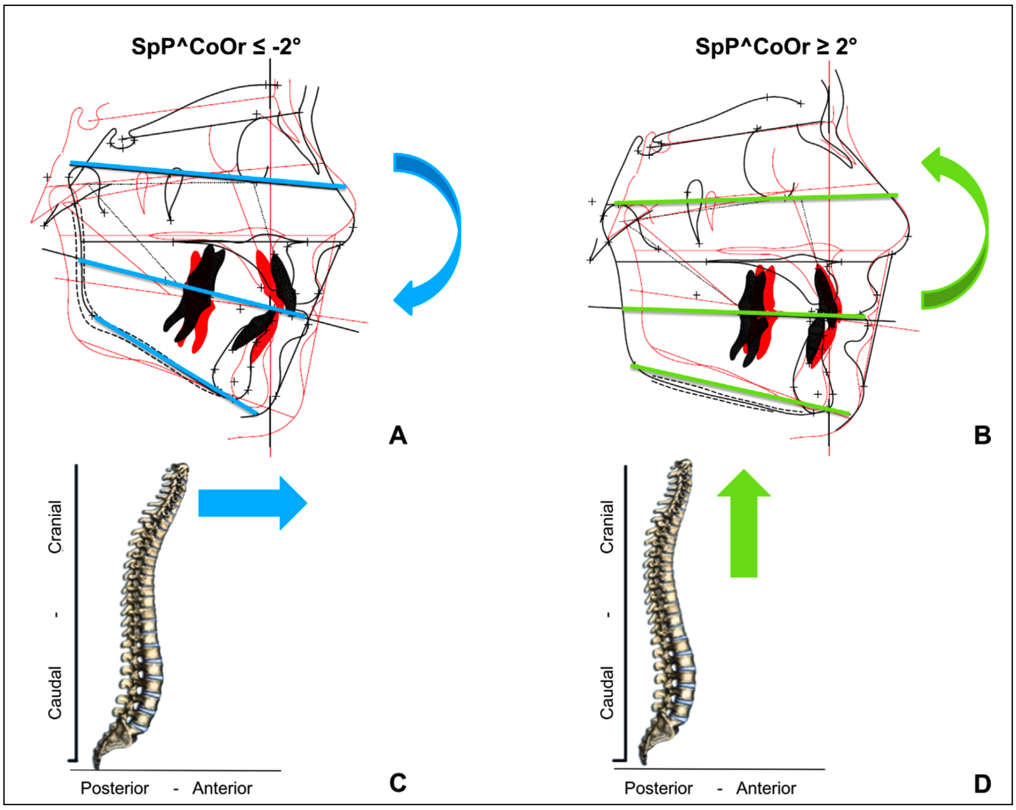


Fig. 1.2.4.b: (A) Cephalometric features of Group 1 (SpP^CoOr ≤ −2°). (B) Cephalometric features of Group 2 (SpP^CoOr ≥ 2°). (C) The spine column tilting of Group 1. (D) the spine column titling of Group 2.

In fact, the forward tilting of the spine might be a predisposing factor to a further and easier deterioration of the sagittal balance during ageing. To this end, a deeper understanding of the link between the craniofacial morphology and the thoracic-lumbar-sacral spine sagittal alignment is of importance to prevent postural discomforts sometimes disabling and not easy to control.

1.3. THE STATE OF THE ART

In recent years a large number of attempts to research the topic of occlusion and posture have been recorded. In fact, the scientific literature features many studies that employ completely different postural evaluation methods, adopt different methodological approaches, perform distinct descriptive, evaluative and statistical analyses, and even use non-scientifically-validated postural evaluation devices. As a result, the global scientific community is perfectly divided into two halves: on the one side, authors who contend the existence of an influence of the stomatognathic apparatus on the tonic-postural system; on the other, authors who negate it by means of more or less efficient statistical and methodological tools.

Most of these 'denier' studies are designed to verify how a certain jaw position can affect the subject's postural control. Among them, the study by Perinetti G. [2006] is worth mentioning. In this study, the authors assessed the differences in stabilometric parameters measured with a stabilometric platform in two occlusal conditions – maximum intercuspation and rest position with free arches – of 26 healthy subjects in I bilateral molar class. The study did not find any statistically significant differences between the two mandibular positions, concluding that it is not possible to clinically assess a correlation between mandibular position and postural stability by using a stabilometric platform [Perinetti G, 2006].

On the contrary, a study by Bracco et al.[2004], conducted in 1993 on 95 athletes, found that an optimal posture (assessed in the study with a stabilometric platform) is associated with a physiological position of the jaw, i.e. characterized by a symmetrical contraction of masticatory muscles. The authors argued that "a good balance of masticatory muscles, the neck and the head seems to be a discriminating factor affecting postural stability" [Bracco P et al., 2004, pag.230, *own translation*]. They concluded that a correct masticatory function is a guarantee of a significant postural stability, demanding reduced postural adjustments and able to maintain a proper and stable center of gravity.

Similar results were obtained by Gangloff et al. [2000], who evaluated the shooting accuracy of 18 professional permit-holding shooters in different experimentally induced jaw posture conditions. They concluded that a condition of jaw symmetry favors a better shooting performance, since the proprioceptive system of postural control and eye stabilization is influenced by the experimental modifications induced on the shooters' posture [Gangloff P et al., 2000].

Other studies, instead, have focused on the electromyographic consequences of cranio-mandibular muscle contraction on neck muscles. Among these, Sforza et al. [2006] analyzed 11 astronauts who were provided with an occlusal splint to force their jaws into a determined position, in order to verify possible influences on the sternocledomastoid muscles' contraction patterns. The evidence they provided suggests that the type and number of dental contacts do condition the activity of neck muscles and the adaptation of the cervical spine; yet it also underlines the great variability of ways the stomatognathic apparatus is able to influence the body as a whole, which are therefore non frequent and difficult to assess statistically [Sforza C et al., 2006]. Earlier, in 2003, a study by Shimazaki et al. had already underscored how an abnormal inclination of the occlusal plane and the non-coordination of the masticatory muscles' activity play an important role in controlling the subject's posture (Shimazaki T et al., 2003).

In the next page, Table 1.3.a summarizes main authors and papers for and against the relationship between occlusion and posture.

As demonstrated, then, consensus about the correlation between occlusion, chewing and posture is lacking, although a certain general interest about the topic is definitely detectable. Authors, however, are aware of the existence of a physiological correlation between tonic-postural system and the cranio-mandibular complex. Equally, they are aware of the difficulty of measuring it with scientific rigor. This is due to various factors that make analyzing occlusion, body posture and the stomatognathic system a rather complex task to perform and debate in scientific literature. In synthesis, these factors refer to:

- An extreme variability of study models and instruments applied to analyze posture and the dental-postural correlation.
- An enormous variability of postural values from individual to individual, also based on age.
- The difficulty of deriving positive statistical results from normality tests, and the subsequent need to perform non-parametric statistical tests.
- The difficulty of evaluating the whole spinal column and not only some regions or districts.
- The presence of many sampling, instrumental and methodological biases.

IN FAVOUR				AGAINST			
Title	Authors	Journal	Year	Title	Authors	Journal	Year
Primary trigeminal afferents to the vestibular nuclei in the rat: existence of a collateral projection to the vestibulo-cerebellum	Gabrielle Pinganaud, Florence Bourcier, Catherine Buisseret-Delmas, Pierre Buisseret	Neuroscience Letters	1999	Occlusion and center of foot pressure variation: Is there a relationship?	Virgilio F. Ferrario, Chiarella Sforza, Johannes H. Schmitz and Alberto Taroni	Craniomandibular Function and Dysfunction	1996
Dental occlusion modifies gaze and posture stabilization in human subjects	Pierre Gangloff, Jean-Paul Louisc, Philippe P. Perrin	Neuroscience Letters	2000	Evaluation of body posture in individuals with internal temporomandibular joint derangement	Wagner Cesar Munhoz, Amélia Pasqual Marques, José Tadeu Tesseroli de Siqueira	CRANIO	2005
The effect of occlusal alteration and masticatory imbalance on the cervical spine	Takahisa Shimazaki, Mitsuru Motoyoshi, Kohei Hosoi, Shinkichi Namura	European Journal of Orthodontics	2003	Postural stability and unilateral posterior crossbite: Is there a relationship?	Ambrosina Michelotti, Gerarda Buonocore, Mauro Farella, Gioacchino Pellegrino, Carlo Piergentili, Stefano Altobelli, Roberto Martina	Neuroscience Letters	2006
Effects of different jaw relations on postural stability in human subjects	P. Bracco, A. Deregibus, R. Piscetta	Neuroscience Letters	2004	Dental occlusion and body posture: No detectable correlation	G. Perinetti	Gait & Posture	2006
Examination of the Relationship Between Mandibular Position and Body Posture	Kiwamu Sakaguchi, Noshir R Mehta, Emad F Abdallah, Albert G Forgione, Hiroshi Hirayama, Takao Kawasaki, Atsuro Yokoyama	CRANIO	2007	Posturography as a diagnostic aid in dentistry: a systematicreview	G. Perinetti, L. Contardo	Journal of Oral Rehabilitation	2009
Cervical column morphology related to head posture, cranial base angle, and condylar malformation	Liselotte Sonnesen, Claus Egemose Pedersen and Inger Kjær	European Journal of Orthodontics	2007	Dental Malocclusion and Body Posture in Young Subjects: A Multiple Regression Study	Giuseppe Perinetti, Luca Contardo, Armando Silvestrini-Biavati, Lucia Perdoni and Attilio Castaldo	Clinics	2010
Dental occlusion and postural control in adults	Corinne Tardieu, Michel Dumitrescu, Anne Giraudeaua, Jean-Luc Blanc, Francois Cheynet, Liliane Borel	Neuroscience Letters	2009	Dental occlusion, body posture and temporomandibular disorders: where we are now and where we are heading for	D. Manfredini, T. Castroflorio, G. Perinetti, L. Guarda-Nardini	Journal of Oral Rehabilitation	2012
Impact of orthognathic surgery on the body posture	M. Paya-Argouda, C. Tardieua, F. Cheynetc, A. Raskina, L. Borel	Gait & Posture	2019	The diagnostic potential of static body-sway recording in orthodontics: a systematic review	Giuseppe Perinetti, Jasmina Primožič, Daniele Manfredini, Roberto Di Lenarda, Luca Contardo	European Journal of Orthodontics	2012
Thoracic-lumbar-sacral spine sagittal alignment and cranio-mandibular morphology in adolescents	Maria Grazia Piancino, Paola Dalmasso, Fabio Borello, Pasquale Cinnella, Vito Crincoli, Umberto Garagiola, Corrado de Biase, Ingrid Tonni, Giada Matacena, Andrea Deregibus	Journal of Electromyography and Kinesiology	2019	Effects of experimental occlusal interference on body posture: an optoelectronic stereophotogrammetric analysis	I. Marini, M. R. Gatto, M. L. Bartolucci, F. Bortolotti, G. Alessandri Bonetti, A. Michelotti	Journal of Oral Rehabilitation	2013
Relationship between Unilateral Posterior Crossbite and Human Static Body Posture	Jorge Zurita-Hernandez, Paul Ayuso-Montero, Meritxell Cuartero-Balana, Eva Willaer and Jordi Martinez-Gomis	International Journal of Environmental Research and Public Health	2020	Influence of dental occlusion on postural control and plantar pressure distribution	Benjamin Scharnweber, Frederic Adjami, Gabriele Schuster, Stefan Kopp, Jörg Natrup, Christina Erbe, Daniela Ohlendorf	CRANIO	2017

Table 1.3.a: Summary of scientific papers for and against the relationship between occlusion and posture.

This last concept is unequivocally expressed by the literature review carried out in 2006 by Olivo et al., who contended the existence of a correlation between the tonic-postural control system and cervical spine, while warning readers, at the same time, about the low quality of the studies analyzed [Olivo SA et al., 2006]. Other testaments to the great confusion surrounding the topic and the difficulty of carrying out high-quality experimental studies are the lack of meta-reviews in the literature and the scarcity of randomized clinical trials [Perinetti G et al., 2009]. The existing few usually involve very small samples and employ methods that are not always sufficiently sound: they can therefore be considered clinical evidence of a change, but their low sample representativeness does not allow for generalization. In sum, there is plenty of literature about the topic but very little high-quality evidence-based medicine.

From this lively debate emerges a pivotal concept for orientating future research in the field: occlusion is part of a neuromuscular control system of the soma, functioning as an important central reference for both inflowing and outflowing proprio-esteroceptive signals of postural condition. Therefore, it appears rational to consider the presence of malocclusion – especially of an asymmetrical type due to the aforementioned neurophysiological and biomechanical reasons – as an endogenous stimulus of postural compensation, capable of generating an abnormal condition that, initially, may be transitory, but if the pathological stimulus is maintained over time, may become structural. Such algic-postural disorders can be extremely complex due to an underlying generalized non-function of a number of postural receptors of primary importance.

In conclusion, we can argue that a functional correlation between occlusion and posture exists. However, it must be researched and evaluated within the neural network described above in order to open up opportunities for the development of a theoretical model confirming such a relation. Conversely, data gathered by scientific studies will never be susceptible to a univocal interpretation [Ciancaglini R et al., 2009].

1.3.1. POSTURAL ANALYSIS

The gold standard method of spinal disorder evaluation is certainly the spinal X ray, routinely employed in the orthopedic field (Fig.1.3.1.a).

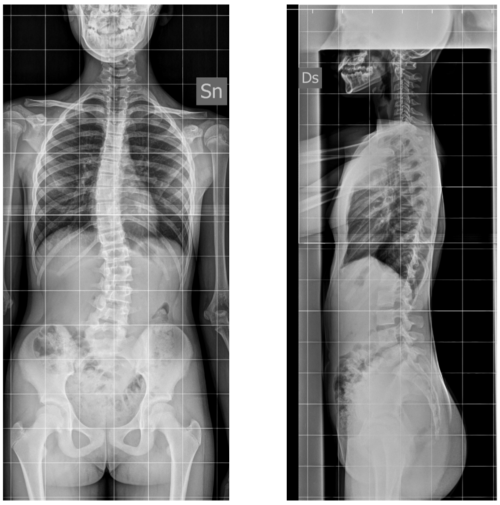


Fig. 1.3.1.a: Spinal X-ray in a female patient with scoliosis (gold standard for diagnosis of spinal deformities).

However, specialists from other disciplines, such as dentists, nutritionists, optometrists and physiotherapists, also need to assess the general posture of patients, especially to understand the influences that their therapies can have on body posture. This requirement has led, in time, to the development and dissemination of non-invasive postural investigation methods, i.e. making no use of ionizing radiation. These are not instruments for orthopedic diagnosis, but global evaluation methods that allow specialists to monitor the postural status of patients before, during and after their treatment. In addition, they can be replicated over time without exposing the patient to any biological risk. It is from this starting point that clinical posturology was developed.

Historically, Charles Bell was the first to begin reflecting, in the mid-19th century, on the factors that enable the body to maintain posture and balance [Bell CC, 1981]. Following Bell, other researchers focused on the analysis of the tonic-postural system adopting different specialist approaches: Moritz Heinrich Romberg evaluated the influence of the visual and podalic systems; François Achille Longet focused on the proprioceptive action of paravertebral muscles; and Élie De Cyon described the effect of ocular receptors on postural stability. None of them, however, were able to consolidate a multidisciplinary approach capable of gathering all disciplines within one diagnostic concept.

1.3.2. POSTURAL AND SPINAL ANALITYCAL METHODS

There are a number of tools and methods to assess the posture of a subject. Some are more reliable, scientifically validated and suitable for providing a host of significant information. Others, conversely, are very commercial, non-validated and usually of little effectiveness. Methods can be divided into two categories: clinical tests and instrumental investigations. The most important and diffused *clinical tests* are the following:

- Romberg's Test (Fig.1.3.2.a): it evaluates the presence of sensory ataxia or balance disorder when patients keep their eyes closed. The doctor asks the patient to stand upright, with heels close together and arms extended forward, for a few second with open eyes. If the patient is able to maintain this position and balance with open eyes – precondition to exclude cerebellum ataxia – the examination is repeated with closed eyes. If the patient begins to stagger or fall within the first 30 seconds, the test is considered *positive*. This leads the examiner to a diagnosis of information ataxia, i.e. a sensory proprioceptive and labyrinthine information deficit. The test would instead result *negative* if the patient keeps standing with closed eyes. A minor fluctuation is not considered pathological.
- Fukuda's test or stepping test (Fig. 1.3.2.b): it evaluates the presence of muscular hypertone during stepping. The doctor asks the patient to stand upright, with free hands forward, head in a neutral position and jaw in resting position. Then, the patient closes the eyes and performs 50 steps on the spot in about a minute. Normal subjects are able to rotate less than 30°. Instead, if the patient's body rotates more than 30°, the test is positive. In this case, the cause is probably a labyrinthine disorder on the side towards which the displacement occurred. A forward displacement (walking) does not indicate a disorder.

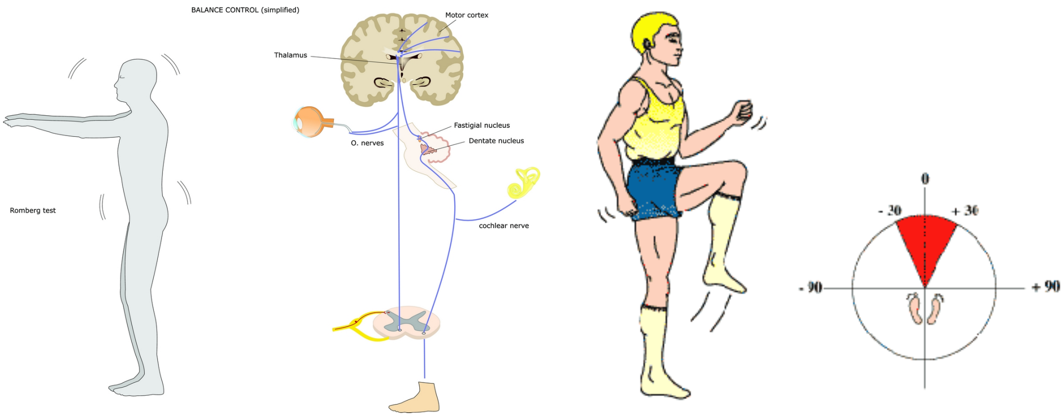


Fig. 1.3.2.a-b: Romberg's and Fukuda's test

- Barré’s vertical axis (Fig.1.3.2.c): reference vertical axis that allows for the evaluation of possible asymmetries on the frontal and sagittal plane, scrutinizing the patient while standing with as little clothing as possible.
- Autet’s test or hip rotators test (Fig.1.3.2.d): used to distinguish whether a postural syndrome is ascending, descending, psycho-emotional or visceral. The patient is placed in supine position with extended legs, looking up to the ceiling. The doctor, placed at the patient’s feet, lifts the two heels and performs an internal rotation of the legs at the height of malleoli. It serves the purpose of verifying the maximum internal rotation width of lower limbs and therefore evaluates the symmetry of the external rotator hip muscles’ tone, as well as the mobility of the femur and coxofemoral joint.

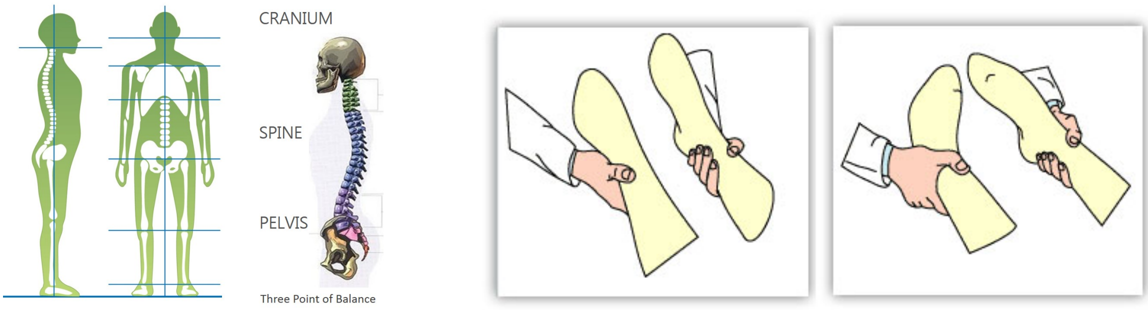


Fig. 1.3.2.c-d: Barre’s vertical axis and hip rotators test.

1.3.3. POSTURAL DEVICES

Non-invasive instruments, instead, are in turn divided into two categories: *skin-surface devices* and *non-skin-surface* devices. The former (e.g. Spinal mouse, Prcereal, Fastrak, CA 6000) record vertebral characteristic sensors or electrodes that are put in contact with the back of the patient, whereas the latter do not touch the skin but use reference points or sensors that are not in contact with the back of the patient (e.g. inclinometers, goniometers, flexicurves, postural platforms).

Among these, the most commonly utilized scientifically-validated instruments are the following:

- Scoliometer (Fig.1.3.3.a): tool to visually evaluate, and then numerically measure, the posture in the frontal, sagittal and transversal projections. To do so, the tool requires a postural grid with reference vertical axes placed on the wall, and a mirror placed on the ceiling at an angle of 30°.

- Osualdo's inclinometer (Fig.1.3.3.b): manual goniometer to measure Cobb's and Gibbo's angles, used during the anteroflexion test and on spinal X rays.
- Anti-gravity goniometer (Fig.1.3.3.c): it is the fundamental tool for performing a biomechanical test. It allows for an extremely precise assessment of malleolus deviations, tibial rotations of patella and knee, and movement ranges in relation to the axes.
- Stabilometric platform (Fig.1.3.3.d): it enables the tester to perform a static posturographic evaluation. It quantitatively assesses postural oscillations employing a fixed-force platform with load/charge cells, which measures the variations of the center of body mass and pressure that the patient traces while standing 'still' in upright position on the platform.
- Baropodometric platform (Fig.1.3.3.e): a modular system consisting of one or more platforms that measure plantar pressure in both static and dynamic phases.
- Podoscope (Fig.1.3.3.f): tool consisting of a metal supporting structure on which a transparent backlit crystal plane is installed, together with an inclined mirror where the soles of the feet are displayed. The podoscope allows for an evaluation of the soles in static condition.
- Spinal Mouse (Fig.1.3.3.g): handy electronic accelerometer that is manually guided along the spine. Via software, it renders a virtual (also 3D) representation of the whole spinal column as well as the intersegmental vertebral angles. This way, the mobility and flexibility of the spine on the sagittal and frontal planes can be evaluated with the aid of graphic and numeric references.

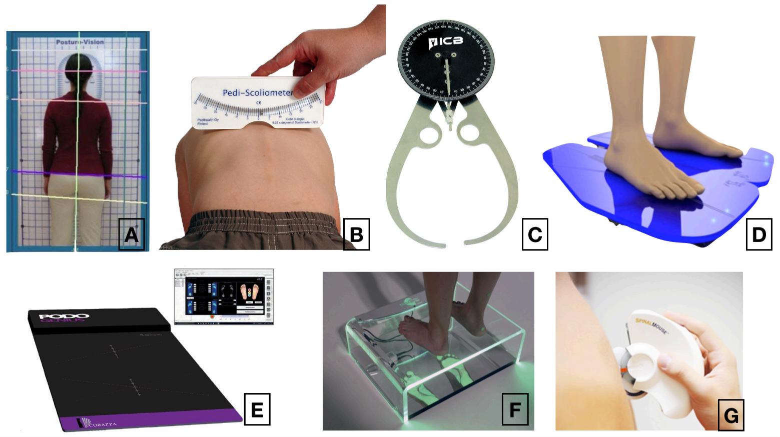


Fig. 1.3.3.: Non invasive postural devices: Scoliometer (a), Inclinometer (b), Goniometer (c), Stabilometric platform (d), Baropodometric platform (e), Podoscope (f), Spinal Mouse (f).

1.3.4. NON-INVASIVE POSTURAL DEVICES: METHODOLOGICAL LIMITS

The existence of such a wide range of postural analysis instruments surely represents an interesting starting point to deepen the accuracy of clinical assessments but it can also lead to confusion and incongruity in the literature. Some methods are used despite not being scientifically validated, others do not have a universally-agreed usage protocol, whereas some others are not even defined by authors. A reliable interpretation of the material available in the literature, therefore, is often hindered. Data obtained from a single research are indeed rarely comparable, thus making the effort of the researcher vain and hardly fruitful.

We shall take as an example a systematic literature review carried out by Perinetti and Contardo [2009], which investigates the different non-invasive instrumental systems of postural analysis, selecting and analyzing 21 articles published between 1996 and 2009. Posturographic analysis – hence a static one – is performed in these studies with completely different methods: purely qualitative clinical methods, quantitative methods, employing a stabilometric platform, rastereography, photogrammetry, surface electromyography, and Fukuda and Fujimoto's test. The same authors affirm that "only one study was judged to be of medium/high quality, with all of the rest classified as of low-quality design" [Perinetti et al., 2009, pp. 935]. They conclude by underlying the methodological problems they found in the literature:

> "With limitations because of the poor methodological quality of the present published studies, conclusions are that a correlation between the stomatognathic system and whole-body posture can be detected, at least under experimental conditions; although posturography has little relevance in the monitoring of body posture responses to changes in the stomatognathic system (including temporomandibular disorders). While more investigations with improved levels of scientific evidence are needed, the current evidence does not support the usefulness of posturography as a diagnostic aid in dentistry." [Perinetti et al., 2009, pp. 936]. The following conditions, necessary to enlarge the investigation scope of such a disputed topic, therefore seem to emerge:

- choice of scientifically-validated investigation instruments;
- creation of universal usage protocols;
- rigorous methods of sample selection;
- increase in availability of high-quality scientific studies.

1.3.5. COMPARISON OF DIFFERENT POSTURAL DEVICES: THE VALUE OF CONCORDANCE

A further limit detectable in the literature about postural evaluation is the usage of a single postural test/device at a time. Most studies in fact focus on evaluating a single postural component, such as measuring stability with a stabilometric platform, spinal mobility with inclinometers, goniometers or accelerometers, or the postural setting through photogrammetry. The tonic-postural system is particularly complex due to the presence of district, structural, systemic and environmental influences and afferents. For this reason, analyzing data deriving from multiple postural investigation methods and the subsequent correlations between results can lead to more significant scientific results and provide the clinician with more useful evaluations. The process of data integration allows for a critical assessment of the concordance between the different methods and highlights the possible presence of dependent variables that influence the posture of the subject before and after the therapy. A correlation analysis of various methods of postural analysis therefore endows the clinician with a greater diagnostic effectiveness.

However, the literature lacks a standardized and disseminated method to integrate data between postural, occlusal, oral and masticatory investigation systems. For this reason, the research efforts of the Orthodontics Department of the Dental School of the University of Turin, Italy, have focused on standardizing an investigation method that integrates postural evaluation with the patient's masticatory activity. All the patients who come to the Department for orthodontic treatment undergo three instrumental tests, which are non-invasive and scientifically-validated. The first two are postural test, while the third is a test of masticatory function, validated and now performed for several decades by the University of Turin:

1. Spinal Mouse: evaluation of the mobility, flexibility and inclination of the spinal column on the sagittal and frontal plane (Fig. 1.3.5.a);
2. Lizard Stabilometric Platform: evaluation of postural stability and postural sway in two conditions, i.e. in dental rest position and in maximum intercuspation (Fig.1.3.5.b);
3. K7-I Kinesiograph: analysis of chewing cycles with soft bolus and hard bolus (Fig.1.3.5.c).

Fig. 1.3.5.: Non invasive postural devices used for protocol test in University of Turin: Spinal Mouse (Idiag, Volestwil, Switzerland) (a), Lizard Stabilometric Platform (Lizard, Lemax s.r.l., Como, Italy) (b), K7-I Kinesiograph (Myotronics, Tukwila, WA, USA) (c).

The analysis and integration of data deriving from these three diagnostic instrumental tests on growing patients with unilateral posterior crossbite, before and before/after functional orthodontic therapy is the core of this thesis.

1.4. THE CROSSBITE

The crossbite is a worsening dental malocclusion characterized by an inverse relationship (on the frontal and/or sagittal plane) of one or more teeth in which the buccal cusps and/or upper incisal margins occlude palatally with the buccal cusps and/or lower incisal margins, on either one or both sides of the dental arches (Fig. 1.4.a).

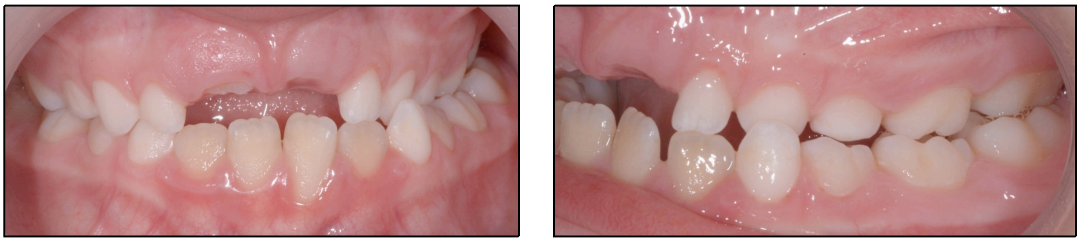


Fig. 1.4.a: Left unilateral posterior crossbite

Daskalogiannakis [2002] defined the crossbite as “an anomalous relationship of one or more teeth with one or more elements of the opposite dental arch, in the buccal–lingual or labial–lingual direction”, adding that a crossbite may be “either *dental or skeletal* in origin” [Daskalogiannakis J, 2002). This ‘modern’ definition recognizes that the skeletal component plays an integral role in malocclusion. In the light of current knowledge, we can add that crossbite is connected to a *worsening structural and functional asymmetry.*

The diffusion of crossbite is reported in the literature as affecting between 8 and 22% of the population [Harrison JB and Ashby D, 2001]. According to a study carried out at the Dental School of the University of Turin [Piancino MG et al., 2006] on 5300 patients aged between 6 and 16 years old with malocclusions requiring orthodontic treatment, crossbite was diagnosed in 19% of the cases. From the total number of crossbite cases, 49% displayed unilateral posterior crossbite, 16% bilateral posterior, 17% anterior only, 15% unilateral anterior and posterior crossbite, 2% bilateral anterior and posterior, and 1% total.

Etiologically, many causes may lie behind this type of malocclusion. Apart from genetic factors, which are often the basis of crossbites characterized by the simultaneous presence of maxillary hypoplasia and mandibular prognathism, attention must be paid to functional changes such as oral respiration, abnormal patterns of deglutition and bad habits such as thumb-sucking or the excessive use of pacifiers and baby bottles. Other causes include congenital alterations such as labial palatal clefts, dystrophic alterations, metabolism disorders, infections or trauma – in other words, all pathologies that slow down or alter the growth of the upper maxillary, thus causing the hypoplasia. Environmental factors also play a part, such as the agenesis or premature extraction of one or more teeth, which decreases the functional matrix of the upper maxillary during childhood development.

1.4.1. CROSSBITE = NEUROMUSCULAR SYNDROME

Crossbite is a malocclusion that is first diagnosed via the teeth, although the effects and symptoms related to dental malposition represent just a small part of the impact of crossbite. In fact, crossbite affects mastication, neuromuscular coordination, neural motor memory, the inner skeletal structure, the TMJ, and all of the stomatognathic system with its related structures [Troelstrup and Moller, 1970; Bracco et al., 2004]. It is characterized by two special features: the type of asymmetry and the early age of onset.

Asymmetry (dental, skeletal and/or positional) is one of the unique and particular features of crossbite, along with its consequential functional effects: it may originate from a skeletal or dental malrelationship, or both, and may lead to a mandibular displacement and a prolonged dyskinesia.

The second feature is the early age at which it may emerge, during eruption of the primary dentition, and it can involve the permanent dentition at a later stage of development. It has an influence on the masticatory function and the effects will worsen over time and are irreversible once the growth stage is complete.

Thus, it is clear that the definition of crossbite as a ‘malocclusion’ is extremely restrictive and that it would be more accurate and useful from a diagnostic point of view to define crossbite as a ‘neuromuscular syndrome’. This is its real defining characteristic, which reflects the approach we suggest to take in developing a suitable therapy for functional correction and ‘cure’ of the patient's stomatognathic system. Teeth are the means through which we can currently achieve this goal.

The functional division of the upper dental arch is similar to that of the lower anterior area (incisor and canine), the posterior area (molar), and intermediary area (premolar), apart from the lower first premolar, which is functionally included in the laterotrusive control. This corresponds to the gnathological concept of organic occlusion – the contrast between the different functional fields of the individual dental groups supplies a mutual protection function in the different dental arches [Slavicek, 2002]. On the basis of this knowledge, it is easy to see that the alteration of masticatory function correlates to the functional region involved by the malocclusion(Fig. 1.4.1.a).

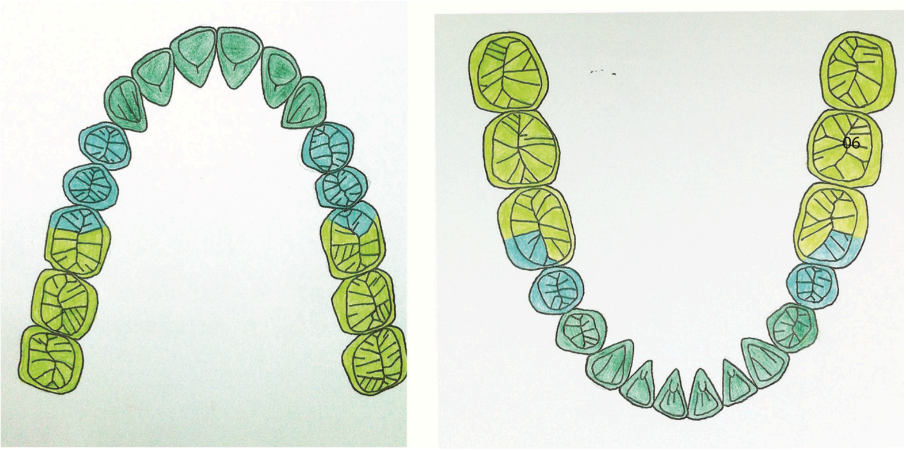


Fig. 1.4.1.a: The functional role of teeth - Anterior and posterior functional region of the occlusion. The diagram in two colours demonstrates the dual role of premolars, which provide support as well as dynamic control.

Correct diagnosis of crossbite requires a dental classification based on the gnathological concept of organic occlusion. Tables for dental classification of crossbite subdivide the malocclusion into anterior, middle, and posterior regions, but it must be added that crossbite may affect just one hemiarch or both arches bilaterally, with significant different functional effects and impact on functional structural development. Therefore, it is necessary to first subdivide the crossbite conditions into unilateral or bilateral categories.

1.4.2. UNILATERAL POSTERIOR CROSSBITE

Unilateral posterior crossbite (UPC) may be defined as a malocclusion where one or more posterior maxillary teeth have a more palatal or lingual position than the corresponding antagonist mandibular tooth (or teeth), on one side of the dental arch only. This type of crossbite is very particular, widespread, and unique within its genre because dento-alveolar occlusion and tissue support are asymmetric, just like the masticatory function (Fig 1.4.2.a).

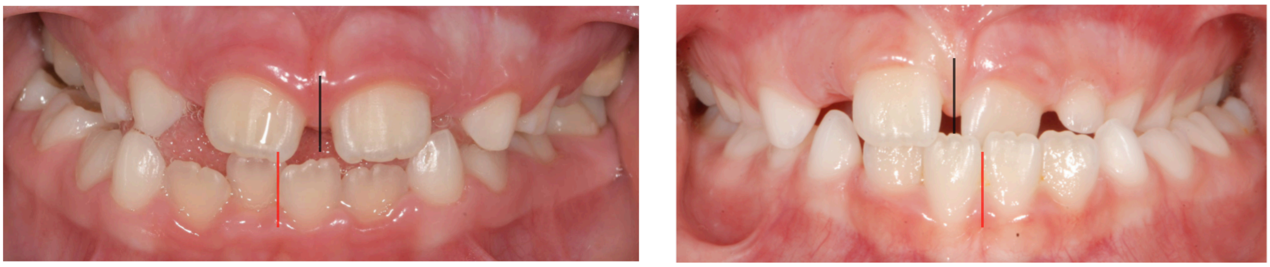


Fig. 1.4.2.a: Right and left unilateral posterior crossbite malocclusions

Usually, the condition emerges during early infancy (between 2 and 5 years of age) and results in a deflected dental contact that causes an asymmetric lateral shift of the mandible. When the first contact position is in place (i.e., when the mandible is in a centered position), cuspid-to-cuspid dental contacts are established between the upper and lower teeth. The inputs generated by the dental mechanoreceptors are received and elaborated by the Central Nervous System, activating masticatory muscles and deviating the mandible as it searches for a position of maximum intercuspation that is stable and necessary for any type of function, avoiding those input signals. Dental stability and the avoidance of cusp-to-cusp contacts are essential in allowing the vital functions of the stomatognathic system (i.e., deglutition and mastication) to be carried out. In other words, the system 'compensates' for the occlusal error of crossbite, trying to obtain the best function. However, it is not able to correct the defect, and the resulting biological consequences over time are unfortunately serious. In fact, owing to the early age at which this malocclusion occurs, all developing structures will unbalance the mandibular shift and functional asymmetry.

The persistent displacement of the mandible and the inversion of the relationship between dental cusps and asymmetric functional compensation cause a disharmonious development of the growing child. This is the fundamental developmental stage during which a child learns all the motor skills, such as walking, climbing and chewing, deeply influencing and adapting the inherited automatism of the motor control of the central nervous system to the peripheral inputs. As Slavicek [2002] stated, oral functions (language, mastication, and deglutition) are ‘formative’, and any dysfunction of these may influence the development of the masticatory system, disturbing its morphological and functional growth, from both static and dynamic points of view [Piancino et al., 2009, Piancino et al., 2016, Piancino et al., 2019, Grippaudo et al., 2016]. This functional asymmetry may lead to morphological asymmetry and it needs early physiological therapies to avoid asymmetrical development. Of course, it is true that early treatment is crucial, but the type of therapy is even more important. The early age at which the condition emerges means that we must consider not only the importance of correcting the malocclusion but also evaluate the therapeutic means to be used on such young patients, with the aim of restoring masticatory function and balancing growth. Obviously, the goal is to find the most physiological therapeutic treatment, in order to avoid any traumatic effect.

1.4.3. ASYMMETRICAL MASTICATORY PATTERNS IN UNILATERAL POSTERIOR CROSSBITE

A number of authors [Lewin, 1985; Ben-Bassat et al., 1993; Throckmorton et al., 2001; Piancino et al., 2006; Sever et al., 2010] demonstrated that children with unilateral posterior crossbite display modified chewing patterns on the crossbite side during mastication, characterized by a significant increase in the frequency of reverse-sequence chewing patterns, which refers to movement of the mandible during the closing phase of chewing. The reverse chewing pattern is characterized by the inversion of the closing direction in the last stage of the chewing cycle, which then is defined as a *reverse chewing cycle* (Fig. 1.4.3.a).

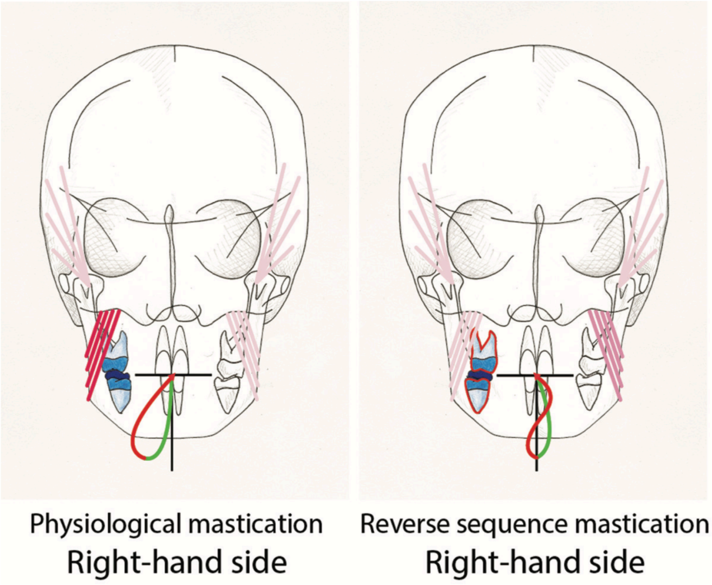


Fig. 1.4.3.a: Physiological mastication and reverse sequence mastication on the right-hand side.

Source: Piancino and Kyrkanides (2016)

When a unilateral posterior crossbite is present, the number of reverse chewing cycles increases significantly during mastication on the crossbite side in comparison with normal physiological and symmetrical occlusion. Reverse patterns may be present in small numbers also in physiological conditions, and represent a form of abnormal cycle that may be due, for instance, to an attempt to recapture the bolus. Such abnormal cycles cannot be considered part of the regular pattern, i.e., of patient's motor memory of mastication. When the number of reverse-sequence patterns increases, they become more significant in the patient's mastication, influencing it unequivocally and establishing clinical consequences. Thus, a reverse-sequence chewing cycle is not pathognomonic of crossbite, but when it emerges with a high frequency, and in significant percentages, then it constitutes an *unequivocal clinical indicator of crossbite* [Piancino et al., 2006, 2008, 2016, 2019].

The closing direction is the vector of the closing pattern in the last stage of the chewing cycle. The direction of closure in physiological occlusion is linked to the side of mastication (i.e., the bolus side), exerted in a clockwise direction when the bolus is between the right-hand hemiarches and in an anti-clockwise direction when the bolus is between the left-hand hemiarches. This means that, in cases of right-hand side crossbite, during mastication on the right, the chewing cycle displays an anti-clockwise closing direction as opposed to the clockwise direction to be found in physiological conditions. On the contrary, in cases of crossbite on the left-hand side, during mastication on the left the closing direction will be clockwise instead of anti-clockwise.

In healthy conditions of occlusion and mastication, during opening, the mandible shifts laterally from the bolus side; then, during closure, it shifts medially via the transcuspal and intercuspal stages of mastication opposing the occlusal tooth surfaces. During a reverse-sequence chewing cycle, the mandible shifts first medially and then laterally, in order to deal with the opposite occluding surfaces of the teeth in crossbite (Fig. 1.4.3.b).

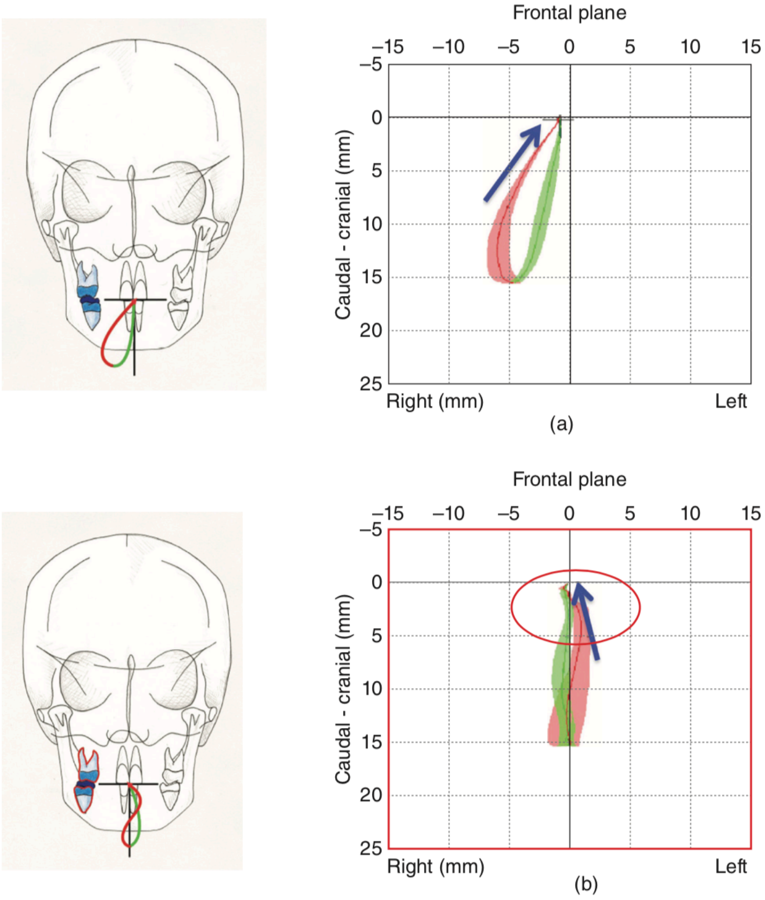


Fig. 1.4.3.b: Physiological (a) versus reverse (b) chewing pattern during chewing on the right side.

The reverse-sequence chewing cycle is set and maintained by the automatisms of the central nervous system's motor control on the basis of peripheral inputs arriving from the periodontal mechanoreceptors [Lund and Kolta, 2006; Morquette et al., 2012]. The reverse closing direction is not an isolated sign, but it is an indicator of an altered pattern and it’s linked with other irregularities: the non-reverse cycles on the crossbite side are usually characterized by a smaller lateral displacement, reduced opening, and larger closure angle in comparison to controls. Moreover, very importantly, the muscular activation is affected, being the masseter of the crossbite side significantly less activated with respect to the normal side [Piancino et al., 2016, 2017, 2019]. Furthermore, both sides increase their activity when the bolus hardness was increased, as in control subjects. This means that *the asymmetry of the occlusion determines an asymmetry of the masticatory function both from a kinematic and neuromuscular point of view,* i.e., an asymmetry of movements, of articular loads, of muscular activation and coordination leading to an asymmetry of bones and structures when the crossbite is not timely corrected [Slavicek, 2002; Simoes, 2013; Tecco et al., 2011].

1.4.4. THE AIM OF EARLY TREATMENT AND THE REASONS OF ORTHODONTIC THERAPY WITH FUNCTION GENERATING BITE (FGB)

The final goal of early orthognathodontic treatment is to achieve (via the teeth) a rebalancing of function, especially that of mastication, in order to respect the known gnathological principles. A physiological and biological knowledge of the masticatory function based on reliable scientific results is necessary for a coherent path from diagnosis through the therapy during development. In fact, nowadays, it is of clinical relevance, for a successful orthognathodontic therapy, to consider not only the repositioning of teeth within the dental arches, but the effects of the therapy on function [Thilander et al., 2002, Piancino et al., 2016] . This is true especially for early therapies in developing children. This can be easily achieved using the functionalizing appliance *Function Generating Bite* (FGB) (Fig. 1.4.4.a), to correct not only the dental malocclusion but especially the anomalous chewing patterns with high significance [Piancino et al., 2006].

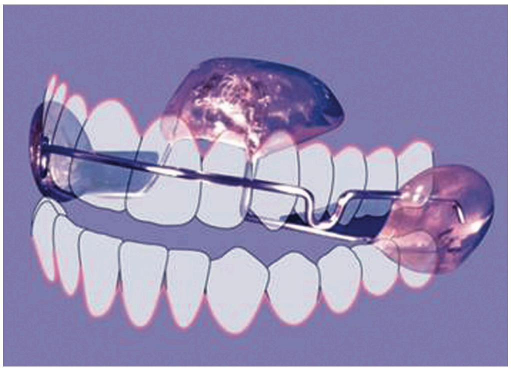


Fig. 1.4.4.a: FGB appliance with posterior bite planes.

In addition, as shown by Piancino et al. (2016), the FGB appliance is capable to re-balance the neuromuscular coordination between sides. To this end, during the early stages of development, the dental mechanical therapies fixed to the teeth should be used with great caution, and limited to the cases when they are really necessary, because they inevitably create mechanical strain and biological traumas in a complex developing system [Mummolo et al., 2014].

1.4.5. WHY FUNCTION GENERATING BITE CORRECTS THE MALOCCLUSION AND THE MASTICATORY PATTERNS?

As described by Piancino and her colleagues in 2019 [Piancino et al., 2019], the restoration of a physiological masticatory function during development is important to obtain a symmetric basal and sutural development and a stable result of therapies. Research on mastication shows that restoration of function after a malocclusion corrected with an FGB device is not a coincidence, and that the features of the device are worth further exploring in order to understand the gnathological and clinical importance of the results (Piancino et al., 2008).

The FGB (Fig. 1.4.5.a) is individually manufactured and composed of acrylic resin and special resilient stainless-steel wires, with posterior metallic bite planes preventing the teeth from intercuspal contacts. [Piancino et al., 2016; Bracco et al., 1979].

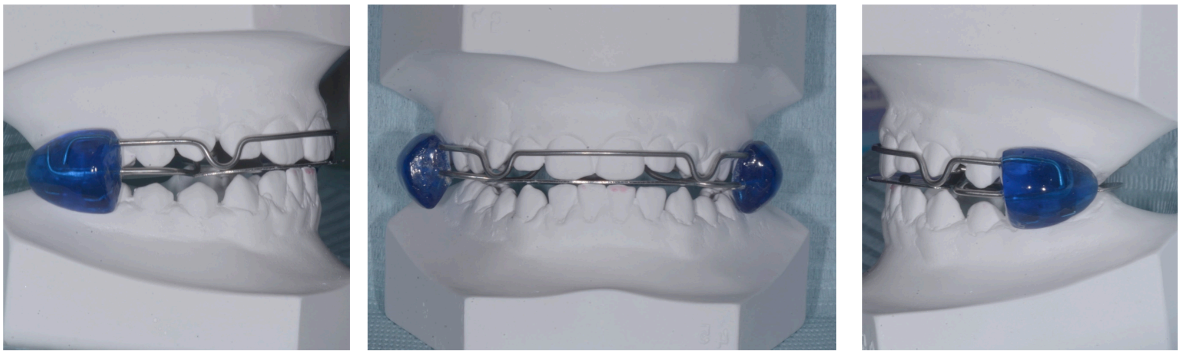


Fig. 1.4.5.a: FGB appliance on model cast.

It allows for a repositioning of teeth while thoroughly respecting the physiological condition of the temporo-mandibular joint (TMJ) and avoiding harmful misaligned cusp-to-cusp dental contacts. This happens thanks to the resilient stainless-steel bite planes located in the posterior regions of the occlusion that disengage the mandible and self-regulate the mandibular position in the three planes of the space during orthodontic movements. Crucially, thanks to the bite planes, the device acts to level the occlusal plane and align the dental arches avoiding dental trauma.

From the orthodontic point of view, the posterior bite planes activate simultaneously with the expansion springs, exerting a couple of forces and a bodily movement of the teeth [Mummolo et al., 2014]. It is of crucial importance to stimulate the bone growth while avoiding tilting movements, to obtain a stable orthodontic correction [Serrano et al., 2014; Rice, 2008; Opperman, 2000; Hinton, 1988; Persson et al., 1978]. The FBG appliance has a muscular anchorage and activates during swallowing, so that the orthodontic forces moving the teeth are intermittent (swallowing) and self-regulated by the muscles of the patient. The gerund term 'function generating' underlines the continuous, rhythmic action of the appliance. It fluctuates in the mouth (no dental anchorage) and is characterized by contact points to the teeth that avoid any dental upper or lower constriction. FGB easily restores the masticatory function because it prevents cusp-to-cusp contacts during orthodontic movements: it is an orthognathodontic device acting in a physiological way.

Lastly, FGB's usefulness to correct dental malocclusion while concurrently restoring the physiological masticatory patterns and the muscular activity and coordination, showing a complete functional symmetrization, has been largely demonstrated. To this end the book "Understanding Masticatory Function in Unilateral Crossbites" [Piancino and Kyrkanides, 2016], argues for a new, coherent approach to the early 'cure' (in medical terms) of one of the most important district of the human body, one that contributes to the mental and physical wellbeing of young patients throughout their lives.

1.4.6. ASYMMETRICAL FUNCTION IN UNILATERAL POSTERIOR CROSSBITE: CORRELATION BETWEEN MASTICATORY PATTERNS AND BODY POSTURE

The deep involvement of neuromuscular control during chewing in crossbite malocclusion strongly suggests a possible effect on body posture. In addition, the correlations between masticatory and neck muscles during chewing are further elements that ought to be considered [Eriksson et al., 2004; Häggman-Henrikson and Eriksson, 2004; Häggman-Henrikson et al., 2014]. A systematic literature review conducted by Huggare in 1998 highlights a greater prevalence of unilateral posterior crossbite among patients affected by scoliosis, stiff neck and spinal column dysmorphia. Such a study underscores the emergence of a bidirectional influence of the two pathological conditions, i.e. postural and occlusal [Huggare, 1998]. Moreover, a very recent study from Zurita-Hernandez et al. [2020] analyzed the body posture, through stabilometry and photogrammetry, of 18 patients affected by posterior crossbite, for then comparing the results with those obtained through analogous tests on 18 patients with physiological symmetrical occlusion. A statistically-significant difference emerged between the study and control groups in terms of static posture control, highlighted both by the stabilometric center of pressure and by photographic analysis. This represents a further confirmation of the theory that explains unilateral posterior crossbite as a relevant factor able to influence the complex regulatory mechanism of the tonic-postural system [Zurita-Hernandez et al., 2020]. For these reasons, unilateral posterior crossbite is to be considered a determining factor of function alteration not only in relation to the stomatognathic district, but also to the whole system of tonic-postural control, therefore prone to affect postural functionality (Fig. 1.4.6a).

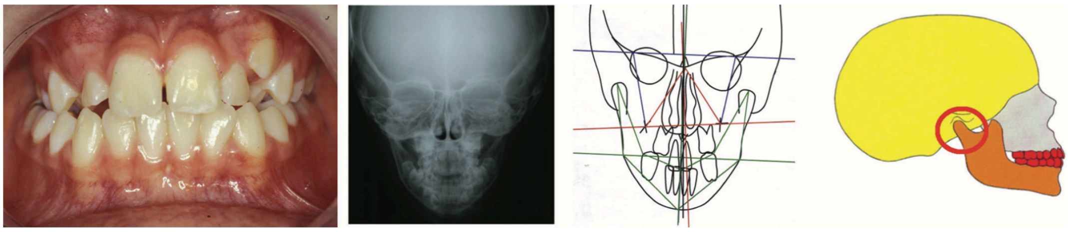


Fig. 1.4.6.a: Basal crossbite: occlusion in maximal intercuspation; the centered position is not detectable. Postero-anterior cephalometry (in the frontal plane): the asymmetries are evident. At the end of growth the compensatory, basal asymmetries to the posterior crossbite malocclusion are irreversible.

Again, to understand the phenomena we need to take a physiological approach. As already stated, research shows that functional asymmetry due to unilateral posterior crossbite (and the resulting effects on growth) can be corrected with the prompt use of an orthognathodontic functional appliance called Function Generating Bite (FGB). Thus, the interest that motivates this research is to verify whether an FGB-based orthodontic therapy is suitable, other than for recovering the masticatory function and the physiological activity of chewing muscles (an instance that is largely demonstrated in literature), for bringing about a rebalance and a symmetrization of the neuromuscular postural control system of young patients during their growth, in order to favor a correct physiological development and a state of general health.

The specific aims of the present study, along with the materials and methods employed, will be detailed in the next section.

2. AIM OF THE STUDY

The aim of this experimental research was to objectively evaluate human posture in growing patients with and without malocclusions, by assessing spinal mobility with the Spinal Mouse, postural balance with the Stabilometric Platform and the masticatory function with the K7-I Kinesiograph.

Our purposes were:

1. To evaluate the posture of growing patients with unilateral posterior crossbite *before* orthodontic therapy *versus* a control group with normal dental occlusion ;
2. To investigate the ‘congruity’ and concordance between posture and masticatory function of patients with unilateral posterior crossbite *before* therapy;
3. To evaluate the effects of the functional orthodontic therapy with the FGB appliance on general posture in patients with unilateral posterior crossbite;
4. To investigate the ‘congruity’ and concordance between posture and masticatory function of patients with unilateral posterior crossbite *after* therapy.

3. MATERIALS AND METHODS

3.1. PATIENT SELECTION

For the purpose of this observational study, from April 2017 through July 2021, we consecutively selected 102 children (50 males, 52 females; age 9.85 ± 2.52 y.o., weight 32.8 ± 4.7 kg, height 139.25 ± 5.5 cm) with unilateral posterior crossbite (60 on the right side, 42 on the left side) and 66 children (36 males, 30 females; age 11.13 ± 2.42 y.o., weight 36.5 ± 3.2 kg, height 143.5 ± 3.8 cm) with normal occlusion, referring to the Orthodontic Department of the University of Turin, Italy. Before entering the study, patients’ parents were informed about its aims and procedures and signed an informed consent to participate. The study was approved by the Institutional Review Board of the University Hospital Company of Turin (n° 0088896), in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

The inclusion criterion for the Patients Group was: unilateral posterior crossbite of two or more posterior teeth during growing. The exclusion criteria were the presence of: previous orthodontic therapy, erupting teeth, caries, dental pain, orthopedic trauma or impairments, back pain, signs or symptoms of dental or myofacial disorders, motor or neurological problems, internal diseases, diabetes and/or celiac disease, spinal pathologies, congenital and hereditary pathologies. The parallel Control Group (CG) was carefully selected for normal occlusion without crossbite and was matched with the Crossbite Study Group (SG) for age and gender.

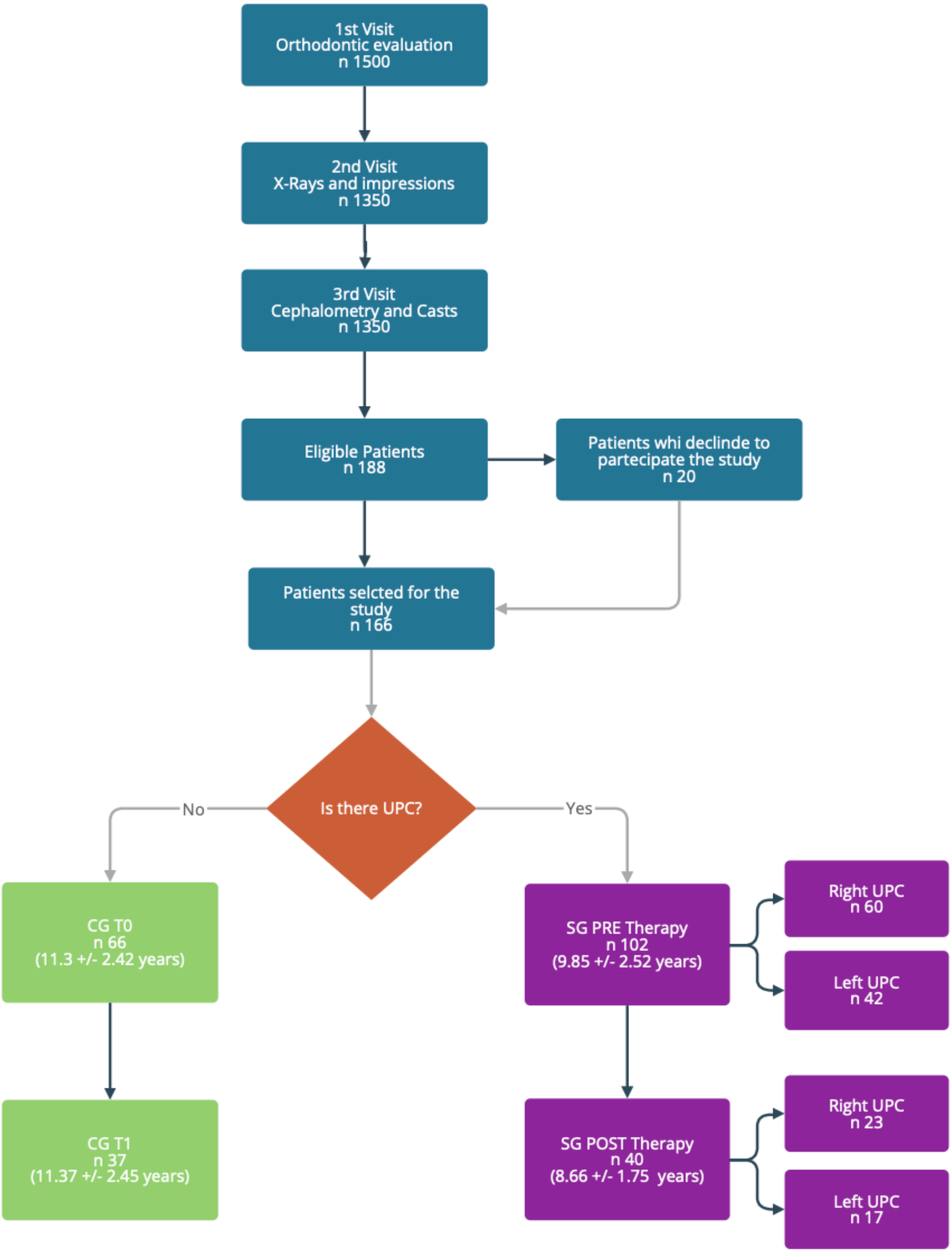
All participants underwent the following sequence of investigations: 1) clinical and orthodontic examination; 2) radiographic evaluation (panoramic, teleradiography in latero-lateral and postero-anterior projection) and subsequent cephalometric analyses; 3) intra- and extra-oral photos; 4) model casts; 5) postural analysis; 6) recording of masticatory patterns. Patients were selected on the basis of occlusal diagnosis, performed by a skilled operator by analyzing model casts.

Afterwards, in order to evaluate the effects of functional orthodontic therapy, 40 children out of the 102 subjects of the starting case group (19 males, 21 females; age 8.66 ± 1.75 y.o., weight 31.3 ± 3.4 kg, height 136.5 ± 4.5 cm) with unilateral posterior crossbite (23 on the right side and 17 on the left side), were treated with the Function Generating Bite.

Upon treatment completion, the malocclusion was corrected and the buccal cusps of the upper teeth, which were previously in crossbite, overlapped the lower teeth on the buccal side. (Piancino et al., 2016). The treatment lasted an average of 8.2 ± 2.7 months plus the retention time of five months. After such retention time, we recorded postural and masticatory assessments of the case group with the same protocol we used before the therapy. Postural and masticatory features after treatment with FGB of these 40 crossbite patients were compared with 37 control patients without crossbite (17 males, 20 females; age 11.37 ± 2.45 y.o., weight 36.7 ± 3 kg, height 144 ± 3.2 cm) out of the starting 66. The control group was carefully matched to the crossbite group for age and gender. During this experimental period the control group did not undergo any orthodontic treatment nor any other kind of dental treatment.

The flow chart of patient selection is illustrated in Fig. 3.1.a.

Fig. 3.1.a: Flow chart of patient selection



3.2. INSTRUMENTATION

Every participant underwent a complete postural analysis through two non-invasive and validated postural devices, the Spinal Mouse System and the Stabilometric Platform, and their masticatory patterns were recorded with K7-I Kinesiograph.

The protocol was executed in a dedicated and quiet room, in the morning. The two operators taking postural measurements and masticatory patterns were unaware of the case/control status of the subjects as well as the purpose of the study and they had more than eight years of experience in the use of all instruments.

Postural and masticatory records were carried out immediately before the intervention and after crossbite correction with FGB plus the retention time for the study group, whereas the control group measurements were recorded during the initial selection. Both cases and controls data were analyzed in the same time period.

3.3. POSTURAL ANALYSIS AND DEVICES

3.3.1. THE SPINAL MOUSE SYSTEM

The Spinal Mouse® system (Idiag, Volestwil, Switzerland) is a wheeled skin-surface electronic inclinometer with accelerometer (Fig.3.3.1.a), which was used to measure spinal curvature, inter-segmental vertebral angles and ROM (Range of Motion) on the sagittal and the frontal plane. It consists of a hand-held computer-assisted electromechanical device that can be used upon spinal curvatures in various postures [Mannion et al. 2004, Post et al. 2004, Livanelioglu et. al., 2016].

Fig. 3.3.1.a: The Spinal Mouse®

This instrument uses accelerometers, which telemetrically record distance and changes of inclination with regard to the vertical line as it is rolled along the length of the spine. This skin-surface device is guided along the midline of the spine starting at the spinous process of C7 and finishing at the top of the anal crease (approximately S3) through its two rolling wheels. These landmarks are firstly determined by palpation and marked on the skin surface with a cosmetic pencil. Particularly, the C2 spinous process is identified by palpating in the midline just below the external occipital protuberance [Kachingwe AF and Phillips BJ, 2005]. Starting from C2, the examiner then counts the spinous processes caudally until C7 by using a cervical extension- flexion motion test. The L4-5 interspace is palpated against the uppermost iliac crest. The S1 vertebra is located by using the technique described by Hoppenfeld [1976] and the T12 spinous process is palpated by counting up from S1 (Fig. 3.3.1.b).

Fig. 3.3.1.b: The clinical identification of vertebral spinous processes by palpating.

Distance and angle measurements are transferred graphically and numerically via an analog-digital converter from the device to a base station positioned approximately 1–2 m away and interfaced to a personal computer. Data is sampled every 1.3 mm as the mouse is rolling along the spine, giving a sampling frequency of approximately 150 Hz. This information is then used to calculate the relative positions of the sacrum and vertebral bodies of the underlying bony spinal column using an intelligent recursive algorithm [Mannion et al., 2004, Post et al., 2004, Livanelioglu et. al., 2016, Piancino et al., 2019].

The Spinal Mouse recording has been validated in literature, showing significant repeatability and reliability [Guermazi et al., 2006; Mannion et al., 2004; Post et al., 2004; Ripani et al., 2008; Livanelioglu et. al., 2016].

3.3.2. SPINAL MOUSE PROCEDURES

All spinal motions and subsequent measurements were performed according to the manufacturer's specifications. The rater was a right-handed skilled operator with more than 8 years of experience in the use of the Spinal Mouse®, blinded to the purpose of the study.

The operator was instructed to perform the measurement at a slow speed to avoid data transmission errors to the base station. The testing procedure was performed in three different positions for both reference planes, in the order as follow:

Sagittal plane (Fig. 3.3.2.a):

1. Standing upright position: the subject assumed a relaxed position, with the head looking forward, the arms hanging by the side, the knees normally extended, and the feet shoulder-width apart;
2. Maximal flexion: the subject was asked to slowly flex the trunk as far as comfortably possible with legs straight, aiming to curl the head into the knees;
3. Maximal extension: the subject had legs straight, arms crossed over the front of the body and extended the trunk as far as comfortably possible, keeping the head in a neutral position.

Frontal plane (Fig. 3.3.2.b):

1. Standing upright position (the same posture of the first measurement in the sagittal plane): the subject assumed a relaxed position, with the head looking forward, the arms hanging by the side, the knees normally extended, and the feet shoulder-width apart;
2. Maximal left-lateral flexion: the subject was asked to slowly flex the trunk laterally on the left as far as comfortably possible, *without turning either shoulders or pelvis*;
3. Maximal right-lateral flexion: the subject was asked to slowly flex the trunk laterally on the right as far as comfortably possible, *without turning either shoulders or pelvis*;

Fig. 3.3.2.a: Spinal Mouse recording protocol in the sagittal plane. (1) upright position, (2) maximal flexion, (3) maximal extension.

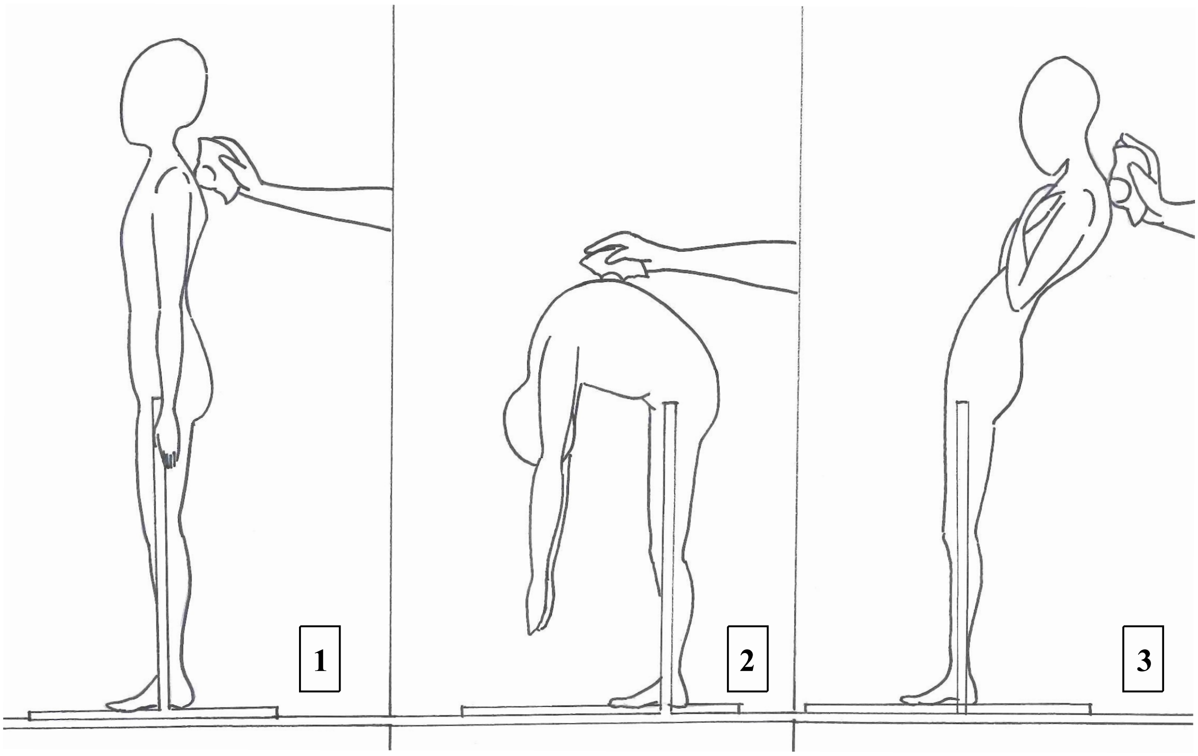
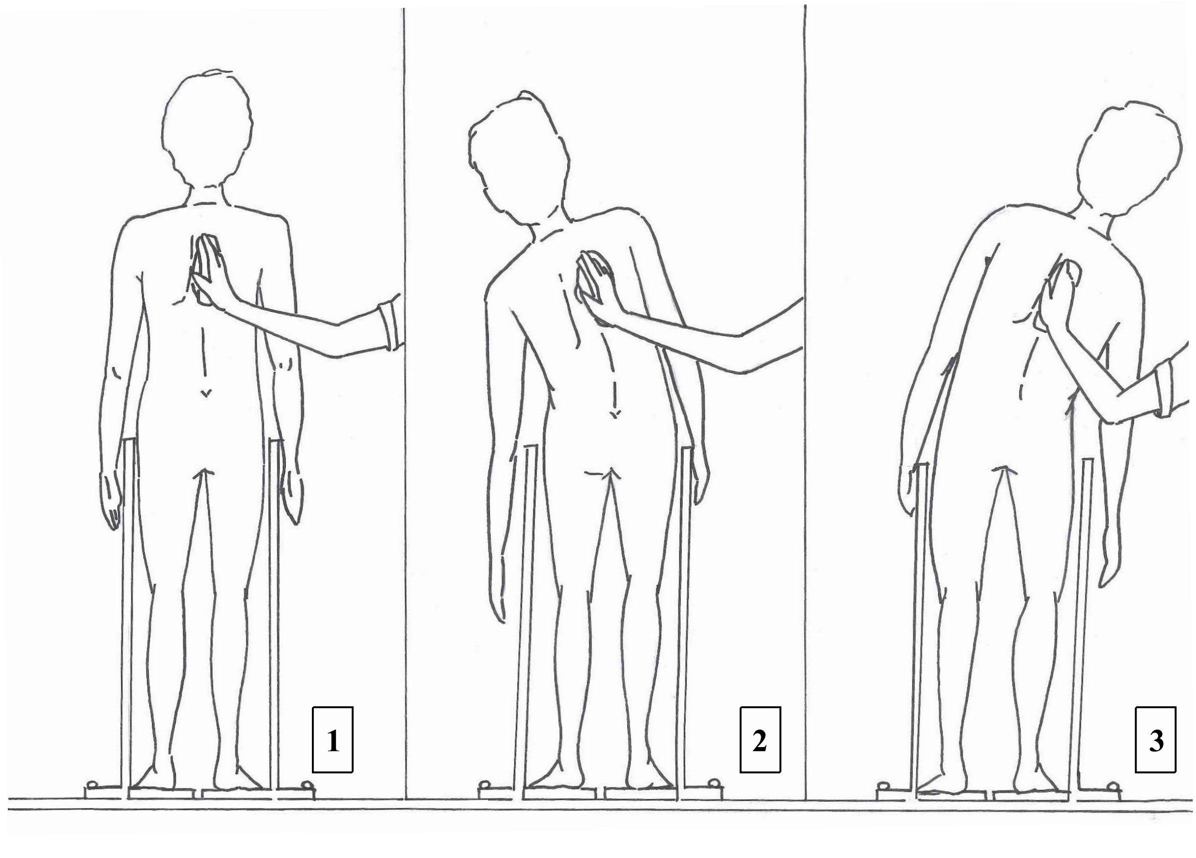


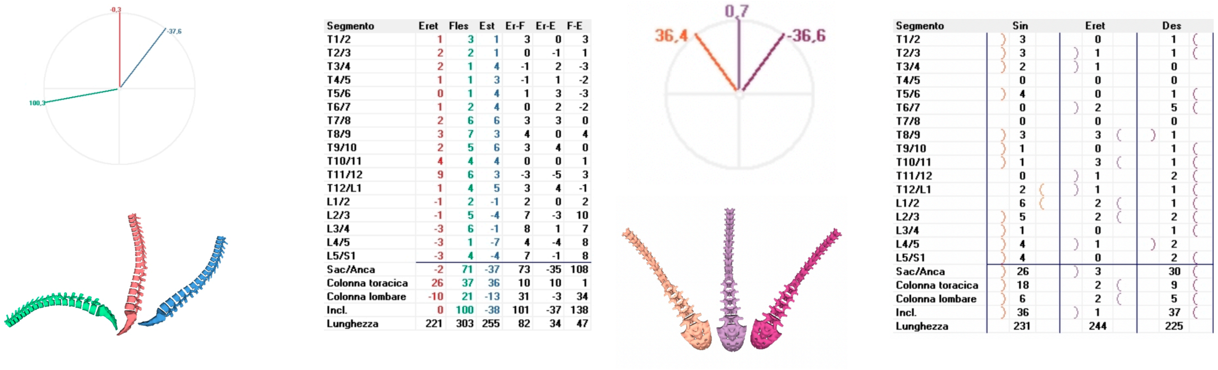
Fig. 3.3.2.b: Spinal Mouse recording protocol in the frontal plane. (1) upright position, (2) maximal left-lateral flexion, (3) maximal right-lateral flexion. *<u>*Hand-made ink drawings, kindly granted by Dr. Roberta Caserta.*</u>



This sequence of testing was the same for all measurements and participants. The positions were first described and demonstrated by the investigator and practiced once by the patient before the six measurements in each posture were taken. The patient was instructed to move at a speed of his/her choosing and to hold the end position for a few seconds while the measurement was made.

The following spinal parameters were evaluated: general inclination (degrees), upright position compared to optimal vertical (degrees), maximal flexion and extension (degrees) on the sagittal plane, left (conventionally expressed in positive degrees) and right (conventionally expressed in negative degrees) bending on the frontal plane.

Among children, the physiological range of spinal mobility in the sagittal plane spans from 90° to 105° of maximal forward flexion, and from 25° to 30° of maximal backward extension. On the frontal plane, instead, a higher symmetry is the normal physiological condition: the spinal lateral flexion, in fact, is commonly considered *asymmetrical* when the difference in inclination between right and left sides is ≥ 2 ° (Fig. 3.3.2.c).



Segmento	Eret	Fles	Est	Er-F	Er-E	F-E
T1/2	1	3	1	3	0	3
T2/3	2	2	1	0	-1	1
T3/4	2	1	4	-1	2	-3
T4/5	1	1	3	-1	1	-2
T5/6	0	1	4	1	3	-3
T6/7	1	2	4	0	2	-2
T7/8	2	6	6	3	3	0
T8/9	3	7	3	4	0	4
T9/10	2	5	6	3	4	0
T10/11	4	4	4	0	0	1
T11/12	9	6	3	-3	-5	3
T12/L1	1	4	5	3	4	-1
L1/2	-1	2	-1	2	0	2
L2/3	-1	5	-4	7	-3	10
L3/4	-3	6	-1	8	1	7
L4/5	-3	1	-7	4	-4	8
L5/S1	-3	4	-4	7	-1	8
Sac/Anca	-2	71	-37	73	-35	108
Colonna toracica	26	37	36	10	10	1
Colonna lombare	-10	21	-13	31	-3	34
Incl.	0	100	-38	101	-37	138
Lunghezza	221	303	255	82	34	47

Segmento		Sin			Eret			Des	
T1/2	)	3			0			1	(
T2/3	)	3		)	1			1	(
T3/4	)	2		)	1			0	
T4/5		0			0			0	
T5/6	)	4			0			1	(
T6/7		0		)	2			5	(
T7/8		0			0			0	
T8/9	)	3			3	(	)	1	
T9/10	)	1			0			1	(
T10/11	)	1			3	(		1	(
T11/12		0		)	1			2	(
T12/L1		2	(	)	1			1	(
L1/2		6	(		2	(		1	(
L2/3	)	5			2	(		2	(
L3/4	)	1			0			1	(
L4/5	)	4		)	1		)	2	
L5/S1	)	4			0			2	(
Sac/Anca	)	26		)	3			30	(
Colonna toracica	)	18			2	(		9	(
Colonna lombare	)	6			2	(		5	(
Incl.	)	36		)	1			37	(
Lunghezza		231			244			225	

Fig. 3.3.2.c: Examples of physiological range of spinal mobility in the sagittal and frontal planes.

3.3.3. A CUSTOM-MADE DEVICE FOR SPINAL MOUSE MEASUREMENTS

Using the Spinal Mouse®, reliable measurements are more difficult to achieve on the frontal than on the sagittal plane, because it is more complex to perform a clean movement of spinal lateral bending without turning the shoulders, trunk or pelvis, which would cause measurement biases. Such a movement, in fact, is a linear lateral inclination that follows a line tangent to the external malleolus of the foot, which must not exceed the boundaries of the imaginary cylinder delimitating the anterior and posterior part of the trunk, that is, not bend forward or backward or turn shoulders to amplify the width of the inclination. It is a movement demanding motor and proprioceptive control, uneasy to immediately execute especially by children.

For this reason, we have built and tested a reproducible custom-made device in order to guide spinal movements, to standardize feet position and improve the repeatability of measurements. It was composed of a big wooden platform, a rail, two smaller wooden footboards and two aluminum guiding rods (Fig. 3.3.3.a).

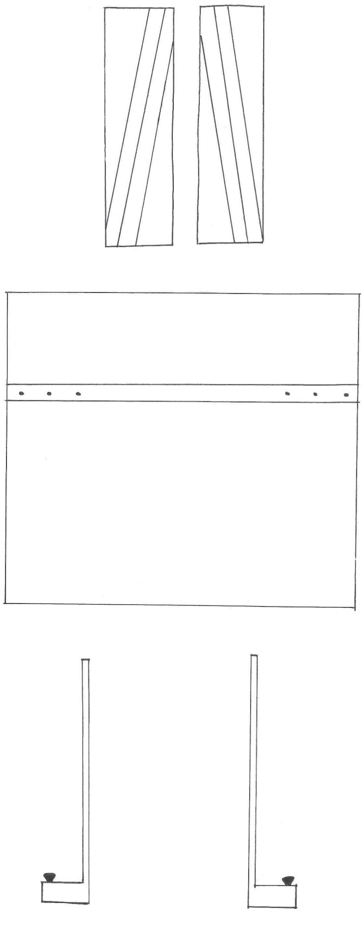


Fig. 3.3.3.a: Single components of the custom-made device for Spinal Mouse measurements. **Hand-made ink drawings, kindly granted by Dr. Roberta Caserta.*

In detail, the platform (Fig. 3.3.3.b-c) was made of a 96 (long side) x 53 (short side) cm wooden base. At 35 cm from the long side of the base, a rail (A) was inserted, running across the entire length of the platform. It allowed for the insertion of two 85 cm long sliding aluminum vertical rods for guiding movements (B) and two 15x40 cm wooden reference footboards for positioning the feet (C). In agreement with Antoniolli and Jones et al. [Antoniolli et al., 2018; Jones et al., 1970;

Mehdikhani et al., 2014], four reference diagonal lines (D) were drawn on feetboards, with an angle of 30°.

Fig. 3.3.3.b: The assembled custom-made device. *<u>*Hand-made ink drawings, kindly granted by Dr. Roberta Caserta.*</u>

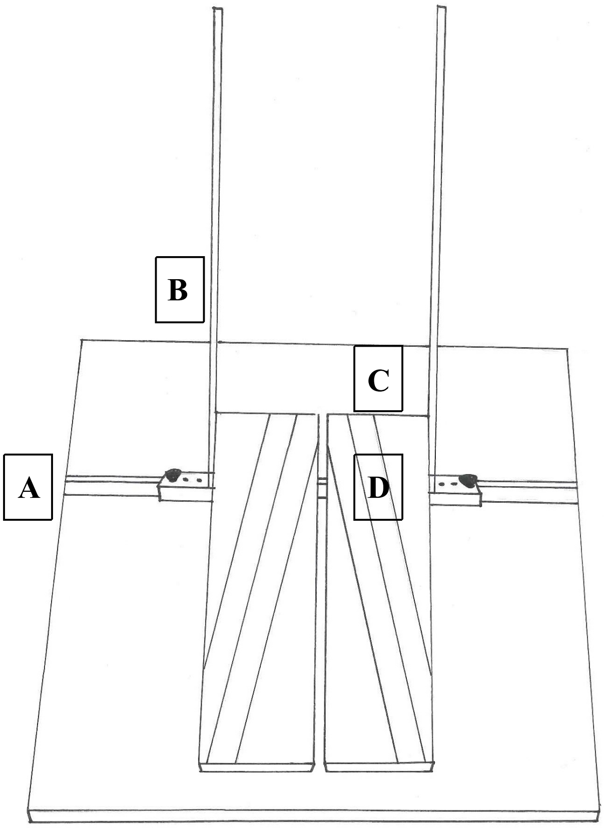
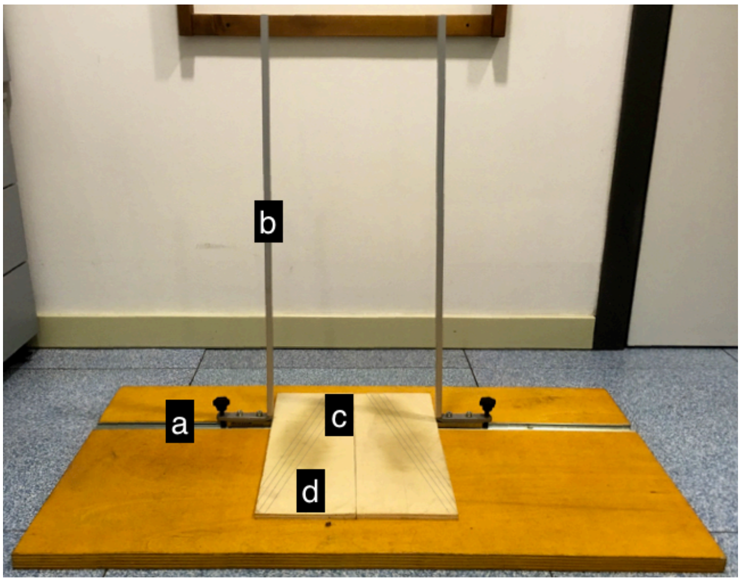


Fig. 3.3.3.c: The assembled custom-made device - clinical view.



The subjects were positioned on the wooden reference footboards, with the 2nd toe and the middle part of the heel placed on the diagonal line, and feet abducted approximately 30° forward between the midline. In this way, the feet were oriented at a 30° anteriorly opened angle (Fig. 3.3.3.d). Thanks to this, the plantar position, and therefore the podalic support, was the same for all patients, making it a reproducible reference within the tested sample [Antoniolli et al., 2018; Jones et al., 1970; Mehdikhani et al., 2014].

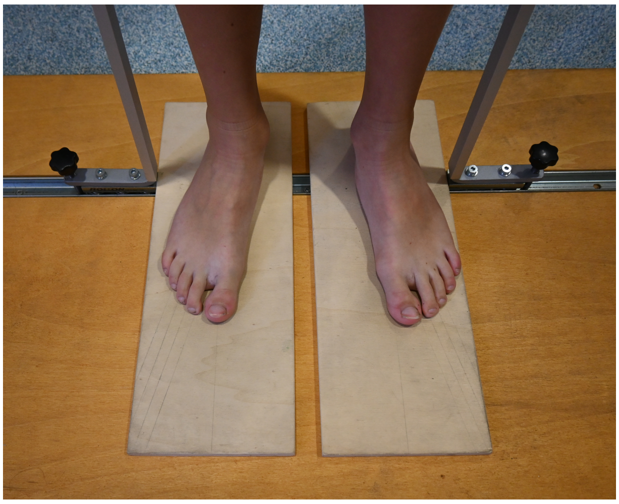


Fig. 3.3.3.d: Protocol plantar position with opened angle of 30° forward thanks to the diagonal lines on the footboards.

To standardize the width of the lower limbs and to obtain postural control, the aluminum rods were positioned in contact with the trochanteric region of the subjects and fixed by tightening their lateral screws. Followingly, the subjects were asked to open their feet on the footboards and their lower limbs until they reached the contact with the rods. This body position was maintained for all tests (Fig. 3.3.3.e).

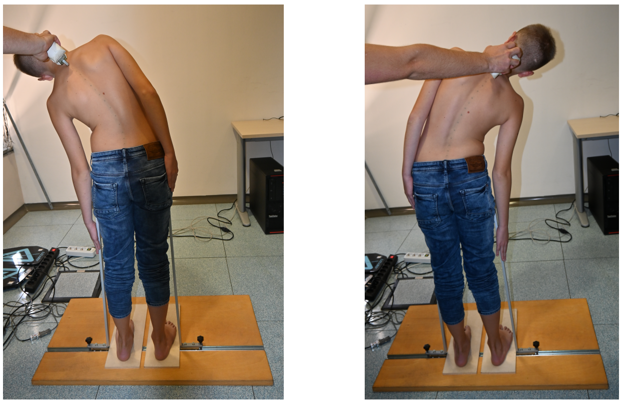


Fig. 3.3.3.e: Custom-made device's guide for lateral flexion.

This custom-made device proved very useful to guide children's movements because, differently than adults, they still lack a mature postural control and a capacity to maintain concentration during spinal test movements. It is surely a good and simple device to improve repeatability and reliability of measurements and we used it for all the recordings.

3.3.4. THE STABILOMETRIC PLATFORM

Posturographic recordings and postural stability assessments were obtained by means of a Lizard Stabilometric Platform (Lizard, Lemax s.r.l., Como, Italy). It is a 10-Hz sampling frequency vertical force platform that measures the weight distribution on the feet-supporting points, the related variations/oscillations during the time of observation (posturometric measurements) and the center of body pressure sway (stabilometric measurements). In typical quiet standing, the center of body mass (CBM) is held forward from the ankles, in such a way that the weight exerts a forward-leaning torque about the ankles [Ferrario et al, 1996, Gangloff et al., 2000, Sakaguchi et al., 2007]. Such a torque is compensated by a backward ground reaction force, which requires the tonic contraction of calf muscles. The operating principle of the stabilometric platform lies precisely in the calculation, measurement and reproduction of the Center of Pressure (COP) displacements and projections (Fig. 3.3.4.a), along with all its variations caused by postural oscillations, which are graphically represented by the *statokinesigram* [Gangloff et al., 2000, Bressan et al., 2019].

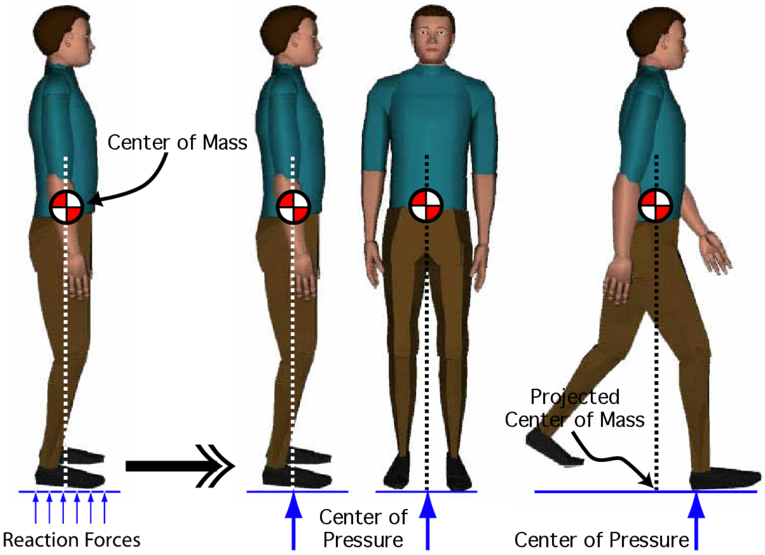


Fig. 3.3.4.a: Reproduction of COP and COM.

Specifically, the statokinesigram is a statistic measurement of the dispersion of COP and therefore a precise evaluation of how the postural system stabilizes the subject in relation to his environment (Fig. 3.3.4.b).

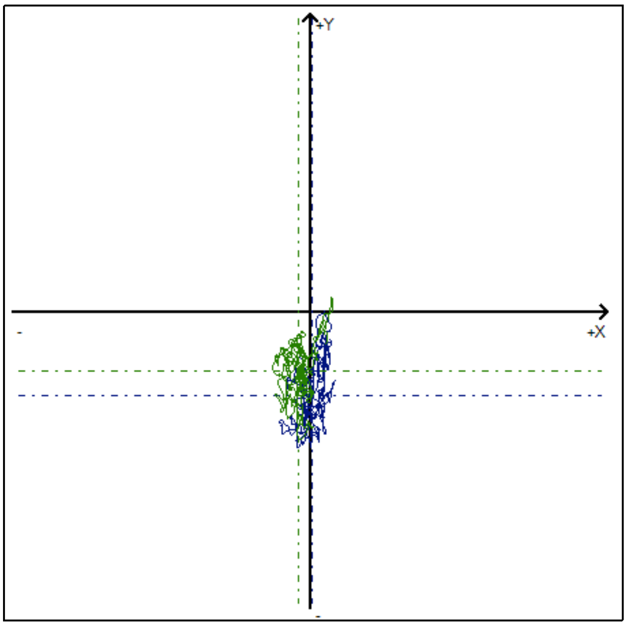


Fig. 3.3.4.b: Example of a statokinesigram.

The stabilometric platform is characterized by highly sensitive load cells with an internal circuit that changes electrical resistance upon the application of a force. It consists of two supporting plates, one for the left and one for the right foot, on which reference lines for feet positioning are drawn. Each plate rests on three load cells placed at the level of the three feet-supporting points: first metatarsus, fifth metatarsus, and heel (*tripod system*) (Fig. 3.3.4.c).

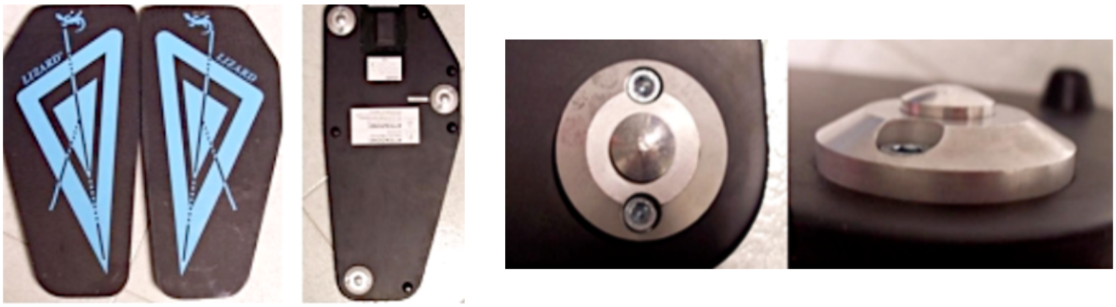


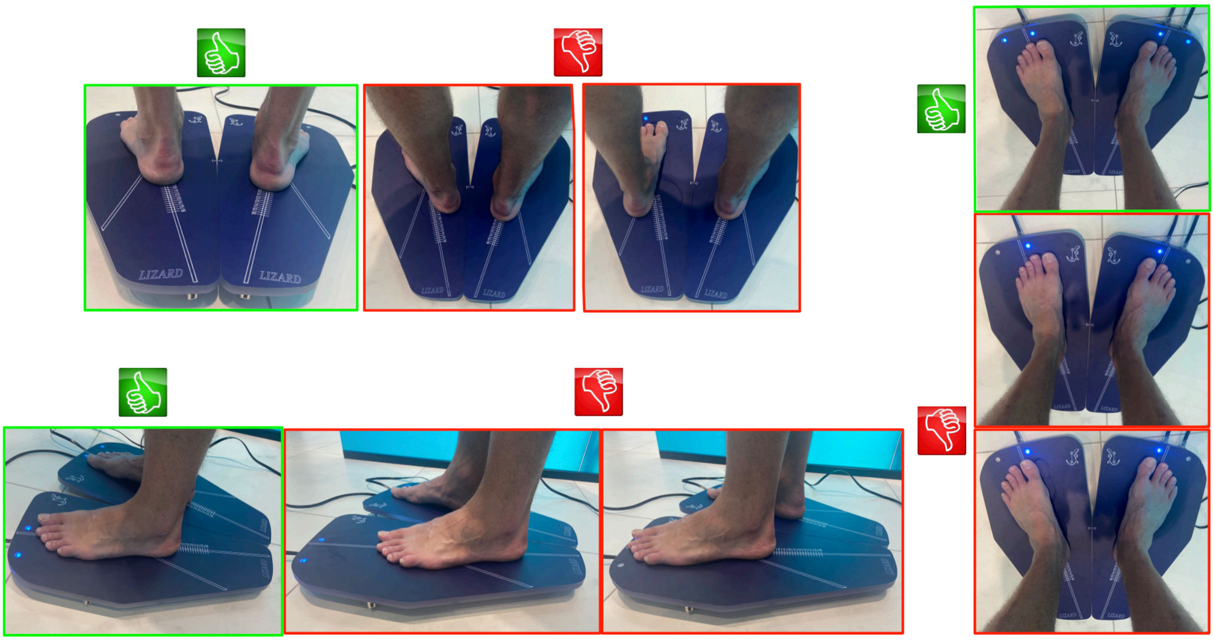
Fig. 3.3.4.c: Three load cells for the tripod system of the Stabilometric Platform.

The system is able to measure the load applied to each cell from the variation of the output current. This output signal, after being amplified, is processed by the specific computer software connected to the platform, showing the results as dynamic processing pictures (weight distribution, variations on feet points and body sway) and numerical data. The sampling of the signal is carried out with a maximum frequency of 10 Hz (i.e. 10 times per second).

3.3.5. STABILOMETRIC PLATFORM PROCEDURES

The subjects were asked to take several steps before getting on the platform in order to achieve neuromuscular and emotive relaxation. Then, they took off their shoes and socks and then stepped upon the platforms, which are side by side with a pre-established diverging 30° angle (the equivalent feet position in the custom-made device for the Spinal Mouse recordings). The examiner accurately placed the subject on the platform, whose positioning was standardized – a fundamental procedure to obtain reliable measurements. A reference map (triangles and lines) was drawn on the surface of both platforms. The root of the second toe (head of the second metatarsal) and the midline of the heel of each foot was aligned with the vertical line of the map, while the perpendicular projection on the ground of the external malleolus fell on the oblique external line (Fig. 3.3.5.a).

Fig. 3.3.5.a: Correct (green) and incorrect (red) feet positioning on the Stabilometric Platform.



The loads, *in ideal situations*, have perfectly identical values for both limbs (Fig. 3.3.5.b), because in the right position of the foot on the platform map, the distances of the anatomical landmarks from the detection cells of the platform are proportional to the real percentages of the loads, which are: 1/6 for the external point, 2/6 for the anterior point and 3/6 for the heel (distribution of loads according to Kapandji) (Fig. 3.3.5.c) [Kapandji AI, 2020].

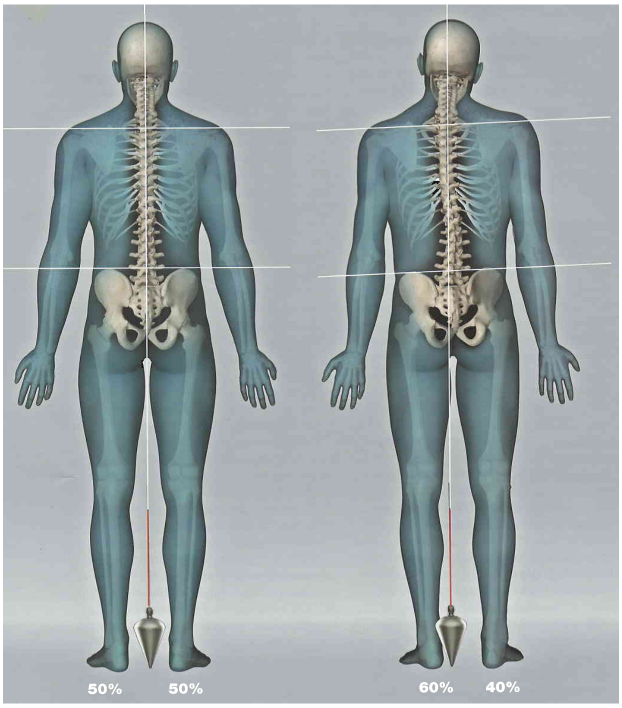


Fig. 3.3.5.b: Symmetrical (ideal) and asymmetrical weight distribution.

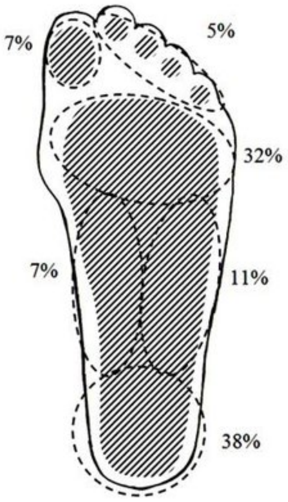


Fig. 3.3.5.c: Physiological weight distribution on the plantar area

The foot, whatever its size, is positioned in a way that the calcaneus is three times as distant from its load cell, in comparison to the root of the second toe, which is two times as distant, and the fifth metatarsal, which is only one time as distant. The reading of the data loads from the program at 33% is therefore already conditioned by these distances and by the length of the foot: for this reason, the reliability of the data strictly depends on the correct positioning of the feet on the recording platforms.

The subjects were asked to keep the correct position during the whole examination, looking straight at a fixed point placed in front of them at a distance of 2 m, and to remain standing, relaxed, as stable as possible, with their arms hanging free next to their trunk. During the test they were not allowed to look at the computer monitor and they did not receive any feedback about their postural position.

Two different conditions were used during this static posturography, in this temporal order:

- eyes open with mandibular rest position (RP);
- eyes open with dental maximal intercuspation (MI);

The RP is defined as the habitual postural position of the mandible when at rest, with the condyles in a neutral, unstrained position in the glenoid fossa; the MI (without clenching) is defined as the most closed, static position which the mandible can assume through the full interdigitation of the opposing teeth irrespective of condyle centricity [International Academy of Gnatology, 1985].

Each recording lasted 51.2 seconds (in accordance with the guidelines of the French Posturology Association) [Baldini A, 2010]. The two tests were recorded consecutively, without moving the subject on the footboard.

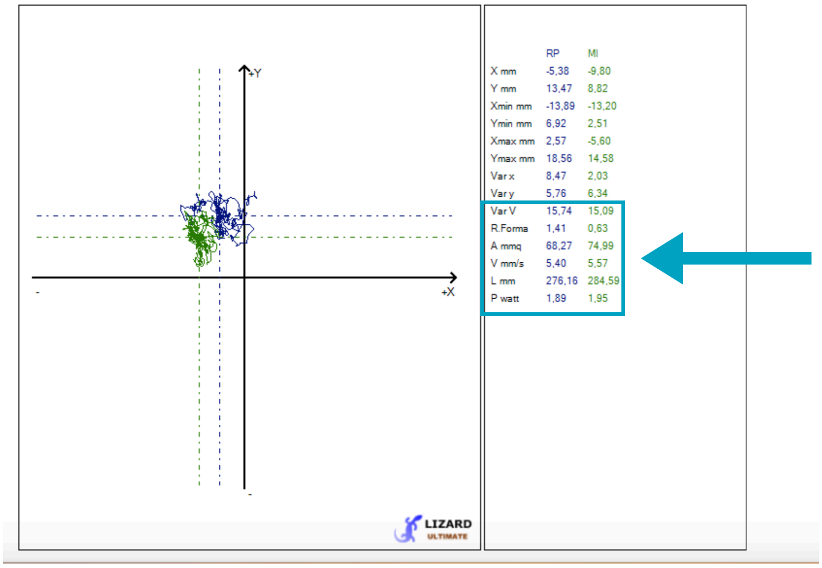
3.3.6. THE STABILOMETRIC PARAMETERS

The following ten stabilometric and posturometric parameters were assessed for both dental conditions (RP and MI):

1. variance of sway velocity (scalar number)
2. sway shape ratio (scalar number)
3. sway area (mm^2)
4. sway velocity (mm/s)
5. sway length (mm)
6. energy consumption (watt)
7. monopodal support (positive/present or negative/absent)
8. higher percentage of weight load distribution (%)

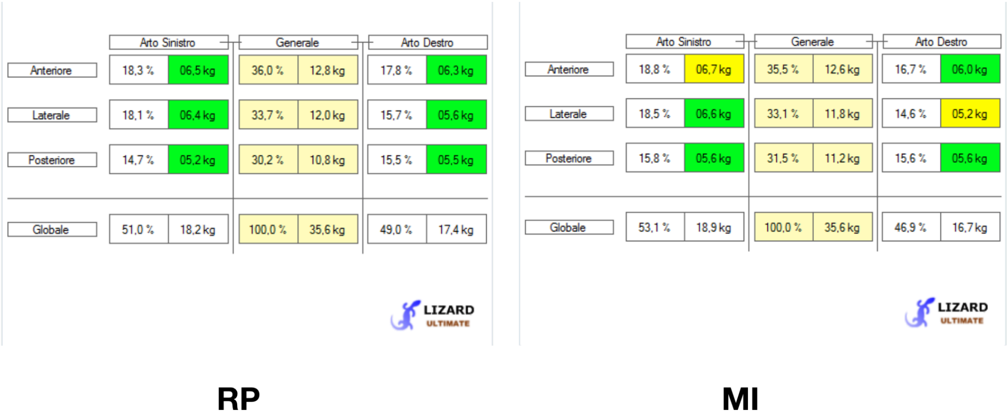
9. type of theoretical angle of support (direction: clockwise or counterclockwise)
10. quantitative theoretical angle of support (degrees)

The first six parameters were extracted from a software window called ‘General Center of Gravity’, which corresponds to the statokinesigram (Fig. 3.3.6.a). Parameters 7 and 8 were reported in the ‘Load Overview’ window (Fig. 3.3.6.b), whereas the ‘Theoretical Angle of Support’ was dedicated a specific window (Fig. 3.3.6.c).



	RP	MI
X mm	-5,38	-9,80
Y mm	13,47	8,82
Xmin mm	-13,89	-13,20
Ymin mm	6,92	2,51
Xmax mm	2,57	-5,60
Ymax mm	18,56	14,58
Var x	8,47	2,03
Var y	5,76	6,34
Var V	15,74	15,09
R.Forma	1,41	0,63
A mmq	68,27	74,99
V mm/s	5,40	5,57
L mm	276,16	284,59
P watt	1,89	1,95

Fig. 3.3.6.a: Software window of ‘General Center of Gravity’



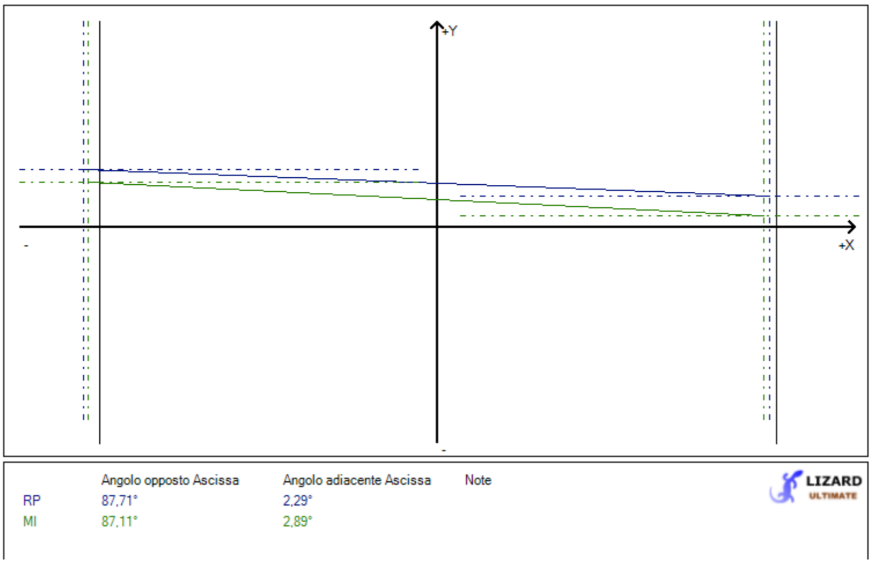
RP

	Arto Sinistro		Generale		Arto Destro	
Anteriore	18,3 %	06,5 kg	36,0 %	12,8 kg	17,8 %	06,3 kg
Laterale	18,1 %	06,4 kg	33,7 %	12,0 kg	15,7 %	05,6 kg
Posteriore	14,7 %	05,2 kg	30,2 %	10,8 kg	15,5 %	05,5 kg
Globale	51,0 %	18,2 kg	100,0 %	35,6 kg	49,0 %	17,4 kg

MI

	Arto Sinistro		Generale		Arto Destro	
Anteriore	18,8 %	06,7 kg	35,5 %	12,6 kg	16,7 %	06,0 kg
Laterale	18,5 %	06,6 kg	33,1 %	11,8 kg	14,6 %	05,2 kg
Posteriore	15,8 %	05,6 kg	31,5 %	11,2 kg	15,6 %	05,6 kg
Globale	53,1 %	18,9 kg	100,0 %	35,6 kg	46,9 %	16,7 kg

Fig. 3.3.6.b: Software window of ‘Load Overview’



	Angolo opposto Ascissa	Angolo adiacente Ascissa	Note
RP	87,71°	2,29°	
MI	87,11°	2,89°	

Fig. 3.3.6.c: Software window of 'Theoretical Angle of Support'

In the following section, each of the postural parameters we took into consideration is further explained:

1. Variance of sway velocity (Var V): it is the ratio between the speed of the movement of the center of pressure during the recordings and the number of measurements. The value – normally ranging from 5 to 30 – is lower when the speed is constant, while it is higher when COP oscillations are characterized by acceleration and deceleration. It is an indicator of the well-being of the system, because it signals the existence or lack of balance in the receptors of the postural system. A patient with a balanced body moves slowly with a low variance, while one who twitches (as the result of continuous acceleration and deceleration) records a high variance (e.g., in the case of spasms and tremors). This is all linked to the presence or lack of harmony among the various control systems. If there is harmony, the subject sways slowly and continuously, whereas if harmony is not present, the subject performs wide oscillations between the positions guided by the various receptors, which are in conflict with one another.

2. Sway shape ratio: it is the ratio between the values and lengths of lateral oscillations (on the X axis) and antero-posterior oscillations (on the Y axis). It expresses the shape of the statokinesigram in a numerical form. The normal value is around 0.45-0.5, which represents an almost rounded statokinesigram (even though it is always longer on the Y axis); a value <0.5 indicates a greater number of sways along the Y axis, hence a long and narrow graph; conversely, a value >0.5 reflects the presence of larger latero-lateral sways on the X axis, thus resulting in a wide and short statokinesigram. The evaluation of such shapes is crucial when a constraint is presence, for instance when teeth are in contact or in cases of dystonia and dyskinesia.

3. Sway area (mm^2): it is the area plotted by the statokinesigram, calculated on 90% of recorded oscillations, hence eliminating the most outlying 10%. It is an essential stabilometric parameter that expresses the effectiveness of the postural system in maintaining the center of pressure close to the average balance position. The smaller the area, the greater the tone of the postural system and its subsequent ability to keep balance. The normal value is around 100 mm^2, although a large influence is exerted by the height of the individual: in children less than 150 cm tall the value can be as low as 60 to 80 mm^2. In physiological conditions, in addition, the presence of any system of constraint, such as dental occlusion in maximal intercuspation, reduces the width of sways. When postural and occlusal conditions are physiological, then, the sway area of subjects in maximal intercuspation is smaller than in resting position with free arches.

4. Sway velocity (mm/s): it expresses the intensity of COP oscillations. The higher the velocity, the greater the effort to maintain orthostatic posture, which requires continuous postural adjustments. The lower the velocity, the more rigid the patient is (hypercontrol). Even though a true normality criterion for sway velocity does not exist, generally-accepted values range from 4 to 10 mm/s.

5. Sway lenght (mm): the statokinesigram is reconstructed by tracing a line that joins all the points recorded moment by moment during the acquisition time of COP movements. Therefore, the length parameter is not linear, but made up of many small segments with different length and direction. The sway length is the sum of all these segments and is measured in mm.

6. Energy consumption (watt): it is the power of the system, i.e. the energy per second used by the postural system to maintain a balanced standing position. It indicates the workload of the system per every meter of sway per every second. The higher the watt, the less efficient the system is, because it uses a larger amount of energy to keep a balance position.

7. Monopodal support and higher percentage of weight load distribution (%): prevalence and percentage of body weight distribution on the plantar surface while keeping an erect position. Other than by sides (right or left), the platform divides the pressure gradient and plantar support by foot zones: external, anterior, heel. The normal condition is characterized by a balanced load distribution with a maximum of 2% body weight difference between the right and left sides of the body. Within the range of 0-2% weight distribution difference, there is no monopodal support.

8. Theoretical angle of support (direction and degrees): it provides, in numerical and graphical form, the rotation angle of the trunk on the frontal plane (transversal), calculated with respect to the X axis (angle adjacent to the X axis) and the Y axis (angle opposite to the X axis). Even though the ideal condition is an angle of 0° with a line parallel to the X axis, a value range between -2° (negative values correspond to a counterclockwise direction of trunk rotation) and 2° (positive values correspond to clockwise direction of trunk rotation) is generally accepted for the theoretical angle of support.

3.3.7. THE NORMAL STABILOMETRIC VALUES IN PHYSIOLOGICAL CONDITIONS

Stabilometric parameters are highly variable and deeply influenced by individual characteristics, such as, among others, age, weight, breathing, visual acuity, ligamentous laxity, muscular elasticity and athletic-sports training. However, what is applicable to every single subject is the concept of *postural constraint*. In physiological conditions, every constraint factor/system enhances postural stability, providing the tonic-postural system with more balance, harmony and tone. The condition of maximum intercuspation is an example of such a constraint system. As a consequence, *in physiological conditions*, for a healthy subject in maximum intercuspation, recorded values of velocity variance, area, length and used energy should be lower than the same parameters recorded in rest position. Moreover, a subject in maximum intercuspation should show a more rounded statokinesigram shape (i.e., closer to 0.5), absence of monopodal support, a close-to-equal distribution of loads between right and left body sides (no more than 2% of weight difference), and a theoretical angle of support of trunk rotation next to 0°.

3.4. MASTICATORY PATTERNS AND CHEWING CYCLES

Kinematic data were recorded concurrently to analyze patients' masticatory patterns.

The instrument used for recording chewing cycles is a Kinesiograph (K7, Myotronics Inc. Tukwila, Washington, USA) which measures mandibular movements within an accuracy of 0.1 mm. Multiple sensors (Hall effect) in a light-weight array (113 g) tracked the motion of a magnet attached to the midpoint of the lower incisors [Jankelson B, 1980]. The *masticatory pattern* is made up of an average of single chewing cycles and displays a personal characteristic morphology for each patient. It is never the same; rather it is in constant flux according to a precise motor program memorized in the central nervous system. Absence of a pattern (i.e., the total irregularity of chewing cycles) indicates a serious malfunction in the masticatory system [Piancino and Kyrkanides, 2016]

3.4.1. SIGNAL ANALYSES

The kinematic signals were analyzed using custom-made software (University of Turin, Italy) that allows for automatic data segmentation and analysis. This approach has been described elsewhere [Piancino et al, 2006, Piancino et al, 2016, Piancino et al, 2019]. The first cycle, during which the bolus was transferred from the tongue to the dental arches, was excluded from the analysis. Jaw movements between two consecutive masticatory pauses were also excluded if they did not represent a chewing cycle based on the presence of at least one of the following characteristics: minimum opening smaller than 4 mm; duration shorter than 300 ms; or vertical opening smaller than 3 mm.

From each cycle, the following variables were extracted: cycle duration; opening duration; closing duration; maximum closing velocity; maximum opening velocity and closure angle. The values computed for each variable were averaged over all cycles recorded for the same side of mastication and the same bolus.

The chewing cycles were divided into non-reverse and reverse, based on the vectorial direction of closure. The closure angle was measured between a straight line obtained by a robust regression procedure on the last part of the curve (from 2.0 to 0.1 mm from the closing point in vertical direction) and the horizontal line of the side of mastication. Next, cycles with a closure angle larger than 90° were grouped in the reverse set.

A *reverse-sequence chewing cycle* is one in which the closing vector in the final stage of the closure pattern has a reverse sequence to the norm. In other words, cycles characterized by clock-wise closure in normal physiological conditions demonstrate anti-clockwise closure, and vice versa when they are reversed (Fig. 3.4.1.a).

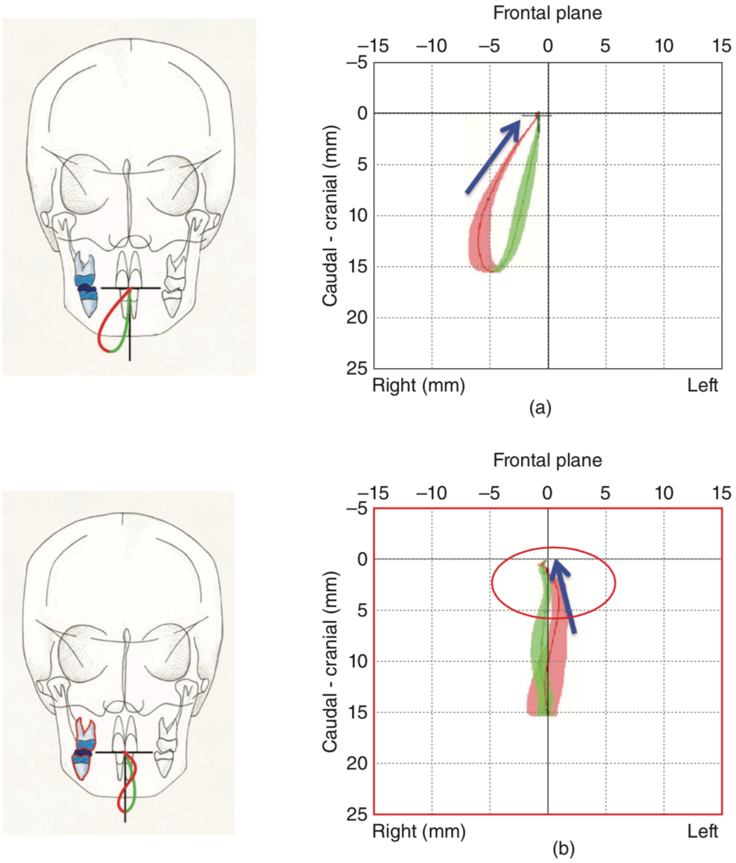


Fig. 3.4.1.a: Physiological (a) versus reverse (b) chewing pattern during chewing on the right side.

A single, or few, reverse-sequence cycles are not pathognomonic and have no clinical significance. What is important is the percentage number of reverse cycles compared with the overall total number of cycles completed. Despite the high degree of individuality of each subjects' masticatory pattern, especially among children, scientific evidence led us to establish a range of non-physiological chewing cycles: the presence of more than 15% reverse chewing cycles on the crossbite side is considered pathological, while more than 35% is deemed a pathognomic sign of crossbite dental malocclusion.

On such premises, this study used the following data were to analyze the masticatory function: different percentage of reverse chewing cycles between the crossbite side and the non-crossbite side in the study group; different percentage of reverse chewing cycles between soft and hard bolus in both groups. Furthermore, the average number of chewing cycles was analyzed in both groups.

3.4.2. MASTICATORY ANALYSIS PROCEDURES

The protocol for recording chewing cycles, like the choice of bolus, was refined after long and careful experimentation and remains the same still today [Lewin A, 1985, Piancino MG 2019]. First, the position of the patient during the test is vital in achieving reliable and repeatable results. Thus, it must be standardized: seated upright, legs at 90° and eyes fixed on a point 1m away. This position is designed to reduce indirect movement to a minimum, in order to record mandibular movement connected to bolus chewing as precisely as possible. In fact, the neck muscles and masticatory muscles mutually coordinate, and holding the head steady allows indirect movement of the mandible to be prevented [Eriksson et al, 1998].

So, the children were comfortably seated on a chair with their back supported. They were asked to fix their eyes on a target (a Donald Duck drawing) on the wall 90 cm directly in front of their siting position, and to avoid movements of the head. The measures were performed in a silent and comfortable environment. Each recording began with the largest number of teeth in contact. The children were asked to find this starting position by lightly tapping their opposing teeth together and clenching. They were asked to hold this position with a test bolus on the tongue. A number of conditions were then performed which consisted of chewing a soft bolus (chewing gum) and then a hard bolus (wine gum) deliberately on the right and left sides. Each condition lasted for 10 s computer controlled and the children were instructed to chew at a natural pace. Each condition was repeated three times consecutively (total of 3 repetitions for 4 conditions). The same skilled operator indicated the side of mastication before each acquisition throughout the session and controlled for its proper execution (visual inspection).

The soft bolus was a piece of chewing gum and the hard bolus was a wine gum, both of which were the same size (20mm in length, 1.2 mm in height, and 0.5 mm in width) but of different weights (2g for the soft bolus and 3g for the hard bolus) and different puncture forces (0.36 N for the soft bolus and 1.85 N for the hard bolus). The wine gum was chosen to provide a rubber-like resistance without sticking to the teeth [Piancino et al., 2016]

3.5. FUNCTIONAL ORTHODONTIC THERAPY WITH FGB

Each crossbite patient of the case group was treated with the orthodontic functional appliance ‘Function Generating Bite’. The characteristics and mechanism of action of the equipment are explained below.

At the end of treatment, the malocclusion was corrected and the buccal cusps of the upper teeth, which were previously in crossbite, overlapped the lower teeth on the buccal side, thus providing the appropriate physiological stimuli from peripheral receptors and proprioceptors (Piancino et al., 2006). The mean treatment time was 8.2 ± 2.7 months plus the retention time of 5 months.

3.5.1. FGB APPLIANCE

The FGB appliance is individually manufactured and is composed of resilient stainless-steel bite plates, expansion springs, acrylic resin buccal shields and palatal button (Fig. 3.5.1.a).

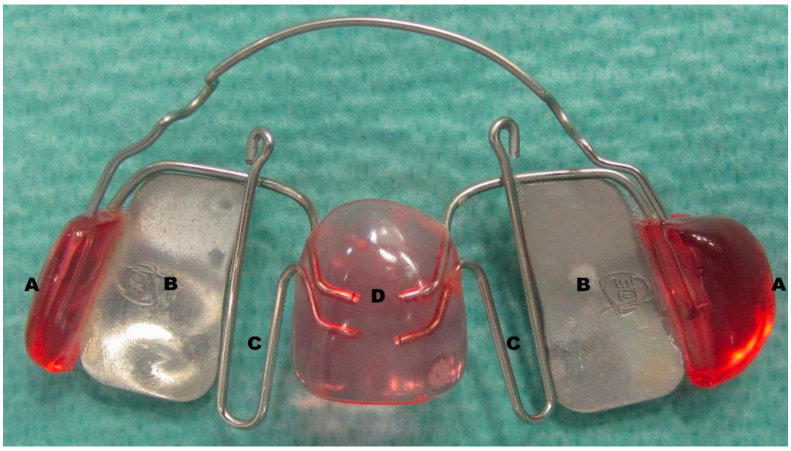


Fig. 3.4.1.a: Components of the FGB appliance. A: Buccal shields, B: resilient stainless steel bite plates; C: Expansion springs; D: Palatal button.

The FGB is characterized by a muscular anchorage and produces self-regulating, rhythmic and intermittent forces. All its components work together simultaneously during swallowing and phonation, both of which activate the appliance.

The FGB is different from other orthodontic appliances in two main aspects:

- the self-regulation of both the mandibular position in space and orthodontic forces;
- the simultaneous performance of actions on the three planes of space (sagittal, vertical, transversal) and in different sectors (skeletal, dental and muscular);

These features make the FGB appliance unique in its field, not only from an orthodontic point of view, but also from a gnathological perspective. It differs greatly from traditional orthodontic mechanics, whose actions are sector-based and never unitary, pre-established and never self-regulating, and overlook considering function, functional compensation or neuromuscular equilibrium.

The main actions and effects of the FGB appliance are:

- disengagement and self-repositioning of the mandible;
- leveling and alignment of the occlusal plane, avoiding trauma and protecting dental cusps;
- muscle anchorage;
- possibility of symmetric and asymmetric activation (fundamental in asymmetrical malocclusion like unilateral crossbites);
- dental repositioning with self-regulating, intermittent forces;
- re-education of the tongue;
- progressive reprogramming of neural motor control via self-regulation (with the possibility of restoring the reverse chewing pattern).

In fact, the FGB appliance has dental-alveolar-basal action and effects, allowing for the improvement of the symmetry of both function and growth [Piancino and Kyrkanides, 2016].

Ultimately, other peculiar features of FGB appliances are as follows: they are non–cariogenic; there is no need to change the appliance in case of permanent teeth eruption, given the possibility of adaptation in case of ectopic eruption of a permanent tooth; they constantly adapt to growing structures, and stimulate growth and balancing; they do not restrict jaw movement; they require minimum time in the dental chair for activation.

3.5.2. FGB MECHANISM AND ACTIVATION

The triangular shape of buccal shields allows masseter action to be intercepted and the FGB to be pushed forward, creating a wedge-like action, which contributes to the activation of the expansion springs. The force, which activates the FGB's expansion springs, depends directly on the action of the muscles on the buccal shields (muscular anchorage): the contraction of the masseter on one side, intercepting the buccal shield, transmits the force to the contralateral expansion spring. This force may be regulated by the thickness of the buccal shields – the thicker they are, the greater their ability to intercept the force of masseter muscle transmitting it to the contralateral spring on the horizontal plane. Via the bites, the occlusal force also pushes the device upwards and pushes the expansion springs to equatorial tooth level, producing a bilateral expansive force, which is again horizontal. These forces are produced simultaneously and work together to achieve an orthodontic force capable of moving teeth in a buccal direction. Thus, the horizontal force of the expansion spring through buccal shields and the simultaneous vertical force produced by the occlusal bite create a dual force on teeth that leads to the bodily repositioning of teeth. The significance of this mechanism is not only orthodontic but also linked to the consequential stimulation of growth and remodeling of the dental-alveolar bone during the phases of growth and development.

Moreover, the FGB appliance allows for a *symmetric* or *asymmetric activation* thanks to its muscular (non-dental) anchorage and so is adaptable to the asymmetry of the malocclusion (like UPC) and to the therapeutic stage in progress. Muscle anchorage allows the teeth to receive an asymmetric force, avoiding side-effects on other teeth. This allows for an authentic correction of both dental and skeletal asymmetry – which is always present in unilateral crossbite – without side effects, as well as for the achievement of forces coherent with treatment objectives. At any moment, by simply adapting the thickness of the buccal shields, it is possible to render the action and force of the appliance symmetrical. The buccal shield must always be distinctly detached from the alveolar bone in order to create a decompression space where the muscle is no longer in contact with the bone. In this way, it promotes the new formation and apposition of bone growth, which is important for rebalancing and stability. The efficacy of the treatment has been addressed elsewhere [Piancino et al., 2016, Piancino et al., 2019].

3.5.3. THE PHYSIOLOGICAL MAXILLARY EXPANSION AND CROSSBITE CORRECTION WITH FGB

The FGB action mechanism applies muscular, intermittent, physiological and self-regulating forces. It contributes to the tensile forces on the palatal suture, which have been proven to be the physiological forces for stimulation of bone apposition, respecting the viscoelastic properties of the suture.

The bodily movement allows for a repositioning of the tooth and its root within the alveolar bone, stimulating growth and remodeling the support bone. As well as stimulating and remodeling the local alveolar bone, the action of the expansion springs is carried out in the palate via dental roots. For this reason, the intercanine and intermolar diametric increase of the upper arch is the consequence not only of the dental movement but also of alveolar and palatal growth. To achieve asymmetric activation (i.e. more intense on the crossbite side that needs correction, as opposed to the healthy side), we can make one side of the buccal shields thicker (i.e. the side contralateral to that of the crossbite). At any moment, by simply adapting the thickness of the buccal shields, it is possible to render the action and force of the appliance symmetrical, adapting it in an appropriate manner to the therapy as it evolves. To maintain the correct arch diameters (supported by the growth of dentoalveolar bone and palate) it is important to give the right level of stimulation to growth at the right time. *Initial correction* can and must be achieved in the briefest time possible. However, it would be a mistake to consider the correction of a serious growth-altered condition, such as unilateral posterior crossbite, in a short period without follow-up maintenance. After crossbite correction, the device should be worn at home and during the night (or during the night only) to allow the child to continue the restoration of correct masticatory function and balanced growth over time. Therefore, the most important action of the FGB, via the teeth, is the restoration of harmony to bone growth and the rebalancing of masticatory function. The goal of orthodontic treatment with an FGB appliance, especially during childhood, is not simple dental repositioning but a true restoral of physiological function to the stomatognathic system, masticatory function and growth [Piancino and Kyrkanides, 2016].

3.6. STARTING HYPOTHESES

The significance of this study lies in its analysis and integration of all data deriving from these three diagnostic instrumental tests on growing patients with unilateral posterior crossbite, before and after functional orthodontic therapy with FGB, *versus* patients with normal occlusion.

The starting hypothesis is whether the growing patient with unilateral posterior crossbite is generally affected not only by a functional asymmetrical mastication with alteration of chewing patterns, as already widely demonstrated, but also by a reduced balance of the tonic-postural system with a significant asymmetrical posture. The other hypotheses concern: whether the growing patient with UPC is characterized by common and repetitive postural features; whether there is a postural pathognomonic sign of UPC; whether postural balance and its compensations are able to affect the masticatory pattern; and, finally, whether the correction of dental malocclusion with FGB and the consequent restoration of physiological masticatory function also leads to the rehabilitation and normalization of the general postural condition, similar to that of the control group without malocclusion. At last, but not the least, the following research question is raised: can an analysis of congruity and concordance of postural and masticatory parameters be useful to the clinician for orthodontic diagnosis and prognosis?

3.7. CONGRUITY ANALYSIS

This scientific research aimed to concomitantly evaluate postural and masticatory characteristics of growing patients with UPC, before and after functional orthodontic therapy. It did so by employing three non-invasive investigation methods. In order to integrate such a threefold assessment, and expand its illustrative scope, we developed the concept – specific to this experimental endeavor – of UPC patient ‘*congruity*’ and subsequently performed a qualitative and quantitative congruity analysis, with these purposes:

- analyzing integration, repetitiveness, and diagnostic value of some specific postural and masticatory signs;

- highlighting common postural attitudes of UPC patients;
- enhancing the clinician's ability to manage UPC cases and orthodontic therapies.

Toward this aim, growing patients with UPC are here defined '*congruous'* if they are characterized by all the following three anomalous (non-physiological) clinical conditions:

a. From the Spinal Mouse assessment: asymmetry of spinal lateral flexion in the frontal plane, with lateral flexion on the crossbite side >2° compared to the unaffected side.

b. From the Stabilometric Platform assessment: at least 3 out of 5 stabilometric parameters (among variance of velocity, sway area, sway velocity, sway length and energy consumption) higher in maximal intercuspation than in rest position.

c. From the chewing cycles assessment: percentage of reverse chewing patterns on the crossbite side ≥15% *versus* the unaffected side, chewing hard bolus.

The following graphic (Fig. 3.7.a) summarizes the necessary conditions for a UPC patient to be considered congruous before the functional orthodontic therapy:

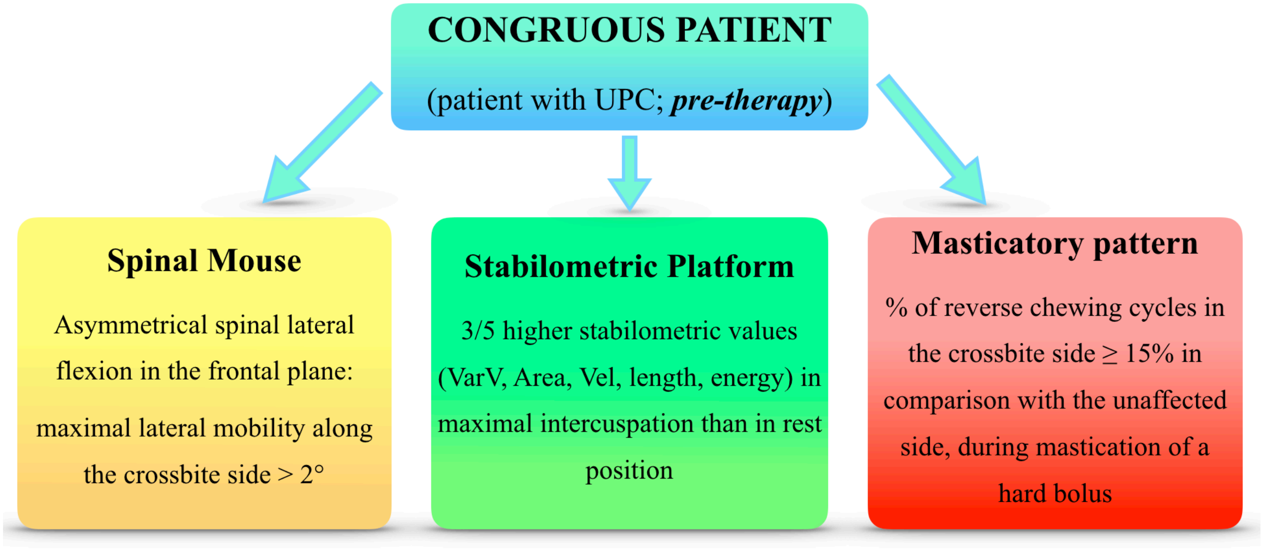


Fig. 3.7.a: Necessary conditions for a UPC patient to be defined 'congruous' before therapy

According to this classification, *before orthodontic FGB therapy*, the growing patient with UPC is defined as:

- Congruous: 3 out of 3 characteristics are concurrently present.
- Semi-congruous: 2 out of 3 characteristics are concurrently present.
- Incongruous: only 1 out of 3 characteristics is present.
- Totally discordant: none of the aforementioned characteristics is present.

It is important to notice, however, that upon completion of the FGB therapy, the concept of congruity takes on a diametrically opposite interpretative connotation. In fact, as the starting hypothesis supports, the three anomalous conditions are specific to UPC, and the functional orthodontic therapy not only corrects the malocclusion, but also favors the complete recovery of masticatory function and muscular balance and coordination. For these reasons, the *post-therapy* classification of patient congruity 'reverses' the pre-therapy one, because rather than a non-physiological state, it indicates the successful correction and restoration of a physiological condition.

Therefore, *after FGB therapy,* growing patients with UPC are defined 'congruous' if they are characterized by all the three physiological clinical conditions:

a. From the Spinal Mouse assessment: symmetry of spinal lateral flexion in the frontal plane, with a difference in lateral flexion between sides <2°.

b. From the Stabilometric Platform assessment: at least 3 out of 5 stabilometric values (variance of velocity, sway area, sway velocity, sway length and energy consumption) in maximal intercuspation equal to or lower than those in rest position.

c. From the chewing cycles assessment: percentage of reverse chewing patterns on the crossbite side <15% (chewing hard bolus), that is, the achievement of a balanced masticatory function between the two sides.

The post-therapy congruity conditions seen in UPC patients are the same conditions that characterize control group patients who have normal occlusion and no crossbite. This is to be expected, as such conditions are indicators of harmony, physiology and correct function.

The following table (Fig. 3.7.b) summarizes the necessary conditions for a UPC patient after the functional orthodontic therapy, as well as a control group patient, to be considered congruous:

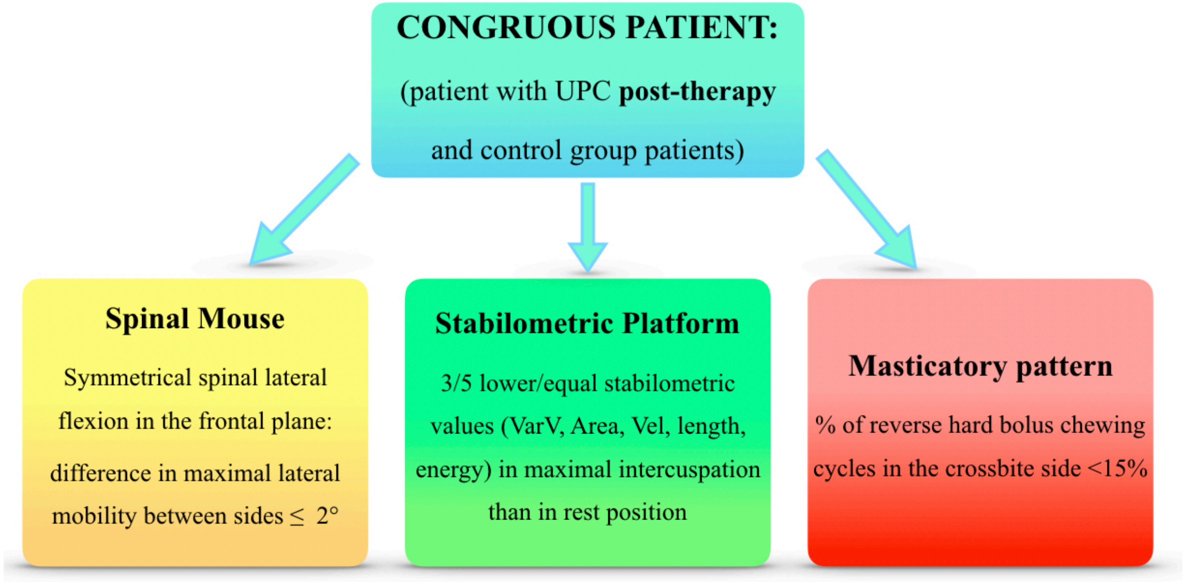


Fig. 3.7.b: Necessary conditions for a UPC patient to be defined ‘congruous’ after therapy (the same conditions of the control group).

According to this classification, growing patiens with UPC *after FGB therapy*, and control group patients are defined as:

- Congruous: 3 out of 3 characteristics are concurrently present.
- Semi-congruous: 2 out of 3 characteristics are concurrently present.
- Incongruous: only 1 out of 3 characteristics is present.
- Totally discordant: none of the aforementioned characteristics is present.

This classifying method also allowed us to empirically analyze the reliability of the instruments we employed, interrogating the valutative/diagnostic value they take on when jointly used on the same patient.

Lastly, the congruity analysis was carried out not only in qualitative terms, but also using quantitative methods. Indeed, we performed an analysis of concordance and agreement with Cohen’s K coefficient, with the ultimate purpose of numerically integrating the data.

3.8. STATISTICAL ANALYSIS

The statistical analysis was made using the software Python for Windows. Data were expressed as a mean with standard deviation, percentage or direction. The quartile method was used to remove outliers: Q1 = lower quartile; Q3 = upper quartile; Interquartile (IQR) = Q3 - Q1. The lower fence was given by $Q1-1.5\ (IQR)$ while the higher one by $Q3 + 1.5\ (IQR)$. The out-of-the-fence values (lower and higher respectively) were considered outliers. The statistical distribution of the quantitative measures and the normality of data were tested using the Shapiro-Wilk test. If necessary, data were log-converted. The following data showed a non-Gaussian distribution, so it was used a non-parametric Mann-Whitney rank-sum U tests for the analysis: Spinal Mouse in the sagittal plane, monopodal support and theoretical angle of support in the Stabilometric Platform, percentage of reverse chewing cycles and average numbers of chewing cycles. The other remaining data were normal and Gaussian distributed, so the analyses were performed using one-sample t-test, independent t-test or chi-squared test, as appropriate.

Cohen's K coefficient was used to evaluate the *concordance and agreement* between the three conditions of congruity. Cohen suggested the K results be interpreted as follows: values ≤ 0 as indicating no concordance; 0.01–0.20 as none to slight; 0.21–0.40 as fair; 0.41– 0.60 as moderate; 0.61–0.80 as good; 0.81–1.00 as almost perfect concordance [Cohen et al., 1960, Brennan et al., 1981]. The significance level was set at 5% for all the analyses.

4. RESULTS

4.1. BEFORE THERAPY WITH FGB

4.1.1. SPINAL MOUSE IN THE FRONTAL PLANE

The crossbite study group (SG) had a significant asymmetrical lateral flexion between right and left, in comparison with the control group (CG), which instead showed a symmetrical lateral flexion with similar inclination between sides ($p = 0.0086$) (Fig. 4.1.1.a).

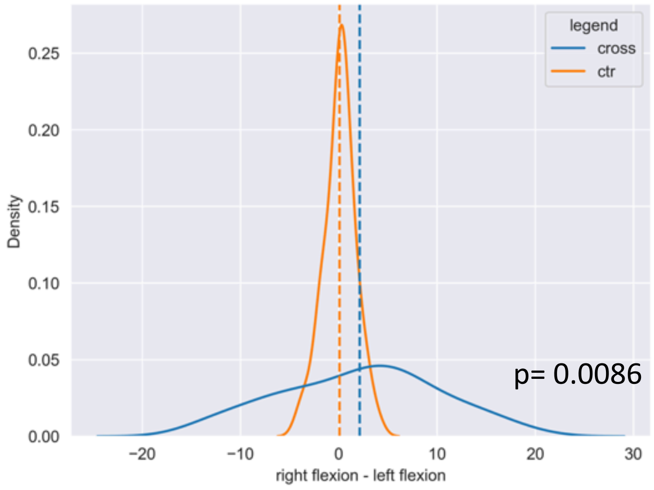


Fig. 4.1.1.a: Difference between right and left spinal flexion in crossbite (blue) *vs* control (orange) group.

The SG recorded an average difference in lateral inclination between sides of 5.6°± 6.16 while the same value for the CG was 0.13°± 2.9° (Fig. 4.1.1.b).

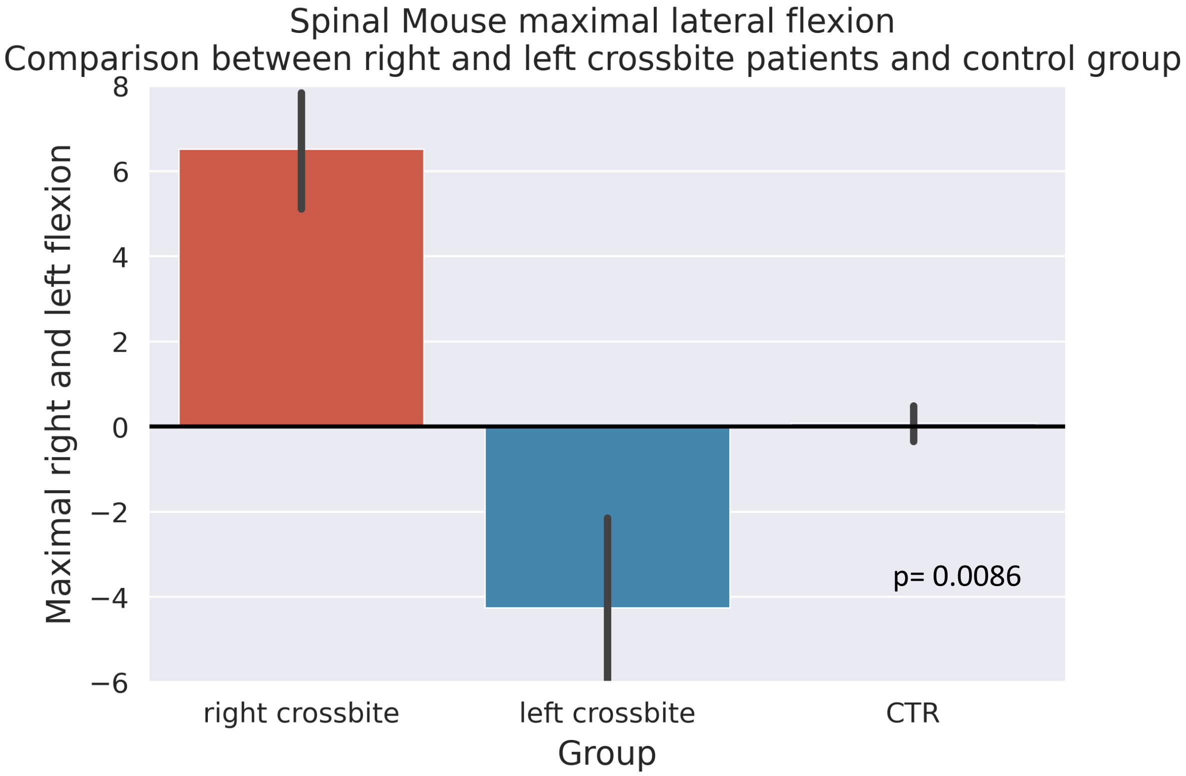


Fig. 4.1.1.b: Spinal Mouse lateral flexion in right (red) and left (blue) crossbite patients and in the control group (black).

Within the crossbite group, patients with right posterior crossbite (right PC) registered significantly greater maximal right-lateral flexion and patients with left posterior crossbite (left PC) had significantly greater left-lateral flexion in comparison with the inclination of the non-crossbite side (p = 0.00027) (Fig. 4.1.1.c). The crossbite side and the side of higher spinal lateral bending were dependent variables with great statistical significance.

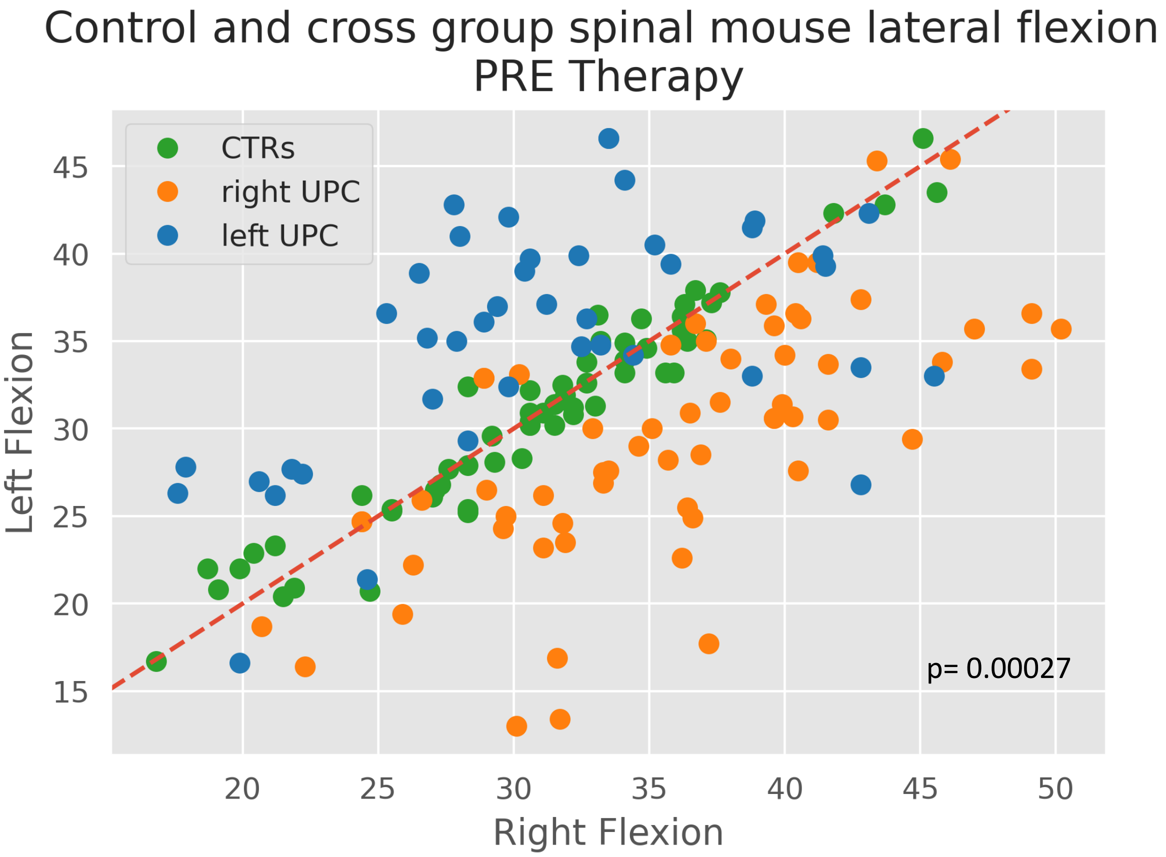


Fig. 4.1.1.c: Spinal Mouse lateral flexion in right (orange) and left (blue) crossbite patients *vs* the control group (green).

4.1.2. SPINAL MOUSE IN THE SAGITTAL PLANE

The study group and the control group did not show statistically significant differences in maximal forward spinal flexion in the sagittal plane (p = 0.127). The two groups are sampled from populations with identical distributions, which exhibit stochastic equality. Nonetheless, we recorded a clinical difference between groups, bearing an analytical-descriptive value for the clinician, although lacking statistical significance: the control group, in fact, demonstrated greater elasticity and spinal mobility, with an average greater anterior maximal flexion, than the study group (SG average maximal flexion ± SD = 95.65° ± 12.65°; CG average maximal flexion ± SD = 101.32° ± 15.44°). The same maximal spinal posterior extension in the sagittal plane was recorded between the two groups, with the same mean ($p = 0.95$). The maximal extension followed a normal distribution (Fig. 4.1.2.a).

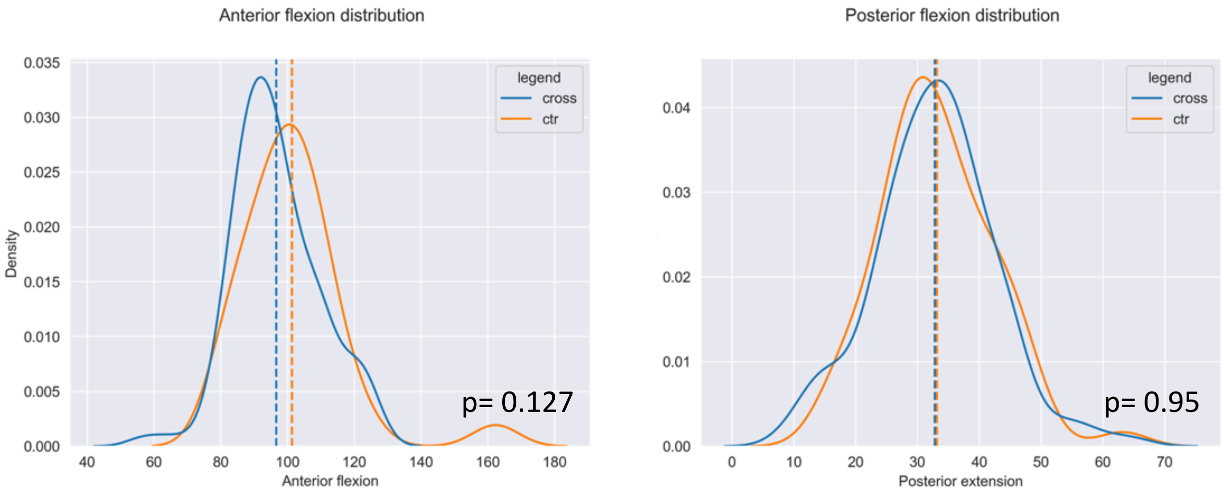


Fig. 4.1.2.a: Difference between spinal anterior flexion and posterior extension in crossbite (blue) *vs* control (orange) group. The groups did not show statistical differences.

4.1.3. STABILOMETRIC RESULTS

All starting hypotheses were confirmed by the Stabilometric Platform test in study group. For crossbite patients, all stabilometric parameters (variance of sway velocity, sway area, sway velocity, sway length, energy consumption, monopodal support with one-side higher percentage of weight load distribution) recorded significantly higher values ($p < 0.005$) in condition of maximal intercuspation than in rest position. Furthermore, the same patients' sway shape ratio, in maximal intercuspation, was significantly far from 0.5 ($p = 0.01$). The stabilometric values of the CG, instead, were very similar between maximal intercuspation and rest position, without significant differences ($p>0.05$) (Table 4.1.3.a).

Table 4.1.3.a: Statistical analysis of the stabilometric parameters (n.h.: MI-RP >0) in crossbite and control group; *p value <0.05

STABILOMETRIC PARAMETERS	CROSSBITE STUDY GROUP	CONTROL GROUP
SWAY SHAPE RATIO	t: -1.608 p: 0.0111*	t: 0.814 p: 0.419
VARIANCE OF SWAY VELOCITY	t: 1.68 p: 0.0097*	t: 1.204 p: 0.234
SWAY AREA (mm2)	t: 1.788 p: 0.0077*	t: 1.32 p: 0.193
SWAY VELOCITY (mm/s)	t: 2.878 p: 0.005*	t: 1.867 p: 0.068
SWAY LENGHT (mm)	t: 2.628 p: 0.01*	t: 1.736 p: 0.089
ENERGY CONSUMED (watt)	t: 2.767 p: 0.007*	t: 1.387 p: 0.171
HIGHER PERCENTAGE OF SUPPORT	t: 0.99 p: 0.0325*	t: -1.156 p: 0.253
THEORETICAL ANGLE OF SUPPORT = TRUNK ROTATION (DEGREES)	t: 0.16 p: 0.873	t: -0.409 p: 0.684

Hence, patients without crossbite showed a greater stability and adopted a similar postural attitude whether teeth were in contact or not. This variable, on the opposite, characterizes and deeply conditions the postural balance of crossbite patients. To further delve into the issue, we selected a subset of the sample composed of 128 patients less than 12 years old, and analyzed their stabilometric characteristics, which resulted in line with our previous observations (p>0.05), thus confirming our hypothesis.

Furthermore, the incidence of monopodalic support in the SG was higher than in the CG (p = 0.037), further increasing in condition of maximal intercuspation (p = 0.035). We developed a contingency table to investigate the hypothesis of a correlation between the crossbite side and the monopodalic support side. We did a chi-squared test that, however, demonstrated no correlation in any condition, neither maximal intercuspation nor free resting arches (p = 1). The only stabilometric parameter for which no statistically-significant differences are detectable is the theoretical angle of support. Indeed, between SG and CG, the direction and value of trunk rotations are similar (p = 0.873). In addition, crossbite and rotation directions are not dependent variables (p = 0.947).

4.1.4. MASTICATORY PATTERNS

For the control subjects, there was no side-by-side difference ($p = 0.173$) in the percentage of reverse cycles during chewing either with soft or hard bolus. Moreover, the percentage of reverse cycles was not affected by bolus type ($p = 0.182$).

Control patients recorded a small percentage of reverse chewing patterns – approximately 11±16% with soft bolus and 8±12% with hard bolus – which fits within the boundaries of normal physiological conditions. Among crossbite patients before the orthodontic intervention, the percentage of reverse cycles when chewing on the crossbite side was 48±32% (soft bolus) and 61.5±36% (hard bolus): a significantly greater value than among controls ($P<0.001$). For the subjects with unilateral posterior crossbite, the percentage of reverse cycles was dependent on side and bolus type, as well as on their interaction ($p = 0.001$). Specifically, the percentage of reverse cycles was higher on the crossbite side compared to the unaffected side for both bolus types ($p = 0.00001$), and was highest while chewing hard bolus ($p = 0.00012$). On the contrary, the percentage of reverse cycles on the non-crossbite side did not differ when chewing either soft or hard bolus ($p > 0.05$) (Fig. 4.1.4.a).

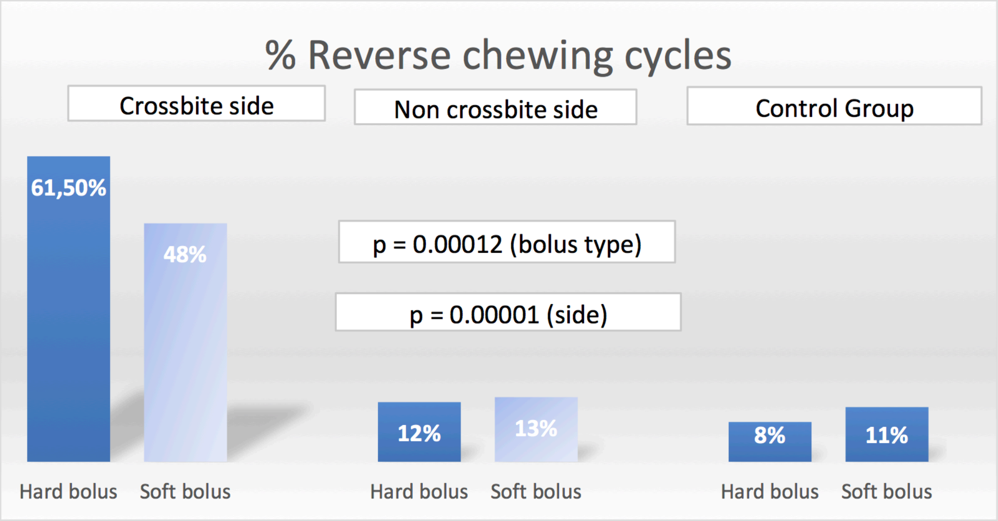


Fig. 4.1.4.a: Percentage of reverse chewing cycles recorded in SG and CG.

The average number of chewing cycles was dependent on both group and bolus type. In fact, crossbite patients had fewer chewing cycles with hard bolus on the crossbite side than on the non-crossbite side ($p = 0.005$). However, with soft bolus, this relationship between a smaller number of chewing patterns and the crossbite side is not detected ($p = 0.92$). In general, crossbite patients recorded a lower mean number of chewing cycles with both soft (p = 0.04) and hard bolus (p = 0.03) compared to the control group.

We also investigated the statistical integration between masticatory function and spinal mobility with far-reaching results. Among patients with UPC, there is a dependent relationship, with a very high statistical significance (p value = 0.0000001), between the side with the greatest percentage of reverse cycles with both soft and hard bolus (measured with K7) and the side of maximum lateral spinal flexion in the frontal plane (measured with the Spinal Mouse).

4.1.5. PRE-THERAPY CONGRUITY ANALYSIS OF UPC PATIENTS

Before the treatment, the sample of UPC patients resulted to be 52% congruous, 38% semi-congruous and 10% incongruous. No patient in the sample was found totally discordant. Within the portion of semi-congruous patients, 55% showed concordance between Spinal Mouse and chewing patterns data, 24% between Spinal Mouse and Stabilometric Platform results, and 21% between stabilometric and masticatory elements. Incongruous patients, instead, were divided as follows: 78% were characterized only by non-physiological masticatory patterns, while 11% showed concordance only in relation to posture and an equal 11% only in relation to spinal mobility. The outcomes of pre-therapy congruity analysis of UPC patients are graphically described in Fig. 4.1.5.a.

Fig. 4.1.5.a: Congruity analysis of UPC patients before therapy.

In line with expectations, in the study group the Spinal Mouse detected a pre-therapy condition of postural asymmetry with a greater spinal bending on the crossbite side in 82.75% of patients. Similarly, the Stabilometric Platform recorded higher values in maximum intercuspation *versus* rest position in 70% of patients; and the Kinesiograph captured a higher-than-15% proportion of reverse hard bolus chewing cycles on the crossbite side in 88.5% of patients.

Cohen's K coefficient underscored a good/fair levels of concordance among the examined tests (k=0.67; 0.37; 0.28).

4.1.6. CONGRUITY ANALYSIS OF CONTROLS

Here is reported the congruity analysis performed on healthy patients belonging to the control group, which was then compared to the UPC patients' before and after the therapy.

Control subjects resulted congruous in 38% of cases, semi-congruous in 53% of cases (among which: 61% spinal mobility and mastication; 25% posture and mastication; 14% spinal mobility and posture) and incongruous in 9% of cases (60% mastication; 20% spinal mobility; 20% posture). Conditions of physiological symmetry and balance were recorded by the Spinal Mouse in 79% of patients, by the Stabilometric Platform in 60% of patients, and by the Kinesiograph in 88.5% of patients.

4.2. BEFORE/AFTER THERAPY WITH FGB

Postural and masticatory records of the crossbite study group were carried out immediately before the intervention and after crossbite correction with FGB plus a retention time of five months. The mean treatment time was 8.2 ± 2.7 months plus the retention time. The control group was measured twice at a distance of six months. Data from both cases and controls were analyzed in the same time period.

4.2.1. SPINAL MOUSE IN THE FRONTAL PLANE

After FGB therapy and the complete resolution of the crossbite malocclusion, the study group patients did no longer present asymmetry of spinal lateral mobility in the frontal plane ($p > 0.05$).

The spinal maximal lateral flexion between right and left side was comparable to that of the control group (p=0.204) (Fig 4.2.1.a).

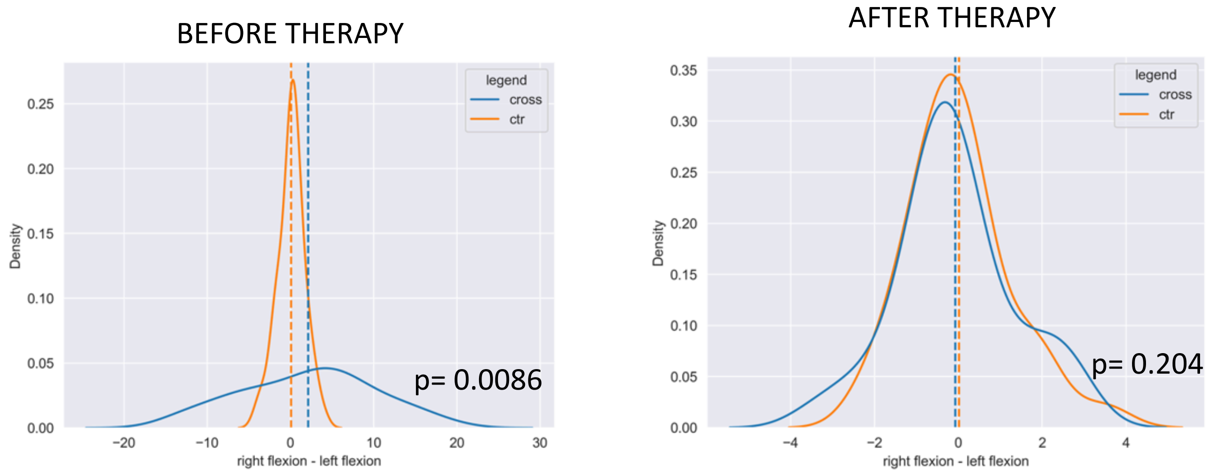


Fig. 4.2.1.a: Difference between spinal lateral flexion in crossbite (blue) *vs* control (orange) group. After therapy no statistical differences were recorded between groups.

The average difference of spinal inclination between sides was 0.36°± 2.86 in the crossbite group (p= 0.745) and 0.13°± 2.7 ° in the control group (p = 0.942) . Such a result indicates that the Spinal Mouse system did not register asymmetry in spinal lateral flexion within both groups after therapy (Fig. 4.2.1.b).

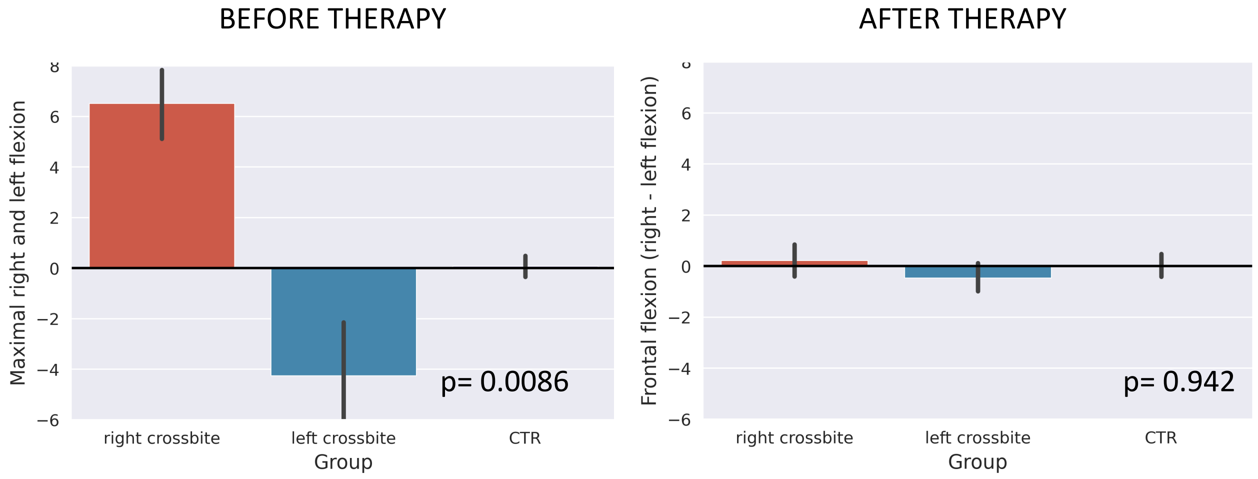


Fig. 4.2.1.b: Spinal Mouse lateral flexion in right (red) and left (blue) crossbite patients and in the control group (black) before and after therapy.

Moreover, the side of greater spinal mobility no longer resulted as dependent on the side of crossbite. After therapy, indeed, corrected left-side UPC patients no longer had a greater spinal flexion on the left (p = 0.151) and, vice versa, right-side UPC patients no longer featured greater flexion on the right side (p = 0.5) (Fig. 4.2.1.c).

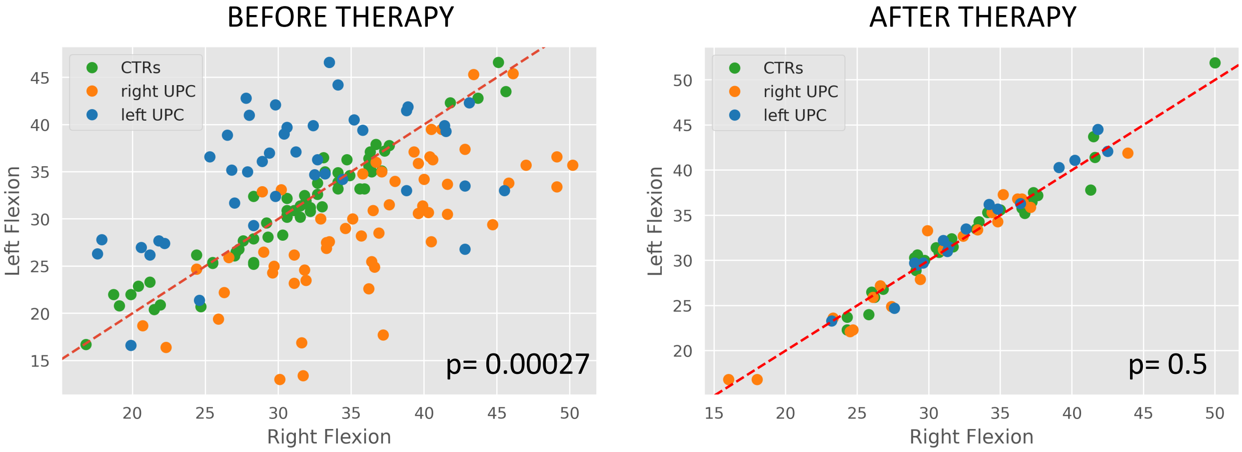


Fig. 4.2.1.c: Spinal Mouse lateral flexion in right (orange) and left (blue) crossbite patients *vs* the control group (green) before and after therapy. Data distribution is highly homogeneous after therapy.

4.2.2. SPINAL MOUSE IN THE SAGITTAL PLANE

The control and study groups recorded the same spinal forward flexion in the sagittal plane without significant differences (p = 0.48). Also, the two groups showed identical distribution with stochastic equality. The average spinal maximal flexion was 94.93° ± 11.68° in the crossbite group and 93.2° ± 11.47° in the control group.

We collected equivalent data also about maximal spinal extension in the sagittal plane. In fact, both groups had the same values with an equal mean (SG: 33.65° ± 7.6°; CG: 34.28° ± 8°) and normal distribution, without any difference (p = 0.9) (Fig. 4.2.2.a).

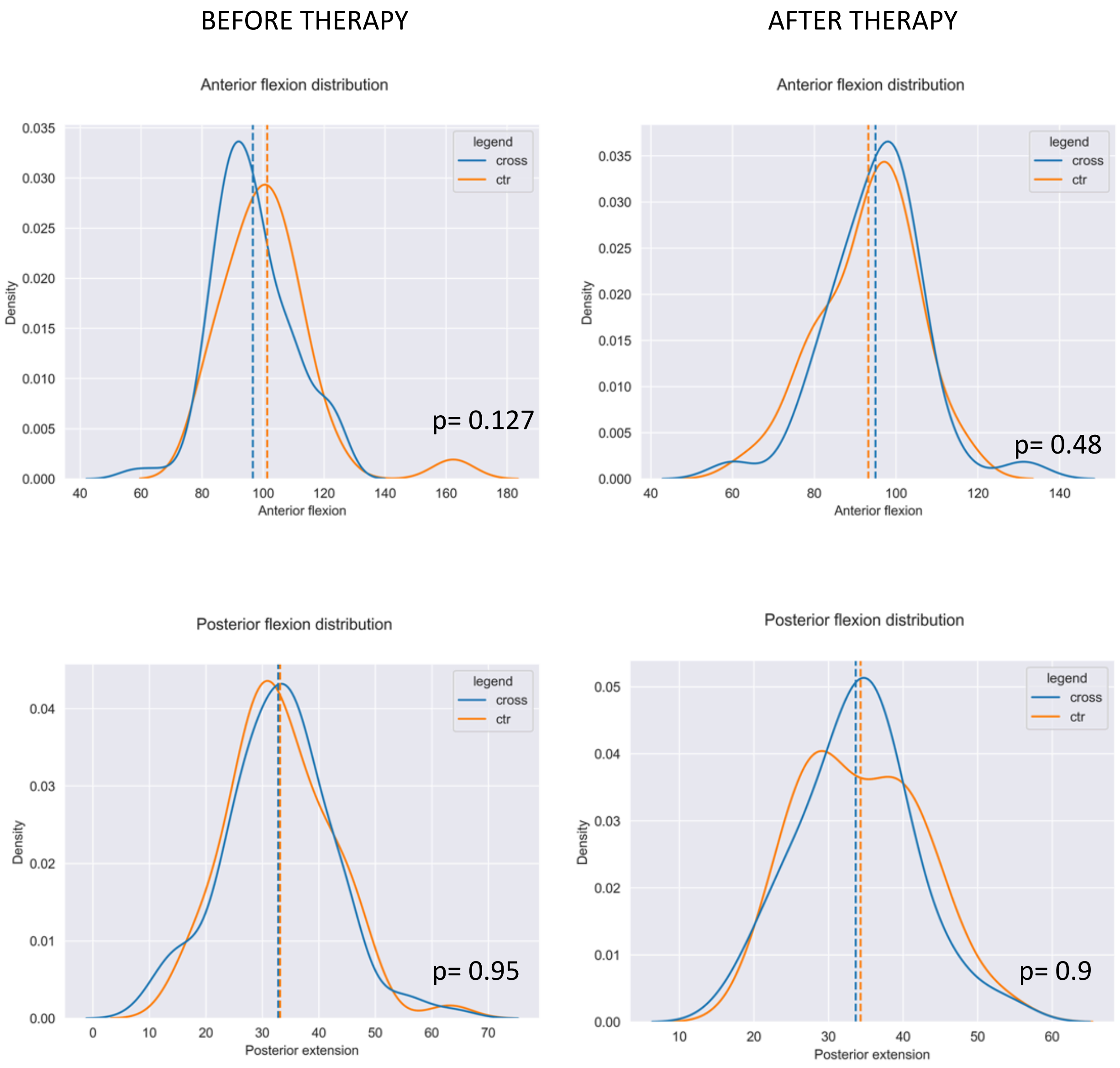


Fig. 4.2.2.a: Difference between spinal anterior flexion and posterior extension in crossbite (blue) *vs* control (orange) group. The groups did not show statistical differences.

4.2.3. STABILOMETRIC RESULTS

The stabilometric platform was the only device that did not record significant changes in the crossbite patients' postural assessment after therapy. Although the differences in the stabilometric values between maximal intercuspation and rest position conditions were slightly smaller, there was greater instability in the postural system with dental contacts after therapy, with significantly high values (variance of sway velocity, sway area, sway velocity, sway length, energy consumption)

(P<0.05). By selecting and analyzing only children under 12 years of age, we were able to confirm these data. The control group continued to have similar stabilometric parameters in both maximal intercuspation and rest position, showing a major postural stability and efficiency.

Only two stabilometric parameters in patients with crossbite significantly changed after therapy: sway shape ratio and monopodal support. The sway shape ratio was closer to 0.5 in the condition of maximal intercuspation, therefore showing a rounded statokinesigram, as in the control group (p = 0.926). Secondly, crossbite patients had no monopodal support (p = 0.74) and their COP load was harmoniously distributed between both sides of the body after therapy. A correlation between the crossbite side and the side of higher percentage of weight load distribution was no longer registered (p = 0.8). Furthermore, the monodopal support and weight distribution in crossbite patients were comparable to those of the control group without significant differences (p= 0.946) (Fig.4.2.3a).

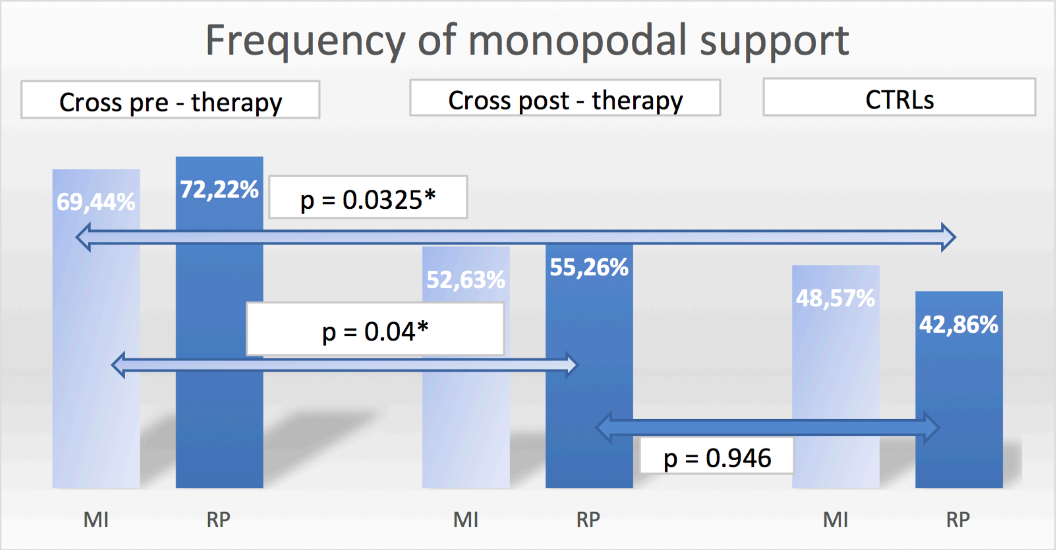


Fig. 4.2.3.a: Frequency of stabilometric monopodal support in crossbite patients before and after therapy and in the controls.

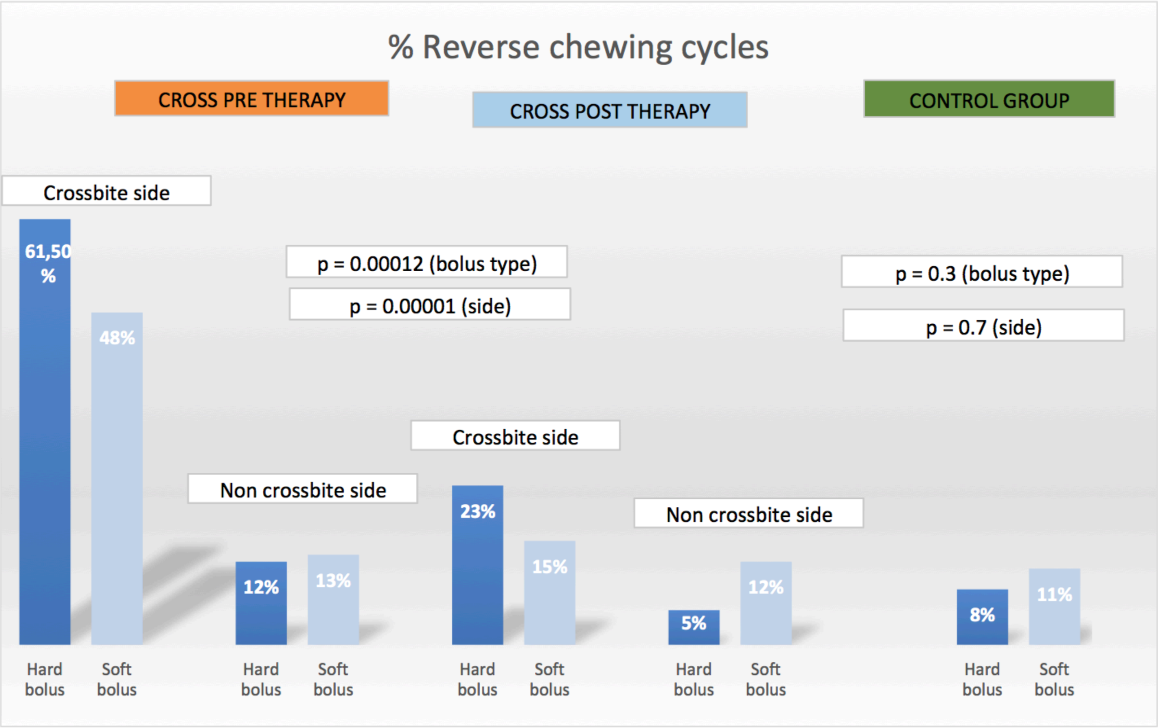
The theoretical angle of support was also similar between crossbite and control groups after crossbite therapy (p = 0.18). There was no correlation between frequency, direction and entity of trunk rotation with the crossbite status (p = 0.1) and crossbite side (p = 0.7).

4.2.4. MASTICATORY PATTERNS

Among the patients with crossbite, the percentage of reverse cycles when chewing on the crossbite side significantly decreased after therapy (p < 0.001), both with soft (15±18.5%) and hard bolus

(23±29%). When chewing on the non-affected side, the post-intervention percentage of reverse cycles was 12±13% (soft bolus) and 5±9% (hard bolus). The percentage of reverse cycles was reduced after the treatment for both sides (p = 0.7) and bolus type (p = 0.3) (Fig. 4.2.4.a). However, crossbite patients maintained a less-than-average number of chewing cycles, especially with hard bolus (SG: 71±13 CG: 76±10 with hard bolus; SG: 71±11; CG: 73±10 with soft bolus), but the difference with controls was not statistically significant (p = 0.3). In sum, the masticatory patterns of the crossbite patients after therapy with FGB resulted similar to the controls (p> 0.01).

Fig. 4.2.4.a: Percentage of reverse chewing cycles in crossbite patients before and after therapy and in the control group.



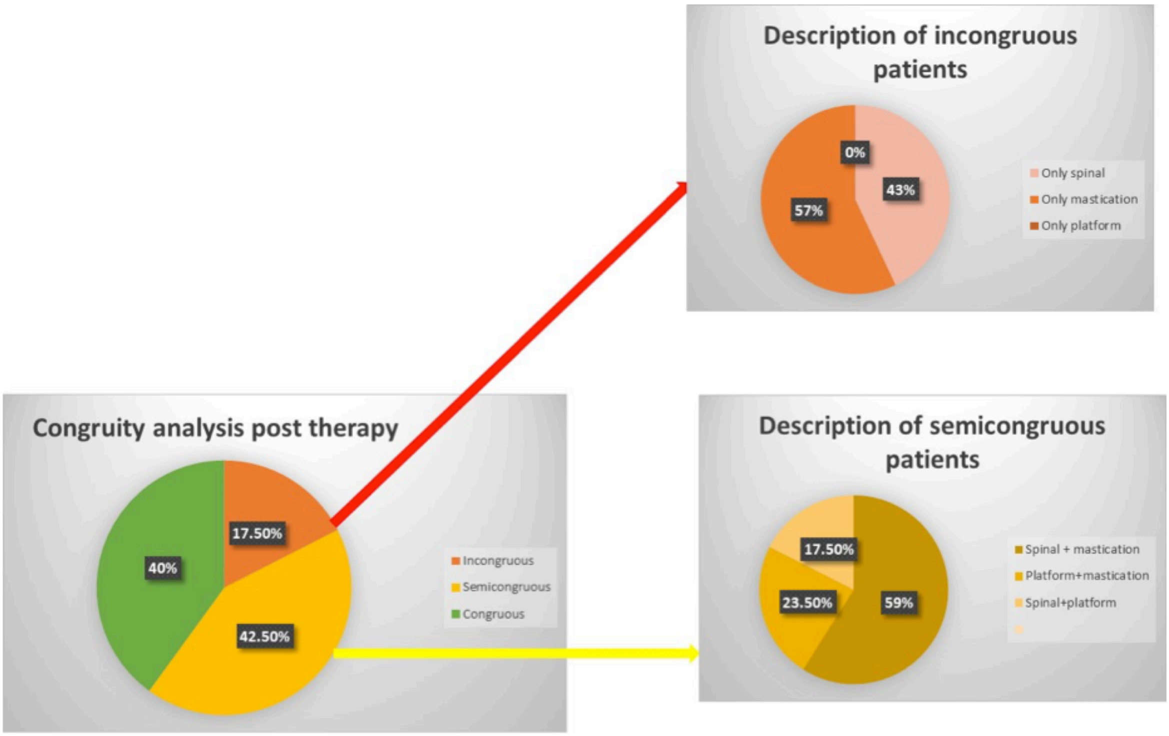
Finally, the integration of spinal mouse and masticatory pattern data did not show any correlation between the side with the larger percentage of reverse cycles and the side with greater spinal mobility in the frontal plane, both with soft (p = 0.7) and hard (p = 0.1) bolus. After orthodontic therapy, then, spinal mobility in the frontal plane and masticatory patterns on the crossbite side were no longer in a relation of dependency.

4.2.5. POST-THERAPY CONGRUITY ANALYSIS OF UPC PATIENTS

As already mentioned, after the FGB treatment the analysis of congruity was repeated. The post-therapy sample resulted to be 40% congruous, 42.5% semi-congruous and 17.5% incongruous. No totally discordant patient was found. Among semi-congruous patients, 59% were found having physiological conditions in relation to spinal mobility and mastication, 23.5% in posture and mastication, and the remaining 17.5% in spinal mobility and posture. Incongruous patients, instead, were grouped as follows: 57% were characterized only by physiological masticatory patterns, while 11% showed concordance only in relation to spinal mobility, whereas no incongruity related only to posture was detected.

The results of post-therapy congruity analysis of UPC patients are graphically summarized in Fig. 4.2.5.a.

Fig. 4.2.5.a: Congruity analysis of UPC patients after therapy.



After the therapy, postural symmetry and a balanced spinal mobility (differences between the right and left sides ≤2°) were detected in 80% of patients. Moreover, lower stabilometric values in maximum intercuspation *versus* rest position were recorded in 57.5% of cases. Lastly, 85% of patients executed less than 15% reverse cycles on the crossbite side while chewing hard bolus.

Cohen's K Cohen's K coefficient underscored a fair statistical level of concordance among the examined tests (k=0.33; 0.25; 0.05).

What crucially emerges from post-therapy congruity analysis of UPC patients is the high degree of similarity of its results to those recorded with control patients. They appear to be strongly overlapping, both in terms of congruity and repetitiveness.

5. DISCUSSION

The aim of this experimental research was to objectively evaluate human posture in growing patients with and without malocclusions, by analyzing data about spinal mobility, postural balance and chewing patterns, recorded by three non-invasive postural devices: these were, respectively, the Spinal Mouse, Stabilometric Platform and K7-I Kinesiograph. Our purposes were to evaluate posture and investigate the 'congruity' and concordance between the posture and masticatory function of growing patients with UPC before and before/after orthodontic therapy, as well as to compare them with a control group with normal dental occlusion.

Over the last three decades, the relation between general body posture and dental occlusion has recorded a growing interest. Many researches have in fact fed a growing scientific body on the topic, which is connoted by sharply contrasting results: half of the studies recognize the existence of such a relation, whereas the other half dismiss it. So far in this field, *Evidence-Based Medicine* have proven unable to produce coherent and significant results, because it lacks the sensitivity, complexity and necessary clinical protocols to investigate and measure the reciprocal relations between these two systems. Current research methods, indeed, are not suitable to irrefutably demonstrate or deny the cause-effect relation between the mouth and the rest of the body, because both the postural system and the stomatognathic apparatus are extremely complex, adaptive and subtle in their compensations. Such a complexity is both due to the *interactions* they reciprocally develop and the *alterations* – at times unpredictable – caused by the visual, auditory, musculo-skeletal, articular, cranio-sacral and, no less important, limbic and psychological systems. Thus, postural alteration is a systemic rather than organic pathology. It is plausible, therefore, for an interference or abnormal input to induce imbalance in the system, generating signs and/or symptoms in different human districts. Involved organs are not only anatomically next to each other; they interact in such a way that creates a complex balance pattern. If altered in any of its parts, such a balance requires an intervention founded on a multidisciplinary approach, which takes into consideration every part of the system. As a consequence, the knowledge and evaluation of the correlations between morpho-functional, cranio-facial, spinal and postural characteristics is of great value to the orthodontist, aiding the delivery of prognosis and treatment.

A large number of studies carried out over the course of many years by researchers from the University of Turin demonstrated that unilateral posterior crossbite is an asymmetrical malocclusion in the frontal plane, which determines an asymmetry of the masticatory function both from a kinematic and neuromuscular point of view, i.e. an asymmetry of movements, articular loads, muscular activation and coordination, leading to an asymmetry of bones and structures when the crossbite is not corrected early [Piancino et al., 2019].

The deep involvement of neuromuscular control during chewing in crossbite malocclusion strongly suggests a possible effect on body posture. For this reason, this study evaluated the effects produced by such a quintessentially asymmetrical type of malocclusion on the balance of the tonic-postural system and on the spinal mobility of growing patients. To do so, we measured the former with the Stabilometric Platform and the latter with the Spinal Mouse. Postural measurements were then integrated with masticatory function values obtained by analyzing chewing cycle with a K7-I Kinesiograph. All three instruments are non-invasive and scientifically-validated by a number of previous studies [Mannion et al. 2004, Post et al. 2004, Guermazi et al. 2006, Livanelioglu et. al. 2016, Gangloff et al. 2000, Kachingwe et al. 2005]. The results were evident and strongly significant from both a clinical and statistical point of view.

The crossbite study group (SG) recorded a significant asymmetrical lateral flexion between right and left sides, in comparison with the control group (CG), which instead showed a symmetrical lateral flexion with similar inclination between sides ($p = 0.0086$). Within the crossbite group, patients with right posterior crossbite (right PC) registered significantly greater maximal right-lateral flexion and patients with left posterior crossbite (left PC) had significantly greater left-lateral flexion, in comparison with the inclination of the non-crossbite side ($p = 0.00027$). No differences were registered between study and control groups about spinal mobility in the sagittal plane ($p = 0.127$).

Patients with unilateral posterior crossbite showed a significantly higher postural instability and extended a greater effort to maintain the standing upright position on the Stabilometric Platform. In fact, for crossbite patients, all stabilometric parameters (variance of sway velocity, sway area, sway velocity, sway length, energy consumption, monopodal support with a higher percentage of weight load distribution on one side) recorded significantly higher values ($p < 0.005$) in condition of maximal intercuspation than in rest position. Furthermore, the same patients' sway shape ratio, in maximal intercuspation, was significantly far from 0.5 ($p= 0.01$). The stabilometric values of the CG, instead, were very similar between maximal intercuspation and rest position, without significant differences. Hence, patients without crossbite showed a greater balance and adopted a similar postural attitude whether teeth were in contact or not. Furthermore, the incidence of monopodal support in the SG was higher than in the CG ($p = 0.037$), further increasing in the condition of maximal intercuspation ($p = 0.035$). The only stabilometric parameter for which no statistically-significant differences were detectable is the theoretical angle of support. Indeed, between the SG and the CG, the direction and value of trunk rotations were similar ($p = 0.803$).

The chewing analyses confirmed previous studies about UPC growing patients conducted by the University of Turin. Control patients recorded a small percentage of reverse chewing patterns – approximately 11±16% with soft bolus and 8±12% with hard bolus – which fits within the boundaries of normal physiological conditions. Among crossbite patients the percentage of reverse cycles when chewing on the crossbite side was 48±32% (soft bolus) and 61.5±36% (hard bolus): a significantly greater value than among controls ($p < 0.001$). For these subjects, the percentage of reverse cycles was dependent on side and bolus type, as well as on their interaction ($p < 0.05$). Specifically, the percentage of reverse cycles was higher on the crossbite side compared to the unaffected side for both bolus types ($p = 0.00001$), and was highest while chewing hard bolus ($p = 0.00012$). On the contrary, the percentage of reverse cycles on the non-crossbite side did not differ when chewing either soft or hard bolus ($p > 0.05$).

The average number of chewing cycles was dependent on both group and bolus type. In fact, crossbite patients had fewer chewing cycles with hard bolus on the crossbite side than on the non-crossbite side (p = 0.005). In general, crossbite patients recorded a lower mean number of chewing cycles with both soft (p = 0.04) and hard bolus (p = 0.03) compared to the control group.

We also investigated the statistical integration between masticatory function and spinal mobility with far-reaching results. Among patients with UPC, there is a dependent relationship, with a very high statistical significance (p value = 0.0000001), between the side with the greatest percentage of reverse cycles with both soft and hard bolus (measured with the K7-I) and the side of maximum lateral spinal flexion in the frontal plane (measured with the Spinal Mouse). The Spinal Mouse System showed excellent reliability, comparable to that of the already highly-reputable K7-I Kinesiograph.

Finally, we performed a quali-quantitative analysis of *congruity* between posture and masticatory function of UPC growing patients that, to the best of our knowledge, is the first in existence within the field literature. The condition of congruity, i.e. of concurrent functional, postural and masticatory asymmetry recorded in the crossbite group, is characterized by the following aspects:

- Spinal Mouse: asymmetry of spinal lateral mobility in the frontal plane – higher flexibility on the crossbite side.
- Stabilometric Platform: dental occlusion increases postural instability – the statokinesigram stabilometric parameters score higher in the condition of maximum intercuspation than in rest position; monopodal support is present and body weight is unevenly distributed between right and left side.
- Chewing cycles: asymmetry of the masticatory function – the percentage of reverse chewing cycles is greater than 15% on the crossbite side, both with soft bolus and – even more pronouncedly – with hard bolus.

The observed repetitiveness and correlation among these three conditions led us to perform a congruity analysis of UPC patients, which was specifically designed for this research in order to evaluate the integration of UPC's postural and masticatory signs. We defined *congruous* a patient conditioned by 3 out of 3 non-physiological characteristics, *semi-congruous* by 2 out of 3, and *incongruous* by only 1 out of 3. In aggregate, before the FGB therapy, 52% of UPC patients resulted congruous, 38% resulted semi-congruous and 10% resulted incongruous. No patient resulted totally discordant.

Chewing cycles showed a reliability rate of 88.5% (excellent), the Spinal Mouse of 82.75% (excellent) and the Stabilometric Platform of 70% (good). Regarding the masticatory function, there is consensus about the existence of pathognomonic signs of unilateral posterior crossbite (CIT) when the proportion of reverse chewing cycles on the crossbite side is greater than 35%. Yet, the highly relevant and repetitive values we recorded also in the postural domain suggest that, for the growing patient, pathognomonic (postural) signs of UPC exist when spinal mobility asymmetry on the side of the crossbite is greater than 6°, and/or stabilometric instability in maximal intercuspation *versus* rest position is greater than 35%.

UPC patients are in fact characterized by all three of these conditions – which are correlated and integrated with one another – the knowledge of which can be crucially important in supporting orthodontists' diagnostic and prognosis efforts. The concurrent use of the three non-invasive instruments we employed in this research (Spinal Mouse, Stabilometric Platform and K7-I) to assess the patient before delivering an orthodontic treatment – and therefore to analyze the correlation between mastication and posture – is of great help to clinicians, since it can support them in identifying the case's complexity, performing a complete diagnosis, and devising a therapy protocol aiming for the highest effectiveness and respect for the patient's condition.

Specifically, incongruous patients (about 10% of total cases) are the most difficult to treat. Their prognoses tend to be more unfavorable, they show a larger number of compensations and, generally, require more attention compared to congruous patients, who instead consistently reflect all the characteristics of malocclusion. Knowing this in advance, the clinician would be able to plan for a longer treatment of incongruous patients and dedicate the correct amount of attention necessary to achieve desired therapy results.

In the dental field, congruity and agreement are already employed as clinical indicators of patients' prognoses and therapies. For instance, the evaluation of *dental-skeletal congruity in the vertical plane* is a commonly accepted indicator of prognosis, used daily by clinicians. In treating deep bite patients, in fact, the hypodivergent ones, i.e. those showing dental-skeletal congruity, are easier to treat and their prognoses are usually more favorable that those of hyperdivergent patients, who instead are characterized by dento-skeletal incongruity.

In the case of our study, the construct of congruity was used to shed light on the differences among crossbite patients and thus to fill a gap that is both cognitive and methodological: the incongruity of malocclusion *in the frontal plane* is indeed rarely detected due to a lack of reliable and scientifically-validated clinical and/or diagnostic devices. For most clinicians, as a consequence, all crossbites are the same. What this study demonstrated, however, is that this assumption is false, and that two crossbites, one characterized by functional general (postural-chewing) congruity and one by incongruity, can be very different, albeit very similar from a clinical point of view, that is, involving the same number of teeth from the same side of the mouth.

We also assessed the posture and masticatory function of the same patients once they completed functional therapy with FGB, i.e., upon complete restoration of crossbite malocclusion. After the initial assessment, 40 UPC patients underwent orthodontic therapy with a functional FGB appliance. The treatment lasted an average of 8.2 ± 2.7 months plus a retention time of five months. We chose an FGB appliance for all patients because it produces (via the teeth) coherent, intermittent, self-regulated, and modulated forces over time in an unrestricted system. FGB is the only *ortho-gnathological* appliance that allows us to *cure*, in the real sense of the word, the stomatognathic system of young patients, producing functional equilibrium and harmonious skeletal growth.

We verified whether the functional balance introduced by the correction of malocclusion with FGB also positively affected the postural system, stimulating a restoration of tonic-postural harmony. All three tests run on patients after therapy highlighted a noteworthy and significant improvement of masticatory and postural functions. The masticatory and postural framework of patients, post-therapy, was indeed similar to that of the control group. The restoration of functional and masticatory symmetry induced by the correction of malocclusion with FGB allowed for:

- symmetrical spinal mobility in the frontal plane;
- better stabilometric conditions in maximum intercuspation and the disappearance of monopodal support, although patients did not reach complete stabilometric postural balance;
- reduced reverse chewing cycles with higher average numbers of chewing patterns.

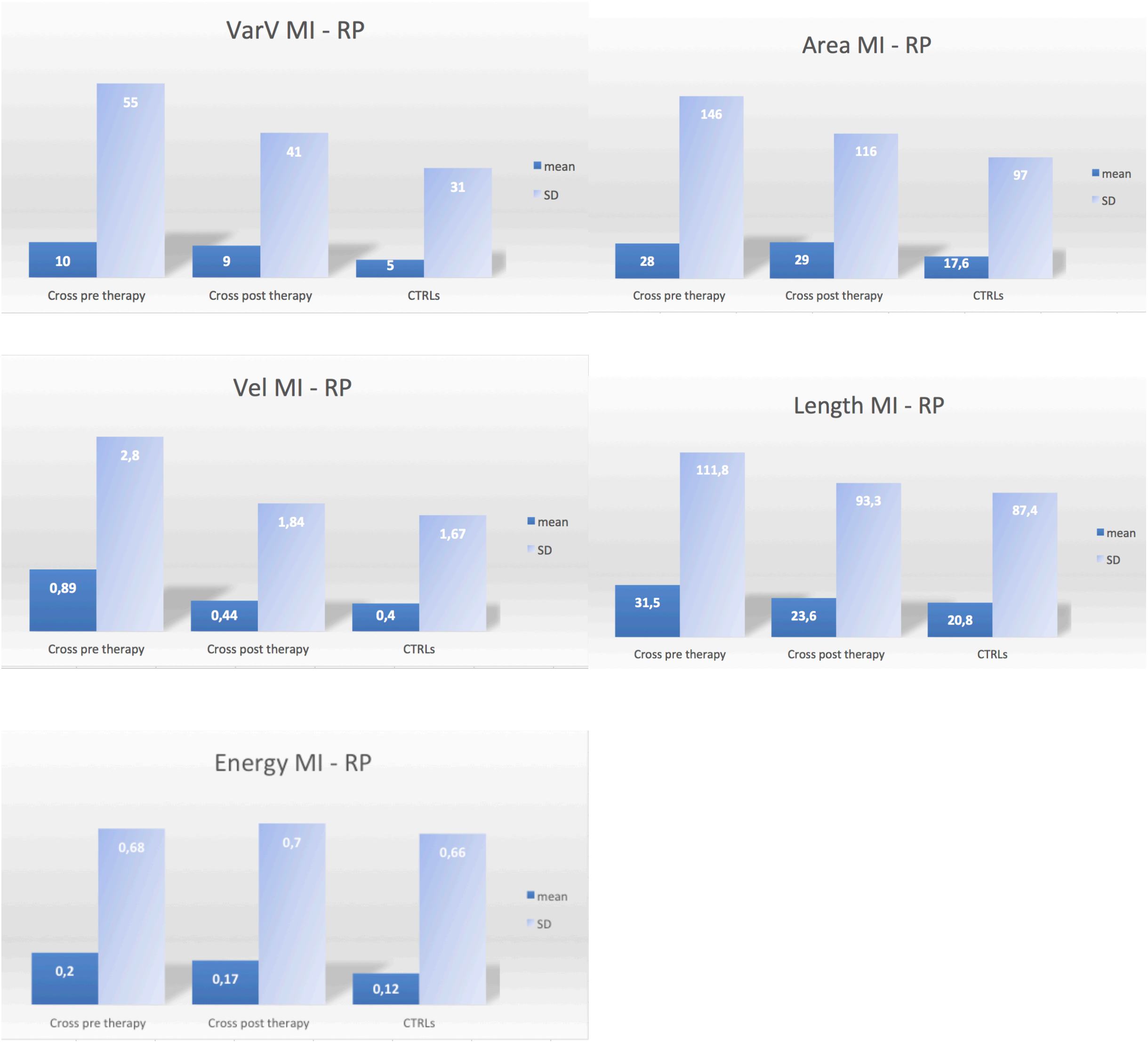
The physiological stimulus to restore the masticatory function induced by crossbite correction with an FGB appliance led to a more efficient general muscular coordination in patients, as well as better postural balance both in terms of stabilometry and spinal mobility.

Post-therapy, congruous patients were 40%, semi-congruous patients were 42.5%, and incongruous ones were 17.5%. The reliability of the K7-I was 85% (excellent), the Spinal Mouse 80% (excellent) and, lastly, the Stabilometric Platform 57.5% (fair). This high degree of reliability of the instruments lends them a powerful value, almost of a diagnostic level, which becomes pathognomonic when they used together rather than individually.

Such results laid the groundwork for a few reflections. Firstly, the Spinal Mouse showed an excellent degree of reliability, almost on par with that of the Kinesiogram used to assess chewing cycles, which is already widely validated in the literature. While the Spinal Mouse has already been validated in the scientific literature, in our study its reliability emerged even stronger, thanks to the custom-made device we built specifically for this doctoral research (Fig. 3.3.3.b). It allowed the operator to avoid the most common bias afflicting Spinal Mouse recordings, i.e., the rotation of shoulder and pelvis. It guided the spinal movements executed by the patients, allowing for an optimal repetitiveness of measurement. This device is particularly useful when test subjects are children, who are endowed with less concentration and proprioceptive abilities than adult patients. The use of scientifically-validated postural tools and the adoption of reliable and repetitive investigative methods and calculating protocols allow for a deeper evaluation of the patient before and during therapy. In fact, clinical experience suggests the need for and the validity of a multidisciplinary approach not only to achieve a more precise classification of the patient but also to guide the clinician in determining the patient’s diagnosis and prognosis.

Secondly, the Stabilometric Platform is the assessment tool that provided the least statistically-significant, though very clinically relevant, data. This can be explained by the enormous individual variability of the stabilometric values. In fact, as shown in Fig. 5.a, the stabilometric parameters of the crossbite and control groups were characterized by very high standard deviations.

Fig. 5.a: Mean and standard deviation of MI-RP differences of all stabilometric parameters before and before/after therapy. The SD of differences is really greater than the average differences.



Even though these standard deviations gradually decreased as we moved from pre-therapy to post-therapy to control patients (Fig. 5.a), they remained very high even among the healthy patients of the control group. It is precisely due to the non-significant post-therapy data derived from the Stabilometric Platform that Cohen’s K coefficient – which indicates concordance and agreement – decreased from a ‘good’ level in pre-therapy to a ‘fair’ level in post-therapy. Cohen’s K coefficient of concordance was weaker in post-therapy (k=0.33; 0.25; 0.05) with respect to the pre-therapy stage (k=0.67; 0.37; 0.28). This weakening can be accounted for by the presence of stabilometric values that did not change significantly in the crossbite group. In addition, it is reasonable to assume that the stabilometric parameters need a longer period of follow-up time to correct themselves, as they are the result of a newly acquired and more mature postural balance. A limit of this study, therefore, is the lack of a significant net change between stabilometric values in maximum intercuspation and rest position before and after therapy. We detected signs of clinical improvement, but they were not statistically significant. A longer follow-up period after UPC treatment is probably necessary in order to obtain more relevant results.

Thirdly, and lastly, this study also demonstrated that a physiological and ortho-gnathological therapy is able to restore not only masticatory function but also balance and postural harmony. The evolution of the orthodontic field does not rest upon further technological advances, which are already widespread in the field. Rather, it calls for the implementation of therapy in accordance with the physiology of the growing patient. This is not possible through the use of fixed orthodontic appliances, which produce predetermined and continuous forces. On the contrary, FGBs determine the application of intermittent and self-regulating forces. These features are important for achieving a functional rebalancing of the stomatognathic system during the orthodontic repositioning of teeth, as well as prompting a harmonious stimulus for the physiological growth of young patients.

Current knowledge does not justify orthodontic treatment on the basis of spinal and postural disorders and vice versa, but the knowledge of these conditions appears fundamental for patients' prognosis and diagnosis. It is necessary to deepen the topic with further research, leveraging on longer follow-up periods, larger study samples and validated investigation protocols and devices.

In a modern world in which the diffusion of the most avant-garde technologies supports growing sectorial hyper-specialization, dentists are paying more and more attention to details of the oral cavity, and the improvement of therapeutic knowledge and techniques applied to intra-oral structures. In doing so, they neglect a more global vision of the human being as a really complex unitary system. In reality, dental occlusion and masticatory function play a key role in the management of patients' general health, not only at a functional and postural level but also at a cognitive and emotional level, both at a developmental stage and in adulthood.

6. CONCLUSIONS

Albeit unable to make orthopedic diagnoses of spinal anomalies and pathologies, the scientifically-validated non-invasive postural devices we employed in this study proved suitable to provide information that is relevant to the work of dentists. We used three different instruments on growing patients with and without malocclusion, and we compared their results. The devices were: the Spinal Mouse, used to measure spinal flexibility; the Stabilometric Platform, used to assess postural balance; and the K7-I Kinesiograph, used to evaluate masticatory cycles.

To the best of our knowledge, this is the first existing research that concurrently analyzes the masticatory function and general posture of growing crossbite patients, assessed before and before/after a therapy conducted with the same orthodontic appliance. The parallel use of multiple postural/masticatory tools on the same patient increases the reliability of the assessment. At the same time, the reliability of the single instruments resulted of good-to-excellent level.

The patients from the study group (n = 102) were affected by unilateral posterior crossbite. After the initial masticatory, postural and spinal assessments, a subset of them (n = 40) underwent orthodontic therapy with a Function Generating Bite appliance to restore the malocclusion. After therapy, the assessments were repeated. All results were compared to those recorded among a control group of subjects with normal dental occlusion (n = 66), matched for age and gender.

The results highlighted that growing UPC patient showed the following repetitive masticatory and postural features before therapy:

- asymmetry of spinal lateral mobility in the frontal plane with higher flexibility on the crossbite side;

- greater postural instability in maximal intercuspation, with higher stabilometric values in the statokinesigram; monopodal support and unbalanced load distribution between right and left sides;

- asymmetry of masticatory function with a percentage of reverse chewing cycles greater than 15% on the crossbite side, both with soft and hard bolus, and a smaller number of average chewing cycles.

The simultaneous presence of all these signs may be considered a *pathognomonic sign* of dental unilateral posterior crossbite malocclusion. Therefore, awareness of these conditions can be crucially important in guiding orthodontists' diagnostic and prognosis efforts. Specifically, we defined the crossbite patient conditioned by all these non-physiological characteristics *congruous*. Congruous patients usually enjoy a favorable prognosis because they typically reflect all the features of the malocclusion. On the opposite, we defined *incongruous* the patient conditioned by only one of those three non-physiological characteristics (about 10% of total cases). Incongruous patients tend to be more difficult to treat, due to a larger number of structured anomalous compensations and the unconventional attitudes they establish. What derives is that all crossbite malocclusions are not the same, even if they appear clinically identical. By knowing this in advance, the clinician is able to plan for a longer and more focused treatment of incongruous patients.

Furthermore, in our research FGB therapy resulted in a restoration of symmetry both in posture and masticatory function for UPC patients, whom, after-therapy, showed symmetrical lateral spinal mobility and load distribution, absence of monopodal support and physiological chewing cycles on both sides.

Our suggestion for future research efforts is to take into consideration that, as our study revealed, the effects of orthodontic therapy on postural evolution and set-up, especially in stabilometric terms, require longer-term observations and broader follow-up periods to be thoroughly assessed. Then, *the future orientation* of our research will entail extending the investigation protocol to include a follow-up period of one year after crossbite correction, in order to analyze postural changes and evaluate the statistical significance of stabilometric parameters after a longer time. In addition, our intention is to apply the same methodological framework, i.e., concurrently analyze and compare posture and masticatory function, to another malocclusion with severe asymmetrical features: the asymmetrical molar class.

In conclusion, the study succeeded in statistically demonstrating that the crossbite is a type of malocclusion that influences the global posture of child patients. Arguably, unilateral posterior crossbite is neither a spinal pathology nor a reason for orthopedic consultation, but it is a dramatic malocclusion which establishes a large number of muscular, postural and functional compensations with widespread anomalous effects on growth. Only a functional orthodontic therapy that respects the biology and physiology of the stomatognathic system allows for a complete restoration of both the masticatory function and postural balance of the growing subject, thus promoting a harmonious functional, cognitive and structural development.

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ACRONYMS

Some acronyms have been used in this thesis, in order to facilitate reading. The acronyms used are usually well-known and are the following:

Central Nervous System = CNS

Unilateral Posterior Crossbite = UPC

Right Posterior Crossbite = right PC

Left Posterior Crossbite = left PC

Electromyography = EMG

Temporo-Mandibular Joint = TMJ

Function Generating Bite appliance = FGB

Center of Body Mass = CBM

Center Of Pressure = COP

Rest Position = RP

Maximal Intercuspation = MI

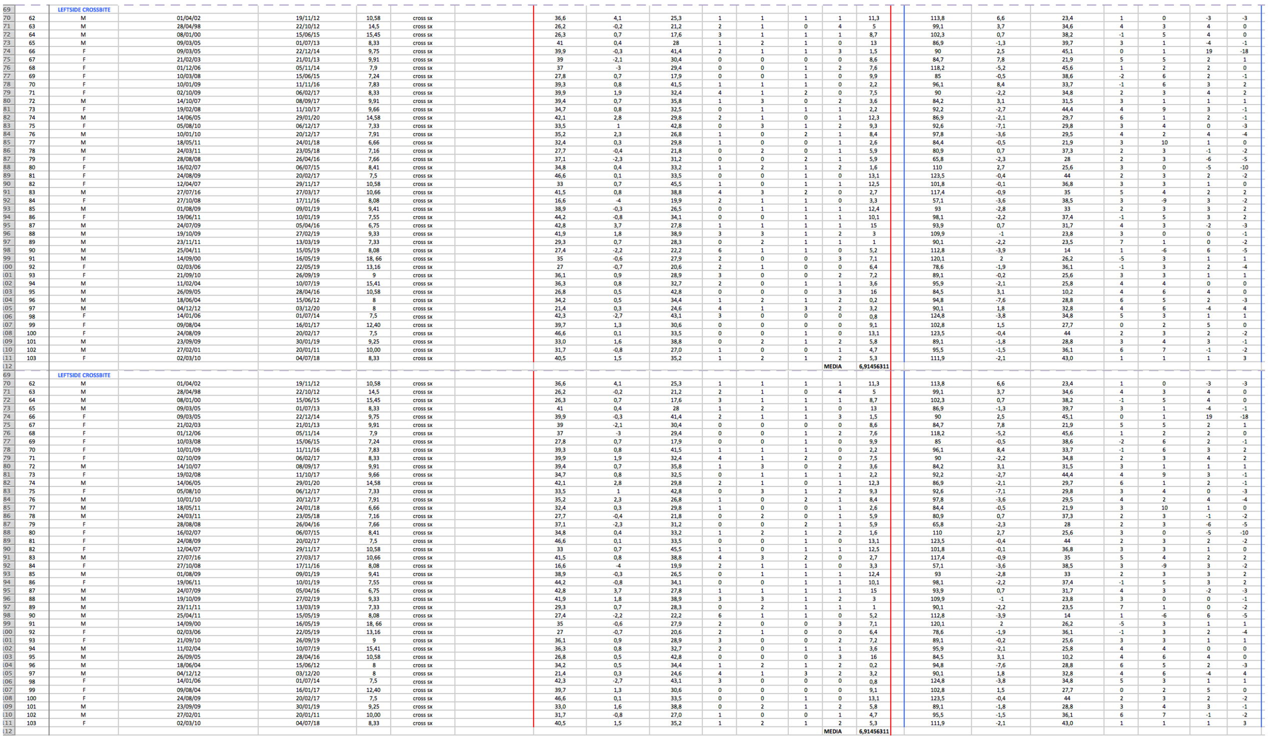
Control Group = CG

Crossbite Study Group = SG

8. APPENDIX

8.1. SUPPLEMENTARY MATERIALS

Table 8.1.a: Spinal Mouse data of crossbite patients before therapy



69		LEFTSIDE CROSSBITE																				
70	62	M	01/04/02	19/11/12	10,58	cross sx		36,6	4,1	25,3	1	1	1	1	11,3	113,8	6,6	23,4	1	0	-3	-3
71	63	M	28/04/98	22/10/12	14,5	cross sx		26,2	-0,2	21,2	2	1	0	4	5	99,1	3,7	34,6	4	3	4	0
72	64	M	08/01/00	15/06/15	15,45	cross sx		26,3	0,7	17,6	3	1	1	1	8,7	102,3	0,7	38,2	-1	5	4	0
73	65	M	09/03/05	01/07/13	8,33	cross sx		41	0,4	28	1	2	1	0	13	86,9	-1,3	39,7	3	1	-4	-1
74	66	F	09/03/05	22/12/14	9,75	cross sx		39,9	-0,3	41,4	2	1	1	3	1,5	90	2,5	45,1	0	1	19	-18
75	67	F	21/02/03	21/01/13	9,91	cross sx		39	-2,1	30,4	0	0	0	0	8,6	84,7	7,8	21,9	5	5	2	1
76	68	F	01/12/06	05/11/14	7,9	cross sx		37	-3	29,4	0	0	1	2	7,6	118,2	-5,2	45,6	1	2	2	0
77	69	F	10/03/08	15/06/15	7,24	cross sx		27,8	0,7	17,9	0	0	1	0	9,9	85	-0,5	38,6	-2	6	2	-1
78	70	F	10/01/09	11/11/16	7,83	cross sx		39,3	0,8	41,5	1	1	1	0	2,2	96,1	8,4	33,7	-1	6	3	2
79	71	F	02/10/09	06/02/17	8,33	cross sx		39,9	1,9	32,4	4	1	2	0	7,5	90	-2,2	34,8	2	3	4	2
80	72	M	14/10/07	08/09/17	9,91	cross sx		39,4	0,7	35,8	1	3	0	2	3,6	84,2	3,1	31,5	3	1	1	1
81	73	F	19/02/08	11/10/17	9,66	cross sx		34,7	0,8	32,5	0	1	1	1	2,2	92,2	-2,7	44,4	4	9	3	-1
82	74	M	14/06/05	29/01/20	14,58	cross sx		42,1	2,8	29,8	2	1	0	1	12,3	86,9	-2,1	29,7	6	1	2	-1
83	75	F	05/08/10	06/12/17	7,33	cross sx		33,5	1	42,8	0	3	1	2	9,3	92,6	-7,1	29,8	3	4	0	-3
84	76	M	10/01/10	20/12/17	7,91	cross sx		35,2	2,3	26,8	1	0	2	1	8,4	97,8	-3,6	29,5	4	2	4	-4
85	77	M	18/05/11	24/01/18	6,66	cross sx		32,4	0,3	29,8	1	0	0	1	2,6	84,4	-0,5	21,9	3	10	1	0
86	78	M	24/03/11	23/05/18	7,16	cross sx		27,7	-0,4	21,8	0	2	0	1	5,9	80,9	0,7	37,3	2	3	-1	-2
87	79	F	28/08/08	26/04/16	7,66	cross sx		37,1	-2,3	31,2	0	0	2	1	5,9	65,8	-2,3	28	2	3	-6	-5
88	80	F	16/02/07	06/07/15	8,41	cross sx		34,8	0,4	33,2	1	2	1	2	1,6	110	2,7	25,6	3	0	-5	-10
89	81	F	24/08/09	20/02/17	7,5	cross sx		46,6	0,1	33,5	0	0	1	0	13,1	123,5	-0,4	44	2	3	2	-2
90	82	F	12/04/07	29/11/17	10,58	cross sx		33	0,7	45,5	1	0	1	1	12,5	101,8	-0,1	36,8	3	3	1	0
91	83	M	27/07/16	27/03/17	10,66	cross sx		41,5	0,8	38,8	4	3	2	0	2,7	117,4	-0,9	35	5	4	2	2
92	84	F	27/10/08	17/11/16	8,08	cross sx		16,6	-4	19,9	2	1	1	0	3,3	57,1	-3,6	38,5	3	-9	3	-2
93	85	M	01/08/09	09/01/19	9,41	cross sx		38,9	-0,3	26,5	0	1	1	1	12,4	93	-2,8	33	2	3	3	2
94	86	F	19/06/11	10/01/19	7,55	cross sx		44,2	-0,8	34,1	0	0	1	1	10,1	98,1	-2,2	37,4	-1	5	3	2
95	87	M	24/07/09	05/04/16	6,75	cross sx		42,8	3,7	27,8	1	1	1	1	15	93,9	0,7	31,7	4	3	-2	-3
96	88	M	19/10/09	27/02/19	9,33	cross sx		41,9	1,8	38,9	3	3	1	2	3	109,9	-1	23,8	3	0	0	-1
97	89	M	23/11/11	13/03/19	7,33	cross sx		29,3	0,7	28,3	0	2	1	1	1	90,1	-2,2	23,5	7	1	0	-2
98	90	M	25/04/11	15/05/19	8,08	cross sx		27,4	-2,2	22,2	6	1	1	0	5,2	112,8	-3,9	14	1	-6	6	-5
99	91	M	14/09/00	16/05/19	18, 66	cross sx		35	-0,6	27,9	2	0	0	3	7,1	120,1	2	26,2	-5	3	1	1
100	92	F	02/03/06	22/05/19	13,16	cross sx		27	-0,7	20,6	2	1	0	0	6,4	78,6	-1,9	36,1	-1	3	2	-4
101	93	F	21/09/10	26/09/19	9	cross sx		36,1	0,9	28,9	3	0	0	2	7,2	89,1	-0,2	25,6	3	3	1	1
102	94	M	11/02/04	10/07/19	15,41	cross sx		36,3	0,8	32,7	2	0	1	1	3,6	95,9	-2,1	25,8	4	4	0	0
103	95	M	26/09/05	28/04/16	10,58	cross sx		26,8	0,5	42,8	0	0	0	3	16	84,5	3,1	10,2	4	6	4	0
104	96	M	18/06/04	15/06/12	8	cross sx		34,2	0,5	34,4	1	2	1	2	0,2	94,8	-7,6	28,8	6	5	2	-3
105	97	M	04/12/12	03/12/20	8	cross sx		21,4	0,3	24,6	4	1	3	2	3,2	90,1	1,8	32,8	4	6	-4	4
106	98	F	14/01/06	01/07/14	7,5	cross sx		42,3	-2,7	43,1	3	0	0	0	0,8	124,8	-3,8	34,8	5	3	1	1
107	99	F	09/08/04	16/01/17	12,40	cross sx		39,7	1,3	30,6	0	0	0	0	9,1	102,8	1,5	27,7	0	2	5	0
108	100	F	24/08/09	20/02/17	7,5	cross sx		46,6	0,1	33,5	0	0	1	0	13,1	123,5	-0,4	44	2	3	2	-2
109	101	M	23/09/09	30/01/19	9,25	cross sx		33,0	1,6	38,8	0	2	1	2	5,8	89,1	-1,8	28,8	3	4	3	-1
110	102	M	27/02/01	20/01/11	10,00	cross sx		31,7	-0,8	27,0	1	0	0	1	4,7	95,5	-1,5	36,1	6	7	-1	-2
111	103	F	02/03/10	04/07/18	8,33	cross sx		40,5	1,5	35,2	1	2	1	2	5,3	111,9	-2,1	43,0	1	1	1	3
112														MEDIA	6,91456311							

69		LEFTSIDE CROSSBITE																				
70	62	M	01/04/02	19/11/12	10,58	cross sx		36,6	4,1	25,3	1	1	1	1	11,3	113,8	6,6	23,4	1	0	-3	-3
71	63	M	28/04/98	22/10/12	14,5	cross sx		26,2	-0,2	21,2	2	1	0	4	5	99,1	3,7	34,6	4	3	4	0
72	64	M	08/01/00	15/06/15	15,45	cross sx		26,3	0,7	17,6	3	1	1	1	8,7	102,3	0,7	38,2	-1	5	4	0
73	65	M	09/03/05	01/07/13	8,33	cross sx		41	0,4	28	1	2	1	0	13	86,9	-1,3	39,7	3	1	-4	-1
74	66	F	09/03/05	22/12/14	9,75	cross sx		39,9	-0,3	41,4	2	1	1	3	1,5	90	2,5	45,1	0	1	19	-18
75	67	F	21/02/03	21/01/13	9,91	cross sx		39	-2,1	30,4	0	0	0	0	8,6	84,7	7,8	21,9	5	5	2	1
76	68	F	01/12/06	05/11/14	7,9	cross sx		37	-3	29,4	0	0	1	2	7,6	118,2	-5,2	45,6	1	2	2	0
77	69	F	10/03/08	15/06/15	7,24	cross sx		27,8	0,7	17,9	0	0	1	0	9,9	85	-0,5	38,6	-2	6	2	-1
78	70	F	10/01/09	11/11/16	7,83	cross sx		39,3	0,8	41,5	1	1	1	0	2,2	96,1	8,4	33,7	-1	6	3	2
79	71	F	02/10/09	06/02/17	8,33	cross sx		39,9	1,9	32,4	4	1	2	0	7,5	90	-2,2	34,8	2	3	4	2
80	72	M	14/10/07	08/09/17	9,91	cross sx		39,4	0,7	35,8	1	3	0	2	3,6	84,2	3,1	31,5	3	1	1	1
81	73	F	19/02/08	11/10/17	9,66	cross sx		34,7	0,8	32,5	0	1	1	1	2,2	92,2	-2,7	44,4	4	9	3	-1
82	74	M	14/06/05	29/01/20	14,58	cross sx		42,1	2,8	29,8	2	1	0	1	12,3	86,9	-2,1	29,7	6	1	2	-1
83	75	F	05/08/10	06/12/17	7,33	cross sx		33,5	1	42,8	0	3	1	2	9,3	92,6	-7,1	29,8	3	4	0	-3
84	76	M	10/01/10	20/12/17	7,91	cross sx		35,2	2,3	26,8	1	0	2	1	8,4	97,8	-3,6	29,5	4	2	4	-4
85	77	M	18/05/11	24/01/18	6,66	cross sx		32,4	0,3	29,8	1	0	0	1	2,6	84,4	-0,5	21,9	3	10	1	0
86	78	M	24/03/11	23/05/18	7,16	cross sx		27,7	-0,4	21,8	0	2	0	1	5,9	80,9	0,7	37,3	2	3	-1	-2
87	79	F	28/08/08	26/04/16	7,66	cross sx		37,1	-2,3	31,2	0	0	2	1	5,9	65,8	-2,3	28	2	3	-6	-5
88	80	F	16/02/07	06/07/15	8,41	cross sx		34,8	0,4	33,2	1	2	1	2	1,6	110	2,7	25,6	3	0	-5	-10
89	81	F	24/08/09	20/02/17	7,5	cross sx		46,6	0,1	33,5	0	0	1	0	13,1	123,5	-0,4	44	2	3	2	-2
90	82	F	12/04/07	29/11/17	10,58	cross sx		33	0,7	45,5	1	0	1	1	12,5	101,8	-0,1	36,8	3	3	1	0
91	83	M	27/07/16	27/03/17	10,66	cross sx		41,5	0,8	38,8	4	3	2	0	2,7	117,4	-0,9	35	5	4	2	2
92	84	F	27/10/08	17/11/16	8,08	cross sx		16,6	-4	19,9	2	1	1	0	3,3	57,1	-3,6	38,5	3	-9	3	-2
93	85	M	01/08/09	09/01/19	9,41	cross sx		38,9	-0,3	26,5	0	1	1	1	12,4	93	-2,8	33	2	3	3	2
94	86	F	19/06/11	10/01/19	7,55	cross sx		44,2	-0,8	34,1	0	0	1	1	10,1	98,1	-2,2	37,4	-1	5	3	2
95	87	M	24/07/09	05/04/16	6,75	cross sx		42,8	3,7	27,8	1	1	1	1	15	93,9	0,7	31,7	4	3	-2	-3
96	88	M	19/10/09	27/02/19	9,33	cross sx		41,9	1,8	38,9	3	3	1	2	3	109,9	-1	23,8	3	0	0	-1
97	89	M	23/11/11	13/03/19	7,33	cross sx		29,3	0,7	28,3	0	2	1	1	1	90,1	-2,2	23,5	7	1	0	-2
98	90	M	25/04/11	15/05/19	8,08	cross sx		27,4	-2,2	22,2	6	1	1	0	5,2	112,8	-3,9	14	1	-6	6	-5
99	91	M	14/09/00	16/05/19	18, 66	cross sx		35	-0,6	27,9	2	0	0	3	7,1	120,1	2	26,2	-5	3	1	1
100	92	F	02/03/06	22/05/19	13,16	cross sx		27	-0,7	20,6	2	1	0	0	6,4	78,6	-1,9	36,1	-1	3	2	-4
101	93	F	21/09/10	26/09/19	9	cross sx		36,1	0,9	28,9	3	0	0	2	7,2	89,1	-0,2	25,6	3	3	1	1
102	94	M	11/02/04	10/07/19	15,41	cross sx		36,3	0,8	32,7	2	0	1	1	3,6	95,9	-2,1	25,8	4	4	0	0
103	95	M	26/09/05	28/04/16	10,58	cross sx		26,8	0,5	42,8	0	0	0	3	16	84,5	3,1	10,2	4	6	4	0
104	96	M	18/06/04	15/06/12	8	cross sx		34,2	0,5	34,4	1	2	1	2	0,2	94,8	-7,6	28,8	6	5	2	-3
105	97	M	04/12/12	03/12/20	8	cross sx		21,4	0,3	24,6	4	1	3	2	3,2	90,1	1,8	32,8	4	6	-4	4
106	98	F	14/01/06	01/07/14	7,5	cross sx		42,3	-2,7	43,1	3	0	0	0	0,8	124,8	-3,8	34,8	5	3	1	1
107	99	F	09/08/04	16/01/17	12,40	cross sx		39,7	1,3	30,6	0	0	0	0	9,1	102,8	1,5	27,7	0	2	5	0
108	100	F	24/08/09	20/02/17	7,5	cross sx		46,6	0,1	33,5	0	0	1	0	13,1	123,5	-0,4	44	2	3	2	-2
109	101	M	23/09/09	30/01/19	9,25	cross sx		33,0	1,6	38,8	0	2	1	2	5,8	89,1	-1,8	28,8	3	4	3	-1
110	102	M	27/02/01	20/01/11	10,00	cross sx		31,7	-0,8	27,0	1	0	0	1	4,7	95,5	-1,5	36,1	6	7	-1	-2
111	103	F	02/03/10	04/07/18	8,33	cross sx		40,5	1,5	35,2	1	2	1	2	5,3	111,9	-2,1	43,0	1	1	1	3
112														MEDIA	6,91456311							

Table 8.1.b: Stabilometric Platform data of crossbite patients before therapy

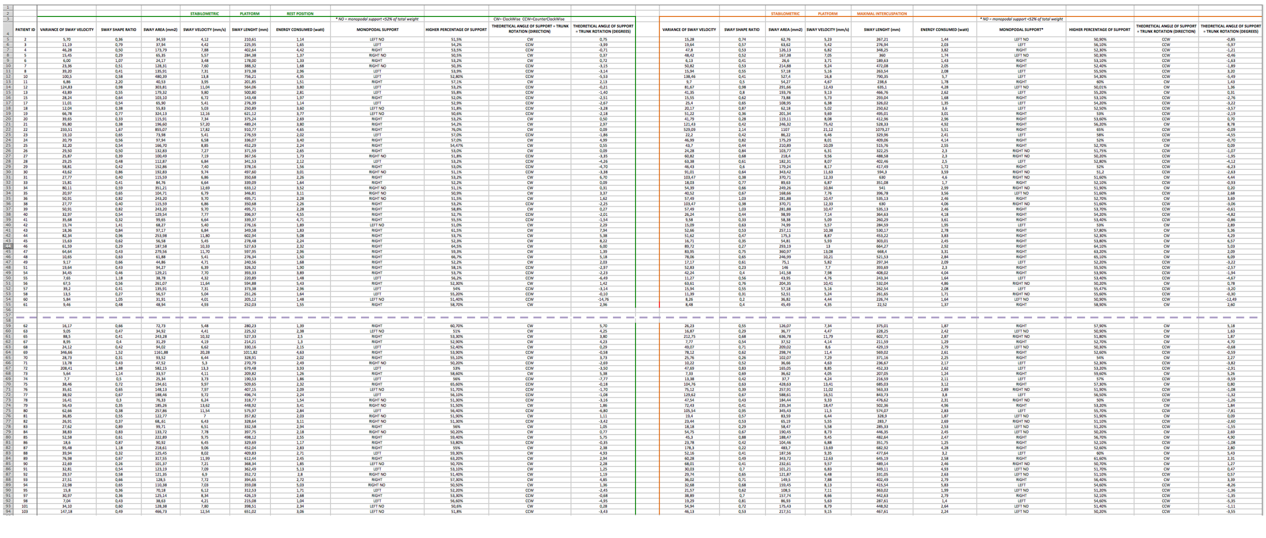
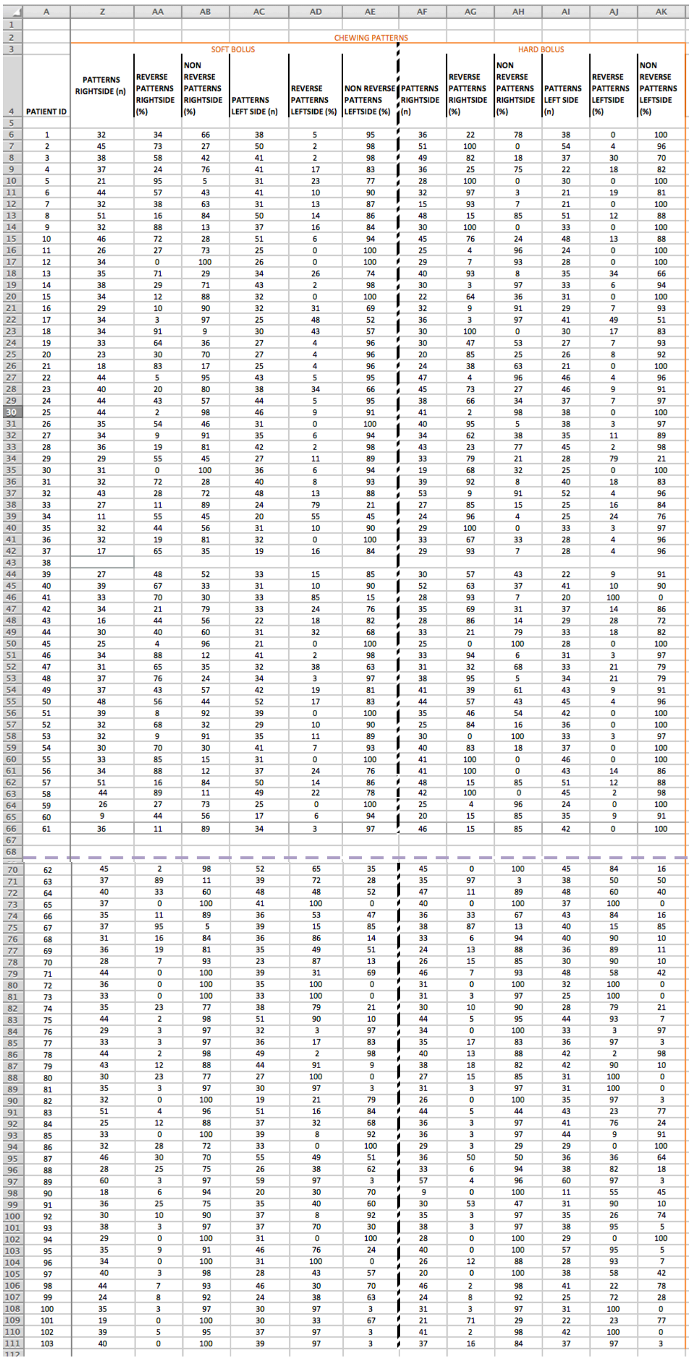
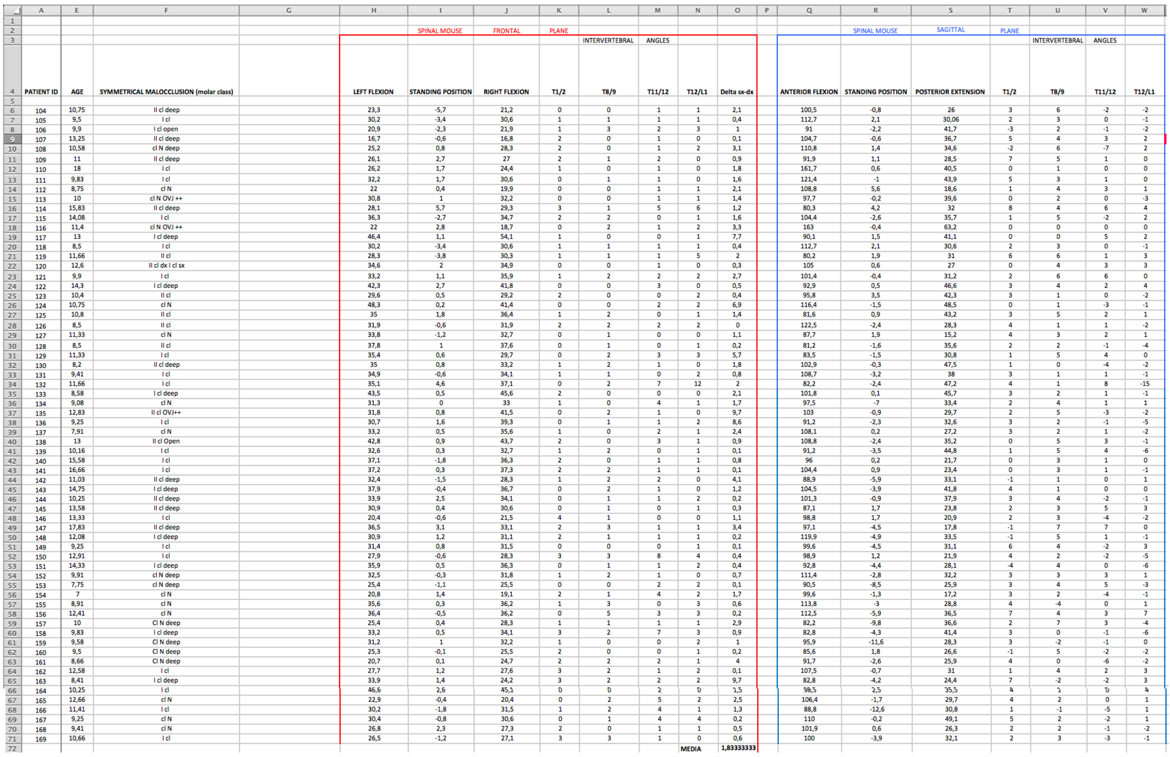


Table. 8.1.c: Chewing cycles data of crossbite patients before therapy



	A	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
1													
2							CHEWING PATTERNS						
3					SOFT BOLUS						HARD BOLUS		
4	PATIENT ID	PATTERNS RIGHTSIDE (n)	REVERSE PATTERNS RIGHTSIDE (%)	NON REVERSE PATTERNS RIGHTSIDE (%)	PATTERNS LEFT SIDE (n)	REVERSE PATTERNS LEFTSIDE (%)	NON REVERSE PATTERNS LEFTSIDE (%)	PATTERNS RIGHTSIDE (n)	REVERSE PATTERNS RIGHTSIDE (%)	NON REVERSE PATTERNS RIGHTSIDE (%)	PATTERNS LEFT SIDE (n)	REVERSE PATTERNS LEFTSIDE (%)	NON REVERSE PATTERNS LEFTSIDE (%)
5													
6	1	32	34	66	38	5	95	36	22	78	38	0	100
7	2	45	73	27	50	2	98	51	100	0	54	4	96
8	3	38	58	42	41	2	98	49	82	18	37	30	70
9	4	37	24	76	41	17	83	36	25	75	22	18	82
10	5	21	95	5	31	23	77	28	100	0	30	0	100
11	6	44	57	43	41	10	90	32	97	3	21	19	81
12	7	32	38	63	31	13	87	15	93	7	21	0	100
13	8	51	16	84	50	14	86	48	15	85	51	12	88
14	9	32	88	13	37	16	84	30	100	0	33	0	100
15	10	46	72	28	51	6	94	45	76	24	48	13	88
16	11	26	27	73	25	0	100	25	4	96	24	0	100
17	12	34	0	100	26	0	100	29	7	93	28	0	100
18	13	35	71	29	34	26	74	40	93	8	35	34	66
19	14	38	29	71	43	2	98	30	3	97	33	6	94
20	15	34	12	88	32	0	100	22	64	36	31	0	100
21	16	29	10	90	32	31	69	32	9	91	29	7	93
22	17	34	3	97	25	48	52	36	3	97	41	49	51
23	18	34	91	9	30	43	57	30	100	0	30	17	83
24	19	33	64	36	27	4	96	30	47	53	27	7	93
25	20	23	30	70	27	4	96	20	85	25	26	8	92
26	21	18	83	17	25	4	96	24	38	63	21	0	100
27	22	44	5	95	43	5	95	47	4	96	46	4	96
28	23	40	20	80	38	34	66	45	73	27	46	9	91
29	24	44	43	57	44	5	95	38	66	34	37	7	97
30	25	44	2	98	46	9	91	41	2	98	38	0	100
31	26	35	54	46	31	0	100	40	95	5	38	3	97
32	27	34	9	91	35	6	94	34	62	38	35	11	89
33	28	36	19	81	42	2	98	43	23	77	45	2	98
34	29	29	55	45	27	11	89	33	79	21	28	79	21
35	30	31	0	100	36	6	94	19	68	32	25	0	100
36	31	32	72	28	40	8	93	39	92	8	40	18	83
37	32	43	28	72	48	13	88	53	9	91	52	4	96
38	33	27	11	89	24	79	21	27	85	15	25	16	84
39	34	11	55	45	20	55	45	24	96	4	25	24	76
40	35	32	44	56	31	10	90	29	100	0	33	3	97
41	36	32	19	81	32	0	100	33	67	33	28	4	96
42	37	17	65	35	19	16	84	29	93	7	28	4	96
43	38												
44	39	27	48	52	33	15	85	30	57	43	22	9	91
45	40	39	67	33	31	10	90	52	63	37	41	10	90
46	41	33	70	30	33	85	15	28	93	7	20	100	0
47	42	34	21	79	33	24	76	35	69	31	37	14	86
48	43	16	44	56	22	18	82	28	86	14	29	28	72
49	44	30	40	60	31	32	68	33	21	79	33	18	82
50	45	25	4	96	21	0	100	25	0	100	28	0	100
51	46	34	88	12	41	2	98	33	94	6	31	3	97
52	47	31	65	35	32	38	63	31	32	68	33	21	79
53	48	37	76	24	34	3	97	38	95	5	34	21	79
54	49	37	43	57	42	19	81	41	39	61	43	9	91
55	50	48	56	44	52	17	83	44	57	43	45	4	96
56	51	39	8	92	39	0	100	35	46	54	42	0	100
57	52	32	68	32	29	10	90	25	84	16	36	0	100
58	53	32	9	91	35	11	89	30	0	100	33	3	97
59	54	30	70	30	41	7	93	40	83	18	37	0	100
60	55	33	85	15	31	0	100	41	100	0	46	0	100
61	56	34	88	12	37	24	76	41	100	0	43	14	86
62	57	51	16	84	50	14	86	48	15	85	51	12	88
63	58	44	89	11	49	22	78	42	100	0	45	2	98
64	59	26	27	73	25	0	100	25	4	96	24	0	100
65	60	9	44	56	17	6	94	20	15	85	35	9	91
66	61	36	11	89	34	3	97	46	15	85	42	0	100
67													
68													
70	62	45	2	98	52	65	35	45	0	100	45	84	16
71	63	37	89	11	39	72	28	35	97	3	38	50	50
72	64	40	33	60	48	48	52	47	11	89	48	60	40
73	65	37	0	100	41	100	0	40	0	100	37	100	0
74	66	35	11	89	36	53	47	36	33	67	43	84	16
75	67	37	95	5	39	15	85	38	87	13	40	15	85
76	68	31	16	84	36	86	14	33	6	94	40	90	10
77	69	36	19	81	35	49	51	24	13	88	36	89	11
78	70	28	7	93	23	87	13	26	15	85	30	90	10
79	71	44	0	100	39	31	69	46	7	93	48	58	42
80	72	36	0	100	35	100	0	31	0	100	32	100	0
81	73	33	0	100	33	100	0	31	3	97	25	100	0
82	74	35	23	77	38	79	21	30	10	90	28	79	21
83	75	44	2	98	51	90	10	44	5	95	44	93	7
84	76	29	3	97	32	3	97	34	0	100	33	3	97
85	77	33	3	97	36	17	83	35	17	83	36	97	3
86	78	44	2	98	49	2	98	40	13	88	42	2	98
87	79	43	12	88	44	91	9	38	18	82	42	90	10
88	80	30	23	77	27	100	0	27	15	85	31	100	0
89	81	35	3	97	30	97	3	31	3	97	31	100	0
90	82	32	0	100	19	21	79	26	0	100	35	97	3
91	83	51	4	96	51	16	84	44	5	44	43	23	77
92	84	25	12	88	37	32	68	36	3	97	41	76	24
93	85	33	0	100	39	8	92	36	3	97	44	9	91
94	86	32	28	72	33	0	100	29	3	29	29	0	100
95	87	46	30	70	55	49	51	36	50	50	36	36	64
96	88	28	25	75	26	38	62	33	6	94	38	82	18
97	89	60	3	97	59	97	3	57	4	96	60	97	3
98	90	18	6	94	20	30	70	9	0	100	11	55	45
99	91	36	25	75	35	40	60	30	53	47	31	90	10
100	92	30	10	90	37	8	92	35	3	97	35	26	74
101	93	38	3	97	37	70	30	38	3	97	38	95	5
102	94	29	0	100	31	0	100	28	0	100	29	0	100
103	95	35	9	91	46	76	24	40	0	100	57	95	5
104	96	34	0	100	31	100	0	26	12	88	28	93	7
105	97	40	3	98	28	43	57	20	0	100	38	58	42
106	98	44	7	93	46	30	70	46	2	98	41	22	78
107	99	24	8	92	24	38	63	24	8	92	25	72	28
108	100	35	3	97	30	97	3	31	3	97	31	100	0
109	101	19	0	100	30	33	67	21	71	29	22	23	77
110	102	39	5	95	37	97	3	41	2	98	42	100	0
111	103	40	0	100	39	97	3	37	16	84	37	97	3
112													

Table. 8.1.d: Spinal Mouse data of the control group



	A	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1																				
2						SPINAL MOUSE	FRONTAL	PLANE							SPINAL MOUSE	SAGITTAL	PLANE			
3									INTERVERTEBRAL	ANGLES								INTERVERTEBRAL	ANGLES	
4	PATIENT ID	AGE	SYMMETRICAL MALOCCLUSION (molar class)		LEFT FLEXION	STANDING POSITION	RIGHT FLEXION	T1/2	T8/9	T11/12	T12/L1	Delta sx-dx		ANTERIOR FLEXION	STANDING POSITION	POSTERIOR EXTENSION	T1/2	T8/9	T11/12	T12/L1
5																				
6	104	10,75	II cl deep		23,3	-5,7	21,2	0	0	1	1	2,1		100,5	-0,8	26	3	6	-2	-2
7	105	9,5	I cl		30,2	-3,4	30,6	1	1	1	1	0,4		112,7	2,1	30,06	2	3	0	-1
8	106	9,9	I cl open		20,9	-2,3	21,9	1	3	2	3	1		91	-2,2	41,7	-3	2	-1	-2
9	107	13,25	II cl deep		16,7	-0,6	16,8	2	0	1	0	0,1		104,7	-0,6	36,7	5	4	3	2
10	108	10,58	cl N deep		25,2	0,8	28,3	2	0	1	2	3,1		110,8	1,4	34,6	-2	6	-7	2
11	109	11	II cl deep		26,1	2,7	27	2	1	2	0	0,9		91,9	1,1	28,5	7	5	1	0
12	110	18	I cl		26,2	1,7	24,4	1	0	1	0	1,8		161,7	0,6	40,5	0	1	0	0
13	111	9,83	I cl		32,2	1,7	30,6	0	1	1	0	1,6		121,4	-1	43,9	5	3	1	0
14	112	8,75	cl N		22	0,4	19,9	0	0	1	1	2,1		108,8	5,6	18,6	1	4	3	1
15	113	10	cl N OVJ ++		30,8	1	32,2	0	0	1	1	1,4		97,7	-0,2	39,6	0	2	0	-3
16	114	15,83	II cl deep		28,1	5,7	29,3	3	1	5	6	1,2		80,3	4,2	32	8	4	6	4
17	115	14,08	I cl		36,3	-2,7	34,7	2	2	0	1	1,6		104,4	-2,6	35,7	1	5	-2	2
18	116	11,4	cl N OVJ ++		22	2,8	18,7	0	2	1	2	3,3		163	-0,4	63,2	0	0	0	0
19	117	13	I cl deep		46,4	1,1	54,1	1	0	0	1	7,7		90,1	1,5	41,1	0	0	5	2
20	118	8,5	I cl		30,2	-3,4	30,6	1	1	1	1	0,4		112,7	2,1	30,6	2	3	0	-1
21	119	11,66	II cl		28,3	-3,8	30,3	1	1	1	5	2		80,2	1,9	31	6	6	1	3
22	120	12,6	II cl dx I cl sx		34,6	2	34,9	0	0	1	0	0,3		105	0,6	27	0	4	3	3
23	121	9,9	I cl		33,2	1,1	35,9	1	2	2	2	2,7		101,4	-0,4	31,2	2	6	6	0
24	122	14,3	I cl deep		42,3	2,7	41,8	0	0	3	0	0,5		92,9	0,5	46,6	3	4	2	4
25	123	10,4	II cl		29,6	0,5	29,2	2	0	0	2	0,4		95,8	3,5	42,3	3	1	0	-2
26	124	10,75	cl N		48,3	0,2	41,4	0	0	2	2	6,9		116,4	-1,5	48,5	0	1	-3	-1
27	125	10,8	II cl		35	1,8	36,4	1	2	0	1	1,4		81,6	0,9	43,2	3	5	2	1
28	126	8,5	II cl		31,9	-0,6	31,9	2	2	2	2	0		122,5	-2,4	28,3	4	1	1	-2
29	127	11,33	cl N		33,8	-1,2	32,7	0	1	0	0	1,1		87,7	1,9	15,2	4	3	2	1
30	128	8,5	II cl		37,8	1	37,6	0	1	0	1	0,2		81,2	-1,6	35,6	2	2	-1	-4
31	129	11,33	I cl		35,4	0,6	29,7	0	2	3	3	5,7		83,5	-1,5	30,8	1	5	4	0
32	130	8,2	II cl deep		35	0,8	33,2	1	2	1	0	1,8		102,9	-0,3	47,5	1	0	-4	-2
33	131	9,41	I cl		34,9	-0,6	34,1	1	1	0	2	0,8		108,7	-3,2	38	3	1	1	-1
34	132	11,66	I cl		35,1	4,6	37,1	0	2	7	12	2		82,2	-2,4	47,2	4	1	8	-15
35	133	8,58	I cl deep		43,5	0,5	45,6	2	0	0	0	2,1		101,8	0,1	45,7	3	2	1	-1
36	134	9,08	cl N		31,3	0	33	1	0	4	1	1,7		97,5	-7	33,4	2	4	1	1
37	135	12,83	II cl OVJ++		31,8	0,8	41,5	0	2	1	0	9,7		103	-0,9	29,7	2	5	-3	-2
38	136	9,25	I cl		30,7	1,6	39,3	0	1	1	2	8,6		91,2	-2,3	32,6	3	2	-1	-5
39	137	7,91	cl N		33,2	0,5	35,6	1	0	2	1	2,4		108,1	0,2	27,2	3	2	1	-2
40	138	13	II cl Open		42,8	0,9	43,7	2	0	3	1	0,9		108,8	-2,4	35,2	0	5	3	-1
41	139	10,16	I cl		32,6	0,3	32,7	1	2	0	1	0,1		91,2	-3,5	44,8	1	5	4	-6
42	140	15,58	I cl		37,1	-1,8	36,3	2	0	1	1	0,8		96	0,2	21,7	0	3	1	0
43	141	16,66	I cl		37,2	0,3	37,3	2	2	1	1	0,1		104,4	0,9	23,4	0	3	1	-1
44	142	11,03	II cl deep		32,4	-1,5	28,3	1	2	2	0	4,1		88,9	-5,9	33,1	-1	1	0	1
45	143	14,75	I cl deep		37,9	-0,4	36,7	0	2	1	0	1,2		104,5	-3,9	41,8	4	1	0	0
46	144	10,25	II cl deep		33,9	2,5	34,1	0	1	1	2	0,2		101,3	-0,9	37,9	3	4	-2	-1
47	145	13,58	II cl deep		30,9	0,4	30,6	0	1	0	1	0,3		87,1	1,7	23,8	2	3	5	3
48	146	13,33	I cl		20,4	-0,6	21,5	4	1	0	0	1,1		98,8	1,7	20,9	2	3	-4	-2
49	147	17,83	II cl deep		36,5	3,1	33,1	2	3	1	1	3,4		97,1	-4,5	17,8	-1	7	7	0
50	148	12,08	I cl deep		30,9	1,2	31,1	2	1	1	1	0,2		119,9	-4,9	33,5	-1	5	1	-1
51	149	9,25	I cl		31,4	0,8	31,5	0	0	0	1	0,1		99,6	-4,5	31,1	6	4	-2	3
52	150	12,91	I cl		27,9	-0,6	28,3	3	3	8	4	0,4		98,9	1,2	21,9	4	2	-2	-5
53	151	14,33	I cl deep		35,9	0,5	36,3	0	1	1	2	0,4		92,8	-4,4	28,1	-4	4	0	-6
54	152	9,91	cl N deep		32,5	-0,3	31,8	1	2	1	0	0,7		111,4	-2,8	32,2	3	3	3	1
55	153	7,75	cl N deep		25,4	-1,1	25,5	0	0	2	2	0,1		90,5	-8,5	25,9	3	4	5	-3
56	154	7	cl N		20,8	1,4	19,1	2	1	4	2	1,7		99,6	-1,3	17,2	3	2	-4	-1
57	155	8,91	cl N		35,6	0,3	36,2	1	3	0	3	0,6		113,8	-3	28,8	4	-4	0	1
58	156	12,41	cl N		36,4	-0,5	36,2	0	5	3	3	0,2		112,5	-5,9	36,5	7	4	3	7
59	157	10	Cl N deep		25,4	0,4	28,3	1	1	1	1	2,9		82,2	-9,8	36,6	2	7	3	-4
60	158	9,83	I cl deep		33,2	0,5	34,1	3	2	7	3	0,9		82,8	-4,3	41,4	3	0	-1	-6
61	159	9,58	Cl N deep		31,2	1	32,2	1	0	0	2	1		95,9	-11,6	28,3	3	-2	-1	0
62	160	9,5	Cl N deep		25,3	-0,1	25,5	2	0	0	1	0,2		85,6	1,8	26,6	-1	5	-2	-2
63	161	8,66	Cl N deep		20,7	0,1	24,7	2	2	2	1	4		91,7	-2,6	25,9	4	0	-6	-2
64	162	12,58	I cl		27,7	1,2	27,6	3	2	1	2	0,1		107,5	-0,7	31	1	4	2	3
65	163	8,41	I cl deep		33,9	1,4	24,2	3	2	2	2	9,7		82,8	-4,2	24,4	7	-2	-2	3
66	164	10,25	I cl		46,6	2,6	45,1	0	0	2	0	1,5		98,5	2,5	35,5	4	1	0	4
67	165	12,66	cl N		22,9	-0,4	20,4	0	2	5	2	2,5		106,4	-1,7	29,7	4	2	0	1
68	166	11,41	I cl		30,2	-1,8	31,5	1	2	4	1	1,3		88,8	-12,6	30,8	1	-1	-5	1
69	167	9,25	cl N		30,4	-0,8	30,6	0	1	4	4	0,2		110	-0,2	49,1	5	2	-2	1
70	168	9,41	cl N		26,8	2,3	27,3	2	0	1	1	0,5		101,9	0,6	26,3	2	2	-1	-2
71	169	10,66	I cl		26,5	-1,2	27,1	3	3	1	0	0,6		100	-3,9	32,1	2	3	-3	-1
72											MEDIA	1,83333333								

Table 8.1.e: Stabilometric Platform data of the control group

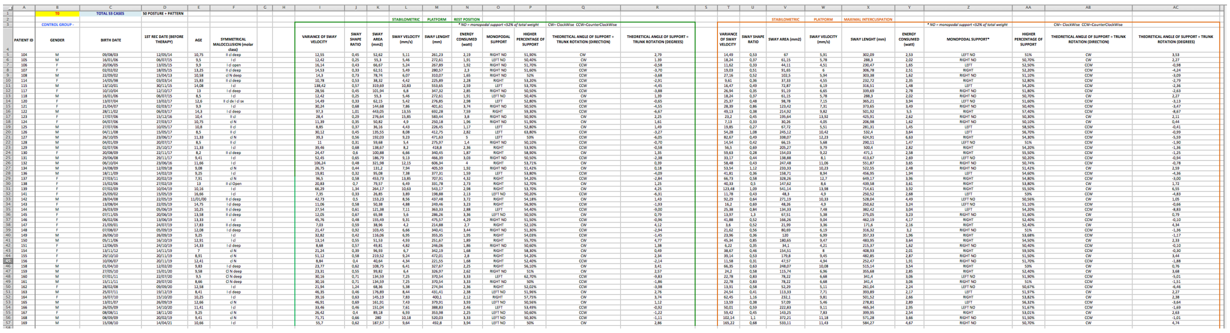
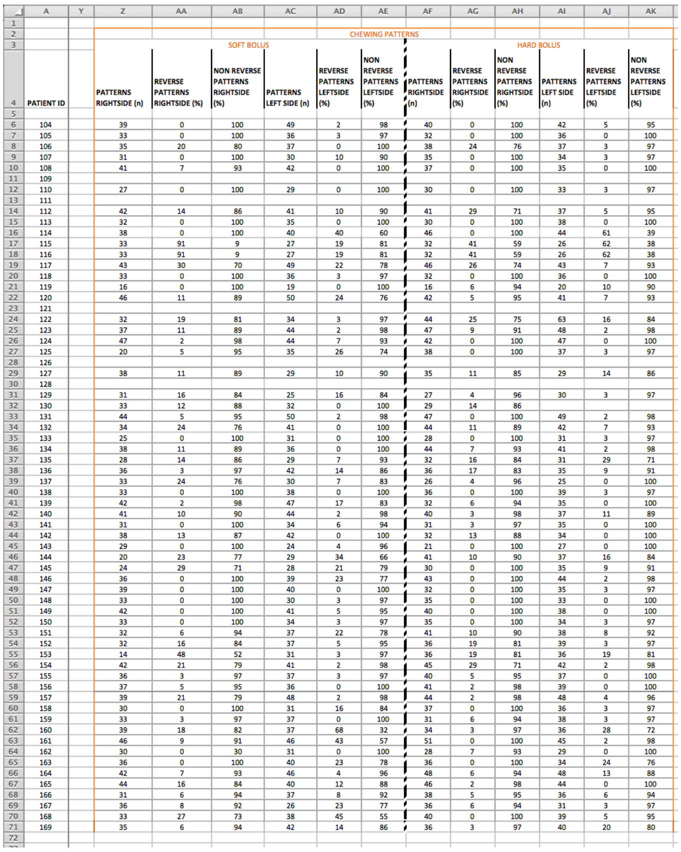
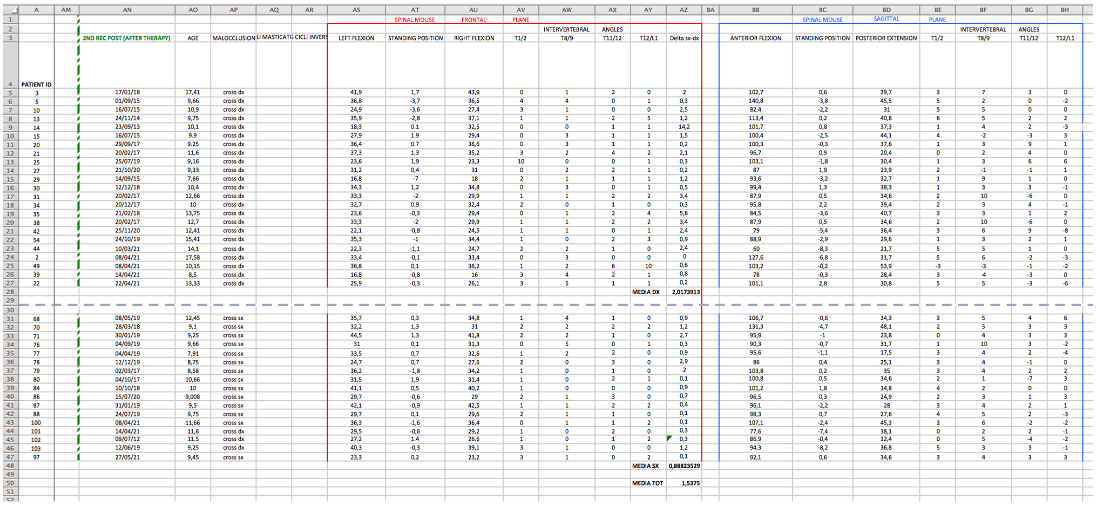


Table. 8.1.f: Chewing cycles data of the control group



	CHEWING PATTERNS											
	SOFT BOLUS						HARD BOLUS					
PATIENT ID	PATTERNS RIGHTSIDE (n)	REVERSE PATTERNS RIGHTSIDE (%)	NON REVERSE PATTERNS RIGHTSIDE (%)	PATTERNS LEFT SIDE (n)	REVERSE PATTERNS LEFTSIDE (%)	NON REVERSE PATTERNS LEFTSIDE (%)	PATTERNS RIGHTSIDE (n)	REVERSE PATTERNS RIGHTSIDE (%)	NON REVERSE PATTERNS RIGHTSIDE (%)	PATTERNS LEFT SIDE (n)	REVERSE PATTERNS LEFTSIDE (%)	NON REVERSE PATTERNS LEFTSIDE (%)
104	39	0	100	49	2	98	40	0	100	42	5	95
105	33	0	100	36	3	97	32	0	100	36	0	100
106	35	20	80	37	0	100	38	24	76	37	3	97
107	31	0	100	30	10	90	35	0	100	34	3	97
108	41	7	93	42	0	100	37	0	100	35	0	100
109												
110	27	0	100	29	0	100	30	0	100	33	3	97
111												
112	42	14	86	41	10	90	41	29	71	37	5	95
113	32	0	100	35	0	100	30	0	100	38	0	100
114	38	0	100	40	40	60	46	0	100	44	61	39
115	33	91	9	27	19	81	32	41	59	26	62	38
116	33	91	9	27	19	81	32	41	59	26	62	38
117	43	30	70	49	22	78	46	26	74	43	7	93
118	33	0	100	36	3	97	32	0	100	36	0	100
119	16	0	100	19	0	100	16	6	94	20	10	90
120	46	11	89	50	24	76	42	5	95	41	7	93
121												
122	32	19	81	34	3	97	44	25	75	63	16	84
123	37	11	89	44	2	98	47	9	91	48	2	98
124	47	2	98	44	7	93	42	0	100	47	0	100
125	20	5	95	35	26	74	38	0	100	37	3	97
126												
127	38	11	89	29	10	90	35	11	85	29	14	86
128												
129	31	16	84	25	16	84	27	4	96	30	3	97
130	33	12	88	32	0	100	29	14	86			
131	44	5	95	50	2	98	47	0	100	49	2	98
132	34	24	76	41	0	100	44	11	89	42	7	93
133	25	0	100	31	0	100	28	0	100	31	3	97
134	38	11	89	36	0	100	44	7	93	41	2	98
135	28	14	86	29	7	93	32	16	84	31	29	71
136	36	3	97	42	14	86	36	17	83	35	9	91
137	33	24	76	30	7	83	26	4	96	25	0	100
138	33	0	100	38	0	100	36	0	100	39	3	97
139	42	2	98	47	17	83	32	6	94	35	0	100
140	41	10	90	44	2	98	40	3	98	37	11	89
141	31	0	100	34	6	94	31	3	97	35	0	100
142	38	13	87	42	0	100	32	13	88	34	0	100
143	29	0	100	24	4	96	21	0	100	27	0	100
144	20	23	77	29	34	66	41	10	90	37	16	84
145	24	29	71	28	21	79	30	0	100	35	9	91
146	36	0	100	39	23	77	43	0	100	44	2	98
147	39	0	100	40	0	100	32	0	100	35	3	97
148	33	0	100	30	3	97	35	0	100	33	0	100
149	42	0	100	41	5	95	40	0	100	38	0	100
150	33	0	100	34	3	97	35	0	100	34	3	97
151	32	6	94	37	22	78	41	10	90	38	8	92
152	32	16	84	37	5	95	36	19	81	39	3	97
153	14	48	52	31	3	97	36	19	81	36	19	81
154	42	21	79	41	2	98	45	29	71	42	2	98
155	36	3	97	37	3	97	40	5	95	37	0	100
156	37	5	95	36	0	100	41	2	98	39	0	100
157	39	21	79	48	2	98	44	2	98	48	4	96
158	30	0	100	31	16	84	37	0	100	36	3	97
159	33	3	97	37	0	100	31	6	94	38	3	97
160	39	18	82	37	68	32	34	3	97	36	28	72
161	46	9	91	46	43	57	51	0	100	45	2	98
162	30	0	30	31	0	100	28	7	93	29	0	100
163	36	0	100	40	23	78	36	0	100	34	24	76
164	42	7	93	46	4	96	48	6	94	48	13	88
165	44	16	84	40	12	88	46	2	98	44	0	100
166	31	6	94	37	8	92	38	5	95	36	6	94
167	36	8	92	26	23	77	36	6	94	31	3	97
168	33	27	73	38	45	55	40	0	100	39	5	95
169	35	6	94	42	14	86	36	3	97	40	20	80

Table 8.1.g: Spinal Mouse data of crossbite patients after therapy



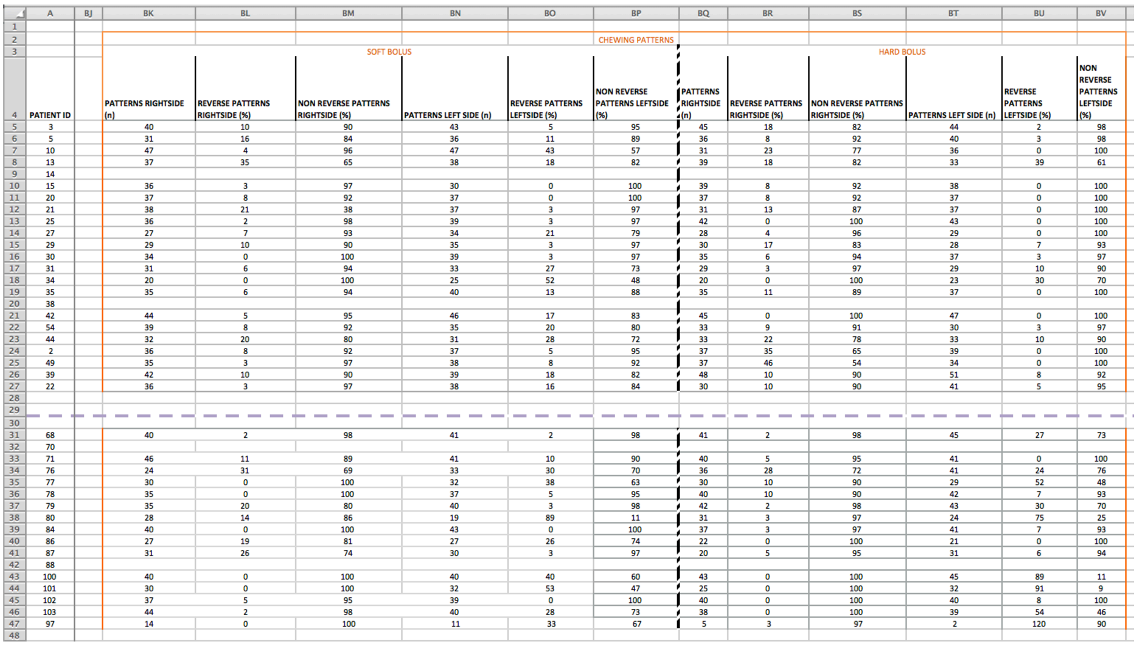
							SPINAL MOUSE	FRONTAL	PLANE						SPINAL MOUSE	SAGITTAL	PLANE			
										INTERVERTEBRAL	ANGLES							INTERVERTEBRAL	ANGLES	
PATIENT ID	2ND REC POST (AFTER THERAPY)	AGE	MALOCCLUSION	LI MASTICATG	CICLI INVERS	LEFT FLEXION	STANDING POSITION	RIGHT FLEXION	T1/2	T8/9	T11/12	T12/L1	Delta sx-dx	ANTERIOR FLEXION	STANDING POSITION	POSTERIOR EXTENSION	T1/2	T8/9	T11/12	T12/L1
3	17/01/18	17,41	cross dx			41,9	1,7	43,9	0	1	2	0	2	102,7	0,6	39,7	3	7	3	0
5	01/09/15	9,66	cross dx			36,8	-3,7	36,5	4	4	0	1	0,3	140,8	-3,8	45,5	5	2	0	-2
10	16/07/15	10,9	cross dx			24,9	-3,6	27,4	3	1	0	0	2,5	82,4	-2,2	31	5	5	0	0
13	24/11/14	9,75	cross dx			35,9	-2,8	37,1	1	1	2	5	1,2	113,4	0,2	40,8	6	5	2	2
14	23/09/13	10,1	cross dx			18,3	0.1	32,5	0	0	1	1	14,2	101,7	0,8	37,3	1	4	2	-3
15	16/07/15	9.9	cross dx			27,9	1.9	29,4	0	3	1	1	1,5	100,4	-2,5	44,1	4	-2	-3	3
20	29/09/17	9.25	cross dx			36,4	0.7	36,6	0	3	1	1	0,2	100,3	-0,3	37,6	1	3	9	1
21	20/02/17	11,6	cross dx			37,3	1,3	35,2	3	2	4	2	2,1	96,7	0,9	20,4	0	2	4	0
25	25/07/19	9,16	cross dx			23,6	1,9	23,3	10	0	0	1	0,3	103,1	-1,8	30,4	1	3	6	6
27	21/10/20	9,33	cross dx			31,2	0,4	31	0	2	2	1	0,2	87	1,9	23,9	2	-1	-1	1
29	14/09/15	7,66	cross dx			16,8	-7	18	2	1	1	1	1,2	93,6	-3,2	32,7	1	9	1	0
30	12/12/18	10,4	cross dx			34,3	1,2	34,8	0	3	0	1	0,5	99,4	1,3	38,3	1	3	3	-1
31	20/02/17	12,66	cross dx			33,3	-2	29,9	1	1	2	2	3,4	87,9	0,5	34,6	2	10	-6	0
34	20/12/17	10	cross dx			32,7	0,9	32,4	2	0	1	0	0,3	95,8	2,2	39,4	2	3	4	-1
35	21/02/18	13,75	cross dx			23,6	-0,3	29,4	0	1	2	4	5,8	84,5	-3,6	40,7	3	3	1	2
38	20/02/17	12,7	cross dx			33,3	-2	29,9	1	1	2	2	3,4	87,9	0,5	34,6	2	10	-6	0
42	25/11/20	12,41	cross dx			22,1	-0,8	24,5	1	1	0	1	2,4	79	-5,4	36,4	3	6	9	-8
54	24/10/19	15,41	cross dx			35,3	-1	34,4	1	0	2	3	0,9	88,9	-2,9	29,6	1	3	2	1
44	10/03/21	14,1	cross dx			22,3	-1,1	24,7	2	2	1	0	2,4	60	-8,3	21,7	5	5	1	0
2	08/04/21	17,58	cross dx			33,4	-0,1	33,4	0	3	0	0	0	127,6	-6,8	31,7	5	6	-2	-3
49	08/04/21	10,15	cross dx			36,8	0,1	36,2	1	2	6	10	0,6	103,2	-0,2	53,9	-3	-3	-1	-2
39	14/04/21	8,5	cross dx			16,8	-0,8	16	3	4	2	1	0,8	78	-0,3	28,4	3	-4	-3	0
22	22/04/21	13,33	cross dx			25,9	-0,3	26,1	3	5	1	1	0,2	101,1	2,8	30,8	5	5	-3	-6
												MEDIA DX	2,0173913							
68	08/05/19	12,45	cross sx			35,7	0,3	34,8	1	4	1	0	0,9	106,7	-0,6	34,3	3	5	4	6
70	28/03/18	9,1	cross sx			32,2	1,3	31	2	2	2	2	1,2	131,3	-4,7	48,1	2	5	3	3
71	30/01/19	9,25	cross sx			44,5	1,3	41,8	2	2	1	0	2,7	95,9	-1	23,8	0	4	3	3
76	04/09/19	9,66	cross sx			31	0,1	31,3	0	5	0	1	0,3	90,3	-0,7	31,7	1	10	3	-2
77	04/04/19	7,91	cross sx			33,5	0,7	32,6	1	2	2	0	0,9	95,6	-1,1	17,5	3	4	2	-4
78	12/12/19	8,75	cross sx			24,7	0,7	27,6	2	0	3	0	2,9	86	0,4	25,1	3	4	-1	0
79	02/03/17	8,58	cross sx			36,2	-1,8	34,2	1	0	1	0	2	103,8	0,2	35	3	4	2	2
80	04/10/17	10,66	cross sx			31,5	1,9	31,4	1	0	2	1	0,1	100,8	0,5	34,6	2	1	-7	3
84	10/10/18	10	cross sx			41,1	0,5	40,2	1	0	0	0	0,9	101,2	1,8	34,8	4	2	0	0
86	15/07/20	9,008	cross sx			29,7	-0,6	29	2	1	3	0	0,7	96,5	0,3	24,9	2	3	1	3
87	31/01/19	9,5	cross sx			42,1	-0,9	42,5	1	1	2	2	0,4	96,1	-2,2	28	3	4	2	1
88	24/07/19	9,75	cross sx			29,7	0,1	29,6	2	1	1	0	0,1	98,3	0,7	27,6	4	5	2	-3
100	08/04/21	11,66	cross sx			36,3	-1,6	36,4	0	1	1	2	0,1	107,1	-2,4	45,3	3	6	-2	-2
101	14/04/21	11,6	cross dx			29,5	-0,6	29,2	1	0	2	0	0,3	77,6	-7,4	38,1	0	2	2	-1
102	09/07/12	11.5	cross dx			27.2	1.4	26.6	1	0	1	2	0,3	86.9	-0,4	32,4	0	5	-4	-2
103	12/06/19	9,25	cross dx			40,3	-0,3	39,1	3	1	0	0	1,2	94,3	-8,2	36,8	5	3	3	-1
97	27/05/21	9,45	cross sx			23,3	0,2	23,2	3	1	0	2	0,1	92,1	0,6	34,6	3	4	3	3
												MEDIA SX	0,88823529							
												MEDIA TOT	1,5375							

Table 8.1.h: Stabilometric Platform data of crossbite patients after therapy

	A	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU
1											
2					STABILOMETRIC	PLATFORM	REST POSITION				
3								* NO = monopodal support <52% of total weight		CW= ClockWise CCW=CounterClockWise	
4	PATIENT ID	VARIANCE OF SWAY VELOCITY	SWAY SHAPE RATIO	SWAY AREA (mm2)	SWAY VELOCITY (mm/s)	SWAY LENGHT (mm)	ENERGY CONSUMED (watt)	MONOPODAL SUPPORT	HIGHER PERCENTAGE OF SUPPORT	THEORETICAL ANGLE OF SUPPORT = TRUNK ROTATION (DIRECTION)	THEORETICAL ANGLE OF SUPPORT = TRUNK ROTATION (DEGREES)
5	3	18,98	0,36	57,29	5,72	292,16	3,03	LEFT	52,80%	CCW	-4,07
6	5	36,15	0,29	173,41	8,12	348,25	1,83	RIGHT NO	50,40%	CW	0,53
7	10	121,39	0,42	508,31	14.90	743,75	4.50	LEFT	54,30%	CCW	-5,53
8	13	49,5	0,82	205,06	10,42	515,85	2,7	LEFT	52,90%	CCW	-0,23
9	15	23,23	0,45	75,31	5,89	293,85	1,94	RIGHT	54,30%	CCW	-2,27
10	20	24,5	0,51	86,71	7,24	369,84	2,86	RIGHT	55,20%	CCW	-1,83
11	21	90,82	0,41	268,28	10,15	518,55	3,75	RIGHT	58,70%	CW	8,78
12	25	19,28	0,39	69,01	6,44	329,29	2,03	RIGHT NO	51,25%	CW	1,73
13	27	29,26	0,66	129,73	7,68	392,27	3,15	LEFT NO	50,95%	CCW	-0,44
14	29	85,82	0,38	206,07	9,34	465,98	2,1	LEFT NO	50,10%	CCW	-1,99
15	30	83,97	0,49	267,15	10,25	523,57	3,83	RIGHT	52,40%	CW	0,64
16	31	21,3	0,41	74,27	5,41	276,31	2,95	RIGHT NO	51,90%	CW	6,03
17	34	18,13	0,55	95,75	6,93	354,12	2,26	RIGHT	56,80%	CW	3,56
18	35	28,45	0,72	111,66	6,91	352,92	3,26	RIGHT NO	50,40%	CW	1,46
19	38	21,3	0,41	74,27	5,41	276,31	2,95	RIGHT NO	51,90%	CCW	-0,64
20	42	27,31	0,67	95	5,91	302,05	2,6	LEFT	52,70%	CCW	-5,97
21	54	16,71	0,47	68,87	6,29	321,33	4,5	RIGHT	53,50%	CW	0,53
22	44	59,95	1,22	195,08	9,03	461,37	3,98	LEFT NO	51,40%	CW	5,41
23	2	2,94	0,15	13,32	2,8	143,06	1,56	RIGHT NO	51,30%	CW	0,35
24	49	25,22	0,36	90,51	6,93	353,9	3,22	LEFT NO	50,80%	CCW	-1,31
25	39	14,34	0,45	53,53	5,01	256,17	1,81	RIGHT NO	54,80%	CW	0,54
26	22	35,53	0,32	193,42	9,47	484,09	4,21	RIGHT	53%	CW	6,40
27											
28											
29											
30	68	38,77	0,67	121,89	7,37	376.56	4,6	RIGHT	59,80%	CW	3,65
31	70	13,67	0,56	81,91	6,14	313,83	2,18	RIGHT	55,30%	CW	3,15
32	71	15,96	0,56	58,91	5,4	251,32	2,87	LEFT NO	51,10%	CW	1,16
33	76	33,33	0,57	169,42	8,82	450,51	2,8	LEFT	54,70%	CW	1,52
34	77	57,53	0,55	252,91	10,34	528,29	2,84	RIGHT	54,10%	CCW	-0,18
35	78	21,7	0,57	113,88	7,25	370,49	2,02	RIGHT NO	51,40%	CCW	-4,57
36	79	10,43	0,43	46,91	4,98	254,6	1,06	RIGHT NO	50,60%	CCW	-1,28
37	80	26,33	0,46	122,12	7,27	371,28	2,1	LEFT	53,40%	CCW	-6,42
38	84	31,86	0,41	97,26	7,14	364,76	2,22	LEFT	54%	CW	6,63
39	86	16,98	0,54	88,7	6,56	335,05	1,45	RIGHT	58,10%	CW	2,10
40	87	7,33	0,63	49,63	4,83	246,66	1,99	LEFT NO	51,30%	CCW	-1,36
41	88	108,1	0,56	362,82	14,15	723,11	6,03	RIGHT	52,60%	CCW	-2,01
42	100	12,87	0,45	45,35	4,53	231,37	2,28	LEFT	54,90%	CW	0,66
43	101	9,59	0,77	45,76	4,87	248,86	2,2	LEFT NO	51,60%	CCW	-3,73
44	103	37,08	0,73	144,48	7,95	406,22	2,17	LEFT NO	50,80%	CCW	-2,75
45	97	16,46	0,64	75,98	6,3	322,15	2,31	LEFT	54,30%	CCW	-2,32
46											

	A	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF
1												
2					STABILOMETRIC	PLATFORM	AXIMAL INTERCUSPATION					
3									* NO = monopodal support <52% of total weight		CW= ClockWise CCW=CounterClockWise	
4	PATIENT ID		VARIANCE OF SWAY VELOCITY	SWAY SHAPE RATIO	SWAY AREA (mm2)	SWAY VELOCITY (mm/s)	SWAY LENGHT (mm)	ENERGY CONSUMED (watt)	MONOPODAL SUPPORT*	HIGHER PERCENTAGE OF SUPPORT	THEORETICAL ANGLE OF SUPPORT = TRUNK ROTATION (DIRECTION)	THEORETICAL ANGLE OF SUPPORT = ROTATION (DEGREES)
5	3		14,41	0,87	47,96	5,23	267,02	2,67	LEFT NO	51,50%	CCW	-2,59
6	5		18,43	0,52	84,72	6,15	260,15	1,27	RIGHT NO	50,10%	CW	0,21
7	10		298,14	0,56	801,58	17,16	856,33	5,19	LEFT	55,80%	CCW	-5,49
8	13		34,72	0,51	152,4	9,18	446,85	2,43	LEFT NO	51,20%	CCW	-0,14
9	15		8,19	0.36	44.68	4.50	224,58	1,48	RIGHT	56,50%	CW	3,06
10	20		36,27	0.25	113.59	8.07	412,54	3,22	RIGHT	54,20%	CCW	-1,42
11	21		50,55	0,32	180,08	9,06	463,01	3,35	RIGHT	52%	CW	2,97
12	25		36,39	0,29	105,94	7,59	387,63	2,39	RIGHT NO	51,25%	CW	2,04
13	27		21,45	0,57	113,52	6,89	352,17	2,82	RIGHT NO	51,91%	CW	3,59
14	29		41,85	0,37	129,15	7,97	397,86	1,79	RIGHT	53,30%	CCW	-4,87
15	30		64,3	0,63	256,9	10,24	523,21	3,83	RIGHT NO	51,90%	CCW	-1,27
16	31		23,46	0,4	63,45	5,35	273,41	2,92	RIGHT NO	51,20%	CW	3,20
17	34		16,96	0,57	91,71	6,55	334,92	2,14	RIGHT	54,30%	CW	5,35
18	35		43,55	0,63	155,72	7,6	388,45	3,6	LEFT	53,50%	CW	0,95
19	38		23,46	0,4	63,45	5,35	273,41	2,92	RIGHT NO	51,20%	CCW	-0,35
20	42		13,52	0,46	45,57	4,53	231,49	1,99	LEFT NO	51,30%	CCW	-0,09
21	54		22,97	0,43	77,42	6,26	320,02	4,49	RIGHT	52,80%	CCW	-0,45
22	44		63,77	0,49	175,15	9,32	476,15	4,11	RIGHT NO	50,80%	CW	3,97
23	2		5,51	0,29	15,04	2,62	133,9	1,46	RIGHT NO	51,50%	CW	3,14
24	49		24,51	0,41	90,24	6,67	340,8	3,1	LEFT NO	51,90%	CCW	-3,39
25	39		22,98	0,72	105,6	6,2	316,7	2,23	RIGHT	59,60%	CW	2,94
26	22		165,96	0,97	756,97	17,64	901,5	7,84	RIGHT	55,40%	CW	6,69
27												
28												
29												
30	68		25,51	0,46	102,75	7,22	368,89	4,51	RIGHT	57,40%	CW	6,12
31	70		17,82	0,34	78,77	6,35	324,33	2,25	RIGHT	53,10%	CW	2,44
32	71		12,5	0,5	46,52	4,32	215,83	2,11	LEFT NO	50,80%	CW	1,82
33	76		69,47	0,44	295,33	11,13	568,97	3,54	LEFT NO	51,50%	CW	3,93
34	77		39,31	0,48	201,01	9,66	493,59	2,65	LEFT NO	50,40%	CCW	-1,07
35	78		38,98	0,53	169,02	8,75	447,28	2,44	RIGHT	52%	CCW	-4,21
36	79		10,47	0,27	54,3	5,43	277,43	1,15	LEFT NO	51,10%	CCW	-1,98
37	80		38,94	0,56	150,05	7,91	404,02	2,28	RIGHT NO	51,20%	CCW	-2,82
38	84		38,1	0,75	130,42	8,65	441,93	2,68	LEFT	52,20%	CW	4,15
39	86		19,12	0,58	107,02	7,04	359,78	1,56	RIGHT	62,90%	CW	1,78
40	87		97,76	0,71	311,15	9,9	506,1	4,09	RIGHT	52,80%	CW	0,00
41	88		94,45	0,58	351,87	13,48	688,97	5,74	RIGHT NO	50,20%	CCW	-2,49
42	100		13,7	0,26	39,88	4,51	230,52	2,27	RIGHT	54,30%	CCW	-0,80
43	101		26,07	0,73	94,49	6,75	344,94	3,05	LEFT	54,40%	CCW	-5,27
44	103		36,64	0,42	159,28	8,28	423,3	2,26	RIGHT	52,20%	CCW	-1,79
45	97		27,55	0,74	128,94	7,63	390,11	2,8	LEFT	55,30%	CCW	-2,81
46												

Table 8.1.i: Chewing cycles data of crossbite patients after therapy



	A	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV
1														
2			CHEWING PATTERNS											
3			SOFT BOLUS						HARD BOLUS					
4	PATIENT ID		PATTERNS RIGHTSIDE (n)	REVERSE PATTERNS RIGHTSIDE (%)	NON REVERSE PATTERNS RIGHTSIDE (%)	PATTERNS LEFT SIDE (n)	REVERSE PATTERNS LEFTSIDE (%)	NON REVERSE PATTERNS LEFTSIDE (%)	PATTERNS RIGHTSIDE (n)	REVERSE PATTERNS RIGHTSIDE (%)	NON REVERSE PATTERNS RIGHTSIDE (%)	PATTERNS LEFT SIDE (n)	REVERSE PATTERNS LEFTSIDE (%)	NON REVERSE PATTERNS LEFTSIDE (%)
5	3		40	10	90	43	5	95	45	18	82	44	2	98
6	5		31	16	84	36	11	89	36	8	92	40	3	98
7	10		47	4	96	47	43	57	31	23	77	36	0	100
8	13		37	35	65	38	18	82	39	18	82	33	39	61
9	14													
10	15		36	3	97	30	0	100	39	8	92	38	0	100
11	20		37	8	92	37	0	100	37	8	92	37	0	100
12	21		38	21	38	37	3	97	31	13	87	37	0	100
13	25		36	2	98	39	3	97	42	0	100	43	0	100
14	27		27	7	93	34	21	79	28	4	96	29	0	100
15	29		29	10	90	35	3	97	30	17	83	28	7	93
16	30		34	0	100	39	3	97	35	6	94	37	3	97
17	31		31	6	94	33	27	73	29	3	97	29	10	90
18	34		20	0	100	25	52	48	20	0	100	23	30	70
19	35		35	6	94	40	13	88	35	11	89	37	0	100
20	38													
21	42		44	5	95	46	17	83	45	0	100	47	0	100
22	54		39	8	92	35	20	80	33	9	91	30	3	97
23	44		32	20	80	31	28	72	33	22	78	33	10	90
24	2		36	8	92	37	5	95	37	35	65	39	0	100
25	49		35	3	97	38	8	92	37	46	54	34	0	100
26	39		42	10	90	39	18	82	48	10	90	51	8	92
27	22		36	3	97	38	16	84	30	10	90	41	5	95
28														
29														
30														
31	68		40	2	98	41	2	98	41	2	98	45	27	73
32	70													
33	71		46	11	89	41	10	90	40	5	95	41	0	100
34	76		24	31	69	33	30	70	36	28	72	41	24	76
35	77		30	0	100	32	38	63	30	10	90	29	52	48
36	78		35	0	100	37	5	95	40	10	90	42	7	93
37	79		35	20	80	40	3	98	42	2	98	43	30	70
38	80		28	14	86	19	89	11	31	3	97	24	75	25
39	84		40	0	100	43	0	100	37	3	97	41	7	93
40	86		27	19	81	27	26	74	22	0	100	21	0	100
41	87		31	26	74	30	3	97	20	5	95	31	6	94
42	88													
43	100		40	0	100	40	40	60	43	0	100	45	89	11
44	101		30	0	100	32	53	47	25	0	100	32	91	9
45	102		37	5	95	39	0	100	40	0	100	40	8	100
46	103		44	2	98	40	28	73	38	0	100	39	54	46
47	97		14	0	100	11	33	67	5	3	97	2	120	90
48														

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Both failures and development come from forward steps: probably the secret is to obtain a refined equilibrium between balance and unbalance in every moment, for every choice, before any challenge.

Thank you, Giada.