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Relationship between body posture and craniofacial morphology in patients affected by temporomandibular disorders and in patients affected by malocclusions: a rasterstereographic study

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1. INTRODUCTION

1.1 Body posture

1.1.1. Definition

The vertebral column sustains the body, protects the nervous axis and is composed by 34 vertebrae that are formed by a vertebral body in the anterior part and by a posterior arch in the back (Fig. 1):

- 7 cervical vertebrae that increase in volume in cranio-caudal direction;
- 12 thoracic vertebrae that articulate with the ribs;
- 5 lumbar vertebrae that present a voluminous body;
- sacrum that articulate with the hips;
- coccyx that is composed by the fusion of 5 vertebrae [1].

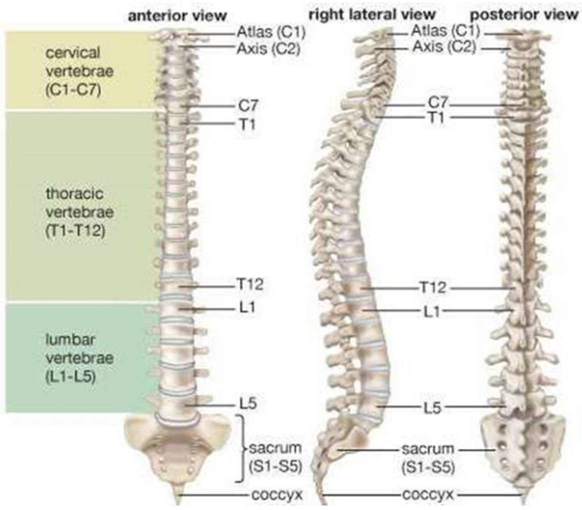

Fig. 1 Vertebral column

On the frontal plane the vertebral column is rectilinear and on the sagittal plane it is possible to identify four curvatures: cervical and lumbar lordosis, with posterior concavity, and dorsal and sacral kyphosis, with posterior convexity. The vertebral column is the axis of the body and has to conciliate two mechanical parameters: rigidity and elasticity. The elasticity of the vertebral column is due to the fact that it is composed by many overlapping segments connected by muscles and ligaments. This structure can change, remaining stiff under the influence of the muscles.

In a normal vertical posture, cranium, back and buttocks are tangent to a vertical plane. The entity of the curvature is defined by the arrows, the distance between the vertical plane and the apex of the

curvature. The presence of the curvature increases the strength of the vertebral column to the stresses of axial compression [2]. The vertebral column is a succession of fixed segments (vertebrae) and mobile segments that join vertebrae (discs and joints) in order to allow a mobility in the three dimensions of the space. The mobility is different in each region following different shapes of the vertebrae. Pressure is transmitted to the vertebral body by the disc that, due to bad mechanical conditions, can be affected by pinching associated to torsions [3].
According to Roussouly it is possible to identify on the sagittal plane four different vertebral column types on the basis of the observation that there are characteristic sagittal profiles that occur as a consequence of the orientation of the pelvis, sacrum and lumbosacral junction (Fig. 2):

- Type 1 Lordosis. The sacral slope is less than 35°. The apex of the lumbar lordosis is located in the center of L5 vertebral body. The lower arc of lordosis is minimal, decreasing toward zero as the sacral slope approaches the horizontal line. The upper spine has a significant dorsal kyphosis.
- Type 2 Lordosis. The sacral slope is less than 35°. The apex of the lumbar lordosis is located at base of the L4 vertebral body. The lower arc of lordosis is relatively flat. The entire spine is relatively hypolordotic and hypokyphotic.
- Type 3 Lordosis. The sacral slope is between 35° and 45°. The apex of lumbar lordosis is in the center of the L4 vertebral body. The lower arc of lordosis becomes more prominent. An average of four vertebral bodies constitutes the arc of lordosis. The spine is well balanced.
- Type 4 Lordosis. The sacral slope is greater than 45°. The apex of the lumbar lordosis is located at the base of the L3 vertebral body or higher. The lower arc of lordosis is prominent, and the lordosis tilt angle is zero or positive. [4].

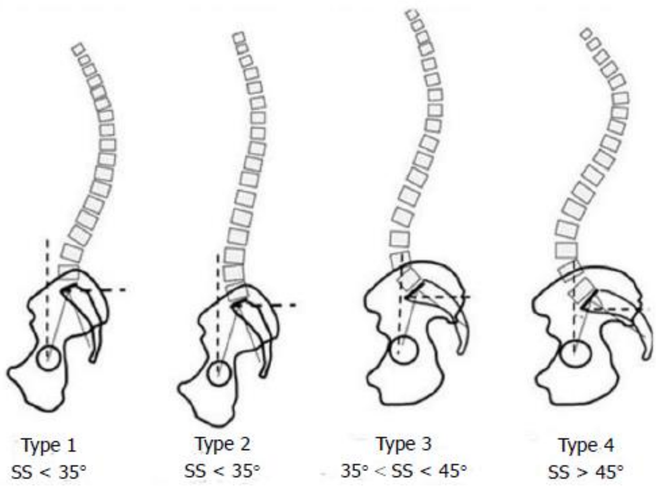

Fig. 2 Vertebral column classification according to Roussouly

The centre of gravity in vertical position is situated ahead the third lumbar vertebra and the feet support the weight of the body thus the projection on the floor of the gravity centre fall in the space between the two feet. When an imbalance occurs, different reflex mechanisms allow to restore the equilibrium. From the exteroreceptors (sole of the feet, inner ear, vision) people receive information regarding their relationship with the world and from the endoreceptors (neuromuscular fuses, stretching tendons and articular receptors) the regulation system is enriched by information about the relative position of different parts of the body. The first source of information on the floor come from the sole of the feet and from the pressure receptors. The ear system and the vision system are also implicated in the interpretation of the space information [5].

Posture refers to the position of the human body and its orientation in space. Posture involves muscle activation that, controlled by the central nervous system (CNS), leads to postural adjustments. Postural adjustments are the result of a complex system of mechanisms that are controlled by multisensory inputs (visual, vestibular and somatosensory) integrated in the CNS.

During human postural control, individuals constantly regulate movements, subconsciously, based on perceived information to achieve postural stability. Through mechanisms of feedback and feedforward, postural adjustments play a critical role in orthostatic and dynamic postural control. These adjustment are evoked by several types of afferent inputs: exteroceptive, proprioceptive, vestibular and visual [6].

Posture is maintained by the neuromuscular system with several afferent pathways from proprioceptors in muscles, tendons and joints, form vestibular and visual receptors, and from the cortical and subcortical motor areas [7].

Balance maintenance involves complex sensorimotor transformations that continually integrate several sensory inputs and coordinate multiple motor outputs to muscles throughout the body. The control of quiet-standing posture and of the displacement of the centre of mass (CoM) under dynamic balance condition consists in the maintenance of the CoM. The spatio-temporal activity of the agonist postural muscles is regulated by the CNS based on one or multiple frames of reference upon which the body scheme is constructed [8]. The CNS regulates the equilibrium of the postural muscles and is activated by information from different receptors such as the postural muscles themselves creating a self-regulating system [9].

While keeping the body stable during the “quiet stance” condition, feedforward mechanisms modulate the tonic activity in antigravity extensor muscles and the correcting bursts in the antagonist muscles, which together control the displacement of the center of foot pressure. In turn, the spatio-temporal patterns of activity rely on the knowledge of the orientation in space and of the relative position of body segments during stance. This knowledge is built on multiple sensory inputs, which concur in the construction of the “internal model” of body and of its relationship with the environment. Feedback contributes to the instant-to-instant control of the stabilizing effort by engaging reflex responses and by continuously updating the internal model. Under steady-state conditions, the feedback contribution may be down-regulated by the brain. During locomotion, alteration of the proprioceptive input from the leg muscle produces little effects on gait variables. The sensorimotor set is a state in which transmission parameters in various sensorimotor pathways have been adjusted to suit a particular task or context. Stance stability depends on the availability and accuracy of the afferent stimuli that are integrated by the brain. Any stabilizing information (e.g., vision) must be rapidly integrated and quickly produce corrective actions. Furthermore, when people maintain the equilibrium during repeated and predictable perturbations of balance, anticipatory postural adjustments occur [8]. Static perturbation in the three dimension of the space can lead to a more or less complex static disturbance, responsible of the mechanical stress on the muscles and ligaments [9].

Literature regarding body posture control showed that healthy and young participants exhibit a better postural control in active vision tasks than in control tasks, highlighting a cognitive model based on the adaptable nature of the CNS to successfully perform different tasks. Young adults’ CNS is able to adjust oculomotor behaviour and postural control in a synergistic manner to perform and succeed in precise active vision task [10].

The biomechanical influences of head posture on occlusion were studied using finite element model (FEM). Results suggested that alteration of head posture was directly related to stress distribution on the cervical column, but didn’t directly influence the occlusal state. Nevertheless FEM could not reproduce the involuntary movement induced by the neuromuscular system and other factors like the respiratory system that exerts functional influences [11]. In another study results suggested that lateral inclination of the occlusal plane and imbalance between right and left masticatory muscles antagonistically act on the displacement of the cervical spine [12].

In a systematic review Gomes affirmed that on the basis of data available from literature, significant associations were found between variables concerning head posture and craniofacial morphology. However, these results suggested that such associations should be carefully interpreted, considering that correlation coefficients ranged from low to moderate. The association between cervical lordosis and head extension mechanism regarding craniofacial morphology was still unclear and further longitudinal studies were needed in order to elucidate the relationship between craniofacial development and functional aspects of head and cervical posture [13].

1.1.2. Rasterstereography

Several authors investigated correlations between the stomatognathic system and body posture using vertical force postural platform or body photographs [14]. All results, particularly with regard to the use of postural platform, didn’t support the existence of clinically relevant correlations between malocclusion traits and body posture [15]. The quality of available studies is relatively low and further investigations with higher quality designs are warranted [16]. There is little use for posturography in the monitoring of body posture responses to changes in the stomatognathic system, with a large failure rate because of the large variability of the recordings. Moreover the different posturographic methods appear to be similar in terms of recording the high variability of parameters and consequently show low diagnostic accuracy [17, 18].

Non-radiographic methods of measuring global sagittal balance have from low to very high reliability, and, limited to plumbline test, surface topography and motion analysis, from low to high validity. Although it is unclear if these methods can be used to evaluate sagittal balance pathology, they can be used with relative confidence for the monitoring of global sagittal balance [19].

A reliable, non-invasive method to analyse three-dimensional (3D) spine morphology is rasterstereography [20, 21]. Back surface topography has gained acceptance in recent decades in the management of patients affected by scoliosis and other deformities of the trunk and spine in order to reduce X-ray exposure. This examination is suitable to follow the severity of the condition and to indicate when a further X-ray examination is necessary [22]. Moreover it brings together skeletal and surface information allowing for a deeper understanding of biomechanics and pathogenesis and it helps to document cosmetic aspects in three dimensions [23]. Many studies focused on the comparison between X-ray and rasterstereography in patients with adolescent idiopathic scoliosis asserting that rasterstereography can be used for monitoring the evolution of adolescent idiopathic scoliosis in growing patients [24, 25]. A recent review by Mohokum et al. concluded that rasterstereography is a radiation-free method useful for screening examinations as well as for follow-ups and the Authors claimed rasterstereography as a good diagnostic method for spinal scoliosis [26]. Furthermore rasterstereography showed a very high reliability for both linear and angular data [27].

Surface topography is able to provide, in one scan, the widest variety of sagittal balance measurements, including trunk inclination, distance offset measurements and sagittal arrows distance measurements and can be used with relative confidence for the monitoring of global sagittal balance [19]. Rasterstereography enable a 3D radiation-free representation of the dorsal profile and it is based on the methods of photometry. In this procedure a projection unit emits a light beam onto the dorsal surface of the patient standing in a standard way toward the projection device, which obtains measuring data on the dorsal profile by means of a video optic device from another direction [28].

The method of rasterstereographic back shape measurements provides a 3D model reconstruction of the back recorded as a whole. The technical solution in recording a surface point with high accuracy is based on the method of photogrammetry, which in turn is based on the geometrical method of triangulation. For this purpose all systems use a projector together with a camera (Fig. 3). Several light sections are simultaneously projected onto the back and recorded with a videocamera in one single frame [23].

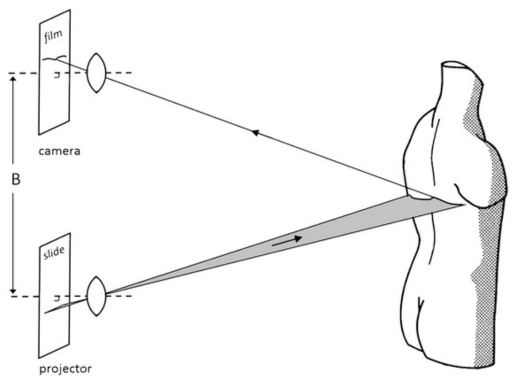

Fig. 3 Photogrammetry method

As a result of the model reconstruction, the back surface initially is given as a set of 3D surface points that is not suitable for analysis [23]. Following the concept of the curvature analysis, the shape of a small surface patch may be characterized by distinguishing four main types of curvature named parabolic, convex, concave and saddle-shaped curvature (Fig. 4).

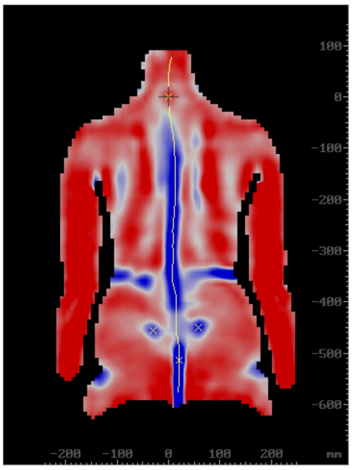

Fig. 4 Reconstruction of the back surface

An automatic recognition, without any manual marking, of anatomical structures, by means of the connected software, provides the basis for a reconstruction of the 3D profile of the dorsal surface: vertebra prominens (VP), right lumbar dimple (DR) and left lumbar dimple (DL). From these landmarks it is possible to identify the midpoint between the two dimples (DM) and the twelfth thoracic vertebra (T12) [29]. The sagittal back shape profile can be obtained by mathematical modelling. Three inflectional points along the profile are indicated: cervicothoracic (ICT), thoracolumbar (ITL) and lumbosacral (ILS) inflection points (Fig. 5).

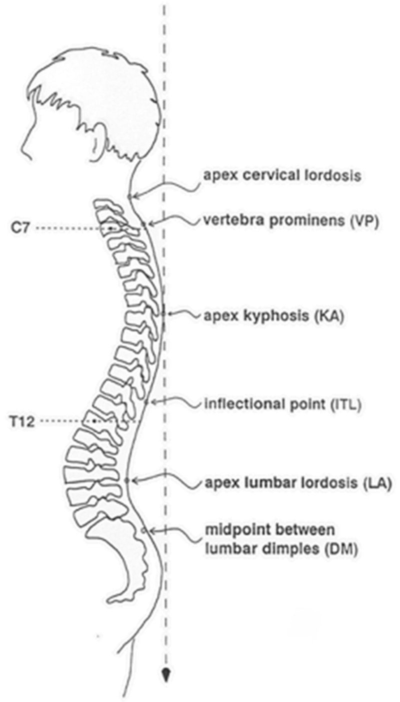

Fig. 5 Sagittal back shape reference points

From these points it is possible to calculate distances and angles on the sagittal and frontal plane.
On the sagittal plane it is possible to consider different measurements (Fig. 6):

- Trunk inclination VP-DM (mm): horizontal distance between DM and the vertical passing through VP
- Cervical arrow (mm): horizontal distance between VP and the tangent to the curve at kyphosis apex (KA) parallel to the VP-DM axis
- Lumbar arrow (mm): horizontal distance between lordosis apex (LA) and the tangent to the curve at KA parallel to the VP-DM axis
- Kyphotic angle ICT-ITL (º): angle between the tangent lines in ICT and ITL
- Lordotic angle ITL-ILS (º): angle between the tangent lines in ITL and ILS

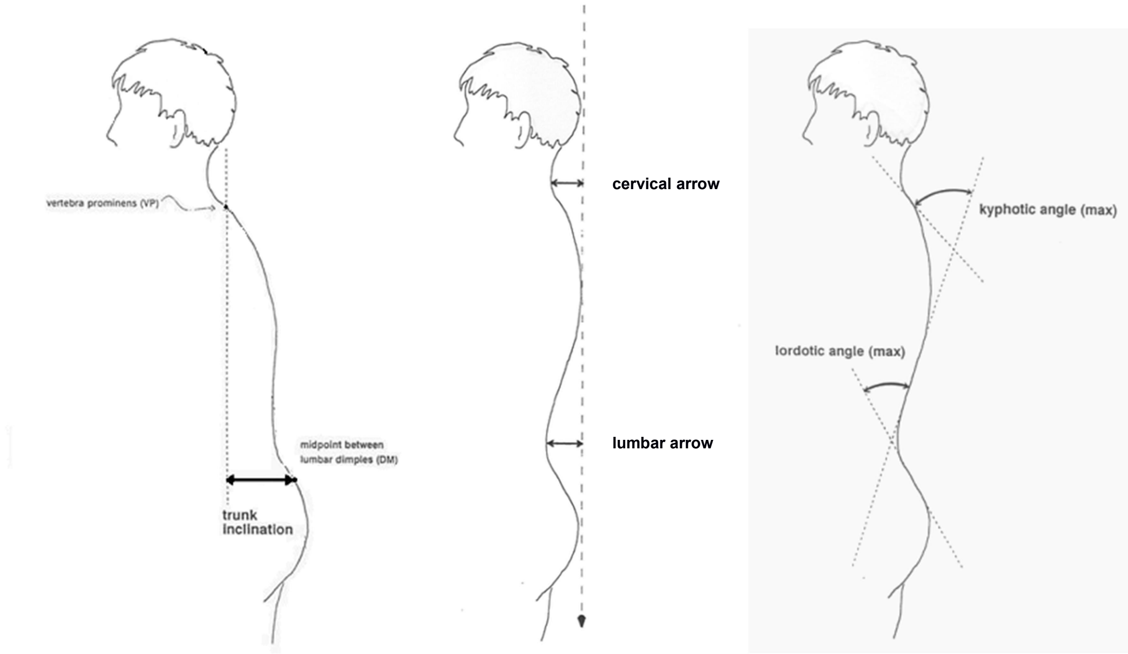

Fig. 6 Back shape distances and angles on the sagittal plane

On the frontal plane it is possible to consider different measurements (Fig. 7):

- Trunk imbalance (mm): horizontal distance between DM and the vertical passing through VP
- Pelvic tilt DL-DR (mm): different height between two lumbar dimples
- Pelvic torsion DL-DR (º): rotation of the surface normal of two lumbar dimples

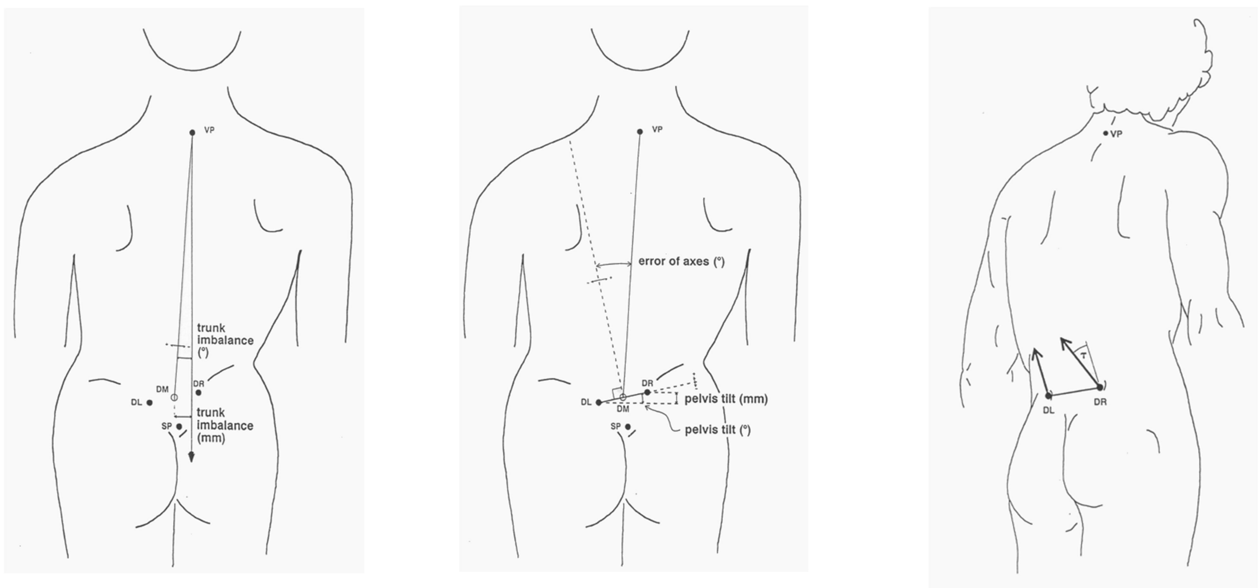

Fig. 7 Back shape distances and angles on the frontal plane

1.2 Temporomandibular disorders

1.2.1. Temporomandibular disorders: diagnosis

Temporomandibular disorders (TMD) is a collective term embracing a number of clinical problems that involve the masticatory musculature, the temporomandibular joint and associated structures, or both [30]. TMD is a significant public health problem affecting approximately 5% to 12% of the population and about half to two-thirds of those with TMD will seek treatment. Among these, approximately 15% will develop chronic TMD [31]. In the etiology of TMD different factors are involved: factors that increase the risk of TMD are called predisposing, factors that cause the onset of TMD are called initiating and factors that interfere with healing or enhance the progression of TMD are called perpetuating. Predisposing factors include structural, metabolic and psychological conditions that adversely affect the masticatory system sufficiently to increase the risk of developing TMD. Initiating factors that lead to the onset of symptoms are primarily related to trauma or repetitive adverse loading of the masticatory system. Perpetuating factors, such as parafunction, hormonal factors or psychosocial factors, can sustain the patient's disorder [32].

The common TMD include arthralgia, myalgia, local myalgia, myofascial pain, myofascial pain with referral, disc displacement disorders, degenerative joint disease, subluxation and headache attributed to TMD [33]. In TMD many muscles are involved, such as masseter, temporalis and pterygoid. (Fig. 8A, 8B).

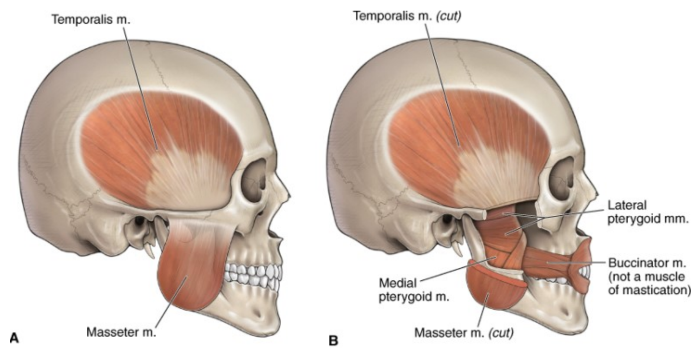

Fig. 8 Facial muscles

The Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) define the most common Pain-Related Temporomandibular Disorders as follows:

- *Myalgia*: pain of muscle origin that is affected by jaw movement, function, or parafunction, and replication of this pain occurs with provocation testing of the masticatory muscles. There are three types of myalgia as differentiated by provocation testing with palpation:

- Local myalgia: pain of muscle origin as described for myalgia with localization of pain only at the site of palpation.
- Myofascial pain: pain of muscle origin as described for myalgia with pain spreading beyond the site of palpation but within the boundary of the muscle.
- Myofascial pain with referral: pain of muscle origin as described for myalgia with referral of pain beyond the boundary of the muscle. Spreading may be also present.

- *Arthralgia*: pain of joint origin that is affected by jaw movement, function, or parafunction, and replication of this pain occurs with provocation testing of the temporomandibular joint.
- *Headache attributed to TMD*: headache in the temple area secondary to pain-related TMD that is affected by jaw movement, function, or parafunction, and replication of this headache occurs with provocation testing of the masticatory system.

In TMD also the Temporomandibular Joint (TMJ) is involved alone or in association with facial muscles (Fig. 9).

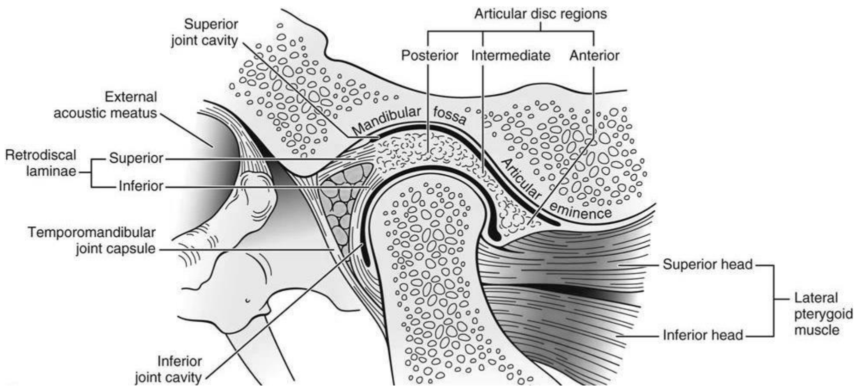

Fig. 9 Temporomandibular joint

The Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) define the most common Intra-articular Temporomandibular Disorders as follows:

- *Disc displacement with reduction*: an intracapsular biomechanical disorder involving the condyle-disc complex. In the closed mouth position, the disc is in an anterior position relative to the condylar head and the disc reduces upon opening of the mouth. Medial and lateral displacement of the disc may also be present. Clicking noises may occur.
- *Disc displacement with reduction with intermittent locking*: an intracapsular biomechanical disorder involving the condyle-disc complex. In the closed mouth position, the disc is in an anterior position relative to the condylar head, and the disc intermittently reduces with

opening of the mouth. Medial and lateral displacement of the disc may also be present. Clicking noises may occur with disc reduction.

- *Disc displacement without reduction with limited opening*: an intracapsular biomechanical disorder involving the condyle-disc complex. In the closed mouth position, the disc is in an anterior position relative to the condylar head and the disc does not reduce with opening of the mouth. Medial and lateral displacement of the disc may also be present.
- *Disc displacement without reduction without limited opening*: an intracapsular biomechanical disorder involving the condyle-disc complex. In the closed mouth position, the disc is in an anterior position relative to the condylar head and the disc does not reduce with opening of the mouth. Medial and lateral displacement of the disc may also be present.
- *Degenerative joint disease*: a degenerative disorder involving the joint characterized by deterioration of articular tissue with concomitant osseous changes in the condyle and/or articular eminence.
- *Subluxation*: a hypermobility disorder involving the disc-condyle complex and the articular eminence. In the open mouth position, the disc-condyle complex is positioned anterior to the articular eminence and is unable to return to a normal closed mouth position without a manipulative maneuver [33].

1.2.2. Temporomandibular disorders: treatment

The majority of TMD patients achieve good relief of symptoms with a conservative model of non-invasive management and this approach is supported by literature [34, 35]. Recent published guidelines for the management of TMD support the concept of the efficacy and appropriateness of conservative TMD treatments, while discourage the routine utilization of aggressive and irreversible treatments [36]. A multidisciplinary model that includes patients education and self-care, cognitive behavioral intervention, pharmacotherapy, physical therapy and occlusal splint is approved for the management of nearly all TMD patients [37].

Occlusal splint therapy is considered a conservative and reversible therapy for TMD patients and can reduce pain in most cases (Fig. 10). Moreover the treatment is considered comfortable by most patients and free from serious adverse events or complications [38]. Splints should reduce the load on the temporomandibular joints by modifying the location of clenching along the occlusal arch so that the smaller bite force, the smaller the joint load [39]. The occlusal support not only can reduce TMD pain but also can decrease the relative activity of temporal muscle and increment muscular symmetry, especially in the masseter muscle [40].

Fig. 10 Occlusal splint

Physical therapy is an effective treatment for TMD because it helps to relieve musculoskeletal pain, restores normal function and promotes the repair and regeneration of tissues [41]. Among the physical treatments suggested for the management of facial myalgia, conventional Transcutaneous Electrical Nerve Stimulation (TENS) has been proposed as a safe, non-invasive, easy to administer therapy with few side effects or drug interactions (Fig. 11). It is defined as the delivery of pulsed electrical currents across the intact surface of the skin using a standard TENS device to stimulate peripheral nerves principally for pain relief [42]. The efficacy of conventional TENS in pain relief in patients with chronic facial myalgia has been demonstrated, in particular showing a decrease in both subjective and objective pain. Moreover, the pain decreased during TENS therapy and the pain level obtained at the end of therapy was maintained also after therapy interruption [43].

Fig. 11 Transcutaneous Electrical Nerve Stimulation

1.2.3. Temporomandibular disorders and body posture

The relationship between dental occlusion and body posture and between TMD and body posture is a controversial topic in literature. Evidences of anatomic and functional connection between masticatory system and postural body regulation system led the authors to postulate several hypotheses of correlation between TMD and postural problems.

A review of the existing literature performed by Michelotti et al. in 1999 concluded that some evidences of correlation between occlusion and posture were available but they were limited to the cranio-cervical tract of the column and tended to disappear when descending in cranio-caudal direction. It wasn't therefore advisable to treat postural imbalance by means of occlusal treatment or vice versa, particularly if the therapeutic modalities were irreversible [44]. In 2006 Olivo et al. asserted that the association between intra-articular and muscular TMD and head and cervical posture was still unclear and better controlled studies with comprehensive TMD diagnoses, greater sample sizes and objectives posture evaluation were necessary [45]. A systematic review by Hanke et al. underlined the lack of methodologically solid clinical studies and a poor quality of most publications analysing the correlation between orthopaedic and dental findings (occlusal, mandibular position, temporomandibular joints, masticatory muscles) [46]. Updating their previous review, in 2011, Michelotti et al. confirmed that even if some associations were found between occlusal factors and postural alterations, there was not enough scientific evidence to support a cause-effect relationship. The stomatognathic system could reasonably affect cervical region function, but the clinical effects and relevance on body posture were not yet well known [47]. Manfredini et al. in a review concerning relationship between dental occlusion, body posture and TMD stated that there was no evidence for the existence of a predictable relationship between occlusal and postural features and it was clear that the presence of TMD pain was not related with the existence of measurable occluso-postural abnormalities [48]. The evidence presented in the systematic review of Rocha et al. in 2013 showed that the relationship between TMD and the head and neck posture was still controversial and unclear. The insufficient number of articles considered of excellent methodological quality was a factor that hindered the acceptance or denial of this association [49]. There was strong evidence of craniocervical postural changes in myogenous TMD, moderate evidence of cervical posture misalignment in arthrogenous TMD and no evidence of absence of craniofacial postural misalignment in mixed TMD patients or of global postural misalignment in patients with TMD [50].

Based on the findings of the current scientific panorama, the rational of the study is to investigate a large number of variables using advanced technology in order to better deep dive the possible correlations between TMD and body posture. Since no data regarding the use of rasterstereography in evaluating posture parameters in TMD patients are available, this method was used in this study to investigate the followings: the relationship between craniofacial morphology and body posture parameters, the effect of an occlusal splint on body posture parameters in patients affected by intra-articular TMJ disorders and the effect of TENS on body posture parameters in patients affected by facial myalgia in different occlusal relationships.

1.3 Malocclusions

1.3.1. Malocclusions: diagnosis

The stomatognathic system consists of the teeth, the periodontal tissues, alveolar and basal bone, the TMJ and the muscles [51]. Malocclusion is a developmental condition. In most instances, malocclusion and dentofacial deformity are caused by moderate distorsions of normal development. Orthodontic problems often result from a complex interaction among multiple factors that influence growth and development and it is impossible to describe a specific etiologic factor. Etiologic factors for malocclusion can be grouped as specific causes (such as disturbances in embryologic development, growth disturbances in the fetal and perinatal period, deformities in childhood and in adolescence), genetic influences and environmental influences.

The first orthodontic classification was the Angle's classification based on the relationship of the first molar teeth and the alignment of the teeth relative to the line of occlusion (Fig. 12):

- Normal occlusion: normal molar relationship, teeth on line of occlusion
- Class I malocclusion: normal molar relationship, teeth crowded
- Class II malocclusion: lower molar distal to upper molar
- Class III malocclusion: lower molar mesial to upper molar

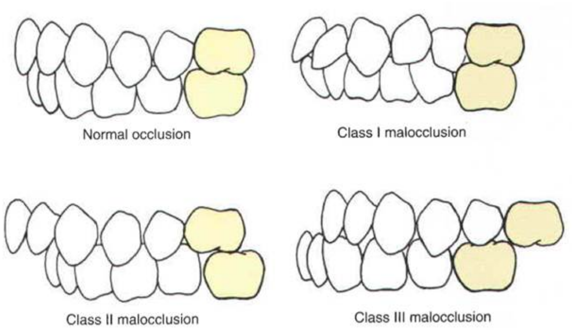

Fig. 12 Orthodontic Angle's classification

In the analysis of characteristics of malocclusion, the following evaluations have to be done: (i) facial proportion and esthetics considering facial asymmetry, anteroposterior and vertical facial proportions and lip-tooth relationship, (ii) alignment and symmetry within the dental arches, (iii) transverse plane of space (posterior crossbite), (iv) anteroposterior plane of space distinguishing between dental and skeletal malocclusion and (v) vertical plane of space such as anterior open-bite, anterior deep-bite or posterior open-bite. Cephalometric analysis is always required for the evaluation of the orthodontic malocclusion in order to identify skeletal and dental problems [52].

1.3.2. Malocclusions: treatment

The need of an orthodontic treatment in young patients was defined in Italy by the Risk Of Malocclusion Assessment index (R.O.M.A. index) that places patients in five grades of need for treatment from “Grade 1” to “Grade 5”. This index was studied in order to rate not only the dental malocclusion, but also skeletal and functional aspects, which in children are determinants of the orofacial development [53].

Orthodontic appliances have evolved significantly in recent years. Technologic advances have brought both improvements in existing appliance systems (such as new brackets and wires for the fixed appliances) and new ways of correcting malocclusions (such as clear aligners).

Functional appliances

Functional appliances are used for growth modification in preadolescent and adolescent and are fabricated from a construction bite that advances the mandible in Class II patients and rotates it downward in Class III patients. Bite blocks for anterior teeth are used in deep-bite patients, and bite blocks for posterior teeth are used in open-bite patients.

Functional appliances for growth modification are divided in four categories:

- Passive tooth-borne: depend only on soft tissue stretch and muscular activity
- Active tooth-borne: produce tooth movement that often replaces jaw growth modification
- Tissue-borne: the contact of the appliance with the teeth is avoided and much of the appliance is located in the vestibule, holding the lips and cheeks away from the dentition
- Hybrid: composed by components that are common to functional appliances but are combined to meet a specific need [52]

Removable appliances for tooth movement in children include arch expansion in which groups of teeth are moved to expand the arch perimeter and reposition teeth within the arch (Fig. 13).

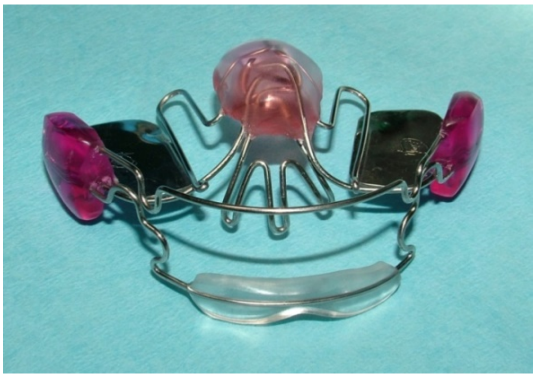

Fig. 13 Functional appliance

Clear Aligners Therapy

For this technique an intraoral optical scan or an impression, a bite registration and photographs are submitted to the company along with the initial instructions. The production process begins when the intraoral scan or impressions are used to create an accurate 3D digital model of each dental arch. Teeth are then digitally sectioned and cleaned up, the dental arches are related to each other, movement is staged and this preliminary plan is placed online for the doctor's review. After the revision, the set of digital models for a patient is transferred to a cast production facility, where a stereolithographic model for each step is fabricated. A clear plastic aligner is formed over each model and the set of aligners is sent to the doctor (Fig. 14).

Fig. 14 Clear aligners

Clear aligner therapy is indicated in cases of:

- Mild-moderate crowding with interproximal enamel reduction or expansion
- Posterior dental expansion
- Close mild-moderate spacing
- Absolute intrusion
- Lower incisor extraction for severe crowding
- Tip molar distally

Moreover in the use of sequential aligners it is important to considerate:

- The use of attachments that are bonded to selected teeth greatly extends the possible tooth movement with aligners;
- Interproximal enamel reduction to obtain space for aligning crowded teeth often is part of the treatment plan;
- Patients must be monitored carefully to verify that tooth movement is tracking with the series of aligners [52].

Fixed appliances

Fixed appliances are commonly used and are composed by different parts: arch, brackets, bands and temporary anchorage devices. Contemporary fixed appliances are predominantly variations of the Edgewise appliance system, based on the principle of a rectangular wire in a rectangular slot, that allow excellent control of crown and root position in all three plane of the space. Contemporary Edgewise system include automatic rotation control of the tooth, different bracket slot dimension and Straight-Wire prescriptions with different brackets for each tooth. The Straight-Wire prescriptions include the use of brackets or tubes that are custom-made for each tooth, with the goal of minimizing the number of bends in archwires needed to produce an ideal arrangement of the teeth (Fig. 15). Fixed appliances have been fabricated entirely from stainless steel for many years and steel remains the standard material for appliance components, even after the introduction of ceramic and titanium brackets [52].

Fig. 15 Fixed appliance

1.3.3. Malocclusions and body posture

Clinical connections or concomitant frequencies can be detected between postural, orthoptic and occlusal alterations in children. Even if it is not possible to state that there is a direct causal connection among them, the treatment of such disorders often requires the intervention of several specialists and a multidisciplinary approach [54]. Evidences of anatomic and functional connection between masticatory system and postural body regulation system induced to postulate several hypotheses of correlation between occlusal and postural problems in children. In particular different studies focused on the analysis of the relationship between cranio-posture and cervical-posture, which is a functional factor that seems to be involved in many clinical orthodontic problems. Regarding anatomic and functional aspects the stomatognathic system and the upper cervical spine are closely interlinked and many studies focused on orthodontic findings in correlation with orthopaedic findings [55]. In 1976 the first study of Solow and Tallgren aimed to describe correlation between craniofacial morphology and head posture analysing the craniocervical angulation, the position of the head in relation to the cervical column. In particular this position was expressed by the angle between the craniofacial reference line (Nasion-sella line) and the cervical column reference line (Odontoid process tangent) (Fig. 16). Nasion-sella line (NSL) is the line through Nasion (the most anterior point of the frontonasal suture) and Sella (the centre of the sella turcica). Odontoid process tangent (OPT) is the posterior tangent to the odontoid process through the most postero-inferior point of the corpus of the second cervical vertebra.

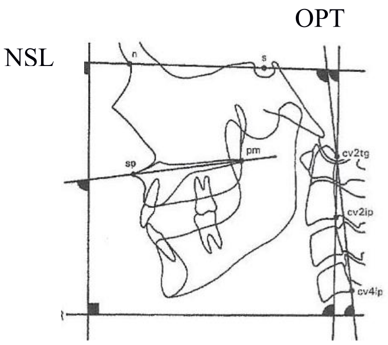

Fig. 16 Craniofacial reference line and cervical column reference line

On the one hand subjects with a small craniocervical angle had a small anterior face height with increased mandibular prognathism and a small mandibular plane inclination (Fig. 17a). On the other hand subjects with a large craniocervical angle had large anterior face heights, maxillary and mandibular retrognathism and a large mandibular plane inclination (Fig. 17b) [56].

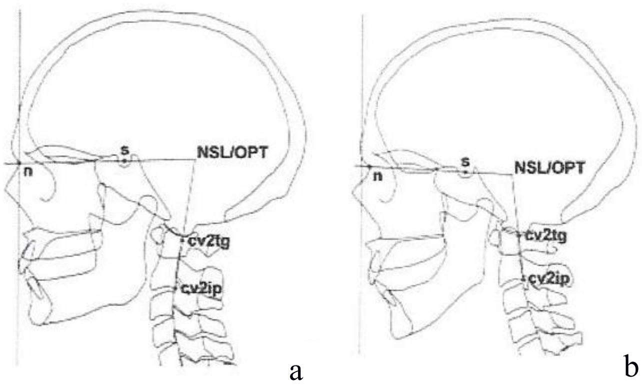

Fig. 17 Subjects with small craniocervical angle (a) and subjects with large craniocervical angle (b)

In 1986 Solow and Siersbaek-Nielsen examined, in a longitudinal sample, the associations between growth changes in head and cervical posture and growth changes in craniofacial morphology [57]. In 1992 Solow and Siersbaek-Nielsen found evidence for a relationship between craniocervical posture in prepubertal children and the direction of facial development during the subsequent period of growth. In particular subjects with a backward inclination of the cervical column and a small craniocervical angle had increased growth in length of the maxilla, increase in maxillary and mandibular prognathism and forward rotation of the mandible (Fig. 18a). On the opposite subjects with an upright position of the cervical column and a large craniocervical angle are likely to exhibit reduced growth in length of the maxilla, reduction of maxillary and mandibular prognathism and no forward rotation of the mandible (Fig. 18b) [58].

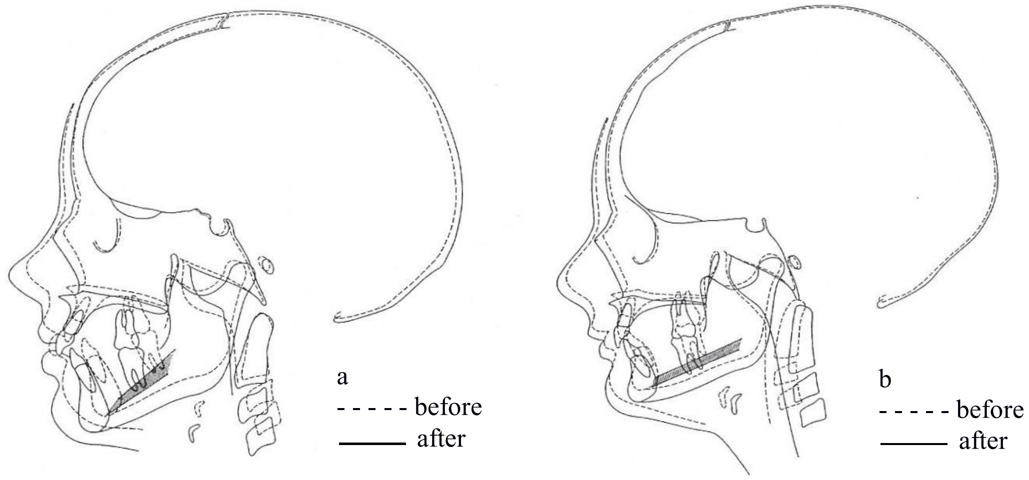

Fig. 18 Craniocervical posture and facial development during growth: subjects with small craniocervical angle (a) and with large craniocervical angle (b)

Other studies focused on the analysis of the correlations between specific orthopaedic findings with orthodontic characteristics (Angle Classes, crossbite, anterior crowding) [55]. The evidence presented in the systematic review of Iodice et al. showed that the association between posterior crossbite and skeletal asymmetry was still unresolved and the majority of the studies, both indicating and not indicating a relationship, were of medium-low scientific and methodological quality [59]. Huggare reviewing selected studies highlighted an increased prevalence of Angle Class II malocclusion with hyperlordosis of the cervical spine and an increased risk of lateral crossbite in children affected by scoliosis and torticollis [60]. In 2011 Arntsen and Sonnesen evaluated cervical vertebral column morphology related to craniofacial morphology and head posture in preorthodontic children with Class II malocclusion dividing patients in skeletal and dentoalveolar overjet group (overjet more than 6 mm). Deviations in cervical vertebral column morphology (fusion anomalies and posterior arch deficiency) occurred significantly more often in skeletal overjet group than in dentoalveolar group. Furthermore deviations in cervical vertebral column were significantly associated with retrognathia of the jaws, large inclination of the jaws, large cranial base angle and extension of the head in relation to the cervical vertebral column [61]. In 2014 the cervical vertebral column morphology was analysed in children and adolescent with open-bite: no significant differences were found between the skeletal and the dentoalveolar open-bite groups. Significant differences were found in head posture between the groups and with regard to associations with craniofacial dimension, indicating a possible respiratory etiologic component in children with open-bite [62]. Solow and Sonnesen found a clear pattern of association between anterior crowding (crowding >2 mm) and craniocervical posture [63].

The association between head posture and craniofacial morphology was explained in terms of "soft-tissue stretching hypothesis", and hypothesis that considered the forces that the soft-tissue layer of facial skin and muscles exert on the facial skeleton (Fig. 19). The idea was that this layer would be passively stretched when the head was extended in relation to the cervical column. This would increase the forces on the skeletal structures and such forces would restrict the forward growth of the maxilla and the mandible and redirect it more caudally. Different conditions could initiate the chain of events, such as pathological craniofacial conditions that prevent the normal development of the upper airway, neural components of postural control, scar tissue and dentofacial orthopaedic and orthognathic surgical intervention. [64, 65].

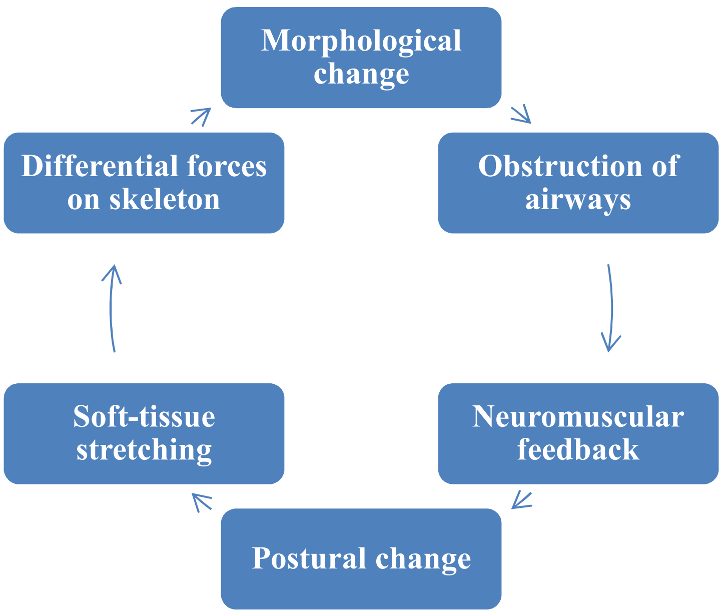

Fig. 19 Soft-tissue stretching hypothesis

Based on the findings of the current scientific panorama, the rational of the study is to investigate a large number of variables using advanced technology in order to better deep dive the possible correlations between malocclusions and body posture. Since no data regarding the use of rasterstereography in evaluating posture parameters in malocclusions patients are available, this method was used in this study to investigate the followings: the relationship between craniofacial morphology and body posture parameters and the effect of different orthodontic therapies in malocclusions patients in different occlusal relationships.

The study was performed on two different groups of patients according to their different diagnosis:

- Gnathology group: patients affected by temporomandibular disorders (intra-articular TMJ disorders and facial myalgia patients)
- Orthodontic group: patients affected by malocclusions

2. TEMPOROMANDIBULAR DISORDERS AND BODY POSTURE: A RASTERSTEREOGRAPHIC STUDY

2.1 Materials and methods

2.1.1 Aims

Rasterstereography was used in a sample of women affected by TMD to investigate the following points:

- the relationship between craniofacial morphology and body posture parameters;
- the effect of an occlusal splint on body posture parameters in patients affected by intra-articular TMJ disorders;
- the effect of TENS on body posture parameters in patients affected by facial myalgia;
- the effect of different occlusal relationship on body posture parameters.

The treated groups were compared to a matched sample of not-treated intra-articular TMJ disorders patients and facial myalgia patients.

The null hypotheses were: (i) no correlations between cephalometric and postural parameters can be detected, (ii) postural parameters are not affected by occlusal splint therapy in intra-articular TMJ disorders patients, (iii) postural parameters are not affected by TENS therapy in facial myalgia patients and (iv) no differences in postural parameters among different occlusal conditions can be revealed.

2.1.2 Subjects

Intra-articular temporomandibular joint disorders subjects

The study was performed on 45 women affected by intra-articular TMJ disorders and consecutively selected among 170 patients referring to the Gnathology Unit of the CIR Dental School of the University of Torino in the period May – October 2016.

The inclusion criteria were: diagnosis of intra-articular intra-articular TMJ disorders with arthralgia (disc displacement with reduction with/without intermittent locking, disc displacement without reduction with/without limited opening), female sex, age between 20 and 60 years and education between 8 and 18 years. The diagnosis of intra-articular TMJ disorders was performed by an expert clinician according to the Diagnostic Criteria for Temporomandibular Disorders [33].

The exclusion criteria were: (i) pain-related TMD and headache (myalgia, headache attributed to TMD), (ii) degenerative joint disease, (iii) loss of more than five teeth, with the exception of the third molars, (iv) medical history of motor or neurological disorders, (v) history of orthopaedic, head and facial trauma, (vi) orthopaedic and orthodontic treatments and (vii) removable prosthesis.

Participants were randomly divided in two groups: the occlusal splint group composed of 24 women (mean age ± SD 42.4±12.9) and the control group composed of 21 women (mean age ± SD 41.0±15.0). The control group was a “waiting list control” group, without any form of treatment.

The randomization sequence was generated using a free online software (www.random.org).

Facial myalgia subjects

The study was performed on 32 women affected by facial myalgia and consecutively selected among 120 patients referring to the Gnathology Unit of the CIR Dental School of the University of Torino in the period May – October 2016.

The inclusion criteria were: diagnosis of facial myalgia, pain present for more than 3 months, female sex, age between 20 and 60 years and education between 8 and 18 years. The diagnosis of facial myalgia was performed by an expert clinician according to the Diagnostic Criteria for Temporomandibular Disorders [33].

The exclusion criteria were: (i) intra-articular temporomandibular disorders (disc displacement and/or degenerative joint disorders), (ii) loss of more than five teeth, with the exception of the third molars, (iii) medical history of motor or neurological disorders, (iv) history of orthopaedic, head and facial trauma, (v) use of cardiac pacemaker devices, (vi) pregnancy (vii) orthopaedic and orthodontic treatment and (viii) removable prosthesis.

Participants were randomly divided in two groups: the TENS group composed of 16 women (mean age ± SD 42.4±12.9) and the control group composed of 16 women (mean age ± SD 33.9±14.4). The control group was a “waiting list control” group, without any form of treatment.

The randomization sequence was generated using a free online software (www.random.org).

The study was conducted in accordance to the Declaration of Helsinki and each subject was made aware of the ability to withdraw from the experiment at any time. A written informed consent was obtained for each participant. The study was approved by the local ethic committee (#3742015).

2.1.3 Cephalometric Analysis

A standardized digital lateral radiograph was obtained for each patient in order to analyse the sagittal position of the maxilla and of the mandible and the parameters of the vertical cranio-facial morphology (Sirona Orthophos XG 5). The cephalometric analysis was performed with a dedicated software (OrisCeph® Rx Elite Computer Italia, Vimodrone, Milano, Italia) (Fig 20).

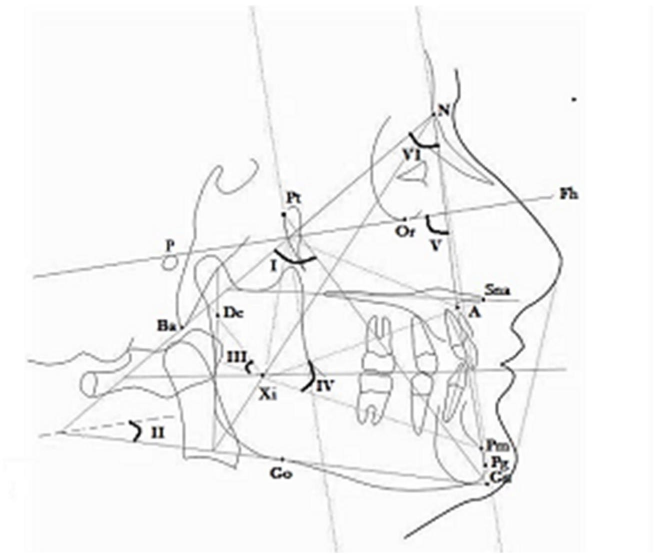

Fig. 20 Cephalometric analysis

On the sagittal plane six angular parameters of the Ricketts Cephalometric Analysis were considered for the study [52] (Table 1):

- Facial Axis: on vertical plane, growth direction of the mandible and vertical facial development (90.0º±3.0);
- Mandibular Plane Angle: on vertical plane, facial growth type (24.0º±4.0)
- Inner Gonial Angle: on vertical plane, tendency of the mandible growth and index of the vertical facial development (29.0º±4.0)
- Lower Facial Height: on vertical plane, skeletal vertical dimension of the lower facial height (47.0º±4.0)
- Facial Depth: on antero-posterior plane, mandible position (89.0º±3.0)
- Maxillary Position: on antero-posterior plane, maxillary position (90.0º±3.0)

I	Ba-N^Pt-Gn	Facial axis
II	Fh^Go-Gn	Mandibular plane angle
III	Dc-Xi^Xi-Pm	Inner gonial angle
IV	Sna-Xi^Xi-Pm	Lower facial height
V	Fh^N-Pg	Facial depth
VI	Fh^N-A	Maxillary position

Table 1 Parameters of the Ricketts Cephalometric Analysis

The clinical evaluation and the cephalometric analyses were performed by operators blinded about the study. The method errors in the cephalometric analysis were determined by applying the Dahlberg formula (mean error ratio $SE^2 = d^2/2n$, where d = differences between the measurements at two different times; n = number of measurements) [66]. Measurements were repeated on ten randomly chosen radiographs by the same examiner after two weeks.

2.1.4. Clinical Data

The subjective level of pain was assessed by the Visual Analogue Scale (VAS), consisting in a 100 mm horizontal line with the words "no pain" on the left side and "most intense imaginable pain" on the right side [67]. Each patient had to indicate, on three different VAS, the mean intensity of pain in the last 30 days, the maximum intensity of pain in the last 30 days and the intensity of pain at the moment of the examination [33]. The level of pain at the muscular palpation sites was assessed by the Pericranial Muscle Tenderness Score and the Cervical Muscle Tenderness Score [68].

2.1.5 Rasterstereography

Rasterstereographic recordings were performed by Formetric III 4D (DIERS International GmbH, Schlangenbad, Germany) in a standardized position and posture (barefoot and in a relaxed posture), following the recommendations of the supplier. Natural head posture is defined as the head position when a person is standing with his visual axis horizontal [69]. All the patients were analysed in a dedicated room.

In order to test the eventual effects of the mandible rest position on body posture and the eventual effects of teeth contact on body posture two Formetric scans were taken: mandibular rest position and maximum voluntary clenching were the analysed conditions. For the occlusal splint group also the clenching on occlusal splint was analysed.

On the sagittal plane five different measurements were considered: trunk inclination VP-DM, cervical arrow, lumbar arrow, kyphotic angle ICT-ITL and lordotic angle ITL-ILS. On the frontal plane three different measurements were considered: trunk imbalance, pelvic tilt DL-DR and pelvic torsion DL-DR.

2.1.6 Intervention

Intervention occlusal splint

The splint was prepared following the biomechanical models proposed by Ferrario and Sforza. After the conventional clinical assessment, a hard acrylic resin stabilization splint was made for the mandibular arch. The appliance was 2 mm thick and it was constructed so that only posterior contacts (from the second premolar to the second ⁄ first permanent molar) were allowed, without static and dynamic anterior contacts. The splint surface was adjusted to obtain an equilibrated muscular activity and checked with conventional clinical control of the dental contacts [70]. Patients wore the occlusal splint all night [71].

The occlusal splint therapy lasted 6 months and data were collected at baseline (T0), after 1 month (T1), 3 months (T2) and 6 months (T3). At T3, 2 out of 24 patients dropped-out (T3=22 patients). The reason for the dropout was represented by the refusal to continue the research protocol.

Data from the control group were collected at baseline (T0), after 1 month (T1) and 3 months (T2).

Intervention TENS therapy

The NeuroTrac® TENS (Verity Medical Ltd, Farley Lane, Braishfield, Hampshire, United Kingdom) was used for the treatment of the facial myalgia. The device, a dual channel device with individually isolated circuits, presents the following characteristics:

- Pulse waveform: biphasic asymmetrical
- Type: Constant Current
- Pulse frequency 50 Hz, pulse duration 50 μs and pulse pattern continuous
- Time duration of the treatment: 60 min
- Electrodes: self-adhering electrodes, 50 mm x 50 mm

Each patient performed the first session of TENS at the Gnathology Unit of the Dental School of Torino to set the device and to learn the exact position of the electrodes and then continued the treatment for twelve weeks at home, one hour per day. The skin was properly prepared before electrodes' placement. On the masseter muscle, the electrode was placed on the muscular belly on the line between the gonial angle and cantus, 1 cm above the gonial angle [72]. On the trapezius the electrode was placed at 50% on the line between the acromion and the spine on vertebra C7 [73] (Fig 21).

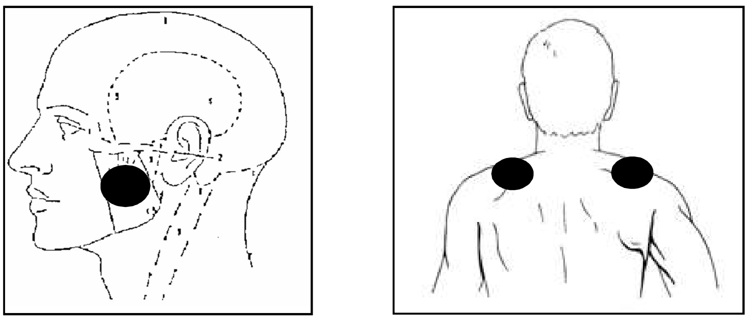

Fig. 21 TENS electrodes' placement

The TENS therapy lasted 3 months and data were collected at baseline (T0), after 1 month (T1), 3 months (T2) and 6 months (T3). At T3, 1 out of 16 patients dropped-out (T3=15 patients). The reason for the dropout was represented by the refusal to continue the research protocol.
Data from the control group were collected at baseline (T0), after 1 month (T1) and 3 months (T2).

2.1.7 Statistical analysis

The normality assumption of the data was evaluated with the Shapiro-Wilk test.
Homoscedasticity and autocorrelation of the variables were assessed using the Breusch-Pagan and Durbin-Watson tests.
Multiple regression analysis was performed to estimate the association between dependent variables and independent variables (age, skeletal class and Ricketts divergence).
Stratification by test type (rest position, maximum voluntary clenching and clenching on occlusal splint) was performed.
Three time follow-up (screening, one month and three months) in intra-group and between-groups analysis was included. For the occlusal splint group and the TENS group a six months follow-up was also included in the intra-group analysis. Delta value (Tn-T0) was performed to estimate the effect size during the follow-up.
Linear correlation at the screening using Pearson correlation coefficient was estimated.
Each value was expressed as mean (SD). For multiple comparisons, the Tukey test was used.
The level of significance was set at $p<0.05$.
Statistical analyses were conducted using the R statistical package (version 3.0.3, R Core Team, Foundation for Statistical Computing, Vienna, Austria).

2.2 Results

2.2.1 Results intra-articular temporomandibular joint disorders subjects

A CONSORT diagram displaying intra-articular TMJ disorders patients flow through the trial is shown in Fig. 22.

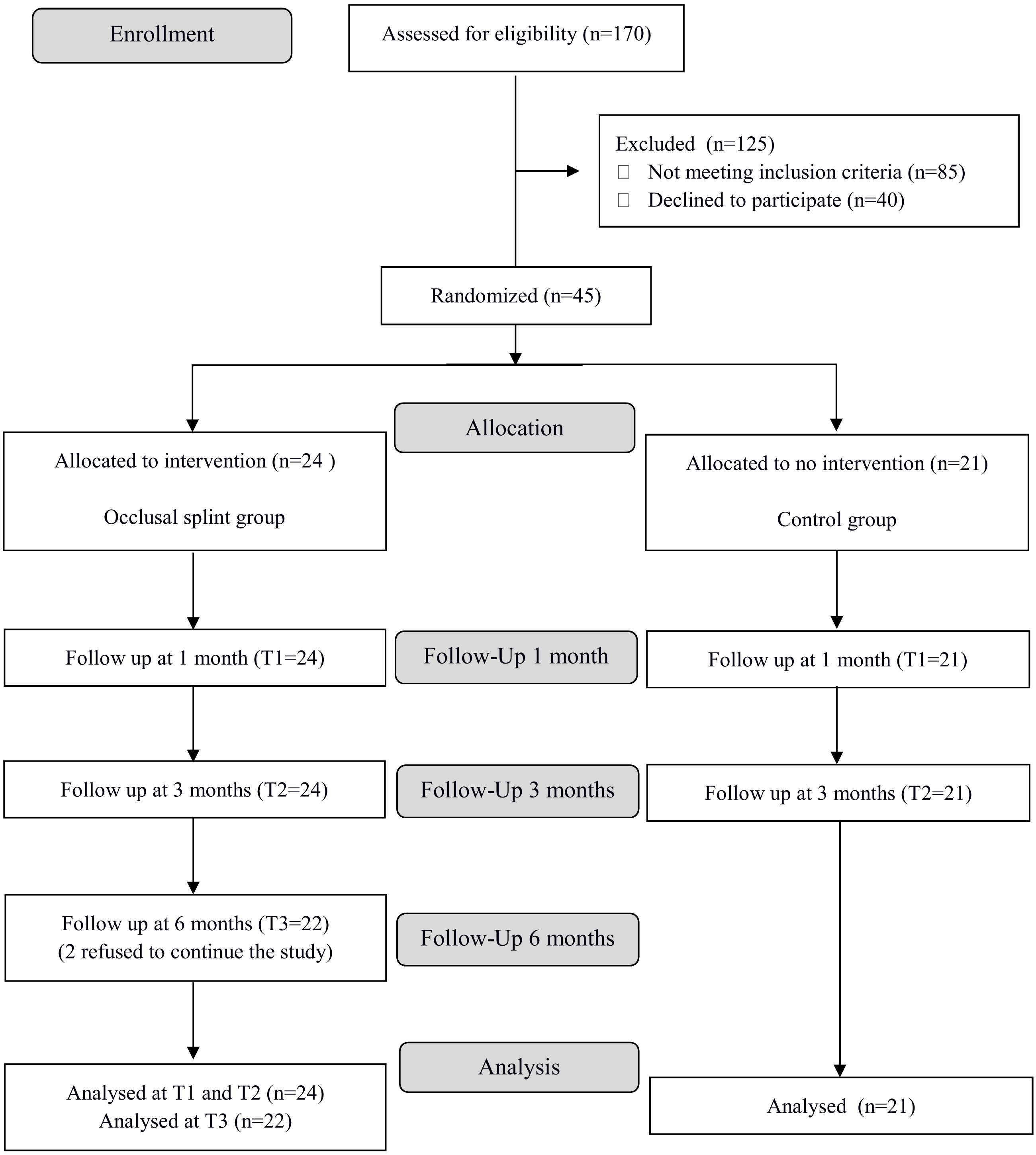

Fig. 22 CONSORT diagram of intra-articular temporomandibular joint subjects

Table 2 reports mean and standard deviation for the occlusal splint group and for the control group regarding the six angular parameters of the Ricketts Cephalometric Analysis.

	OCCLUSAL SPLINT	CONTROL
FACIAL AXIS	89.13±4.95	89.26±4.89
MANDIBULAR PLANE ANGLE	27.86±7.13	26.15±6.30
INNER GONIAL ANGLE	34.41±10.58	34.91±4.93
LOWER FACIAL HEIGHT	45.30±5.13	45.27±3.36
FACIAL DEPTH	86.09±4.84	86.61±4.94
MAXILLARY POSITION	89.62±4.65	88.05±4.66

Table 2 Mean and standard deviation for the occlusal splint group and for the control group regarding six angular parameters of the Ricketts Cephalometric Analysis

Table 3 reports mean and standard deviation for the occlusal splint group and for the control group regarding the three different Visual Analogue Scales, mean intensity of pain in the last 30 days (VAS MEAN), maximum intensity of pain in the last 30 days (VAS MAX) and intensity of pain at the moment of the examination (VAS NOW) and the Pericranial Tenderness Muscle Score (PTS) and Cervical Muscle Tenderness Score (CTS).

	OCCLUSAL SPLINT	CONTROL
VAS MEAN	38.33±21.66	35.19±25.52
VAS MAXIMUM	53.29±27.03	43.57±30.48
VAS NOW	21.04±17.28	19.90±24.47
PERICRANIAL TENDERNESS SCORE	1.03±0.50	1.15±0.46
CERVICAL TENDERNESS SCORE	1.31±0.76	1.14±0.71

Table 3 Mean and standard deviation for the occlusal splint group and for the control group regarding three different Visual Analogue Scales, Pericranial Tenderness Muscle Score and Cervical Muscle Tenderness Score

Table 4 reports mean and standard deviation for each postural parameter in occlusal splint group (G1) and in control group (G2) and in three different mandibular positions: rest position (RP), maximum voluntary clenching (MVC), clenching on occlusal splint (COS). Data were collected at baseline (T0), after 1 month (T1), 3 months (T2) and 6 months (T3).

			TRUNK INCLINATION	CERVICAL ARROW	LUMBAR ARROW	KYPHOTIC ANGLE	LORDOTIC ANGLE	TRUNK IMBALANCE	PELVIC TILT	PELVIC TORSION
T0	RP	G1	19.23±22.05	61.47±13.06	43.05±14.91	55.31±8.59	47.42±8.35	9.00±5.75	2.54±2.70	2.04±1.20
		G2	18.55±18.72	57.75±14.51	39.89±9.26	50.09±12.73	47.07±9.45	9.29±7.38	2.86±2.59	2.19±1.86
	MVC	G1	18.27±21.69	59.79±13.76	43.29±14.18	53.67±8.09	46.41±7.73	7.96±6.38	3.00±2.65	2.08±1.14
		G2	19.57±22.81	58.82±16.82	41.17±9.00	53.37±9.21	47.99±9.42	9.14±7.43	3.43±1.96	2.05±2.09
	COS	G1	19.29±21.59	56.30±13.27	40.59±15.17	52.06±9.73	47.20±7.35	7.54±7.55	3.13±2,72	2.08±1.50
T1	RP	G1	18.36±24.45	58.39±13.73	44.59±14.75	54.17±8.97	47.82±7.76	9.29±5.50	2.83±2.96	1.96±1.63
		G2	21.10±20.61	61.96±17.73	40.73±8.73	55.25±10.16	47.90±8.62	9.57±8.61	3.00±2.32	1.81±1.89
	MVC	G1	18.85±24.25	59.34±14.59	44.12±13.84	53.39±9.86	47.78±6.77	8.79±5.16	3.17±2.76	1.63±1.21
		G2	23.24±22.93	61.56±17.22	40.80±9.12	54.75±9.86	48.92±8.75	8.05±5.54	3.52±2.58	2.19±2.14
	COS	G1	18.44±25.10	54.36±17.79	43.49±15.70	53.28±9.52	48.21±7.65	8.50±5.87	2.63±2.70	1.83±1.13
T2	RP	G1	21.51±22.66	60.56±13.51	43.29±14.09	54.00±7.90	46.64±7.19	7.71±5.23	3.29±2.82	1.71±1.30
		G2	16.28±17.96	59.99±15.89	43.16±9.14	54.84±7.85	49.30±8.51	10.76±6.87	2.67±2.50	2.19±1.81
	MVC	G1	17.55±23.11	57.76±13.07	43.92±13.23	53.43±7.58	47.17±6.60	7.25±4.55	2.83±2.58	1.92±1.18
		G2	17.90±21.10	57.37±16.82	42.22±8.38	52.98±8.44	49.00±7.81	9.10±7.13	3.05±2.99	2.14±1.93
	COS	G1	19.96±24.00	58.54±14.78	41.89±14.82	53.24±8.38	46.72±7.57	7.58±4.61	3.08±2.69	1.96±1.33
T3	RP	G1	19.77±21.33	58.78±12.86	41.21±13.02	52.53±7.35	46.25±6.01	7.86±6.04	3.36±2.98	2.18±1.26
	MVC	G1	20.16±24.21	58.18±12.38	40.71±11.47	52.29±7.51	46.20±5.74	7.77±4.89	3.55±3.02	2.27±1.28
	COS	G1	21.93±22.95	56.93±11.33	40.93±13.77	52.28±7.03	47.36±5.32	6.87±4.61	3.82±2.96	2.32±1.30

Table 4 Mean and standard deviation for each postural parameter in occlusal splint group (G1) and in control group (G2) at RP, MVC, COS

Table 5 reports the analysis at T0 at rest position of the **Pearson correlations** between each cephalometric parameter and each postural parameter (95% Confidence Interval, p<0.05).

	FACIAL AXIS	MANDIBULAR PLANE ANGLE	INNER GONIAL ANGLE	LOWER FACIAL HEIGHT	FACIAL DEPTH	MAXILLARY POSITION
TRUNK INCLINATION	0.14 (-0.16, 0.42)	-0.25 (-0.51, 0.05)	0.08 (-0.22, 0.36)	**-0.30 (-0.54, -0.04)***	0.21 (-0.09, 0.47)	0.11 (-0.19, 0.39)
CERVICAL ARROW	0.07 (-0.23, 0.36)	0.27 (-0.03, 0.52)	0.01 (-0.29, 0.30)	-0.16 (-0.43, 0.14)	**0.32 (0.03, 0.56)***	0.27 (-0.03, 0.52)
LUMBAR ARROW	**-0.37 (-0.60, -0.10)***	0.15 (-0.15, 0.42)	-0.01 (-0.30, 0.29)	**0.43 (0.16, 0.64)***	-0.22 (-0.48, 0.08)	-0.07 (-0.36, 0.23)
KYPHOTIC ANGLE	-0.03 (-0.32, 0.26)	-0.09 (-0.38, 0.21)	0.05 (-0.25, 0.34)	-0.01 (-0.30, 0.28)	0.01 (-0.28, 0.30)	0.15 (-0.15, 0.42)
LORDOTIC ANGLE	**-0.31 (-0.55, -0.02)***	0.11 (-0.19, 0.39)	0.26 (-0.03, 0.52)	0.20 (-0.10, 0.46)	-0.23 (-0.49, 0.07)	-0.03 (-0.32, 0.26)
TRUNK IMBALANCE	0.27 (-0.03, 0.52)	-0.02 (-0.31, 0.28)	-0.02 (-0.31, 0.28)	-0.05 (-0.34, 0.25)	-0.10 (-0.38, 0.20)	-0.16 (-0.43, 0.15)
PELVIC TILT	-0.04 (-0.33, 0.26)	0.08 (-0.22, 0.36)	-0.21 (-0.48, 0.09)	-0.16 (-0.43, 0.14)	-0.04 (-0.33, 0.26)	0.02 (-0.27, 0.31)
PELVIC TORSION	-0.12 (-0.40, 0.18)	0.15 (-0.15, 0.43)	-0.08 (-0.37, 0.22)	0.17 (-0.13, 0.44)	-0.15 (-0.42, 0.16)	-0.04 (-0.33, 0.25)

Table 5 Pearson correlations between each cephalometric parameter and each postural parameter

The **screening analysis** revealed no differences between the two analyzed groups concerning the postural parameters, the cephalometric parameters and the level of subjective and objective pain.
Regarding the postural parameters in the **intragroup analysis** of the occlusal splint group and of the control group no significant differences were detected between T0 and T1, T0 and T2. For the occlusal splint group between T0 and T3 no significant differences were detected too.
The **analysis between the two groups** at different times of the study considering the delta value Tn-T0 revealed significant differences concerning many postural parameters. The evaluation of the *cervical arrow* at rest position showed statistical significant difference at T1 between the occlusal splint group (58.39 mm±13.73) and the control group (61.96 mm±17.73) (p=0.001). Concerning the *kyphotic angle* at rest position a statistical significant difference was found at T1 between occlusal splint group (54.17º±8.97) and the control group (55.25º±10.16) (p=0.012) and also at T2 between the occlusal splint group (54.00º±7.90) and the control group (54.84º±7.85) (p=0.019).
With regard to the *lordotic angle* a statistical significant difference was found at rest position at T2 between the occlusal splint group (46.64º±7.19) and the control group (49.30º±8.51) (p=0.017).
Each postural parameter in each group was compared among the **different mandibular positions** at T0: for the occlusal splint group and the control group the mandibular rest position was compared with the maximum voluntary clenching and for the occlusal splint group the clenching on occlusal splint was evaluated too. No statistical significant differences were detected.

2.2.2. Results facial myalgia subjects

A CONSORT diagram displaying facial myalgia patients flow through the trial is shown in Fig. 23.

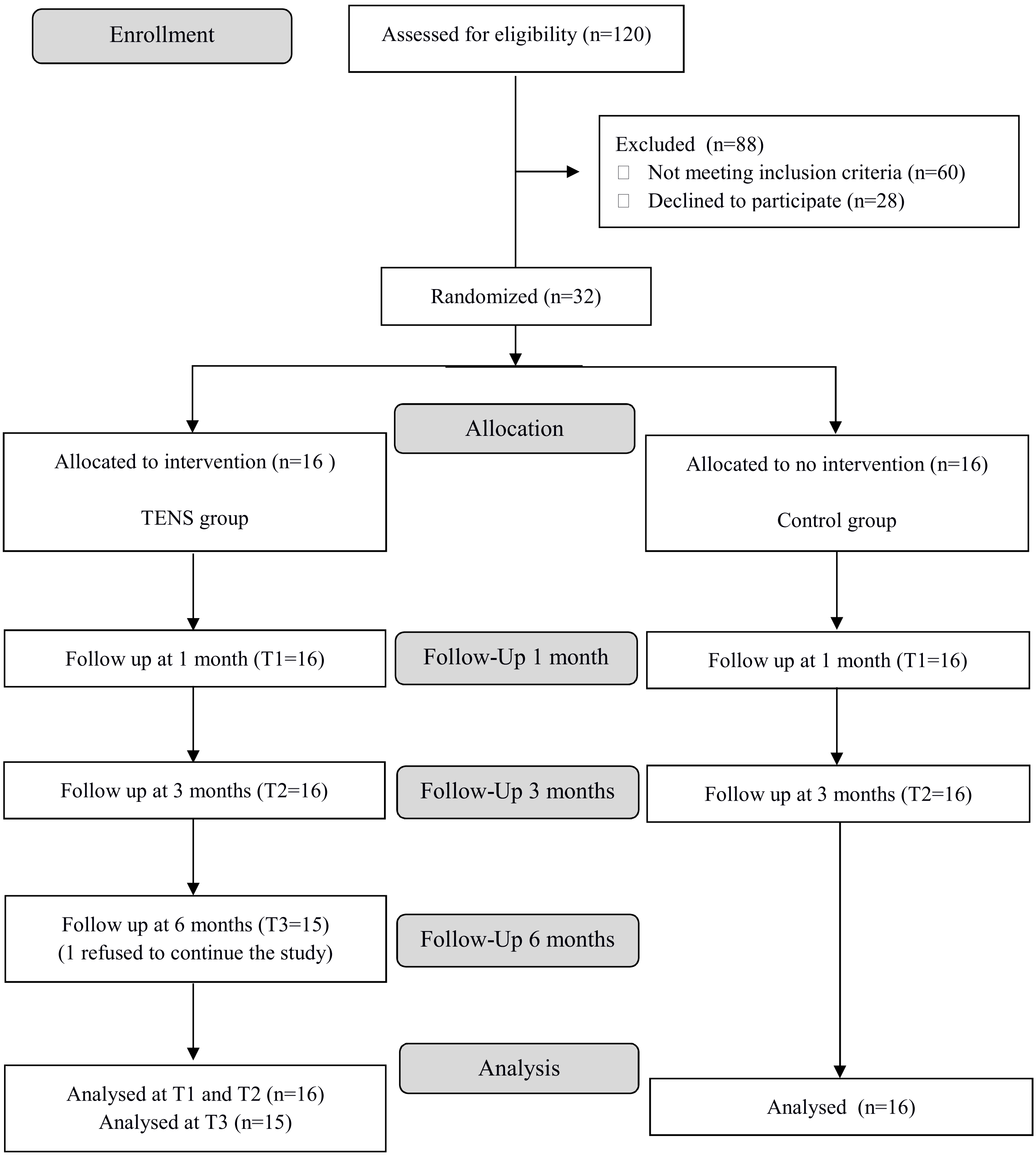

Fig. 23 CONSORT diagram of facial myalgia subjects

Table 6 reports mean and standard deviation for the TENS group and for the control group regarding the six angular parameters of the Ricketts Cephalometric Analysis.

	TENS	**CONTROL**
FACIAL AXIS	91.31±5.81	89.79±7.63
MANDIBULAR PLANE ANGLE	23.30±4.75	24.19±9.54
INNER GONIAL ANGLE	33.81±4.83	37.51±14.44
LOWER FACIAL HEIGHT	43.93±4.28	43.68±7.10
FACIAL DEPTH	90.13±3.70	88.39±3.98
MAXILLARY POSITION	90.79±4.16	90.45±3.84

Table 6 Mean and standard deviation for the TENS group and for the control group regarding six angular parameters of the Ricketts Cephalometric Analysis

Table 7 reports mean and standard deviation for the TENS group and for the control group regarding the three different Visual Analogue Scales, mean intensity of pain in the last 30 days (VAS MEAN), maximum intensity of pain in the last 30 days (VAS MAX) and intensity of pain at the moment of the examination (VAS NOW) and the Pericranial Tenderness Muscle Score and Cervical Muscle Tenderness Score.

	TENS	**CONTROL**
VAS MEAN	44.94±21.81	49.88±19.26
VAS MAXIMUM	64.94±20.67	66.69±24.29
VAS NOW	29.88±25.74	43.75±28.80
PERICRANIAL TENDERNESS SCORE	1.82±0.63	1.49±0.64
CERVICAL TENDERNESS SCORE	2.24±0.73	1.96±0.77

Table 7 Mean and standard deviation for the TENS group and for the control group regarding three different Visual Analogue Scales, Pericranial Tenderness Muscle Score and Cervical Muscle Tenderness Score

Table 8 reports mean and standard deviation for each postural parameter in TENS group (G1) and in control group (G2) and in two different mandibular positions: rest position (RP) and maximum voluntary clenching (MVC). Data were collected at baseline (T0), after 1 month (T1), 3 months (T2) and 6 months (T3).

			TRUNK INCLINATION	CERVICAL ARROW	LUMBAR ARROW	KYPHOTIC ANGLE	LORDOTIC ANGLE	TRUNK IMBALANCE	PELVIC TILT	PELVIC TORSION
T0	RP	G1	19.35±15.30	56.36±11.81	40.42±8.04	49.91±6.69	46.36±8.06	8.44±7.38	2.56±2.16	1.63±1.86
		G2	24.39±24.34	58.93±22.57	38.56±14.80	50.06±12.66	45.73±7.07	8.38±6.27	3.63±2.78	2.31±1.78
	MVC	G1	20.91±18.29	59.30±13.03	40.81±7.98	51.40±7.32	47.08±8.48	8.38±6.06	2.38±2.25	1.81±1.72
		G2	21.06±24.69	58.44±22.29	40.76±16.26	49.68±11.60	46.41±7.28	9.31±6.65	3.69±2.60	2.75±2.02
T1	RP	G1	21.16±14.02	58.22±12.38	41.86±5.89	51.59±7.52	47.46±8.12	7.56±5.70	3.19±3.54	2.13±1.20
		G2	17.51±17.86	57.27±22.61	41.56±14.83	50.54±11.06	46.38±7.76	9.38±5.98	5.25±4.77	2.81±1.91
	MVC	G1	22.91±14.05	60.02±12.86	40.87±5.64	51.77±8.24	47.06±8.03	8.94±6.40	3.56±3.50	1.75±1.65
		G2	22.16±21.89	58.62±23.33	40.09±14.68	50.40±11.27	45.88±7.64	9.69±7.57	4.50±5.02	2.38±1.71
T2	RP	G1	16.60±12.70	58.45±13.72	42.19±6.49	51.94±9.23	47.63±9.47	8.50±8.44	3.63±1.71	1.81±0.91
		G2	19.03±16.23	55.00±21.92	40.26±13.23	49.33±10.80	46.56±7.29	8.69±6.31	5.63±6.38	2.50±1.83
	MVC	G1	18.34±11.80	59.39±12.09	42.88±6.26	52.13±9.25	47.50±9.12	10.19±6.27	3.88±2.42	1.88±1.59
		G2	24.66±20.86	59.67±22.16	39.38±13.62	49.68±11.25	45.78±6.25	9.19±6.48	6.38±5.24	2.75±1.48
T3	RP	G1	20.99±16.72	57.23±14.86	39.51±6.70	50.37±8.84	47.81±7.72	6.80±6.06	3.13±2.42	1.60±1.40
	MVC	G1	19.22±17.39	59.42±15.22	42.21±6.18	52.49±8.59	49.05±8.26	5.60±5.60	3.40±2.23	1.80±1.08

Table 8 Mean and standard deviation for each postural parameter in TENS group (G1) and in control group (G2) at RP and MVC

Table 9 reports the analysis at T0 at rest position of the **Pearson correlations** between each cephalometric parameter and each postural parameter (95% Confidence Interval, p<0.05).

	FACIAL AXIS	MANDIBULAR PLANE ANGLE	INNER GONIAL ANGLE	LOWER FACIAL HEIGHT	FACIAL DEPTH	MAXILLARY POSITION
TRUNK INCLINATION	0.26 (-0.09, 0.56)	-0.15 (-0.47, 0.21)	0.15 (-0.21, 0.47)	-0.10 (-0.43, 0.26)	0.24 (-0.12, 0.54)	-0.15 (-0.48, 0.21)
CERVICAL ARROW	0.17 (-0.19, 0.49)	-0.13 (-0.46, 0.23)	-0.09 (-0.43, 0.26)	0.15 (-0.21, 0.47)	0.23 (-0.12, 0.54)	0.06 (-0.29, 0.40)
LUMBAR ARROW	-0.10 (-0.44, 0.25)	0.03 (-0.33, 0.37)	**-0.37 (-0.64, -0.02)***	0.24 (-0.12, 0.54)	0.01 (-0.35, 0.34)	**0.31 (0.03, 0.60)***
KYPHOTIC ANGLE	0.07 (-0.28, 0.41)	-0.07 (-0.41, 0.29)	-0.24 (-0.54, 0.12)	0.19 (-0.17, 0.50)	0.15 (-0.21, 0.47)	0.16 (-0.20, 0.48)
LORDOTIC ANGLE	0.26 (-0.10, 0.56)	-0.16 (-0.48, 0.20)	0.05 (-0.31, 0.39)	-0.10 (-0.43, 0.26)	0.16 (-0.20, 0.48)	**0.32 (0.03, 0.60)***
TRUNK IMBALANCE	**0.40 (0.05, 0.65)***	**-0.35 (-0.62, -0.01)***	0.20 (-0.16, 0.51)	**-0.46 (-0.70, -0.14)***	0.19 (-0.16, 0.51)	0.03 (-0.33, 0.37)
PELVIC TILT	-0.02 (-0.37, 0.33)	-0.10 (-0.43, 0.26)	-0.14 (-0.46, 0.22)	-0.12 (-0.45, 0.23)	0.17 (-0.19, 0.49)	0.10 (-0.25, 0.44)
PELVIC TORSION	-0.13 (-0.46, 0.23)	0.02 (-0.33, 0.37)	-0.05 (-0.39, 0.30)	0.14 (-0.22, 0.47)	0.01 (-0.35, 0.34)	0.09 (-0.27, 0.43)

Table 9 Pearson correlations between each cephalometric parameter and each postural parameter

The **screening analysis** revealed no differences between the two analyzed groups concerning the postural parameters, the cephalometric parameters and the level of subjective and objective pain.

Regarding the postural parameters in the **intragroup analysis** of the TENS and of the control group no significant differences were detected between T0 and T1, T0 and T2. For the TENS between T0 and T3 no significant differences were detected too.

In the **analysis between the two groups** at different times of the study considering the delta value Tn-T0, the evaluation of the *trunk inclination* at rest position showed statistical significant difference at T1 between the TENS group (21.16 mm±14.02) and the control group (17.51 mm±17.86) (p=0.014).

Each postural parameter in each group was compared among the **different mandibular positions** at T0: for the TENS and the control group we compared the mandibular rest position with the maximum voluntary clenching. No statistical significant differences were detected.

2.3 Discussion

The association between intra-articular and muscular TMD and head and cervical posture is still unclear, and literature suggests that better controlled studies with comprehensive TMD diagnoses, greater sample size and objective posture evaluation are necessary [45]. The observation that many patients contemporary present facial muscle pain, spinal pain and headache induce to speculate the presence of a strong comorbidity between TMD and other pain arising from different areas of the spine [74].

There is strong evidence of craniocervical postural changes in myogenous TMD, moderate evidence of cervical posture misalignment in arthrogenous TMD and no evidence of absence of craniofacial postural misalignment in mixed TMD patients or of global postural misalignment in patients with TMD. Moreover is important to note the poor methodological quality of the studies, particularly those regarding global body postural misalignment in TMD patients [50]. According to the literature it is possible to hypothesize that there are correlations between posture and stomatognathic system, however, due to the multiplicity and complexity of the factors involved, existing studies have left important gaps in understanding this relationship [75].

Analyzing the head posture in TMD patients compared with control group using photographs taken with a plumb line, Lee et al. found that the head was positioned more forward in the group with temporomandibular disorders than in the control group [76]. Other studies reported that postural and muscle function abnormalities were more common in TMD group than in control group [77]. Nevertheless not all studies in the literature support the relationship between posture and TMD. Using a photograph method Hackney et al. didn't find a significantly greater degree of forward head position in intra-articular TMJ disorders patients than in control group [78].

The use of clinical and instrumental approaches for assessing body posture is not supported by the wide majority of the existing literature, mainly because of wide variations in the measurable variables of posture [48]. Particularly, evidences didn't support the usefulness of posturography as a diagnostic aid in dentistry because these analysis systems didn't add significant advances [16, 17].

Rasterstereography is a reliable, non-invasive method to analyze three-dimensional (3D) spine morphology [20, 21]. This approach allows a radiation free examination of the back surface of the body and it has been demonstrated to be reliable when analyzing spinal posture and pelvic position. Normative rasterstereography values for spinal posture and pelvic position in healthy people were studied by Stagnara, concerning cervical arrow (60-80 mm) and lumbar arrow (40-60 mm), and by Harzmann, concerning the kyphotic angle (47-50º) and lordotic angle (38-42º), the trunk imbalance

(0-5 mm), the pelvic tilt (0-4º) and the pelvic torsion (0-1.9º) [79, 80]. All the values obtained in our study are in line with the normative values of Stagnara and Harzmann.
Using resterstereography in adults patients with II and III class malocclusion, Lippold found a relationship between the jaw position and the body posture in the upper part of the spine and excluded any connection with the lower part of the spine. In particular evaluating the trunk inclination, the cervical arrow and lumbar arrow he found correlations only between the cervical arrow and facial axis, mandibular plane angle and facial depth [81].
In accordance with Lippold et al., concerning the intra-articular TMJ disorders subjects, we found a positive correlation between the ***cervical arrow*** and facial depth indicating a relationship between the antero-posterior mandible position and the musculoskeletal anatomy of the cervical spine. This result is in accordance with the statements of Michelotti et al. who reported correlations between jaw position and body posture for the upper spine sections but not for lower spine sections [47].
Nevertheless, regarding the ***lumbar arrow***, in the intra-articular TMJ disorders subjects we found negative correlation with facial axis and positive correlation with lower facial height and in the facial myalgia subjects we found negative correlation with inner gonial angle and positive correlation with maxillary position. These results indicate a possible relationship between the skeletal vertical parameters and the lumbar parameters.
Moreover in our study, in the intra-articular TMJ disorders subjects, we found a correlation between the ***trunk inclination*** and the lower facial height indicating the more vertical craniofacial pattern the lowest the trunk inclination.
Furthermore, Lippold et al. examined the ***lordotic angle*** and the ***kyphotic angle*** in adult patients with II and III class malocclusion and found correlations only between the lordotic angle and facial axis, inner gonial angle and mandibular plane angle [82]. Likewise we found negative correlation in the intra-articular TMJ disorders subjects between lordotic angle and facial axis and a positive correlation in the facial myalgia subjects between lordotic angle and maxillary position. As Lippold et al., we suggest that there is some clinical evidence for a relationship between the vertical jaw position and the body posture and, differently from Lippold et al., we also suggest that this relationship regards not only the mandible but also the maxilla.
Concerning the posture analysis on the frontal plane, for the ***pelvic parameters*****,** we didn't observe any correlation with the cephalometric parameter so that we can speculate that cephalometric parameters didn't affect pelvic position. Conversely, Lippold et al. found correlations between the vertical and sagittal mandible position and pelvic torsion in adults patients with II and III class malocclusion [83].

We also found correlations regarding the ***trunk imbalance*** relatively to facial axis, mandibular plane angle and lower facial height in the facial myalgia subjects. These findings suggest that there are some correlations on the frontal plane too, thus indicating that postero-anterior radiographs for determining facial asymmetry could be used in future studies.

Our study also analyzed postural parameters during splint therapy for the intra-articular TMJ disorders patients and during TENS therapy for the facial myalgia patients. Concerning the ***splint group*** we didn't observe any statistical significant difference in the intragroup analyses. Nevertheless some differences were found between the occlusal splint and the control group at 1 and 3 months at rest position indicating that some changes occurred. Patients wearing the occlusal splint showed better values for the lordotic and the kyphotic angles, while a worse result was showed in these patients for the cervical arrow compared to the normative rasterstereographic values. However the low range of statistical significance made these results not significant from a clinical point of view.

In literature the use of occlusal splint was studied with lateral craniocervical radiographs with and without splint showing that the occlusal splint caused a significant extension of the head on the cervical spine and a reduction of the cervical lordosis [84]. Strini et al. evaluated the head position with a physical examination in TMD patients under use of occlusal splint and found that there were statistical differences for the head position between the initial values and after one week and one month of use of the occlusal device with a tendency of rectification of the head position [85]. Huggare and Raustia too, analyzing with radiographs TMD patients before and after occlusal splint therapy, found that the lordosis of the cervical spine straightened after therapy [86].

Conversely, Root et al. after increasing the vertical dimension by means of occlusal splint noted no significant changes in the cervical curvature and position of the head [87]. Likewise Andrighetto and de Fantini found that after the neuromuscular deprogramming by occlusal splint there was an extension of the head, but no changes were observed in the cervical position in asymptomatic individuals. Authors suggested that the possible sequence of biomechanical events responsible for craniocervical and craniovertical extensions, is that, with the increase of the vertical dimension, the mandible is moved down, relaxing the suprahyoid muscles. This causes the hyoid to be released from its previous lifting traction and to move downwards, thus reducing the pharyngeal airway space. In compensation, the head is extended and passively pulls the hyoid bone forward, through the stretching of the suprahyoid muscles, thus restoring the dimensions of the pharyngeal airway space. Another factor that may be responsible for changes in the head position is the complex muscular involved in maintaining the muscle–head position so that any changes in the activity of some muscles will lead to compensatory adjustments in other muscles [88].

Concerning the ***TENS group*** we didn't observe any statistical difference in the intragroup analyses, indicating that TENS therapy didn't affect postural parameters during treatment. The only postural parameter that showed a statistical difference between the two groups was the trunk inclination at 1 month at rest position. This result is not significant from a clinical point of view and, since this is the first evaluation on patients treated with TENS, comparison with other studies are not available.

Each postural parameter in each group was compared among the ***different mandibular positions*** at T0: in both the intra-articular TMJ subjects and the facial myalgia subjects we didn't detect any statistical significant difference. We can speculate that the clenching on teeth or the clenching on the occlusal splint didn't affect directly and immediately body posture compared to the rest position.

The study regarding TMD patients showed that correlations exist between cephalometric parameters and postural parameters, in both cervical and lumbar regions. Concerning the therapy, the use of an occlusal splint statistically affects the cervical arrow, the kyphotic and lordotic angles and the use of TENS statistically affects the trunk inclination.

The ***limitations*** of our study were represented by the lack of a radiographic confirmation of the Formetric measurements. However rasterstereography provides a reliable method for three-dimensional back shape analysis and reconstruction of spinal deformities [21, 89]. In our knowledge this is the very first study in which the postural analysis of TMD was performed with this device. Therefore no data to which compare our results are available.

3. MALOCCLUSIONS AND BODY POSTURE: A RASTERSTEREOGRAPHIC STUDY

3.1 Materials and methods

3.1.1. Aims

Rasterstereography was used in a sample of patients affected by malocclusion to investigate the following points:

- the relationship between craniofacial morphology and body posture parameters;
- the effect of functional appliances on body posture parameters in patients aged 6-12 years affected by malocclusion;
- the effect of fixed appliances and clear aligners therapy on body posture parameters in patients aged 13-30 years affected by malocclusion;
- the effect of different occlusal relationship on body posture parameters.

The treated groups were compared to a matched sample of not-treated orthodontic patients.

The null hypotheses were: (i) no correlations between cephalometric and postural parameters can be detected, (ii) postural parameters are not affected by functional appliances therapy in patients affected by malocclusion, (iii) postural parameters are not affected by fixed appliances and clear aligners therapy in patients affected by malocclusion and (iv) no differences in postural parameters among different occlusal condition can be revealed.

3.1.2 Subjects

Patients functional appliances study

The study was performed on 72 patients consecutively recruited among the patients referring to the Specialization School of Orthodontics of the CIR Dental School of the University of Torino in the period May – October 2016.

The group was composed by 72 children (mean age ± SD 9.4±1.5) of which 33 were male (mean age ± SD 9.7±1.3) and 39 were female (mean age ± SD 9.1±1.6).

The inclusion criteria were: age between 6 and 12 years, pre-pubertal growth phase (CS1 and CS2 according to the cervical vertebra maturation method) and need for orthodontic treatment (Grade 3 and 4 according to the Risk of Malocclusion Assessment index) [90, 91]. The diagnosis of dental malocclusion was performed on the basis of a clinical evaluation and on the basis of the Ricketts cephalometric analysis.

The exclusion criteria were: (i) syndromes, (ii) medical history of motor or neurological problems, (iii) internal diseases, (iv) history of orthopaedic, head and facial trauma, (v) orthopaedic treatment, (vi) orthodontic treatment.
Participants were randomly divided in two groups: the functional appliances group composed of 44 patients (mean age ± SD 9.3±1.6) and the control group composed of 28 patients (mean age ± SD 9.6±1.4). The control group was a "waiting list control" group, without any form of treatment. They were enrolled in a control program consisting in monthly appointments to perform routine evaluations. Their orthodontic treatments were planned to start 6 months after the beginning of the study. The randomization sequence was generated using a free online software (www.random.org).

Patients fixed appliances and clear aligners study

The study was performed on 48 patients consecutively recruited among the patients referring to the Specialization School of Orthodontics of the CIR Dental School of the University of Torino in the period May – October 2016.
The group was composed by 48 patients (mean age ± SD 18.5±5.7) of which 16 were male (mean age ± SD 18.9±6.4) and 32 were female (mean age ± SD 18.3±5.4).
The inclusion criteria were: age between 13 and 30 years, post-pubertal growth phase (CS5 and CS6 according to the cervical vertebra maturation method), class I malocclusion, crowding <8 mm, permanent dentition (complete dentition, with the exception of the third molar) and need for orthodontic treatment (Grade 3 and 4 according to the Risk of Malocclusion Assessment index) [90, 91]. The diagnosis of dental malocclusion was performed on the basis of a clinical evaluation and on the basis of the Ricketts cephalometric analysis.
The exclusion criteria were: (i) syndromes, (ii) medical history of motor or neurological problems, (iii) internal diseases, (iv) history of orthopaedic, head and facial trauma, (v) orthopaedic treatment, (vi) orthodontic treatment.
Participants were randomly divided in three groups: the fixed appliances group composed of 14 patients (mean age ± SD 14.2±1.8), the clear aligners group composed of 19 patients (mean age ± SD 17.3±4.3) and the control group composed of 15 patients (mean age ± SD 24.0±5.5). The control group was a "waiting list control" group, without any form of treatment. They were enrolled in a control program consisting in monthly appointments to perform routine evaluations. Their orthodontic treatments were planned to start 6 months after the beginning of the study. The randomization sequence was generated using a free online software (www.random.org).

The study was conducted in accordance to the Declaration of Helsinki and each subject was aware to withdraw from the experiment at any time. A written informed consent was obtained for each participant. The study was approved by the local ethic committee (#3732015).

3.1.3. Cephalometric Analysis

For each patient the following data were collected: anamnesis, photos, gypsum casts of the dental arches, ortopantomography and lateral skull radiograph. A standardized digital lateral radiograph was obtained for each patient in order to analyse the sagittal position of the maxilla and of the mandible and the parameters of the vertical cranio-facial morphology (Sirona Orthophos XG 5). The cephalometric analysis was performed with a dedicated software (OrisCeph® Rx Elite Computer Italia, Vimodrone, Milano, Italia).

On the sagittal plane six angular parameters of the Ricketts Cephalometric Analysis were considered for the study [52]:

- Facial Axis: on vertical plane, growth direction of the mandible and vertical facial development (90.0º±3.0);
- Mandibular Plane Angle: on vertical plane, facial growth type (24.0º±4.0)
- Inner Gonial Angle: on vertical plane, tendency of the mandible growth and index of the vertical facial development (29.0º±4.0)
- Lower Facial Height: on vertical plane, skeletal vertical dimension of the lower facial height (47.0º±4.0)
- Facial Depth: on antero-posterior plane, mandible position (89.0º±3.0)
- Maxillary Position: on antero-posterior plane, maxillary position (90.0º±3.0)

The clinical evaluation and the cephalometric analyses were performed by operators blinded about the study.

The method errors in the cephalometric analysis were determined by applying the Dahlberg formula (mean error ratio $SE^2 = d^2/2n$, where d = differences between the measurements at two different times; n = number of measurements) [66]. Measurements were repeated on ten randomly chosen radiographs by the same examiner after two weeks.

3.1.4. Rasterstereography

Rasterstereographic recordings were performed by Formetric III 4D (DIERS International GmbH, Schlangenbad, Germany) in a standardized position and posture (barefoot and in a relaxed posture), following the recommendations of the supplier. Natural head posture is defined as the head position

when a person is standing with his visual axis horizontal [69]. All the patients were analysed in a dedicated room.
In order to test the eventual effects of the mandible rest position on body posture and the eventual effects of teeth contact on body posture two Formetric scans were taken: mandibular rest position and maximum voluntary clenching were the analysed conditions. For the functional appliances group and the clear aligners group also the clenching on functional appliances and the clenching on clear aligners respectively were analysed.
On the sagittal plane five different measurements were considered: trunk inclination VP-DM, cervical arrow, lumbar arrow, kyphotic angle ICT-ITL and lordotic angle ITL-ILS. On the frontal plane three different measurements were considered: trunk imbalance, pelvic tilt DL-DR and pelvic torsion DL-DR.

3.1.5. Intervention

Intervention functional appliances

All children in the treatment group received a functional treatment and the choice of the functional appliance, according to the University of Torino, was determined by the divergence and the skeletal classes (Class I and II or Class III). Mesodivergent or hypodivergent patients were treated with Function Generating Bite deep appliance (FGB-D) and hyperdivergent patients were treated with Function Generating Bite open appliance (FGB-O) (Fig. 24). The FGB appliance is a functional device, individually wrapped, made of acrylic resin and resilient stainless wires and bites [92, 93].

Fig. 24 Functional appliances

The children were instructed to use the appliance every night and 2 hours during the day.

The functional appliances therapy lasted for 12 months and data were collected at baseline (T0), after 1 month (T1), 3 months (T2), 6 months (T3) and 12 months (T4). At T4, 3 out of 44 patients dropped-out (T4=41 patients). The reason for the dropout was represented by the refusal to continue the research protocol.

Data from the control group were collected at baseline (T0), after 1 month (T1), 3 months (T2) and 6 months (T3). At T3, 3 out of 28 control patients dropped-out (T3=25 control patients). The reason for the dropout was represented by the refusal to continue the research protocol.

Intervention fixed appliances and clear aligners

Fixed appliances followed the Straight Wire technique with Roth prescription brackets [94].

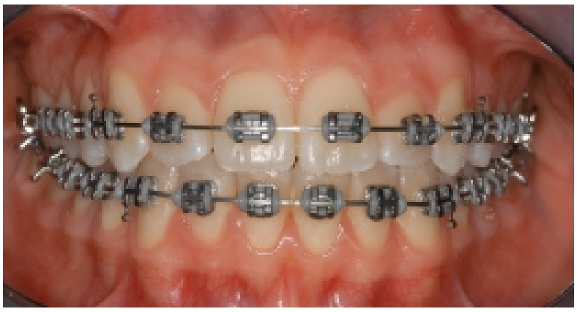

Fig. 25 Fixed appliances

Clear aligners treatment was provided with Invisalign aligners (Align Technology, San José, CA, USA). The treatment plan of each patient was designed by the same operator. Treatment was conducted by post-graduate students under the supervision of an expert operator. All patients were provided with a precise sequence of aligners, to be replaced every two weeks, according to the standard treatment protocol [95]. Every month each patient was monitored to perform routine controls. Every patient was instructed to wear the aligners for 21 hours per day as recommended by the producer (Fig. 26).

Fig. 26 Clear aligners

The fixed and clear aligners therapy lasted for 12 months and data were collected at baseline (T0), after 1 month (T1), 3 months (T2), 6 months (T3) and 12 months (T4). At T4, 2 out of 14 fixed appliances patients dropped-out (T4=12 fixed appliances patients). The reason for the dropout was represented by the refusal to continue the research protocol.

Data from the control group were collected at baseline (T0), after 1 month (T1), 3 months (T2) and 6 months (T3). At T3 1 out of 15 control patients dropped-out (T3=14 control patients). The reason for the dropout was represented by the refusal to continue the research protocol.

3.1.6 Statistical analysis

The normality assumption of the data was evaluated with the Shapiro-Wilk test.

Homoscedasticity and autocorrelation of the variables were assessed using the Breusch-Pagan and Durbin-Watson tests.

Multiple regression analysis was performed to estimate the association between dependent variables and independent variables (age, skeletal class and Ricketts divergence).

Stratification by test type (rest position, maximum voluntary clenching, clenching on functional appliances, clenching on clear aligners) was performed.

Three time follow-up (screening, one month, three months and six months) in intra-group and between-groups analysis was included. For the functional appliances group, fixed appliances group and clear aligners group a twelve months follow-up was also included in the intra-group analysis. Delta value (Tn-T0) was performed to estimate the effect size during the follow-up.

Linear correlation at the screening using Pearson correlation coefficient was estimated.

Each value was expressed as mean (SD). For multiple comparisons, the Tukey test was used.

The level of significance was set at $p<0.05$.

Statistical analyses were conducted using the R statistical package (version 3.0.3, R Core Team, Foundation for Statistical Computing, Vienna, Austria).

3.2 Results

3.2.1. Results functional appliances study

A CONSORT diagram displaying orthodontic patients flow through the trial is shown in Fig. 27.

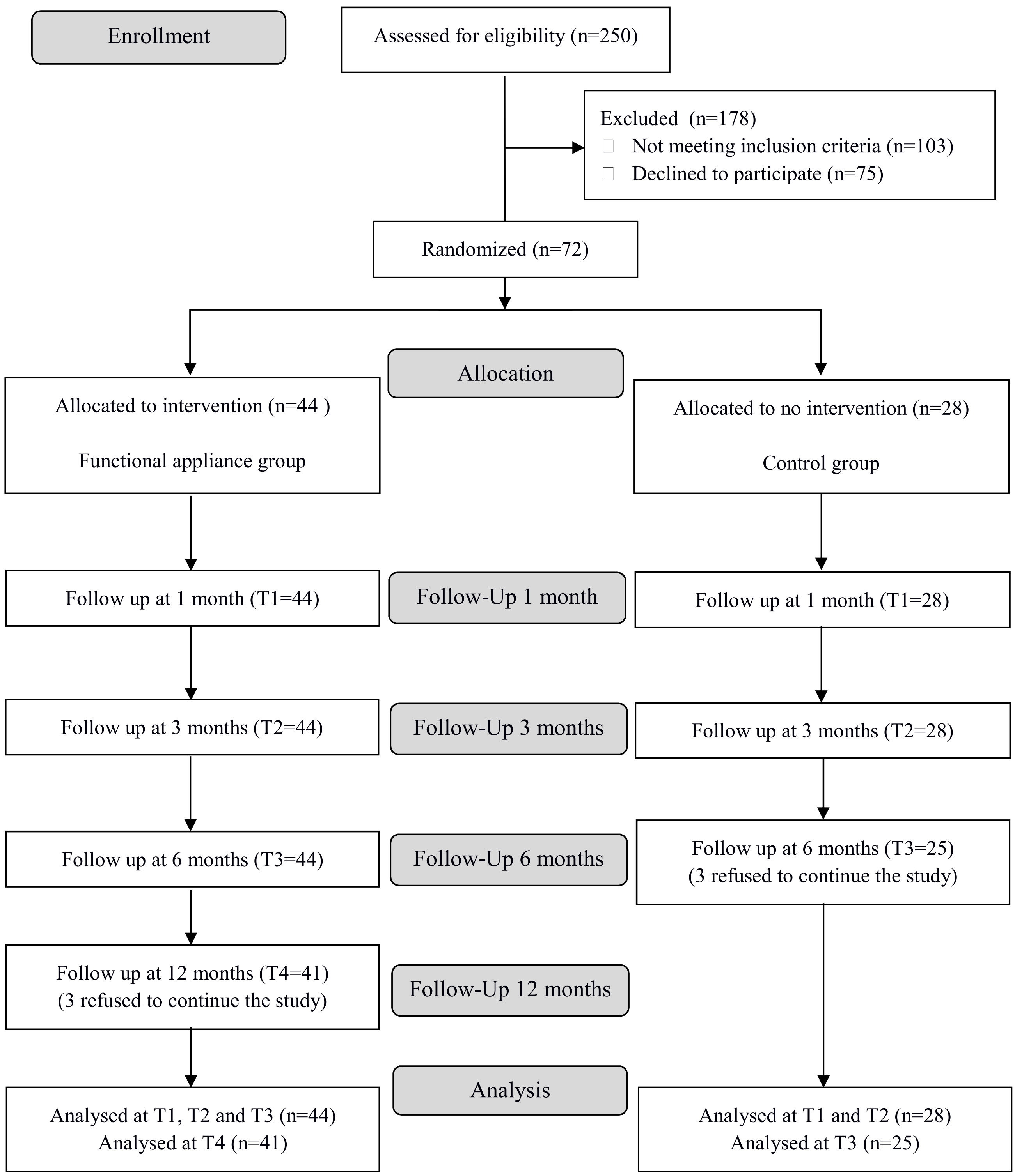

Fig. 27 CONSORT diagram of orthodontic patients (functional appliances study)

Table 10 reports mean and standard deviation for the functional appliances group and for the control group regarding the six angular parameters of the Ricketts Cephalometric Analysis.

	FUNCTIONAL APPLIANCES	CONTROL
FACIAL AXIS	91.98±7.23	90.38±4.39
MANDIBULAR PLANE ANGLE	24.58±6.27	26.56±5.55
INNER GONIAL ANGLE	36.97±32.55	28.39±6.74
LOWER FACIAL HEIGHT	43.82±4.99	43.80±4.58
FACIAL DEPTH	87.20±4.69	84.41±3.52
MAXILLARY POSITION	90.54±4.56	88.62±4.11

Table 10 Mean and standard deviation for the functional appliances group and for the control group regarding the six angular parameters of the Ricketts Cephalometric Analysis

Table 11 reports mean and standard deviation for each postural parameter in functional appliances group (G1) and in control group (G2) and in three different mandibular positions: rest position (RP), maximum voluntary clenching (MVC), clenching on functional appliance (CFA). Data were collected at baseline (T0), after 1 month (T1), 3 months (T2), 6 months (T3) and 12 months (T4).

			TRUNK INCLINATION	CERVICAL ARROW	LUMBAR ARROW	KYPHOTIC ANGLE	LORDOTIC ANGLE	TRUNK IMBALANCE	PELVIC TILT	PELVIC TORSION
T0	**RP**	**G1**	8.23±18.97	42.15±14.83	32.12±12.77	41.74±8.88	40.91±9.74	6.41±5.56	2.39±2.10	1.66±1.31
		G2	9.81±19.32	46.04±14.18	29.86±11.14	42.81±8.85	38.34±8.91	8.50±5.37	3.79±3.25	2.29±1.80
	MVC	**G1**	7.14±18.61	43.90±15.10	33.16±11.10	43.50±7.48	41.42±8.98	5.77±4.27	2.14±2.36	1.89±1.47
		G2	8.99±18.31	47.75±13.79	31.14±10.45	44.37±9.26	38.56±7.66	8.54±5.61	4.61±3.11	2.75±2.20
	CFA	**G1**	7.71±18.36	43.88±13.94	32.82±11.81	43.52±8.12	42.21±10.46	6.39±4.59	2.52±2.50	1.93±1.19
T1	**RP**	**G1**	6.82±20.83	44.40±14.49	34.43±11.39	44.20±6.64	42.49±9.40	5.20±4.28	2.56±2.35	2.02±1.61
		G2	5.25±18.19	46.85±15.67	34.43±12.79	44.93±7.34	41.49±9.49	5.79±3.79	4.57±2.91	2.00±1.19
	MVC	**G1**	6.89±17.21	45.34±14.35	34.35±9.64	45.08±6.93	42.32±8.21	6.36±4.20	2.45±2.53	2.07±1.32
		G2	7.89±21.69	48.41±15.98	33.12±13.96	45.51±8.68	40.77±9.86	5.89±4.20	4.46±3.44	2.64±1.50
	CFA	**G1**	10.74±16.53	44.55±12.94	32.16±10.20	43.67±7.40	42.63±9.21	6.25±5.25	2.82±2.45	2.02±1.59
T2	**RP**	**G1**	12.12±16.49	46.51±11.81	31.80±10.92	43.72±7.63	42.08±8.67	6.32±5.11	2.98±2.43	2.09±1.49
		G2	9.94±20.08	45.94±17.10	31.95±12.76	43.80±9.02	42.45±7.79	7.75±6.13	3.79±3.00	2.14±1.33
	MVC	**G1**	9.98±18.88	46.23±14.53	33.69±13.23	44.81±9.10	42.92±9.16	6.39±4.89	2.59±2.62	2.16±1.58
		G2	11.31±19.11	48.45±15.38	31.54±14.61	44.07±9.69	41.43±9.43	7.21±6.16	4.04±2.80	2.68±1.87
	CFA	**G1**	13.03±19.68	43.88±13.56	31.60±13.12	43.75±8.26	42.32±10.17	6.20±4.75	3.00±2.33	2.16±1.63
T3	**RP**	**G1**	12.34±18.10	44.50±13.47	31.79±13.02	43.75±7.79	42.88±9.40	6.07±5.05	3.33±2.81	2.11±1.51
		G2	10.82±21.57	45.18±14.02	30.14±13.56	42.77±9.16	40.62±8.15	5.48±3.85	4.36±3.19	2.36±1.44
	MVC	**G1**	13.61±18.27	45.23±12.66	31.48±11.80	44.12±8.09	43.38±7.89	5.82±5.02	3.09±2.91	2.07±1.50
		G2	15.58±20.21	47.53±17.13	28.31±10.26	42.99±8.29	40.96±7.50	6.80±5.19	3.96±3.21	1.88±1.62
	CFA	**G1**	10.49±18.58	44.42±14.20	32.57±13.21	43.91±8.63	43.50±8.73	5.75±4.36	2.84±2.88	1.98±1.27
T4	**RP**	**G1**	13.92±17.70	46.25±15.38	30.97±12.80	43.17±8.86	42.47±8.78	7.32±5.12	3.34±3.28	1.78±1.24
	MVC	**G1**	16.34±19.63	48.06±15.57	31.56±13.30	43.20±9.88	42.02±8.31	6.12±5.22	3.32±3.13	2.05±1.87
	CFA	**G1**	16.73±19.09	47.38±14.45	30.63±13.40	43.46±8.59	42.28±8.79	7.22±4.81	2.61±3.02	2.15±1.68

Table 11 Mean and standard deviation for each postural parameter in functional appliances group (G1) and in control group (G2) at RP, MVC and CFA

Table 12 reports the analysis at T0 at rest position of the **Pearson correlations** between each cephalometric parameter and each postural parameter in the orthodontic group 6-12 years at rest position (95% Confidence Interval, p<0.05).

	FACIAL AXIS	MANDIBULAR PLANE ANGLE	INNER GONIAL ANGLE	LOWER FACIAL HEIGHT	FACIAL DEPTH	MAXILLARY POSITION
TRUNK INCLINATION	0.11 (-0.13, 0.33)	-0.06 (-0.29, 0.17)	0.02 (-0.21, 0.25)	-0.07 (-0.30, 0.16)	0.02 (-0.21, 0.25)	0.06 (-0.17, 0.29)
CERVICAL ARROW	-0.01 (-0.23, 0.23)	**-0.23 (-0.44, 0.02)***	-0.16 (-0.38, 0.08)	-0.17 (-0.38, 0.07)	0.09 (-0.14, 0.32)	-0.01 (-0.24, 0.23)
LUMBAR ARROW	-0.05 (-0.28, 0.18)	-0.02 (-0.25, 0.22)	-0.04 (-0.27, 0.19)	0.03 (-0.21, 0.26)	-0.02 (-0.25, 0.21)	-0.09 (-0.31, 0.15)
KYPHOTIC ANGLE	0.01 (-0.22, 0.24)	-0.12 (-0.34, 0.12)	-0.12 (-0.34, 0.11)	-0.07 (-0.29, 0.17)	0.02 (-0.21, 0.25)	-0.06 (-0.28, 0.18)
LORDOTIC ANGLE	-0.04 (-0.27, 0.19)	0.07 (-0.16, 0.30)	0.03 (-0.20, 0.26)	0.01 (-0.22, 0.25)	-0.05 (-0.28, 0.18)	-0.01 (-0.24, 0.23)
TRUNK IMBALANCE	0.16 (-0.08, 0.37)	0.22 (-0.01, 0.43)	0.22 (-0.01, 0.43)	0.20 (-0.04, 0.41)	**-0.38 (-0.56, -0.16)***	**-0.27 (-0.47, -0.04)***
PELVIC TILT	-0.22 (-0.43, 0.01)	0.22 (-0.01, 0.43)	0.03 (-0.20, 0.26)	**0.24 (0.01, 0.44)***	-0.17 (-0.39, 0.06)	-0.11 (-0.33, 0.12)
PELVIC TORSION	-0.13 (-0.35, 0.11)	-0.01 (-0.24, 0.22)	-0.10 (-0.32, 0.14)	0.01 (-0.22, 0.24)	0.02 (-0.22, 0.25)	0.04 (-0.20, 0.27)

Table 12 Pearson correlations between each cephalometric parameter and each postural parameter

The **screening analysis** revealed no differences between the functional appliances group and the control group concerning the postural parameters and the cephalometric parameters.

Regarding the postural parameters in the **intragroup analysis** of the **functional appliances group** many statistical differences were detected between T0 and different times of the study.

Concerning the *trunk inclination* we detected statistical significant differences at rest position between T0 (8.23 mm±18.97) and T1 (6.82 mm±20.83) (p=0.014), at maximum voluntary clenching between T0 (7.14 mm±18.61) and T4 (16.34 mm±19.63) (p=0.020) and at clenching on appliance between T0 (7.71 mm±18.36) and T4 (16.73 mm±19.09) (p=0.012).

Regarding the *cervical arrow* we found statistical significant differences at rest position between T0 (42.15 mm±14.83) and T1 (44.40 mm±14.49), T2 (46.51 mm±11.81), T3 (44.50 mm±13.47) and at maximum voluntary clenching between T0 (43.90 mm±15.10) and T1 (45.34 mm±14.35), T2 (46.23 mm±14.53), T3 (45.23 mm±12.66) (p=0.000).

Analyzing the *lumbar arrow* we investigated statistical significant differences at rest position between T0 (32.12 mm±12.77) and T1 (34.34 mm±11.39), T2 (31.80 mm±10.92), T3 (31.79 mm±13.02) and at maximum voluntary clenching between T0 (33.16 mm±11.10) and T1 (34.35 mm±9.64), T2 (33.69 mm±13.23), T3 (31.48 mm±11.80) (p=0.000).

Concerning the *kyphotic angle* we detected statistical significant differences at rest position between T0 (41.74º±8.88) and T1 (44.20º±6.64), T2 (43.72º±7.63), T3 (43.75º±7.79) and at maximum voluntary clenching between T0 (43.50º±7.48) and T1 (45.08º±6.93), T2 (44.81º±9.10), T3 (44.12º±8.09) (p=0.000).

Evaluating the *lordotic angle* we found statistical significant differences at rest position between T0 (40.91º±9.74) and T1 (42.49º±9.40), T2 (42.08º±8.67), T3 (42.88º±9.40) and at maximum voluntary clenching between T0 (41.42º±8.98) and T1 (42.32º±8.21), T2 (42.92º±9.16), T3 (43.38º±7.89) (p=0.000).

Analyzing the *trunk imbalance* we investigated statistical significant differences at rest position between T0 (6.41 mm±5.56) and T1 (5.20 mm±4.28), T2 (6.32 mm±5.11), T3 (6.07 mm±5.05) and at maximum voluntary clenching between T0 (5.77 mm±4.27) and T1 (6.36 mm±4.20), T2 (6.39 mm±4.89), T3 (5.82 mm±5.02) (p=0.000).

Pelvic tilt showed statistical significant differences at rest position between T0 (2.39 mm±2.10) and T1 (2.56 mm±2.35) (p=0.000), T2 (2.98 mm±2.43) (p=0.001), T3 (3.33 mm±2.81) (p=0.008) and at maximum voluntary clenching between T0 (2.14 mm±2.36) and T1 (2.45 mm±2.53) (p=0.000), T2 (2.59 mm±2.62) (p=0.000), T3 (3.09 mm±2.91) (p=0.019), T4 (3.32 mm±3.13) (p=0.019).

Evaluating *pelvic torsion* we found statistical significant differences at rest position between T0 (1.66º±1.31) and T1 (2.02º±1.61), T2 (2.09º±1.49), T3 (2.11º±1.51) and at maximum voluntary clenching between T0 (1.89º±1.47) and T1 (2.07º±1.32), T2 (2.16º±1.58), T3 (2.07º±1.50) (p=0.000).

In the **intragroup analysis** of the **control group** many statistical differences were detected too.

Concerning the *trunk inclination* we detected statistical significant differences at rest position between T0 (9.81 mm±19.32) and T1 (5.25 mm±18.19) (p=0.009), at maximum voluntary clenching between T0 (8.99 mm±18.31) and T1 (7.89 mm±21.69) (p=0.046).

Regarding the *cervical arrow* we found statistical significant differences at rest position between T0 (46.04 mm±14.18) and T1 (46.85 mm±15.67), T2 (45.94 mm±17.10), T3 (45.18 mm±14.02) and at maximum voluntary clenching between T0 (47.75 mm±13.79) and T1 (48.41 mm±15.98), T2 (48.45 mm±15.38), T3 (47.53 mm±17.13) (p=0.000).

Analyzing the *lumbar arrow* we investigated statistical significant differences at rest position between T0 (29.86 mm±11.14) and T1 (34.43 mm±12.79), T2 (31.95 mm±12.76), T3 (30.14 mm±13.56) and at maximum voluntary clenching between T0 (31.14 mm±10.45) and T1 (33.12 mm±13.96), T2 (31.54 mm±14.61), T3 (28.31 mm±10.26) (p=0.000).

Concerning the *kyphotic angle* we detected statistical significant differences at rest position between T0 (42.81º±8.85) and T1 (44.93º±7.34), T2 (43.80º±9.02), T3 (42.77º±9.16) and at maximum

voluntary clenching between T0 (44.37º±9.26) and T1 (45.51º±8.68), T2 (44.07º±9.69), T3 (42.99º±8.29) (p=0.000).
Evaluating the *lordotic angle* we found statistical significant differences at rest position between T0 (38.34º±8.91) and T1 (41.49º±9.49), T2 (42.45º±7.79), T3 (40.62º±8.15) and at maximum voluntary clenching between T0 (38.56º±7.66) and T1 (40.77º±9.86), T2 (41.43º±9.43), T3 (40.96º±7.50) (p=0.000).
Analyzing the *trunk imbalance* we investigated statistical significant differences at rest position between T0 (8.50 mm±5.37) and T1 (5.89 mm±4.20) and at maximum voluntary clenching between T0 (8.54 mm±5.61) and T1 (5.89 mm±4.20) (p=0.000).
Pelvic tilt showed significant differences at rest position between T0 (3.79 mm±3.25) and T1 (4.57 mm±2.91), T2 (3.79 mm±3.00), T3 (4.36 mm±3.19) and at maximum voluntary clenching between T0 (4.61 mm±3.11) and T1 (4.46 mm±3.44), T2 (4.04 mm±2.80), T3 (3.96 mm±3.21) (p=0.000).
Evaluating *pelvic torsion* we found significant differences at rest position between T0 (2.29º±1.80) and T1 (2.00º±1.19), T2 (2.14º±1.33), T3 (2.36º±1.44) and at maximum voluntary clenching between T0 (2.75º±2.20) and T1 (2.64º±1.50), T2 (2.68º±1.87), T3 (1.88º±1.62) (p=0.000).

The **analysis between the two groups** at different times of the study considering the delta value Tn-T0 revealed significant differences concerning two postural parameters. *Trunk imbalance* at maximum voluntary clenching showed statistical significant difference at T1 between the functional appliances group (6.36 mm±4.20) and the control group (5.89 mm±4.20) (p=0.012). Concerning the *pelvic torsion* at maximum voluntary clenching a statistical significant difference was found at T3 between the functional appliances group (2.07º±1.50) and the control group (1.88º±1.62) (p=0.030).

Each postural parameter in each group was compared among the **different mandibular positions** at T0: for the functional appliances group and the control group the mandibular rest position was compared with the maximum voluntary clenching. No statistical significant differences were detected. Statistical difference were detected for the functional appliances group between the rest position and the clenching on functional appliance for *trunk inclination* (RP: 8.23 mm±18.97, CFA: 7.71 mm±18.36), *cervical arrow* (RP: 42.15 mm±14.83, CFA: 43.88 mm±13.94), *lumbar arrow* (RP: 32.12 mm±12.77, CFA: 32.82 mm±11.81), *kyphotic angle* (RP: 41.74º±8.88, CFA: 43.52º±8.12), *lordotic angle* (RP: 40.91º±9.74, CFA: 42.21º±10.46), *trunk imbalance* (RP: 6.41 mm±5.56, CFA: 6.39 mm±4.59), *pelvic tilt* (RP: 2.39 mm±2.10, CFA: 2.52 mm±2.50) and *pelvic torsion* (RP: 1.66º±1.31, CFA: 1.93º±1.19) (p=0.000).

3.2.2. Results fixed appliances and clear aligners study

A CONSORT diagram displaying orthodontic patients flow through the trial is shown in Fig. 28.

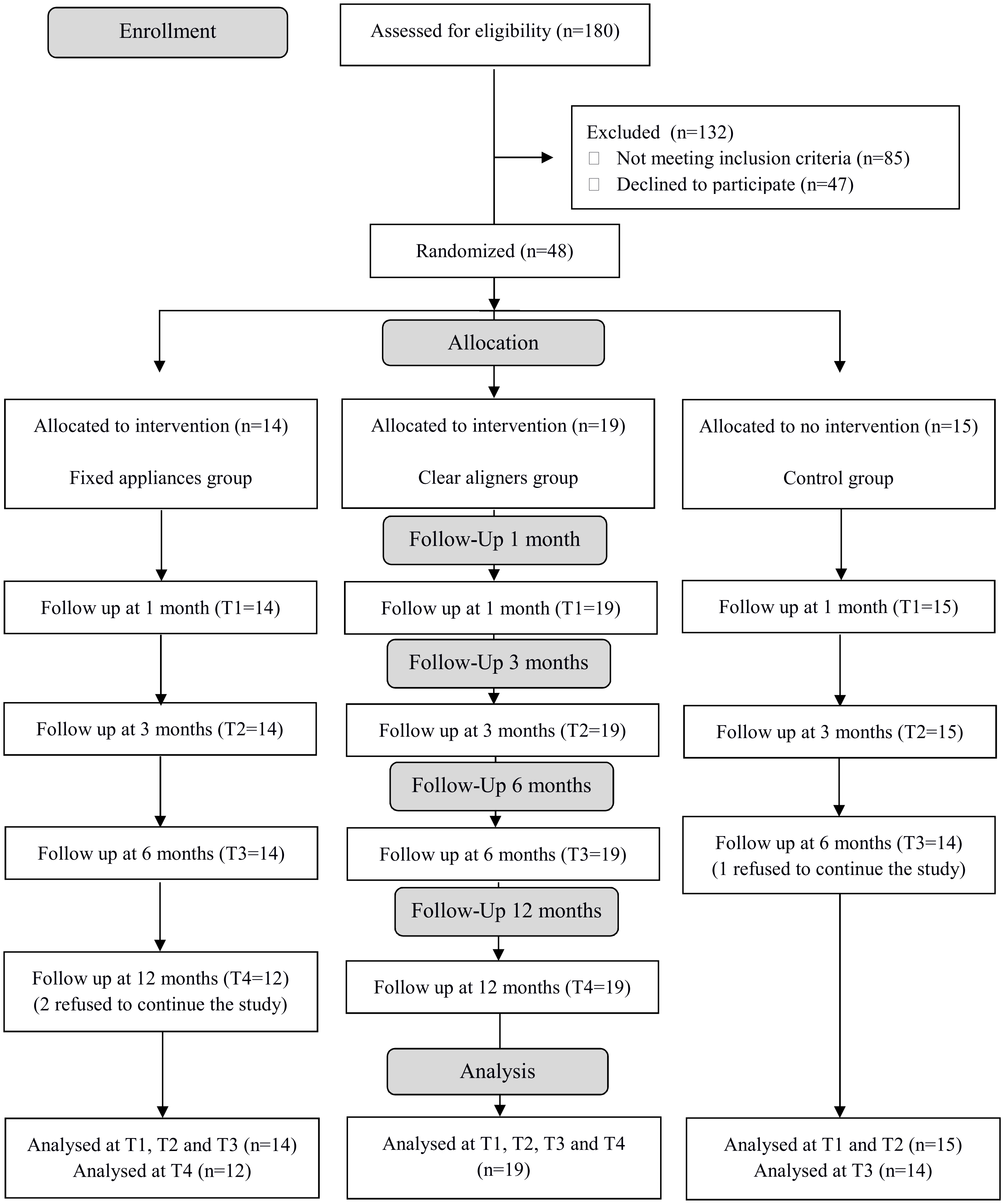

Fig. 28 CONSORT diagram of orthodontic patients (fixed appliances and clear aligners study)

Table 13 reports mean and standard deviation for the fixed appliances group, the clear aligners group and the control group regarding the six angular parameters of the Ricketts Cephalometric Analysis.

	FIXED APPLIANCES	**CLEAR ALIGNERS**	**CONTROL**
FACIAL AXIS	89.11±2.93	91.19±3.88	92.18±4.97
MANDIBULAR PLANE ANGLE	25.52±4.96	22.21±5.87	22.08±5.11
INNER GONIAL ANGLE	34.42±13.89	34.84±6.25	34.13±5.58
LOWER FACIAL HEIGHT	43.60±5.05	41.55±3.90	40.89±3.04
FACIAL DEPTH	87.01±2.39	88.64±4.61	90.34±4.11
MAXILLARY POSITION	90.14±3.40	90.59±5.22	91.21±5.47

Table 13 Mean and standard deviation for the fixed appliances group, the clear aligners group and the control group regarding the six angular parameters of the Ricketts Cephalometric Analysis

Table 14 and Table 15 report mean and standard deviation for each postural parameter in fixed appliances group (G1), clear aligners group (G2) and control group (G3) and in three mandibular positions: rest position (RP), maximum voluntary clenching (MVC), clenching on clear aligners (CCA). Data were collected at baseline (T0), after 1 month (T1), 3 months (T2), 6 months (T3) and 12 months (T4).

			TRUNK INCLINATION	CERVICAL ARROW	LUMBAR ARROW	KYPHOTIC ANGLE	LORDOTIC ANGLE	TRUNK IMBALANCE	PELVIC TILT	PELVIC TORSION
T0	RP	G1	14.08±11.24	52.84±9.48	39.46±10.36	46.04±6.43	43.13±8.57	6.79±5.59	5.36±3.75	2.71±1.38
		G2	19.11±15.77	57.87±13.56	35.69±13.05	47.10±8.82	39.21±8.80	7.89±7.80	4.21±4.26	2.37±1.80
		G3	14.17±22.16	54.24±19.15	40.21±14.97	48.35±6.14	43.39±9.15	9.07±4.85	3.13±1.81	2.33±1.45
	MVC	G1	13.51±14.60	55.50±10.94	40.16±10.58	47.70±6.90	42.73±7.89	4.93±6.32	3.14±2.93	2.79±1.93
		G2	17.22±15.27	59.73±12.29	39.22±12.18	48.33±8.00	41.74±11.00	5.42±4.34	4.74±4.39	1.95±1.65
		G3	22.54±21.77	57.80±17.61	37.31±13.48	48.27±4.99	42.71±8.57	8.67±5.31	1.95±2.23	2.20±1.01
	CCA	G2	22.95±16.72	57.37±12.20	33.11±13.40	44.51±8.28	37.98±9.28	8.68±8.04	4.11±3.77	1.89±1.24
T1	RP	G1	16.84±14.54	55.86±15.43	35.15±9.05	45.46±6.41	41.12±8.07	8.14±6.98	4.64±3.03	3.29±1.98
		G2	15.63±18.08	56.35±13.37	38.47±13.20	46.15±7.01	41.12±9.60	7.47±6.06	4.42±3.79	2.37±2.19
		G3	16.47±22.85	58.05±15.53	40.00±14.98	49.45±5.84	43.23±8.58	8.60±5.73	3.00±1.96	2.13±1.36
	MVC	G1	17.31±22.18	55.61±13.03	34.93±13.36	45.10±6.52	41.24±8.80	6.71±3.20	4.43±2.87	3.14±1.96
		G2	18.51±15.21	57.22±10.39	38.47±11.87	45.88±7.44	41.79±7.99	10.16±7.38	4.89±4.82	2.53±1.95
		G3	19.09±25.04	60.15±15.95	38.79±15.21	49.56±6.34	43.20±8.49	8.93±5.68	2.93±1.87	2.40±1.18
	CCA	G2	22.39±17.96	57.47±14.86	35.38±11.68	45.96±9.12	41.33±8.73	8.84±6.40	4.11±4.03	2.00±1.60

Table 14 Mean and standard deviation for each postural parameter in fixed appliances group (G1), clear aligners group (G2) and in control group (G3) at RP, MVC and CCA at T0 and T1

			TRUNK INCLINATION	CERVICAL ARROW	LUMBAR ARROW	KYPHOTIC ANGLE	LORDOTIC ANGLE	TRUNK IMBALANCE	PELVIC TILT	PELVIC TORSION
T2	RP	G1	17.88±11.45	58.30±15.88	38.46±8.93	47.50±8.25	42.61±8.22	7.14±6.70	5.14±3.21	2.57±1.55
		G2	17.29±16.40	57.43±12.73	38.04±12.04	46.47±8.87	41.28±8.85	7.74±6.26	3.47±3.78	2.21±2.27
		G3	13.85±16.50	55.01±16.29	38.97±13.62	47.49±5.41	42.57±8.73	8.67±6.80	2.33±1.68	2.13±1.60
	MVC	G1	15.30±18.50	59.03±13.82	40.44±11.12	48.57±7.44	43.95±8.01	6.79±6.99	5.14±3.42	2.57±1.83
		G2	19.27±14.09	56.76±10.26	37.33±12.57	45.46±9.13	40.75±8.39	8.32±7.07	4.37±4.31	2.16±1.71
		G3	17.59±18.05	55.87±16.45	39.20±14.74	48.39±6.73	42.69±9.20	9.33±6.60	2.67±1.40	2.27±1.16
	CCA	G2	18.15±16.24	55.98±12.93	36.88±11.36	45.78±8.38	40.79±7.54	8.68±8.39	3.74±3.74	2.21±1.58
T3	RP	G1	18.94±23.44	57.29±15.39	37.55±14.39	46.57±9.23	41.50±8.26	5.86±5.10	5.29±3.50	2.36±1.82
		G2	20.54±22.31	57.26±16.79	36.46±14.23	46.22±8.34	40.48±9.18	9.16±6.24	4.05±4.25	2.16±1.95
		G3	13.31±18.23	57.27±14.00	40.82±12.25	49.24±5.76	44.28±8.20	8.43±5.97	2.79±2.19	2.50±1.61
	MVC	G1	16.84±26.50	57.51±17.05	38.08±13.19	45.92±7.45	41.13±6.51	7.07±4.65	5.14±3.98	2.21±1.97
		G2	23.12±21.48	57.28±16.96	35.46±13.56	45.31±9.17	40.29±8.70	7.58±6.81	3.44±3.45	2.00±1.91
		G3	14.46±19.06	59.62±16.29	40.83±12.61	49.80±5.93	43.56±7.60	8.71±5.27	3.59±3.23	2.29±1.59
	CCA	G2	21.14±21.73	58.84±16.85	37.37±14.01	46.93±10.07	41.74±8.80	8.05±7.12	3.67±4.28	1.84±1.26
T4	RP	G1	21.60±14.32	61.31±15.66	38.60±9.59	47.72±8.92	42.03±8.95	8.08±10.20	6.00±3.84	1.83±1.19
		G2	19.66±17.23	56.04±15.09	36.95±15.22	45.29±9.44	40.27±10.08	9.63±7.93	3.95±3.61	2.37±1.26
	MVC	G1	23.39±19.16	62.58±12.73	38.33±11.34	47.98±8.38	42.61±8.70	6.08±5.78	5.75±5.19	2.08±0.90
		G2	19.62±18.49	57.67±14.79	38.03±14.30	47.33±7.94	41.31±8.99	8.11±7.61	3.95±3.47	1.63±1.61
	CCA	G2	19.09±18.31	56.49±14.21	36.76±13.09	45.69±6.98	40.21±9.17	8.89±7.92	4.63±4.27	2.32±1.73

Table 15 Mean and standard deviation for each postural parameter in fixed appliances group (G1), clear aligners group (G2) and in control group (G3) at RP, MVC and CCA at T2, T3 and T4

Table 16 reports the analysis at T0 at rest position of the **Pearson correlations** between each cephalometric parameter and each postural parameter in the orthodontic group 13-30 years at rest position (95% Confidence Interval, p<0.05).

	FACIAL AXIS	MANDIBULAR PLANE ANGLE	INNER GONIAL ANGLE	LOWER FACIAL HEIGHT	FACIAL DEPTH	MAXILLARY POSITION
TRUNK INCLINATION	-0.19 (-0.45, -0.10)	-0.07 (-0.34, 0.22)	-0.28 (-0.52, 0.01)	0.02 (-0.27, 0.30)	0.06 (-0.22, 0.34)	0.09 (-0.20, 0.36)
CERVICAL ARROW	-0.15 (-0.42, 0.14)	-0.12 (-0.39, 0.17)	-0.11 (-0.38, 0.18)	0.09 (-0.20, 0.36)	-0.09 (-0.37, 0.20)	-0.12 (-0.39, 0.17)
LUMBAR ARROW	0.05 (-0.23, 0.33)	0.07 (-0.22, 0.35)	0.17 (-0.12, 0.44)	0.15 (-0.14, 0.41)	0.01 (-0.28, 0.29)	-0.02 (-0.30, 0.27)
KYPHOTIC ANGLE	-0.12 (-0.39, 0.17)	-0.06 (-0.34, 0.23)	0.02 (-0.26, 0.30)	0.08 (-0.21, 0.36)	-0.13 (-0.40, 0.16)	-0.12 (-0.39, 0.17)
LORDOTIC ANGLE	0.06 (-0.23, 0.34)	0.20 (-0.09, 0.46)	0.14 (-0.15, 0.41)	0.11 (-0.18, 0.38)	0.03 (-0.25, 0.31)	0.13 (-0.16, 0.40)
TRUNK IMBALANCE	0.05 (-0.24, 0.33)	0.05 (-0.24, 0.33)	-0.06 (-0.34, 0.22)	-0.17 (-0.43, 0.12)	-0.26 (-0.51, 0.02)	**-0.32 (-0.56, -0.05)***
PELVIC TILT	-0.09 (-0.37, 0.20)	0.10 (-0.19, 0.37)	-0.09 (-0.36, 0.20)	0.01 (-0.28, 0.29)	-0.18 (-0.44, 0.11)	-0.02 (-0.30, 0.27)
PELVIC TORSION	0.09 (-0.20, 0.37)	-0.21 (-0.46, 0.08)	0.18 (-0.10, 0.45)	-0.03 (-0.31, 0.26)	0.10 (-0.19, 0.37)	**0.30 (0.02, 0.54)***

Table 16 Pearson correlations between each cephalometric parameter and each postural parameter

The **screening analysis** revealed no differences between the control group and both the fixed appliances and the clear aligners groups concerning the postural and the cephalometric parameters.

Regarding the postural parameters in the **intragroup analysis** we detected many statistical significant differences between T0 and different times of the study.

In the fixed appliances group concerning the *trunk imbalance* we detected statistical significant differences at maximum voluntary clenching between T0 (4.93 mm±6.32) and T3 (7.07 mm±4.65) (p=0.049). Analyzing the *lumbar arrow* we found a statistical significant difference at rest position between T0 (39.46 mm±10.36) and T2 (38.46 mm±8.93) (p=0.026).

In the clear aligners group we investigated a statistical significant difference regarding the *trunk imbalance* at maximum voluntary clenching between T0 (5.42 mm±4.34) and T1 (10.16 mm±7.38) (p=0.034).

In the control group no statistical significant differences were detected.

In the **analysis between the fixed appliances group and the control group** at different times of the study considering the delta value Tn-T0 we found many statistical significant differences.

Concerning the *trunk inclination* we detected statistical significant differences at maximum voluntary clenching at T2 between the fixed appliances group (15.30 mm±18.50) and the control group (17.59 mm±18.05) (p=0.011).

We found statistical significant differences for the *cervical arrow* at rest position at T2 between the fixed appliances group (58.30 mm±15.88) and the control group (55.01 mm±16.29) (p=0.000) and at T3 between the fixed appliances group (57.29 mm±15.39) and the control group (57.27 mm±14.00) (p=0.011). At maximum voluntary clenching there was a difference at T2 between the fixed appliances group (59.03 mm±13.82) and the control group (55.87 mm±16.45) (p=0.000) and at T3 between the fixed appliances group (57.51 mm±17.05) and the control group (59.62 mm±16.29) (p=0.021).

Analyzing the *lumbar arrow* we investigated statistical significant differences at rest position at T2 between the fixed appliances group (38.46 mm±8.93) and the control group (38.97 mm±13.62) (p=0.002) and at T3 between the fixed appliances group (37.55 mm±14.39) and the control group (40.82 mm±12.25) (p=0.000). Also at maximum voluntary clenching there was a difference at T2 between the fixed appliances group (40.44 mm±11.12) and the control group (39.20 mm±14.74) (p=0.003) and the and at T3 between the fixed appliances group (38.08 mm±13.19) and the control group (40.83 mm±12.61) (p=0.044).

Concerning the *kyphotic angle* we detected statistical significant differences at rest position at T2 between the fixed appliances group (47.50º±8.25) and the control group (47.49º±5.41) and at T3 between the fixed appliances group (46.57º±9.23) and the control group (49.24º±5.76) (p=0.000). Also at maximum voluntary clenching there was a difference at T2 between the fixed appliances group (48.57º±7.44) and the control group (48.39º±6.73) and at T3 between the fixed appliances group (45.92º±7.45) the control group (49.80º±5.93) (p=0.000).

Evaluating the *lordotic angle* we found statistical significant differences at rest position at T3 between the fixed appliances group (41.50º±8.26) and the control group (44.28º±8.20) (p=0.000). Also at maximum voluntary clenching there was a difference at T2 between the fixed appliances group (43.95º±8.01) and the control group (42.69º±9.20) and at T3 between the fixed appliances group (41.13º±6.51) and the control group (43.56º±7.60) (p=0.000).

In the **analysis between the clear aligners group and the control group** at different times of the study considering the delta value Tn-T0 we found many statistical significant differences.

Concerning the *trunk inclination* we detected statistical significant differences at rest position at T2 between the clear aligners group (17.29 mm±16.40) and the control group (13.85 mm±16.50)

(p=0.033). Also at maximum voluntary clenching there was a difference at T2 between the clear aligners group (19.27 mm±14.09) and the control group (17.59 mm±18.05) (p=0.020).
Regarding the *cervical arrow* we found statistical significant differences at rest position at T2 between the clear aligners group (57.43 mm±12.73) and the control group (55.01 mm±16.29) and at T3 between the clear aligners group (57.26 mm±16.79) and the control group (57.27 mm±14.00) (p=0.000). Also at maximum voluntary clenching there was a difference at T2 between the clear aligners group (56.76 mm±10.26) and the control group (55.87 mm±16.45) and at T3 between the clear aligners group (57.28 mm±16.96) and the control group (59.62 mm±16.29) (p=0.000).
Analyzing the *lumbar arrow* we investigated statistical significant differences at rest position at T2 between the clear aligners group (38.04 mm±12.04) and the control group (38.97 mm±13.62) and at T3 between the clear aligners group (36.46 mm±14.23) and the control group (40.82 mm±12.25) (p=0.000). Also at maximum voluntary clenching there was a difference at T2 between the clear aligners group (37.33 mm±12.57) and the control group (39.20 mm±14.74) and at T3 between the clear aligners group (35.46 mm±13.56) and the control group (40.83 mm±12.61) (p=0.000).
Concerning the *kyphotic angle* we detected statistical significant differences at rest position at T2 between the clear aligners group (46.47º±8.87) and the control group (47.49º±5.41) and at T3 between the clear aligners group (46.22º±8.34) and the control group (49.24º±5.76) (p=0.000). Also at maximum voluntary clenching there was a difference at T2 between the clear aligners group (45.46º±9.13) and the control group (48.39º±6.73) and at T3 between the clear aligners group (45.31º±9.17) and the control group (49.80º±5.93) (p=0.000).
Evaluating the *lordotic angle* we found statistical significant differences at rest position at T2 between the clear aligners group (41.28º±8.85) and the control group (42.57º±8.73) and at T3 between the clear aligners group (40.48º±9.18) and the control group (44.28º±8.20) (p=0.000). Also at maximum voluntary clenching there was a difference at T2 between the clear aligners group (40.75º±8.39) and the control group (42.69º±9.20) and at T3 between the clear aligners group (40.29º±8.70) and the control group (43.56º±7.60) (p=0.000).
For the *trunk imbalance* we investigated statistical significant differences at rest position at T2 between the clear aligners group (7.74 mm±6.26) and the control group (8.67 mm±6.80) (p=0.003).

Each postural parameter in each group was compared among the **different mandibular positions** at T0: for the fixed appliances and the control group the mandibular rest position was compared with the maximum voluntary clenching. No statistical significant differences were detected.

For the clear aligners group the mandibular rest position was compared with the maximum voluntary clenching and with the clenching on clear aligners. No statistical significant differences were detected too.

3.3 Discussion

3.3.1. Discussion functional appliances group

The first systematic rasterstrereographic analysis of spinal posture in children between 6 and 11 years was conducted in 2013 and affirmed that during childhood spinal posture and pelvic position didn't change significantly with increasing age. A mean kyphotic angle of 47.1º±7.5 and a mean lordotic angle of 42.1º±9.9 were measured. On the sagittal plane the trunk imbalance varied between girls (5.85 mm±0.74) and boys (7.48 mm±0.83). Pelvic tilt (2.75 mm) and pelvic torsion (1.53º) were comparable for all age groups and genders [96]. All the values obtained in our study of orthodontic subject 6-12 years are in line with these values.
Lippold et al. in 2010 analyzed the ***correlations*** between the sagittal back contour and parameters of craniofacial morphology in healthy children. Significant correlations were found with respect to the inner gonial angle and the cervical arrow, the lumbar arrow and the trunk inclination, the mandibular plane angle and the lumbar arrow, the lower facial height and the lumbar arrow [97]. In our study we also found correlations between craniofacial morphology and body posture parameters: correlations regarded mandibular plane angle and cervical arrow, lower facial height and pelvic tilt, facial depth and trunk imbalance, maxillary position and trunk imbalance. Contrary to Lippold we didn't find any correlation between craniofacial morphology and lumbar parameters. Moreover in our study cervical arrow correlated negatively with mandibular plane angle, suggesting a relationship between the vertical facial growth and the cervical lordosis even if a clear cause-effect relationship was not evident.
Segatto et al. in 2014 studied the relation of craniofacial features with morphological and positional characteristics of the cervical vertebrae and the spine during growth and found correlations between body posture, morphology of the vertebra C2 and craniofacial parameters. On the one hand he found correlations between dental indices and body posture parameters and between body posture parameters and formation of the craniobasal configuration during growth. On the other hand and in accordance with our study he didn't observe any correlation between postural parameters represented by trunk inclination, cervical and lumbar arrows and craniofacial morphology represented by facial depth, facial axis and lower facial height [98].

The study of Castellano et al. on growing-phase patients showed signs of postural alteration in all subgroups of patients affected by different malocclusions and the presence of statistically significant correlations between cephalometric parameters and rasterstereographic parameters. In particular like our study they found correlation between the cervical arrow and the mandibular plane angle. A clear cause-effect relationship was not evident particularly because of the sample number of the variables involved [99].

In order to evaluate if ***functional appliances*** had an effect on postural parameters the second part of our evaluation considered the trend of postural parameters in patients treated with functional appliances and in patients not treated. In the intragroup analysis of the functional appliances group statistical significant difference were found for all body posture parameters between initial values and 1, 3, 6 months at both rest position and maximum voluntary clenching. Likewise we detected statistical significant differences for all postural parameters in the intragroup analysis of the control group. We can hypothesize that these postural changes are physiologically and related to the growth phase of the sample analyzed.

Lippold in 2012 studied the effect of early orthodontic treatment for unilateral cross bite in the late deciduous and early mixed dentition using orthopedic parameters hypothesizing that early orthodontic treatment could induce negative changes in body posture. The results demonstrated that no clinically relevant differences between the control and the therapy groups were detected after one year of therapy regarding kyphotic and lordotic angles, surface rotation, lateral deviation, pelvic tilt and pelvic torsion [100]. As Lippold in our study the analysis between the functional appliances group and the control group didn't highlight any statistical difference at 1, 3, 6 months. The only difference were detected at maximum voluntary clenching regarding trunk imbalance at one month and pelvic torsion at six months but these data were clinically not relevant. These results supported the hypothesis that the differences that we detected in the intragroup analysis are related to modification of the body posture during growth and not to the use of functional appliances.

Each postural parameter in each group was compared among the ***different mandibular positions*** at T0: in both groups we didn't detect any statistical significant difference between rest positon and maximum voluntary clenching. We detected statistical difference for all parameters between rest position and clenching on functional appliances. Nevertheless postural values during functional appliance clenching remained conform to range values. It is possible to suggest that there is an immediate adaptation of the body posture when children clench on appliance, but this adaptation is not prolonged during treatment and do not affect posture.

3.3.2. Discussion fixed appliances and clear aligners group

Normative rasterstereography values for spinal posture and pelvic position in healthy adults people were studied by Stagnara, concerning cervical arrow (60-80 mm) and lumbar arrow (40-60 mm), and by Harzmann, concerning the kyphotic angle (47-50º) and lordotic angle (38-42º), the trunk imbalance (0-5 mm), the pelvic tilt (0-4º) and the pelvic torsion (0-1.9º) [79, 80]. All the values obtained in our study of orthodontic subjects 13-30 years are in line with the normative values of Stagnara and Harzmann.

In the study of orthodontic subjects aged 13-30 years we found ***correlations*** at T0 between maxillary position and both trunk imbalance and pelvic torsion. This correlation suggest a relationship between the sagittal position of the maxilla and frontal spine values. Moreover it can also suggest a relationship with pelvic values similarly with Lippold who found statistical correlations between the vertical and sagittal position of the lower jaw and pelvic torsion [83].

In order to evaluate if ***fixed appliances*** and ***clear aligners*** had an effect on postural parameters the second part of our evaluation considered the trend of postural parameters in patients treated with fixed appliances or clear aligners and in patients not treated. Regarding the intragroup analysis only two parameters showed statistical differences: the lumbar arrow in the fixed appliances group and the trunk imbalance in both the fixed appliances and the clear aligners groups. From a clinical point of view these results were isolated and didn't have significance.

Since this is the first study to our knowledge analysing the effect of fixed appliances and clear aligners therapy on body posture using rasterstereography no comparable data are available.

In the analysis between the therapy groups and the control group many statistical differences were found. In particular differences were detected between the control group and both the fixed appliances group and the clear aligners group at 3 and 6 months in both rest position and maximum voluntary clenching regarding cervical arrow, lumbar arrow, kyphotic angle and lordotic angle. For the clear aligners group also trunk inclination showed a statistical significant difference at 3 months compared to the control group. These results suggest that both treatments compared with the control group could modify posture in cervical and lumbar areas and that these changes occur at least after three months of therapy.

The only study available referred to the clear aligners therapy and analysed only kyphotic and lordotic angles, upper thoracic inclination and pelvic inclination. The study demonstrated modifications after 6 months of orthodontic treatment with clear aligners regarding kyphotic angle, upper thoracic inclination and pelvic inclination [101].

Since all the values in the fixed appliances group, the clear aligners group and the control group are in line with the normative values it is difficult to assert if the fixed appliances or the clear aligners therapy influence positively or negatively body posture. Moreover body posture is a set of relationships between cervical, lumbar and pelvic values and the interpretation of the results is a complex summary of all values. Nevertheless these results highlighted the fact that some body changes occur during fixed appliances and clear aligners therapy in comparison with the control group.

Each postural parameter in each group was compared among the ***different mandibular positions*** at T0: in all groups we didn't detect any statistical significant difference. We can speculate that the clenching on teeth or the clenching on the clear aligners didn't affect body posture.

The study regarding malocclusions patients showed that correlations exist between cephalometric parameters and postural parameters, in cervical, lumbar and pelvic regions. Concerning the therapy, the age of the patients recruited in the functional appliance group influenced the results of the study because of the growing phase of the column and the entire body structure. However, the fixed appliance and clear aligner groups highlighted differences between the control group and the treated group regarding cervical and lumbar arrows, kyphotic and lordotic angles and trunk inclination.

The ***limitations*** of our study were represented by the lack of a radiographic confirmation of the Formetric measurements. However rasterstereography provides a reliable method for three-dimensional back shape analysis and reconstruction of spinal deformities. Moreover, studies with greater sample size are required in order to confirm the existence of a the relationship between malocclusions and body posture. In our knowledge this is the very first study in which this device was used for the postural analysis in patients affected by malocclusions and treated with functional appliances, fixed appliances and clear aligners. Therefore no data to which compare our results are available.

4. CONCLUSIONS

Posture involves muscle activation that, controlled by the central nervous system, leads to postural adjustments. Postural adjustments are the result of a complex system of mechanisms that are controlled by multisensory inputs integrated in the central nervous system. During human postural control, individuals constantly and subconsciously regulate movements, based on perceived information to achieve postural stability. Through mechanisms of feed-back and feed-forward, postural adjustments play a critical role in orthostatic and dynamic postural control.

The study regarding **TMD patients** showed that correlations exist between cephalometric parameters and postural parameters, in both cervical and lumbar regions. Concerning the therapy, the use of an occlusal splint statistically affects the cervical arrow, the kyphotic and lordotic angles and that the use of TENS statistically affect the trunk inclination.

Based on these findings, especially for the patients treated with an occlusal splint, from a clinical point of view, it is should be useful to suggest a multidisciplinary approach, including orthopedics and physiotherapists, in order to evaluate the cervical and lumbar regions. Involving orthopedics and physiotherapists in further studies could add data regarding clinical postural evaluation, could increase the sample size and could allow to deeper understand the normal or pathological range of postural parameters.

The analysis regarding **malocclusions** indicated correlations between cephalometric parameters and postural parameters, in cervical, lumbar and pelvic regions.

Regarding the functional appliances therapy in children aged 6-12 years we detected statistical significant differences for all postural parameters in the intragroup analysis of both the functional appliances group and the control group, but none statistical significant difference in the analysis between the two groups. We can hypothesize that these postural changes are related to modification of body posture during growth and not to the use of functional appliances.

Nevertheless fixed appliances and clear aligners therapy in patients ages 13-30 years seemed to affect trunk inclination and imbalance, cervical and lumbar arrows, kyphotic and lordotic angles.

Based on these findings, especially for the patients treated with fixed appliances and clear aligners, from a clinical point of view, it is should be useful to suggest a multidisciplinary approach, including orthopedics and physiotherapists, in order to evaluate the cervical and lumbar regions. Involving orthopedics and physiotherapists in further studies could add data regarding clinical postural evaluation, could increase the sample size and could allow to deeper understand the normal or pathological range of postural parameters, taking in account that body posture in children is mainly influenced by growth.

Since all the values in both studies are in line with the normative values it is difficult to assert if the therapy influence positively or negatively body posture. Moreover body posture is a set of relationships between cervical, lumbar and pelvic values and the interpretation of the results is a complex summary of all values. Nevertheless these results highlighted the fact that some body changes occur during therapy but the clinical significance of those differences is very poor.

Other studies are necessary to investigate the relationship between temporomandibular disorders and body posture and between dental occlusion and body posture,.

In conclusion it is possible to state that an interdisciplinary approach should be recommended to make a diagnosis and to develop a treatment plan in patients affected by temporomandibular disorders and in patients affected by malocclusions.

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