Pain Research and Management

Orofacial Pain as a Challenge in Modern Medicine

Lead Guest Editor: Aneta Wieczorek
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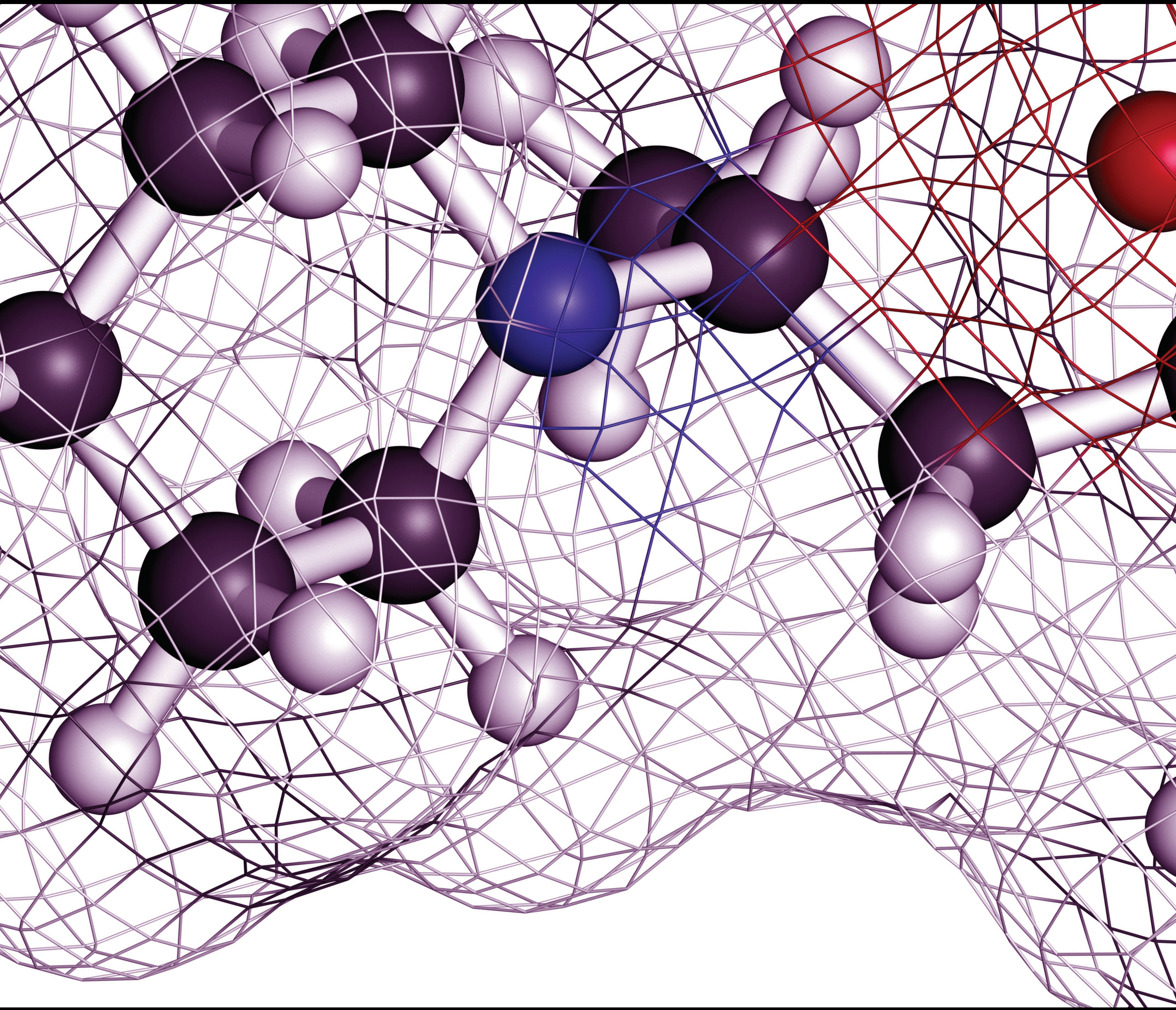

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Contents

Hindawi
Pain Research and Management
Volume 2023, Article ID 1002235, 12 pages
https://doi.org/10.1155/2023/1002235

Review Article

Accurate Diagnosis and Treatment of Painful Temporomandibular Disorders: A Literature Review Supplemented by Own Clinical Experience

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Received 21 March 2022; Revised 4 September 2022; Accepted 21 January 2023; Published 31 January 2023

Academic Editor: Tomasz Kaczmarzyk

Introduction. Temporomandibular disorders (TMD) is a multifactorial group of musculoskeletal disorders often with combined etiologies that demand different treatment plans. While pain is the most common reason why patients decide to seek help, TMD is not always painful. Pain is often described by patients as a headache, prompting patients to seek the help of neurologists, surgeons, and ultimately dentists. Due to the unique characteristics of this anatomical area, appropriate diagnostic tools are needed, as well as therapeutic regimens to alleviate and/or eliminate the pain experienced by patients. *Aim of the Study*. The aim of this study is to collect and organize information on the diagnosis and treatment of pain in TMD, through a review of the literature supplemented by our own clinical experience. *Material and Methods*. The study was conducted by searching scientific databases PubMed, Scopus, and Google Scholar for documents published from 2002–2022. The following keywords were used to build the full list of references: TMD, pain, temporomandibular joint (TMJ), TMJ disorders, occlusal splint, relaxing splints, physiotherapy TMD, pharmacology TMD, natural therapy TMD, diagnostic criteria for TMD, and DC/TMD. The literature review included 168 selected manuscripts, the content of which was important for pain diagnosis and clinical treatment of TMD. *Results*. An accurate diagnosis of TMD is the foundation of appropriate treatment. The most commonly described treatments include physiotherapy, occlusal splints therapy, and pharmacological treatment tailored to the type of TMD. *Conclusions*. Based on the literature review and their own experience, the authors concluded that there is no single ideal form of pain therapy for TMD. Treatment of TMD should be based on a thorough diagnostic process, including the DC/TMD examination protocol, psychological evaluation, and cone beam computer tomography (CBCT) imaging. Following the diagnostic process, once a diagnosis is established, a treatment plan can be constructed to address the patient's complaints.

1. Introduction

Temporomandibular disorders (TMD) can present with pain, prompting patients to seek help from various specialists [1–4]. TMD is most frequently seen in people aged between 20 and 40 years [5–8] and is more common in women due to hormonal changes and greater influence of psychosocial factors [9–12]. Thus, it can be concluded that TMD is a civilization problem, which may escalate due to the increasing pace of life, omnipresent stress, and improper use of the masticatory system [13–24]. One unquestionable causative factor is stress, which has a destructive effect on all masticatory structures, and if chronic, it may expose or aggravate temporomandibular disorders [25–32].

Pain in temporomandibular disorders may have a diverse etiology, i.e., central or peripheral, as demonstrated by the 2020 study by Yin et al., finding that TMD is accompanied by functional and structural changes in the primary somatosensory cortex, prefrontal cortex, and basal ganglia of the brain, which should inform treatment decisions [33]. Temporomandibular disorders (TMD) are characterized by abnormalities in the temporomandibular joint, masticatory muscles, and other adjacent structures, often described by patients as a headache [34–40]. According to research findings, typical TMD symptoms are more common in patients with migraine or tension headaches. It has also been shown that patients with diagnosed TMD are more likely to experience migraines, and the coexistence of both problems exacerbates the symptoms of each [41–47]. This unique anatomical region does not lend itself easily to diagnosis and treatment. It is not uncommon for patients to be referred to neurologists, otolaryngologists, surgeons, and dentists. Undoubtedly, the involvement of many specialists in the problems affecting this area may be beneficial in the classification and differentiation of disorders [48–51].

Masticatory dysfunction can be diagnosed when at least three of the following symptoms are reported: pain and acoustic symptoms during mandibular movements, limited mandibular mobility, difficulty with jaw opening, and occlusal or nonocclusal parafunction. The modern diagnosis of TMD should be based on the DC/TMD examination protocol because only with the correct diagnosis is the correct treatment possible [52–54].

2. Aim of the Study

The aim of this study is to collect and organize information on the accurate diagnosis and treatment of pain in TMD through a review of the literature supplemented by our own clinical experience.

3. Materials and Methods

The study was conducted by searching scientific databases PubMed, Scopus, and Google Scholar for documents published from 2002–2022. The literature review included 168 selected manuscripts, the content of which was important for pain diagnosis and clinical treatment of TMD. These aspects mentioned previously were the criteria for the inclusion of the manuscripts in the review. The following keywords were used to build the full list of references: TMD, pain, TMJ disorders, occlusal splints, relaxing splints, physiotherapy TMD, pharmacology TMD, and natural therapy TMD.

4. The Essence of the Matter

4.1. TMD Pain Diagnosis

4.1.1. Myalgia. Myalgia (muscle pain) can be caused by mandibular movements, parafunctions, and excessive muscle tension due to the increased activity of masticatory muscles. Pain occurs upon provocation testing. The patient's history may include pain in the jaw, temple, ear, or in front of the ear. Pain may be modified with jaw movement, function, or parafunction.

Upon physical examination of the patient, the physician is able to confirm the location of pain in the temporalis or masseter muscle, additionally using muscle palpation and maximum unassisted or assisted jaw opening [55–75].

4.1.2. Myofascial Pain. Myofascial pain can be local or referred to and is experienced by the patient as deep and dull. Unlike myalgia, this pain spreads beyond the palpated area, remaining inside the boundary of the examined muscle or in the case of referred myofascial pain–beyond the area of the examined muscle. Myofascial trigger points may also be felt during palpation [76–80].

4.1.3. Arthralgia. The term arthralgia refers to pain in the temporomandibular joint without signs of joint inflammation. The onset of pain is associated with mandibular movement, function, and parafunction. Pain is also triggered during provocation testing. The patient's history includes pain in the jaw, temple, ear, or in front of the ear. On physical examination, the physician confirms pain in the TMJ area, especially the lateral region, and examines the maximum range of jaw opening with and without assistance [81–83].

4.1.4. TMD-Attributed Headache. Headache attributed to temporomandibular dysfunction is characterized by a history of temporal pain of any nature. The pain can be modified by mandibular movement, function, and parafunction. Upon physical examination, pain in the temporalis region can also be observed in provocative tests. Pain may occur during palpation and when testing jaw opening [84].

4.1.5. Disc Displacement with Reduction or with Intermittent Locking. An intracapsular disorder involving the condyle-disc complex. To make the diagnosis, it is necessary to determine the closed mouth position according to the protocol. At the Department of Propaedeutics, Physical Diagnostics, and Dental Physiotherapy, we ask the patient to assume their habitual occlusion and then relax the mandible. In this way, we are able to assess the actual intraarticular status, which is confirmed by palpation, joint sound inspection (with a stethoscope), and diagnostic imaging (CBCT). When performing diagnostic imaging, it is essential to perform the examination under the same conditions, without the bite stick.

In this disorder, the disc is positioned anteriorly relative to the condylar head and reduces with mouth opening movements. In some cases, medial and lateral displacement of the articular disc can be observed, as well as noises such as clicking, crackling, or popping [85–93]. Please note that if the patient has a history of joint locking and chewing problems, this diagnosis is ruled out.

To make the diagnosis, the patient is asked to report all TMJ noises that have occurred in the last 30 days during mandibular movements, and additionally, the patient should report any noises during the examination:

(i) Clicking, popping, and/or snapping noise during both opening and closing movements, detected with palpation during at least one of three repetitions of jaw opening and closing movements; or

(ii) Clicking, popping, and/or snapping noise detected with palpation during at least one of three repetitions of opening or closing movement(s);

(iii) Clicking, popping, and/or snapping noise detected with palpation during at least one of three repetitions of right or left lateral, or protrusive movement(s) [94–100].

When discussing this disorder, it should be stated that imaging should be the reference standard for this diagnosis [101–103].

4.1.6. Disc Displacement without Reduction with Limited Opening. In this intracapsular disorder, in the closed mouth position, the disc is positioned anteriorly relative to the condylar head and does not reduce in size with the opening of the mouth. Characteristically, the disorder is associated with persistent limited mandibular opening, sometimes referred to as a closed lock, which is not resolved by a manipulative manoeuvre performed by the physician.

Patient history includes a locked jaw, limited movement, and eating difficulties. In physical examination, during assisted jaw opening, the distance between the upper and lower incisors is less than 40 mm. Passive movements may be accompanied by noise [104–107].

4.1.7. Osteoarthritis of the Temporomandibular Joint. This disorder involves joint tissue deterioration with concomitant osseous changes in the condylar head and/or articular eminence.

In history, the patient reports noise when chewing or opening the mouth in the last 30 days, and these phenomena may also appear during the examination. On physical examination, the physician detects snapping, popping sounds in the joint during the abduction, adduction, and lateral or protrusive movements. Imaging is required, as CBCT may help visualize subchondral cysts, erosions, generalized sclerosis/calcification, or osteophytes [108–111]..

4.1.8. Subluxation. A hypermobility disorder involving the disc-condyle complex and the articular eminence. In the open mouth position, the disc is anterior to the articular eminence and the normally closed mouth position cannot be restored without a manipulative manoeuvre. The difference between subluxation and luxation is that in the former the patient is able to reduce the dislocation on their own, whereas the latter requires professional intervention. Patient history includes jaw locking upon abduction movement in the last 30 days. These locks may have been incidental and temporary, resulting in an inability to close the mouth [112, 113].

The RDC/TMD and DC/TMD protocols make it possible to establish a diagnosis but do not shed any light on the etiology of the disorder, and elimination of the cause or an attempt to create the optimal conditions will be crucial in the treatment process.

At the Department of Propaedeutics, Physical diagnostics, and Dental Physiotherapy, the treatment team consists of an orthodontist, a physician dealing with dental prosthetics and restorative dentistry, a physiotherapist, and a dentist who coordinates the work of the whole team [114]. One of the most common signs of a disease process within the TMJ are sounds emitted by the articular structures, such as popping, clicking, humming, grinding, or crunching [114].

Egermark et al., after examining 320 children aged 7, 11, and 15 years, reported that acoustic symptoms were more common in those with malocclusion (24%), with a predominance of transverse malocclusion. In their conclusions, they noted that there were no significant differences in the prevalence of masticatory dysfunction in the studied population between patients with malocclusion and those with a normal bite [115].

Research findings provide no clear-cut conclusion as to how temporomandibular joint disorders are affected by a malocclusion. The consequences of malocclusion in terms of TMD development may be manifold and are undoubtedly related to age, gender, as well as the severity of the disorder.

A fairly significant problem reported and observed in patients is nocturnal bruxism, which affects 8% of the population, and awake bruxism, the prevalence of which is estimated at 20%. At present, bruxism is defined not as a disorder but as a physiological stress-coping mechanism [116–121].

Based on our own experience, we would like to note the relatively frequent coexistence of TMD with orthodontic disorders and temporomandibular disorders in post-orthodontic patients, where the teeth were often aligned in arches while the condylar heads were displaced posteriorly with reduced joint space [122]. In addition, it is important to consider that dental arches are somatic sites where excessive emotional tension can be diffused and reduced [123].

Research into the associations between malocclusion and TMD, as well as the influence of malocclusion treatments on TMD should be conducted in large study samples..

4.2. TMD Pain Therapy

4.2.1. Natural Methods. Acupuncture is the best-known method of traditional Chinese medicine that is often used, also in Poland, in the treatment of chronic pain. Acupuncture points often coincide with so-called trigger points and correspond to sites of increased density of $A\text{-}\delta$ and C fibre nerve endings that conduct pain sensations. Warm compress therapy is used for chronic inflammation and muscle strains. Ideally, a warm compress at 35–40 degrees C should be applied for 20–30 minutes. Cold compresses, on the other hand, are good for acute inflammation with pain and swelling [124, 125].

4.2.2. Psychological and Behavioural Methods. Psychological and behavioural programmes are effective in alleviating the psychological crisis, allowing the patient to change their perception of pain and improving functioning in patients with chronic pain. The therapeutic effect is not affected by the duration of the programme or by whether the treatment is delivered in an individual or group setting.

Behavioural approaches aim to reduce the frequency of pain-promoting behaviours and increase the frequency of health-promoting behaviours. They include:

(i) improving physical fitness
(ii) social and employment activation
(iii) reducing the amount of medication
(iv) reducing overuse of health services

Psychological methods include the following:

(i) modifying ways of thinking about pain (misconceptions about pain) that cause prolonged suffering and disability
(ii) replacing a sense of helplessness with a sense of control over pain and one's own life
(iii) developing strategies for adequate and effective pain management
(iv) returning to work and promoting an active lifestyle [126, 127]

It must be remembered that effective pain control requires a multidimensional approach, aiming to reduce the pain but also to improve the patient's quality of life.

4.2.3. Interventional Methods-Splint Therapy. Occlusal splint therapy can be used in all TMD disorders; however, it is vitally important to use the right splint for the patient's unique situation.

An occlusal splint is an appliance that affects the mutual relationship of the upper and lower teeth and, consequently, the relationship of the condylar process to the mandibular fossa and articular eminence within the TMJ. The purpose of splints is to stabilize occlusion or to protect teeth from excessive abrasion [128, 129].

According to numerous studies, the use of splints has a significant effect on alleviating or even eliminating the patient's pain symptoms. In cases of disc displacement, repositioning splints are used to stabilize the mandible in the centric relation, and in cases of masticatory muscle disorders, relaxation splints are used to prevent parafunctional effects [130, 131].

Splints are most commonly made by obtaining dental impressions and making a bite registration with wax or silicone mass. An intraoral scanner and electronic bite registration can also be used.

The technique recommended by our team for making occlusal splints is 3D printing using special resin, which makes it possible to avoid the mistakes common in the conventional hand-made process. On the basis of our own experience, research findings, and patient feedback, we use two types of splints in the Department of Propaedeutics, Physical diagnostics, and Dental Physiotherapy: the Michigan-type relaxation splint and the maxillomandibular repositioning splint [132, 133].

The Michigan-type relaxation splint with canine guidance is used in cases involving: myalgia, myofascial pain, and TMD-attributed headache.

The relaxation splint is made from hard resin and always applied to a single arch, with the upper usually being the arch of choice–unless there are missing teeth in the back. Importantly, in the case of missing teeth, the design of the splint should allow for retention elements.

The hard repositioning splint joined interocclusal in the correct construction bite relationship is used in the following situations: arthralgia, disc displacement with reduction, disc displacement with reduction with intermittent locking, disc displacement without reduction with a limited opening, disc displacement without reduction and without limited opening, osteoarthritis of the temporomandibular joint, subluxation.

4.2.4. Physiotherapy. Physiotherapy is a discipline of health science that aims to eliminate, alleviate, and prevent various ailments, as well as restore functional ability through movement and various physical agents. Physiotherapists are part of the treatment process in the case of dysfunctions involving the neuromuscular, musculoskeletal, and other systems [134].

In their work, physiotherapists use kinesiotherapy and physical therapy techniques.

(i) Self-therapy and muscle training. The patient is taught how to perform the correct opening, closing, lateral and protrusive movements of the mandible, as well as how to deal with sudden pain. Exercises should be performed daily in front of a mirror, and if the treatment includes a splint, it should also be used during exercises. The purpose of the exercises is to shorten the overstretched muscles and relax them, which may help improve symmetry and regulate muscle tone [135].
(ii) Manual therapy makes use of trigger points. For disc displacement, a joint mobilization technique is applied, which involves the physiotherapist performing traction and gliding movements with low velocity but increasing amplitude. These movements are performed parallel and perpendicular to the joint surface. If the mandibular range of motion is limited, muscle energy techniques (MET) can be used. Treatments using the MET involve the repetition of three steps: in step one, the muscle is stretched to the point of resistance of the tissues; in step two, the patient slightly contracts muscles for about 10 seconds trying to resist the force generated by the physiotherapist; in the last step, the patient relaxes the muscles [136].
(iii) Massage is used for myofascial pain in order to achieve pain relief and improve muscle length and flexibility, as well as loosen fascia [137, 138]. The

frequency of massage sessions should be 30 minutes twice a week. With subsequent visits, the treatment should be applied with increasing force.

(iv) Physical therapy, such as ultrasound and transcutaneous electrical nerve stimulation (TENS) can be used for pain of muscular origin. Therapeutic ultrasound can be applied in three modalities: using continuous waves, short bursts (pulsed ultrasound), and ultrasound combined with electrical stimulation, the latter of which has proven to be the most effective.

TENS relieves pain and relaxes masticatory muscles in symptomatic patients with TMD [139–142]. In the pain of intracapsular origin, positive results have been observed after the application of a magnetic field combined with LED light therapy. The Solux infrared lamp can be used in cases of arthropathy and rheumatic diseases. The beneficial effects of heat therapy include the alleviation of pain.

(i) The Kinesio Taping method is used for TMJ stabilization. It should be applied bilaterally. The tapes work by reducing the tension in the masticatory muscles, as well as the adjacent structures such as the muscles of the neck, shoulders, and spine [143–146]. The application of tapes also stimulates lymphatic drainage, which has a beneficial effect on inflammation accompanied by tissue swelling.

(ii) Iontophoresis is the use of direct electrical current to accelerate the transdermal delivery of nonsteroidal anti-inflammatory drugs (NSAIDs), corticosteroids, and analgesics. While it is not associated with pain relief, a significant improvement in the range of motion in the joint has been observed [147].

4.2.5. Pharmacotherapy. The decision on the use of medications in temporomandibular disorders should be preceded by a thorough analysis of the risks and benefits of the drug [148–152]. Medications used to treat TMD include analgesics, nonsteroidal anti-inflammatory drugs, anticonvulsants, muscle relaxants, and benzodiazepines [153, 154].

4.2.6. Nonsteroidal Anti-Inflammatory Drugs (NSAID). NSAIDs are beneficial for patients with acute temporomandibular arthritis resulting from sudden disc displacement. Treatment should continue for a minimum of two weeks, and it is important to combine NSAIDs with gastroprotective agents. Among NSAIDs, ibuprofen appears to be the safest for the gastrointestinal tract [155].

It should also be noted that taking NSAIDs for more than 5 days may reduce the efficacy of antihypertensive drugs, such as diuretics, beta-blockers, and ACE inhibitors [154, 155]. In addition, NSAIDs used with anticoagulants such as warfarin or acenocoumarol may increase the risk of bleeding.

4.2.7. Opioids. Due to the interactions of NSAIDs with anticoagulants, as well as the risk of gastritis, physicians sometimes choose to administer oral opioids, such as codeine and oxycodone. The intraarticular delivery route has been studied, but the findings are conflicting [156]. It is essential to bear in mind the side effects of opioid use, which include: dizziness, excessive sedation, nausea, vomiting, constipation, physical dependence and addiction, and respiratory depression. Because of the mentioned reasons, the use of opioids for the management of TMD should be discouraged [157–159].

4.2.8. Corticosteroids. Corticosteroids are helpful in the treatment of moderate to severe TMD. They can be administered by intraarticular injection or by oral route. They have an anti-inflammatory effect which can help relieve pain.

For intraarticular injections, it is a good idea to combine corticosteroid preparation with a local anaesthetic, such as lidocaine. According to research findings, this approach provides for a significant reduction in pain, lasting 4 to 6 weeks, and a reduced risk of complications.

Corticosteroids should be used with caution or discontinued in patients with hypertension, adrenal disease, or electrolyte problems. On day 4 after injection, it is recommended to introduce NSAIDs [160–163].

4.2.9. Myorelaxants. Muscle relaxants are used to reduce skeletal muscle tone and, therefore, may be helpful in the management of TMD of muscular origin and chronic orofacial pain [164]. The most common myorelaxants include cyclobenzaprine, metaxalone, methocarbamol, and carisoprodol. Based on numerous studies, cyclobenzaprine is considered to be the drug of choice due to relieving the pain of muscular origin and improving sleep quality [165].

Caution should be exercised when using this type of medication due to its potential to induce significant sedation. These drugs are contraindicated in patients with hyperthyroidism, heart failure, after myocardial infarction, and heart rhythm disorders. The recommended dose is 10 mg at bedtime for 30 days, followed by a 2-week period to flush the drug out of the system and a medical follow-up. In the course of the therapy, the patient should always remain under medical supervision.

4.2.10. Anticonvulsants. When discussing anticonvulsants, it is worth noting gabapentin, a GABA analogue. Gabapentin is thought to inhibit neurotransmitter release and reduce postsynaptic excitability [166].

The use of gabapentin reduces the pain of muscular origin, particularly from the temporal and masseter muscles. The drug is generally well tolerated and is associated with transient and mild side effects, including dizziness, drowsiness, dry mouth, weight gain, and impaired concentration [167].

4.2.11. Benzodiazepines. Benzodiazepines facilitate transmission in the GABAergic system. They have been found to produce anxiolytic, sedative, hypnotic, anticonvulsant, and myorelaxant effects. Due to the risk of tolerance and dependence, as well as side effects including confusion, amnesia, and impaired motor coordination, these drugs are not recommended for the treatment of TMD [168].

5. Summary

Based on the literature review, the authors concluded that there is no single, ideal form of pain therapy for TMD. Treatment of TMD should be based on a thorough diagnostic process, including the DC/TMD examination protocol, psychological evaluation, and CBCT imaging. Following the diagnostic process, once a diagnosis is established, a treatment plan can be constructed to address the patient's complaints.

The treatment of temporomandibular dysfunctions requires a thorough diagnostic process, taking into account the etiology of the disorder. Having reviewed the relevant literature, the authors emphasize the need to combine multiple methods. For severe pain, pharmacotherapy may be used, while in other cases, it will be more appropriate to apply a combination of splint therapy and physiotherapy. While waiting for a custom-tailored occlusal splint, the patient can take advantage of behavioural and psychological methods, which should be continued after they have been fitted with the splint, as well as during physiotherapy treatments. Follow-up visits are an essential part of the TMD treatment process. The first follow-up visit should take place after one month of therapy and the next after three months. In the meantime, the patient should keep a diary describing their symptoms, pain levels, sleep quality, and wellbeing upon awakening and at bedtime. These observations, which should be reviewed at the follow-up visit, help build a full picture of the effects of the splint and other treatments, as well as inform the psychological assessment of the patient. An accurate diagnosis of TMD is the foundation of appropriate treatment. The most commonly described treatments include physiotherapy, occlusal splint therapy, and pharmacological treatment tailored to the type of TMD.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Faculty of Medicine and Dentistry, Pomeranian Medical University, Szczecin, Poland.

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Hindawi
Pain Research and Management
Volume 2022, Article ID 3604386, 11 pages
https://doi.org/10.1155/2022/3604386

Research Article

Multidisciplinary and Nonpharmacological Management of Pain in Temporomandibular Disorders (TMDs)

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Received 8 April 2022; Revised 6 August 2022; Accepted 16 September 2022; Published 11 October 2022

Academic Editor: Sivakumar Nuvvula

Temporomandibular joint dysfunction (TMD) is not a single diagnosis, but a term covering a group of conditions that involve pain and dysfunction of the masticatory muscles within the temporomandibular joint (TMJ) and associated structures. It is a set of disease entities comprising various ailments and clinical symptoms. One of the most distressing symptoms for TMD patients is pain. Pain is subjective and always unpleasant. The VAS (visual analogue scale) was used in this research. The aim of this study was to assess the influence of physical stimuli, namely extremely low frequency magnetic field (ELF-MF) and LED light, on the experience of pain caused by increased tension in the masticatory muscles in adults. Out of 150 people examined, 104 were enrolled in the study after meeting the eligibility criteria. The study group was divided into 4 subgroups. Each subgroup received physical therapy treatment using a different physical stimulus. The effects of four therapeutic modalities were compared. In terms of VAS scores, pain attenuation was observed in all subgroups. The study confirmed the analgesic effect of the selected physical therapy methods. The authors focused on the analysis of the results obtained for each subgroup, comparing the effects of individual modalities on pain intensity (according to VAS scores). After the treatment, pain relief was observed in each of the studied subgroups. Treatment using ELF-MF and ELF-MF in combination with LED light in the course of TMD brings about a significant improvement in the subjective pain experience expressed in VAS pain scores. The use of selected physical stimuli and their beneficial effect on pain symptoms during mandibular movements has important implications for patients' daily life and work. Incorporation of therapeutic methods can help enhance patient satisfaction and comfort during manual TMJ therapy and lengthy dental procedures.

1. Introduction

Temporomandibular joint dysfunction (TMD) is not a single diagnosis, but rather an umbrella term covering a group of conditions that involve pain and dysfunction of the masticatory muscles within the temporomandibular joint (TMJ) and associated structures. It is a set of disease entities comprising various ailments and, by the same token, clinical symptoms [1]. Fast-paced lifestyles, numerous stressors, and problems of daily life generate strong emotions which have a significant impact on the muscular system controlling the temporomandibular joint (TMJ) function [2]. Due to pain and limited mobility of the mandible, patients need help to eliminate these dysfunctions. Abnormal occlusion, missing teeth, and cervical spine disorders play a significant role in the development of TMD [3–6]. Disorders in the stomatognathic system have a serious impact on the surrounding tissues and can also manifest themselves as severe ear pain, tinnitus, or a feeling of ear congestion. There may also be problems with swallowing, a feeling of discharge, or a foreign body remaining in the throat choking [7]. The most important step towards successful treatment is to find the cause of the symptoms. It takes an entire team, including a dentist, physiotherapist, prosthetist, psychologist, and a holistic approach to the patient to find the cause of a given disorder and direct the treatment process. What is treated and how depends on a thorough diagnostic process and accurate diagnosis of a disease entity [8]. One of the methods to achieve pain relief in patients suffering from disorders within the masticatory system is the use of physical therapy, e.g., ELF-MF and LED light therapy.

Extremely low frequency magnetic field (ELF-MF) therapy is based on the application of a weak, slow-alternating electromagnetic field. The frequency of the basic waveform ranges from a few to 3000 Hz. Magnetic flux density is 1 pT–15 μT [9]. The alternating electromagnetic field generates the so-called Lorentz forces which cause ions to oscillate around their positions as the field changes. This may result in their increased transport across cell membranes, affecting tissues and their components, like collagen, dentin, keratin, and other proteins. The effects of electromagnetic fields have also been demonstrated in the spinal cord, adrenal cortex, sex hormones, DNA, and inner layers of cell membranes [10,11]. Their action influences the permeability of biological barriers. Analgesic effects of the electromagnetic field have been demonstrated by many researchers [12,13]. Stimulation of immunological processes has also been shown [14–17].

Due to the extensive scope of its biological action, the low-frequency electromagnetic field is widely used in clinical practice, including complications in bone healing, bone mineralisation disorders, degenerative joint disease, reduced muscle tone, nerve regeneration, pain syndromes of various origins, and soft tissue regeneration [18].

In dentistry, the use of the alternating magnetic field to restore functional balance has been reported in the treatment of inflammation of the pulp and periapical region, as well as in post-traumatic conditions of oral soft and hard tissues. Beneficial effects have also been observed in post-operative conditions, in cases of difficult eruption of third molars and complications following tooth extraction (e.g. alveolar osteitis), as well as in the treatment of electrochemical metallosis in the oral cavity. Moreover, this method has been used in the treatment of neuralgia and damage or paralysis of nerves (lingual, inferior alveolar, and facial) [19,20].

The alternating electromagnetic field exerts an analgesic effect on the human body, by increasing the secretion of endogenous opiates from the β-endorphin group. This action can be attributed to the modulation of neuronal activity, as well as the secretion of melatonin by the pineal gland [21]. Apart from the direct effect on the opioid system, the alternating electromagnetic field has an indirect anti-inflammatory effect. Another very important therapeutic effect that can be achieved with the use of the fields is the anti-swelling effect, which is especially appreciated in the treatment of postsurgical complications. The most noteworthy advantage of the alternating magnetic field in the therapeutic process is increasing blood flow in arterial vessels and capillaries, stimulating oxygen utilisation, and cellular respiration. Other significant aspects include its impact on wound healing and beneficial effects of tissue regeneration following mechanical or thermal damage, and other states of interruption of tissue continuity [20,22]. In addition, it should be emphasized that the abovementioned analgesic, anti-inflammatory, and regenerative effects are some of the main objectives pursued by the therapist in the treatment following dental and surgical procedures, and in the course of TMD. The main indications for the use of the therapy include acute and chronic pain, periapical inflammatory lesions, nonphysiological masticatory muscle tension, and tissue damage involving interruption of tissue continuity.

Magnetic field with LED therapy makes use of the synergistic effect of an alternating electromagnetic field and optical radiation, combining the curative and stimulating effects of magnetic field therapy and LED light therapy. In the literature, it is referred to as extremely low frequency magnetic field (ELF-MF) and LED (Light Emitting Diode) therapy. Magnetic field LED therapy (ELF-MF + LED) harnesses light energy from high-energy LEDs in combination with a magnetic field with a frequency of 180 to 195 Hz and magnetic flux density up to 15 μT. Electromagnetic radiation is emitted by LEDs in the wavelength range corresponding to red (R-red), infrared (IR-infrared), and mixed (RIR) light. The energy of optical radiation in the visible and infrared range produced by LEDs brings about tissue regeneration, anti-inflammatory, and analgesic effects.

Simultaneous use of both types of electromagnetic radiation provides a synergistic effect, extremely beneficial in analgesic treatment, extensive skin inflammation, burns, as well as trauma [23]. The synergistic effect results from the action on the same surface of the human body and the summation of the local and systemic action of both physical stimuli [24,25].

The electromagnetic field is capable of penetrating any body structure, and its action can be deep and uniform. Light of an appropriate length, used simultaneously, can be introduced deeper if used on its own. This effect of treatment is possible only with a combined influence of magnetic field and light, because other physical factors reach only a given depth of the tissue undergoing treatment. The objective of the procedure with the use of the electromagnetic field depends on its parameters [19]. Red light is readily absorbed by surface tissues, which makes it useful in dermatology and plastic surgery, e.g. in the management of impaired wound healing and hypertrophic scars. Infrared light has a much deeper effect, and is used therapeutically in the course of discopathy, sinusitis, neuralgia, lymphoedema, and following trauma, overuse injuries, in the treatment of sciatica and osteoarthritis [26–29].

As mentioned earlier, one of the most distressing symptoms for TMD patients is pain. Pain is subjective and always unpleasant. In daily clinical practice, dentists do not have the tools or tests to objectively assess the severity of pain. On the other hand, researchers have developed many scales and questionnaires based on the patient's self-assessment to determine the severity of pain. Scales and questionnaires are auxiliary tools that, apart from the assessment of pain intensity at any point in time, can also be used to monitor treatment efficacy, as well as to determine impact on the physical and psychosocial functioning of the patient. Pain assessment instruments can be divided into one-dimensional and multi-dimensional scales. The use of several assessment methods allows for both qualitative and quantitative clinical evaluation, and enables the patient to provide comprehensive information on how they experience pain. On the other hand, the most appropriate methods are those that are clear, quick, understandable, and effective. That is why the visual analogue scale (VAS) was used in our study.

1.1. Aim. The aim of this study was to assess the influence of physical stimuli, namely extremely low frequency magnetic field (ELF-MF) and LED light therapy (Light Emitting Diode), on the experience of pain caused by increased masticatory muscle tension in adults.

2. Material and Methods

The research was conducted at the Department of Propaedeutics, Physical Diagnostics, and Dental Physiotherapy of the Pomeranian Medical University in Szczecin from 2016 to 2019. Out of 150 people examined, 104 were enrolled in the study after meeting the eligibility criteria. Accordingly, the study group consisted of 104 patients with diagnosed TMD in the form of increased masticatory muscle tone confirmed in clinical examination.

To be eligible, respondents had to meet at least one of the following criteria:

(i) muscle tension and pain in the TMJ region (spontaneous or during palpation),
(ii) patients who were diagnosed with myofascial disorders (Ia/Ib) as per RDC-TMD
(iii) impaired mobility of the mandible,
(iv) tenderness on palpation in the TMJ region,
(v) bruxism (centric or eccentric),
(vi) acoustic symptoms in TMJ

The following exclusion criteria were adopted:

(i) smoking (chewing) tobacco,
(ii) use of removable dental prostheses,
(iii) absence of articular and muscular disorders in the masticatory organ,
(iv) active neoplastic processes or history of neoplastic disease,
(v) pregnancy and breastfeeding,
(vi) use of/having implanted electronic medical devices such as a heart pacemaker, cochlear implant,
(vii) intellectual disability,
(viii) systemic diseases.

All participants in the study were generally healthy (no chronic systemic conditions were found in physical examination), meaning that none of them took medication on a permanent basis, which could have had a potential adverse effect on the results of the pain analysis. Moreover, we excluded patients who self-reported smoking (or chewing) tobacco or had an active infection (due to the potential unregimented use of pain and anti-inflammatory medication). The tests were performed in the morning, i.e. no later than midday, to minimise the impact of fatigue, stress, and other external factors on the perception of pain.

Prior to enrolment in the study, all patients were informed about research objectives and procedure, as well as about medical recommendations during the course of therapy, and gave informed written consent to participate. The study was approved by the Bioethics Committee of the Pomeranian Medical University (Resolution No. KB-0012/149/15 of 14/12/2015). Participation in the study was voluntary, and patient anonymity was maintained in accordance with the Polish Personal Data Protection Act.

The 104 patients included in the study were consecutively allotted into each subgroup. Patients in each subgroup received physical therapy treatment using a different physical stimulus. The division into subgroups, as described below, was introduced to conduct therapy with the use of four different physical therapy modalities, and to compare their efficacy in the respective subgroups of patients qualified for participation through history and physical examination. The four therapy modalities to be compared employed the following physical stimuli: extremely low frequency magnetic field (ELF-MF) therapy and combination therapy wherein the action of the magnetic field was synchronised with LED light of a specific wavelength range (red light—R, infrared light—IR, and mixed light—RIR).

The above physical stimuli were compared for efficacy in terms of the analgesic effect. Before commencing a series of treatments and after its completion, the patients underwent a clinical examination with the use of an examination chart designed specifically for the purpose of the study and their level of perceived pain/discomfort was quantified in VAS scores.

The population of 104 patients included in the study was randomly divided into four study subgroups:

(1) Subgroup one included patients who underwent extremely low frequency magnetic field (ELF-MF) treatments. The subgroup consisted of 21 people (12 women and 9 men).
(2) Subgroup two received treatments combining magnetic field therapy with infrared light (ELF-MF + IR). The subgroup consisted of 22 people (18 women and 4 men).
(3) In subgroup three, magnetic field therapy was combined with red light (ELF-MF + R). In this subgroup, there were 24 women and 7 men.
(4) Subroup four was exposed to physical stimuli in the form of magnetic field and mixed light: red/infrared

(ELF-MF + RIR). This subgroup included 29 people (22 women and 7 men).

The therapy was continued for 3 weeks, with daily treatments excluding the weekends, totalling 15 physical therapy treatments per person.

Patient history was taken so as to adequately identify the patients who were eligible for participation in the study, eliminating the influence of possible systemic conditions or injuries on the development of TMD. Medical history was taken from all patients in each subgroup. As a result, it was possible to determine the presence of abnormalities and the associated subjective complaints, as well as the potential causes leading to the development of dysfunctions. The signs and symptoms were then verified in a clinical examination, performed according to the international RDC/TMD questionnaire, which is the most widely used diagnostic tool for patients with TMD. The protocol makes it possible to classify the patient's symptoms according to predefined algorithms and to compare results between different clinical and research centres. The next step in the diagnostic process was a manual examination of the structures of the masticatory motor system based on the RDC/TMD questionnaire. Patients who were diagnosed in this way with myofascial disorders (Ia/Ib) were qualified to participate in the study.

ELF-MF and LED light therapy was administered with the use of a single device—Viofor JPS (Med & Life) (Figure 1). The device emits a low frequency alternating electromagnetic field and light via high-energy LEDs (red light with a wavelength of 630 nm, infrared light with a wavelength of 850 nm, and mixed light—red and infrared with the relevant wavelengths). Physical therapy stimuli were applied using the system's proprietary elliptical applicators, respectively: for EMF-MF therapy—a magnetic applicator, and for EMF-MF + LED therapy—magnetic-light applicators.

During application of the treatment, the patient was in a comfortable sitting or lying position, and the two applicators of the device were placed parallel to the treated surface at the level of the TMJ, in close contact with the skin. Each time, the application continued for 10 minutes. ELF-MF and ELF-MF + LED treatments were performed using the Viofor JPS apparatus in the following settings: method M_1, programme P_3, intensity 6, which ensures a constant application of the selected intensity and uses the highest values of ion cyclotron resonance created in the cells. This means that the frequency of the basic wave was in the range of 180–195 Hz, the frequency of the wave packets was in the range of 12.5–29 Hz, and the packet group was in the range of 2.8–7.6 Hz, and that of series 0.08–0.3 Hz (Figure 2). The patient was encouraged to rest and relax during the therapy session.

Characteristics of the Viofor JPS system applicators:

(i) Magnetic applicator—generates a low-frequency pulsed magnetic field for ELF-MF therapy (Figure 3).

(ii) IR magnetic-light applicator—emits pulsed LED radiation—855 nm infrared radiation (IR) combined with the action of the electromagnetic field. Penetration depth—several centimetres (Figure 4).

(iii) R magnetic-light applicator—emits pulsed LED radiation—630 nm red light (*R*) combined with the action of the electromagnetic field. Penetration depth—several millimetres (Figure 5).

(iv) RIR magnetic-light applicator—emits pulsed LED radiation—with mixed wavelengths: 630 nm red (*R*) and 855 nm infrared radiation (IR) combined with the action of the electromagnetic field (Figure 6).

Figure 1: Viofor JPS device (Med & Life) with a magnetic-light applicator (source: author).

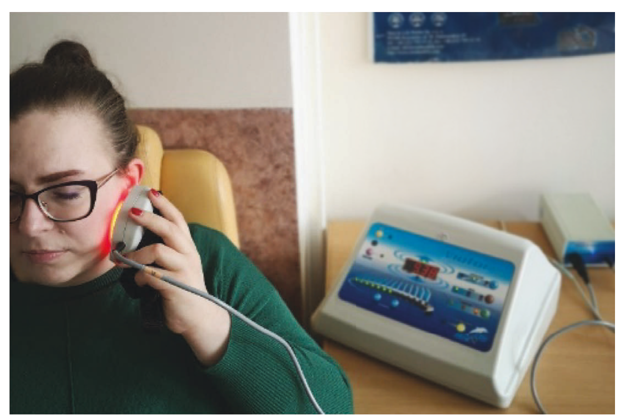


Figure 2: ELF-MF + LED treatment using a magnetic-light applicator (source: author).

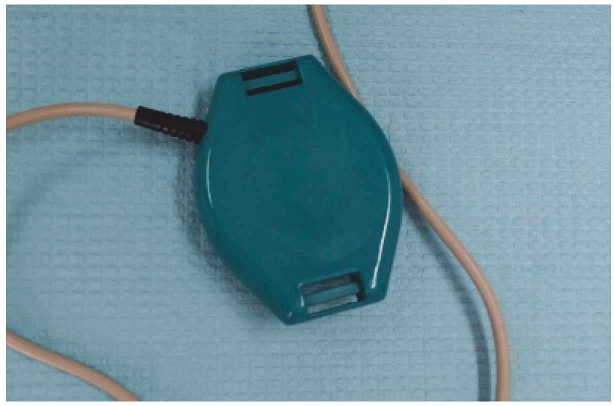
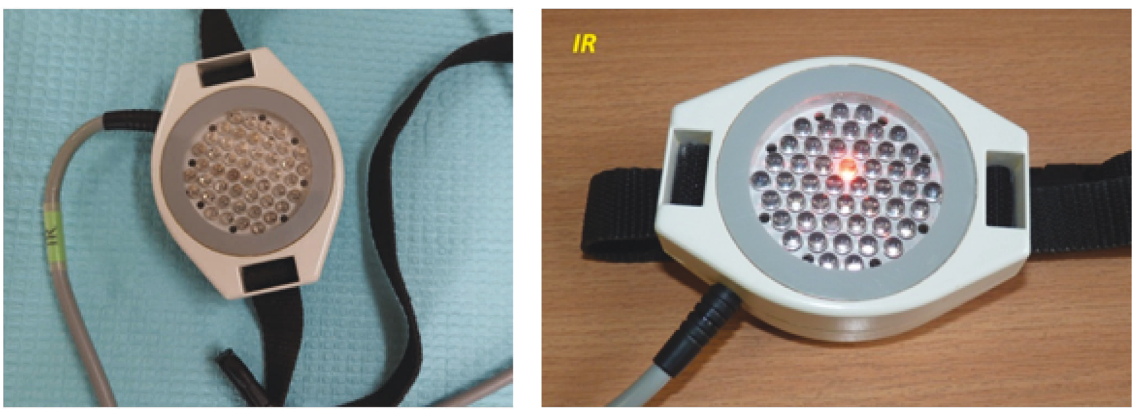
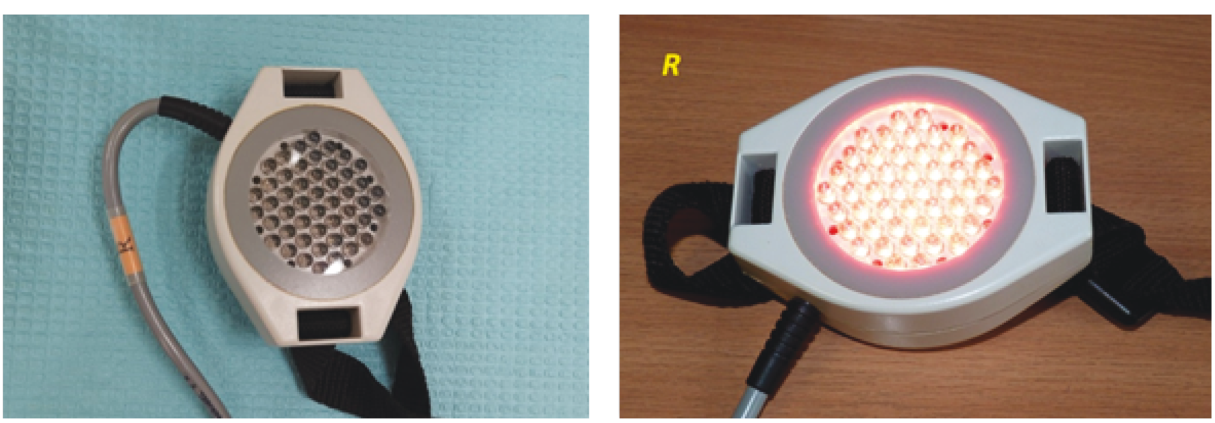


Figure 3: Magnetic-light applicator of the Viofor JPS system for local ELF-MF therapy (author's photo).



(a) (b)

Figure 4: Magnetic-light applicator of the Viofor JPS system for local ELF-MF + LED therapy using infrared light (source: author).



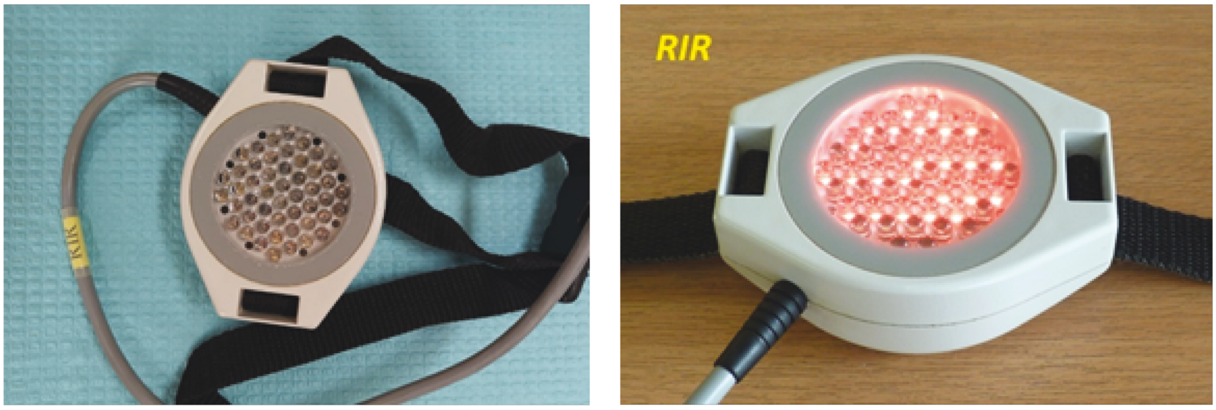
(a) (b)

Figure 5: Magnetic-light applicator of the Viofor JPS system for local ELF-MF + LED therapy using red light (source: author).

3. Results

The data collected in the present study were subjected to qualitative and quantitative statistical analysis using the IBM SPSS Statistics v. 25 package. The following statistical tests were used to analyse the data statistically:

(i) Kolmogorov–Smirnov test
(ii) Kruskal–Wallis test
(iii) Wilcoxon test
(iv) Spearman rank correlation
(v) Pearson chi-squared test



(a) (b)

Figure 6: Magnetic-light applicator of the Viofor JPS system for local ELF-MF + LED therapy using combined red and infrared light (source: author).

Table 1: Key parameters of the distribution of VAS scores in all patients before the series of treatments.

	Minimum	Maximum	Mean	Standard deviation	Median	Normality of distribution
VAS	3.00	9.00	6.79	1.24	7.00	<0.001

Source: own study. VAS—visual analogue scale for rating pain.

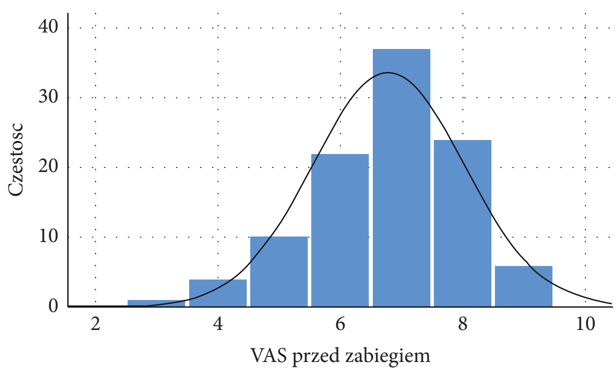


Figure 7: Histogram of VAS scores for all patients before treatment (source: own study).

(vi) Mann-Whitney *U* test.

Nonparametric tests were selected due to significant deviations from the assumptions of a normal distribution found in most of the studied variables. The p value <0.05 was adopted to determine statistical significance.

There were 104 patients in the study, aged 19 to 51 years, mean age of $M = 27.50$ and standard deviation $SD = 7.20$.

Analysis of baseline results for all the examined patients prior to the application of any physical therapy modality is presented in Table 1. The table contains information on key parameters of the distribution of all VAS scores in the entire study group before the application of the selected physical therapy method.

The parameter under analysis was the subjective pain rating expressed as a VAS score. The data distribution was significantly different from a normal distribution, as shown in Figure 7. The histogram is slightly left-skewed, which means that above-average results were more common than below-average results.

Analysis of differences in VAS scores between the subgroups before the application of a specific physical stimulus is presented in Table 2. In order to be able to evaluate the effects of therapy and the differences between them depending on the treatment modality, the subgroups included in the comparison should not differ significantly in terms of the VAS scores measured at baseline. Table 2 contains information on the means (M) and standard deviations (SD) of all baseline measurements in four subgroups before receiving different treatments.

The differences between the subgroups were tested for significance using the nonparametric Kruskal-Wallis test. Pain intensity according to VAS scores was found to be the highest in subgroups 1 and 3, and the lowest in subgroup 4. Detailed results are presented in Table 2.

3.1. Subgroup 1 (ELF-MF). Following the diagnostics performed after the application of physical therapy using ELF-MF, a significant decrease was observed in pain intensity self-reported by the respondents using the VAS—the pain intensity experienced by patients decreased by an average of 26.9%. Results are presented in Table 3. Comparison of VAS pain scores before and after the series of treatments is shown in Figure 8.

3.2. Subgroup 2 (ELF-MF + IR). Following the diagnostics performed after the application of physical therapy using ELF-MF + LED (using infrared light), a significant decrease was observed in pain intensity self-reported by the respondents using the VAS—the pain intensity experienced by patients decreased by an average of 41.18%. The results are

Table 2: Comparison of mean baseline measurements across the four subgroups allocated to different treatments.

Variable	Treatment modality				Kruskal–Wallis test		
	1	2	3	4	H	df	p
VAS	7.10 (M) (1.18) (SD)	7.09 (M) (0.85) (SD)	7.10 (M) (1.01) (SD)	6.00 (M) (1.44) (SD)	11.995	3	0.007

Source: own study. VAS—visual-analogue scale for rating pain.

Table 3: Comparison of VAS scores before and after treatment among patients in subgroup 1.

Subgroup 1	Before min.-max. M (SD)	After min.-max. M (SD)	Wilcoxon test Z	p
VAS	5–9 7.10 (1.18)	3–7 5.19 (1.17)	−4.289	<0.001

Source: own study. VAS—visual-analogue scale for rating pain.

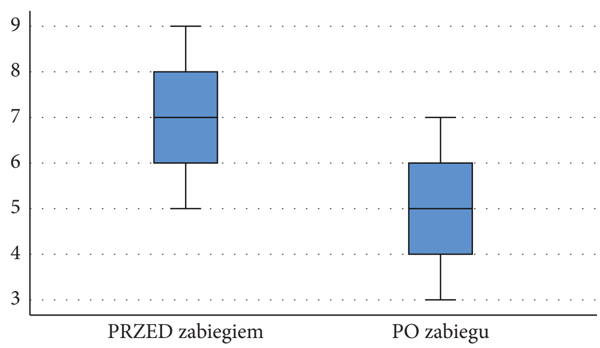


Figure 8: Comparison of VAS pain scores before and after treatment among patients in subgroup 1.

Table 4: Comparison of VAS scores before and after the series of treatments among patients in subgroup 2.

Subgroup 2	Before min.-max. M (SD)	After min.-max. M (SD)	Wilcoxon test Z	p
VAS	6–9 7.09 (0.85)	3–6 4.17 (0.98)	−4.318	<0.001

Source: own study. VAS—visual-analogue scale for rating pain.

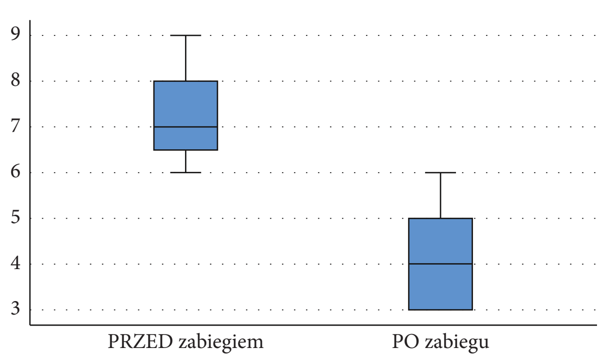


Figure 9: Comparison of VAS pain scores before and after the series of treatments among patients in subgroup 2 (source: own study).

Table 5: Comparison of VAS scores before and after the series of treatments among patients in subgroup 3.

Subgroup 3	Before min.-max. M (SD)	After min.-max. M (SD)	Wilcoxon test Z	p
VAS	5–9 7.10 (1.01)	3–9 5.03 (1.40)	−4.913	<0.001

Source: own study. VAS—visual-analogue scale for rating pain.

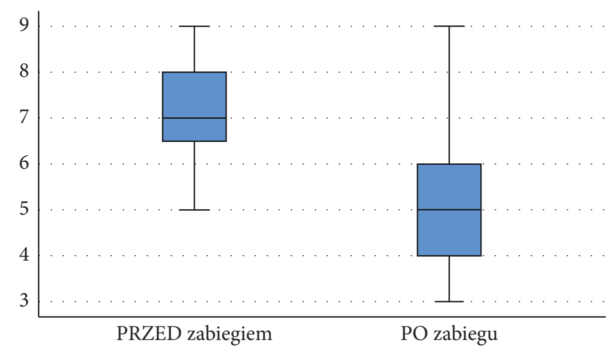


Figure 10: Comparison of VAS pain scores before and after the series of treatments among patients in subgroup 3 (source: own study).

presented in Table 4. Comparison of VAS pain scores before and after the series of treatments is shown in Figure 9.

3.3. Subgroup 3 (ELF-MF + R). Following the diagnostics performed after the application of physical therapy using ELF-MF + LED (with the use of red light), a significant decrease was observed in pain intensity self-reported by the respondents using the VAS—the pain intensity experienced by patients decreased by an average of 29.15%. The results are presented in Table 5. Comparison of VAS pain scores before and after the series of treatments is shown in Figure 10.

3.4. Subgroup 4 (ELF-MF + RIR). Following the diagnostics performed after the application of physical therapy using ELF-MF + LED (with the use of mixed red and infrared light), a significant decrease was observed in pain intensity self-reported by the respondents using the VAS—the pain intensity experienced by patients decreased by an average of 39.67%. The results are presented in Table 6. Comparison of VAS pain scores before and after the series of treatments is shown in Figure 11.

Comparison of changes in tested parameters across all subgroups following the completion of physical therapy.

Table 6: Comparison of VAS scores before and after the series of treatments among patients in subgroup 4.

Subgroup 4	Before min.-max. M (SD)	After min.-max. M (SD)	Wilcoxon test Z	Wilcoxon test p
VAS	3–8 6.00 (1.44)	1–7 3.62 (1.70)	−4.776	<0.001

Source: own study. VAS—visual-analogue scale for rating pain.

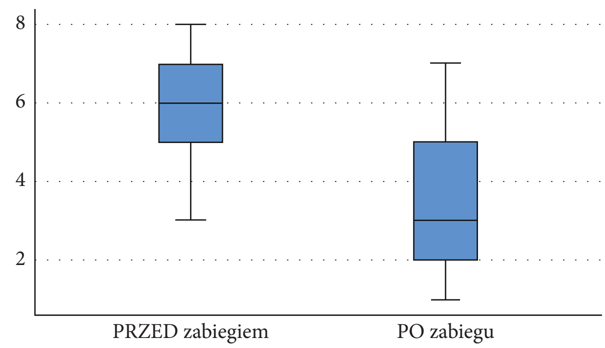


Figure 11: Comparison of VAS pain scores before and after the series of treatments among patients in subgroup 4 (source: own study).

Table 7: Comparison of mean measurements following a series of treatments in four subgroups receiving different treatments.

Variable	Type of treatment				Kruskal–Wallis test		
	1	2	3	4	H	df	p
VAS	−1.90 (0.44)	−2.91 (0.73)	−2.06 (0.98)	−2.38 (0.82)	22.183	3	<0.001

Source: own study. VAS—visual-analogue scale for rating pain.

Table 7 presents the results of the analysis comparing post-treatment differences in four subgroups. Baseline scores were subtracted from the post-treatment scores, resulting in positive indicators for increasing post-treatment scores and negative for decreasing scores. In terms of VAS scores, decreases were observed across the board, with the most pronounced change in subgroup 2, followed by subgroup 4, 3, and then 1.

4. Discussion

Pain is difficult to measure because it is a subjective experience influenced by the current situation and health of the person, cultural norms, and several psychological factors [30,31]. Disorders of the stomatognathic system, apart from pain, are often manifested by limited or asymmetric movements of the mandible, acoustic phenomena originating from the joint, hypertrophy/hyperplasia of the masticatory muscles, the occurrence of parafunctions, and symptoms indicative of bruxism [32]. There are many factors, such as the morphological structure of the joints, indication of parafunctional activities, postural disturbances, and psychological factors that can cause perpetuate pain in the stomatognathic system [33]. The correct diagnosis of pain has a great importance because only patients who suffered from it were enrolled in the study, which is confirmed by the research methods adapted by other authors of studies on similar topics, including Melo [34]. VAS is a scale that can be used to quantify pain intensity, making it possible to compare the level of pain before and after a specific type of therapy, and to monitor the effects of the measures taken [30]. The study used a visual analog scale to ensure effective interpretation of the results. Numerous scientific reports indicate that about 85% of patients experience (partial or complete) alleviation of pain symptoms as a result of multidisciplinary treatment combining dentistry and physiotherapy, which is confirmed by the findings of Nicolakis [35] and Oh [36]. However, the results obtained in studies based solely on physiotherapeutic methods were similar [37,38].

This study confirmed the analgesic effect of the applied methods of physical therapy. The authors focused on the analysis of the results obtained for each subgroup, comparing the influence of individual modalities on pain intensity (according to the results obtained on the VAS scale). After treatment, significant pain relief was observed in each of the treatment subgroups, but in the overall comparison, ELF-MF + IR was statistically significantly better than the other methods.

There are many publications on the anti-inflammatory and analgesic effects of ELF MF. In research, Thomas used this therapeutic approach to treat chronic musculoskeletal pain, achieving relief for patients. The results obtained in the group of these patients were close to statistical significance ($p = 0.06$) [39]. On the other hand, Calderhead proved that light therapy with LEDs, which is used in the field of aesthetic medicine, affects target tissues and can penetrate them [24]. The above findings of the authors confirm the observed results, indicating the influence of the discussed therapeutic methods in the place of pain and the appropriate penetration into the tissues, which gives the analgesic effect. Simpson showed that near infrared diodes achieve the deepest penetration of waves in tissues, and that is why they are used in targeted therapy in subcutaneous structures [40]. There is a lot of research into the extensive use of LEDs that generate red light, especially in wound healing, treating precancerous lesions, warts, and preventing oral mucositis. It has been observed that the infrared light generated by LEDs is able to penetrate the skin tissue and provide a therapeutic stimulus there [41]. From the research and observations of the authors, it can be concluded that the discussed modality has a beneficial effect on the human body. At the same time, the analgesic effect of this use and a specific factor has been shown. In turn, Arneja et al. used the electromagnetic field in the treatment of chronic back pain in patients with degenerative disease. Arneja research indicates, first of all, the safety and effectiveness of the method as well as its great clinical significance [42]. Iannitti et al. in clinical study using pulsed electromagnetic field therapy in the elderly obtained favorable results with improvement in the perception of joint pain, stiffness, and physical function [43]. These studies indicate the enormously beneficial importance of the therapeutic factor in the form of electromagnetic fields. In authors study, pain relief is reported at the same level of significance. On the other hand, Nelson found that noninvasive electromagnetic field therapy led to a rapid and significant reduction in pain in the early stages of osteoarthritis of the knee. The analgesic effect was obtained in the studied group of patients at the significance level $p < 0.001$ [26]. The analgesic effect of slowly changing, low-frequency electromagnetic fields is particularly important in the treatment of patients. According to Wheeler, discomfort from musculoskeletal and fascial structures affects about 85% of people who struggle with post-traumatic pain. In addition, over 90% of people report pain in the course of other diseases. Such ailments can also be found in 55% of patients suffering from the head and neck pain [44].

The present study in the subgroup of patients undergoing local treatment with ELF-MF and LED light demonstrated an analgesic effect, even though, in the author's comparison, ELF-MF + LED yielded better results than ELF-MF alone. This may be due to a deeper local effect and the simultaneous application of both stimuli in a single treatment. The light with a fixed wavelength applied together with electromagnetic field penetrates deeper than if used on its own. Such a synergy of the two treatment modalities is therefore more beneficial from a therapeutic point of view.

The studies cited above are consistent with the present findings. Moreover, in terms of pain intensity, a statistically significant decrease was observed as a result of treatment. Similar results were obtained by other authors in research of a similar scope.

Więckiewicz et al. emphasized a very important issue, discussing the pain in the masticatory muscles and the mental state of the patients. The authors found a relationship between the pain in the masticatory muscles and changes in mental state [45]. This is undoubtedly an extremely important aspect that should be taken into account when determining the patient's qualification for treatment, as well as during therapy. This will allow for multidirectional and multidisciplinary treatment.

It should be emphasized that the treatment of patients with TMD should include appropriately selected physiotherapy. Positive therapeutic effects are achieved through the use of various factors (eg laser therapy, heat therapy, light therapy, electromagnetic field, manual therapy, relaxation techniques, and autogenic training) [46]. Hals et al. noted that this particular group of patients suffering from TMD is often considered "difficult patients." This is because few healthcare professionals feel they can help on an individual basis. Therefore, it is necessary to provide TMD patients with the care of a multidisciplinary team that will ensure a comprehensive treatment process [47].

Vaca-González et al. focused attention to a very important point—magnetic stimulation is a promising noninvasive therapy that can be used to treat different kind of musculoskeletal pathologies. However, there are some limitations to highlight. The stimulation scheme, different ranges of frequencies, and application of various time stimulation mean that there is no standardized protocol in which ways of stimulation are the most appropriate to be able to treat a specific pathology. Even though studies described in this review showed positive results in treatment of musculoskeletal diseases, there is a need to carry out a standardization of the magnetic stimulation parameters application so that they are implemented in a regulated way at the clinical level [48].

5. Conclusions

The use of ELF-MF and ELF-MF in combination with LED light brings a significant improvement in subjective pain perception—this action can be successfully used in the management of pain in the course of TMD. The physical factors reduced the intensity of experienced pain during the examination.

The use of selected physical stimuli and their beneficial effect on the reduction of pain is of significant importance for patients in everyday life or work. The use of the abovementioned therapeutic methods may help to increase the patient's comfort and improve the results of manual TMJ therapy or the effects of dental procedures.

Each patient has a different pain sensitivity threshold, determining the level of its severity, it is subjective, and thus there is no possibility to objectify the results of the research. The duration of the physical treatments lasted 3 weeks—from the initial observations, the reduction of pain in patients allowed for manual TMJ therapy.

At the moment, authors do not have sufficient data on the follow up after the cycle of application of physical factors and enabling the determination of the duration of the reduction in the pain level in individual subgroups. However, research is being carried out on the abovementioned issues.

Data Availability

The datasets used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Acknowledgments

All Article Processing Charges for manuscript 3604386 has been waived.

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Hindawi
Pain Research and Management
Volume 2022, Article ID 6115782, 9 pages
https://doi.org/10.1155/2022/6115782

Research Article

The Axial Length of the Eyeball and Bioelectrical Activity of Masticatory and Neck Muscles: A Preliminary Report

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Received 14 March 2022; Accepted 12 July 2022; Published 16 August 2022

Academic Editor: Aneta Wieczorek

Objective. The present study aimed to evaluate the correlation of eye length and bioelectric activity of temporalis, masseter, digastric, and sternocleidomastoid muscles in women with myopia compared to healthy women. *Methods*. Based on the exclusion and inclusion criteria, 42 women aged 24 years (±2 years) were eligible for the study. Two equally sized groups with myopic ($n = 21$) and emmetropic healthy subjects ($n = 21$) were formed. An electromyographic study of the examined muscles was performed in four conditions: at rest, during maximal voluntary clenching in the intercuspal position, during maximal voluntary clenching on dental cotton rollers, and during maximal mouth opening using BioEMG III (BioResearch Associates, Inc. Milwaukee, WI, USA). The IOL Master 500 (Carl Zeiss Meditec, Jena, Germany) was used to examine the eyeball length. Statistical analysis showed significant positive correlations during mouth opening in both groups with open and closed eyes. *Results*. A greater number of correlations between the analyzed variables was observed in emmetropic women. In almost all cases, the longer axial eye length was associated with an increase in the bioelectrical activity of the analyzed muscles. Significant correlations were most often observed within the masseter and digastric muscles during the maximum mouth opening and at rest. *Conclusion*. There is a relationship between the bioelectrical activity of the masticatory muscles and the axial length of the eyeball on the same side.

1. Introduction

Myopia is a prevalent condition that typically starts in childhood and early adulthood and is characterized by a blurring of objects viewed at a distance [1]. Globally, myopia is estimated at 42.9% in people aged 43–52 years and up to 14.4% in those aged 75 years and older [2]. In Poland, myopia affects between 30.6% and 52% of the adult population [3, 4].

It is predictable that by 2050, there will be over 4750 million people with myopia [5]. This condition is also the most frequent cause of irreversible refractive error in the working population [6, 7]. The etiology of myopia is multifactorial and not fully understood. Evidence suggests that myopia is a consequence of the interaction between genetic and environmental components [8]. Myopia is connected with numerous ocular complications, such as retinal detachment, cataract, glaucoma, optic nerve disc changes, and maculopathy [9]. Moreover, the age of onset and myopia progression are the most important predictors of high myopia in later youth [10].

The refractive state of a human eye consists of 4 ocular structures, including the cornea, aqueous fluid, lens, and vitreous [11]. The refractive error results from a mismatch between different optical components of the eye, one of which is the length of the eyeball. The most common type of myopia is axial myopia, which results from the excessive elongation of the eyeball. The eyeball length increases during childhood and adolescence, leading to myopia if this increase in eyeball axial length exceeds the eye's focus [12]. The eyeball length parameters are important data in diagnosing refractive errors in nearsighted (the eyeball is elongated) and farsighted (the eyeball is shortened) patients. The measurements of the parts of the eye, namely the anterior chamber depth, lens thickness, vitreous chamber depth, and axial length, are widely evaluated in ocular diseases (Figure 1). The eyeball length is 24 mm for low myopia (-6 D < refractive error <0 D), whereas the eyeball length for high myopia is approximately 30 mm (refractive error < -6 D) [11].

Several studies suggest the effect of visual impairment on electromyographic activity within the masticatory muscles in myopic subjects [13–16]. As we previously reported, closing and opening eyes may be related to changes within the bioelectric activity of the cervical and masticatory muscles in myopic patients [16]. Increased bioelectric activity and reorganization of electromyographic patterns within the masticatory muscles may be associated with a predisposition to temporomandibular disorders (TMDs) [17]. Moreover, people with refractive conditions are more affected by headaches than healthy subjects, which may be related to increased bioelectric activity within the anterior temporalis muscles [18, 19]. However, no studies have evaluated the correlation between the axial length of the eyeball and the electromyographic activity within masticatory muscles. Therefore, this study aimed to analyze the correlation between the axial length of the eyeball and bioelectric activity of temporalis, masseter, digastric, and sternocleidomastoid muscles in women with myopia in comparison to healthy women.

2. Materials and Methods

2.1. Study Population. One hundred and one women were invited to participate in the study. The Bioethics Committee of the Medical University of Lublin approved the presented research (KE-0254/229/2020). The study was conducted following the current principles of the Declaration of Helsinki (64th WMA General Assembly, Fortaleza, Brazil, October 2013). Participants were informed about the study's objectives during the recruitment procedure, and written consent was obtained from all subjects involved.

The inclusion criteria applied in the presented research were as follows: female gender, no visual impairment (control group), myopia based on clinical examination (myopia group), four zones of arch support, and complete dentition.

The following exclusion criteria were applied in the research: hyperopia, eye diseases, optic nerve diseases, TMDs based on the research diagnostic criteria for temporomandibular disorders (RDC/TMD), II and III class according to Angle's classification, oral inflammation, open bite, crossbite, neurological disorders in the head and neck, neoplastic diseases, head, neck, and upper limb pain of any etiology within the last six months, trauma and previous surgical treatment in the head and neck region within the last six months, and pregnancy.

Based on the exclusion and inclusion criteria, 42 women aged 24 years (±2 years) were eligible for the study. Two equally sized groups with myopic $n = 21$ and emmetropic subjects $n = 21$ were formed. The intraocular pressure in the refractive error subjects was 17 mm·Hg (±4 mm·Hg) in the right eye and 14 mm·Hg (±4 mm·Hg) in the left eye. Intraocular pressure in the emmetropic subjects was 17 mm·Hg (±3 mm·Hg) in the right eye and 14 mm·Hg (±4 mm·Hg) in the left eye (Tonopen, Reichert, Depew, New York, USA). The groups did not statistically differ in intraocular pressure between each other ($p > 0.05$).

It was decided to study women because of the more frequent occurrence of myopia [20, 21] and more frequent TMD [22] in comparison to men.

2.2. Study Protocol

2.2.1. Ophthalmic Examination. The Snellen chart was used to test visual acuity. The Snellen chart remains the most widely used method for visual acuity testing [23]. It was, therefore, selected for this study. The Snellen chart uses a geometric scale to measure visual acuity, with correction vision at a distance set to 20/20. In the emmetropic group, visual acuity was 20/20. In the refractive error group tested under correction, visual acuity was 20/20.

According to the existing clinical and epidemiologic studies standards, people with myopia were defined as those with a refractive error ≤-0.50 diopters (D) [24]. The myopia group included women with a refractive error of -0.50 D to -5.75 D. The mean refractive error value was -2.5 D (±-1.00 D) for the right eye and -2.5 D (±-1.5 D) for the left eye. No visual impairment was found in the emmetropic group.

An IOL Master 500 (Carl Zeiss Meditec, Jena, Germany) was used to examine the eyeball length. This device is precise and is used in ophthalmology to calculate the power of artificial intraocular lenses. It is a noninvasive optical biometer that uses 780 nm partial coherence interferometry to measure the eye's axial length. The axis data are obtained from the optical path distance from the anterior corneal surface to the retinal pigment epithelium [25]. All ophthalmic tests were performed by the same researcher [26]. Participants sat in front of the head of the device, resting their chin and forehead against the tripod (Figure 2). The eyes were focused when the apparatus head was approximately 5.5 cm from the patient. Participants were asked to perform a full blink before the examination to spread an

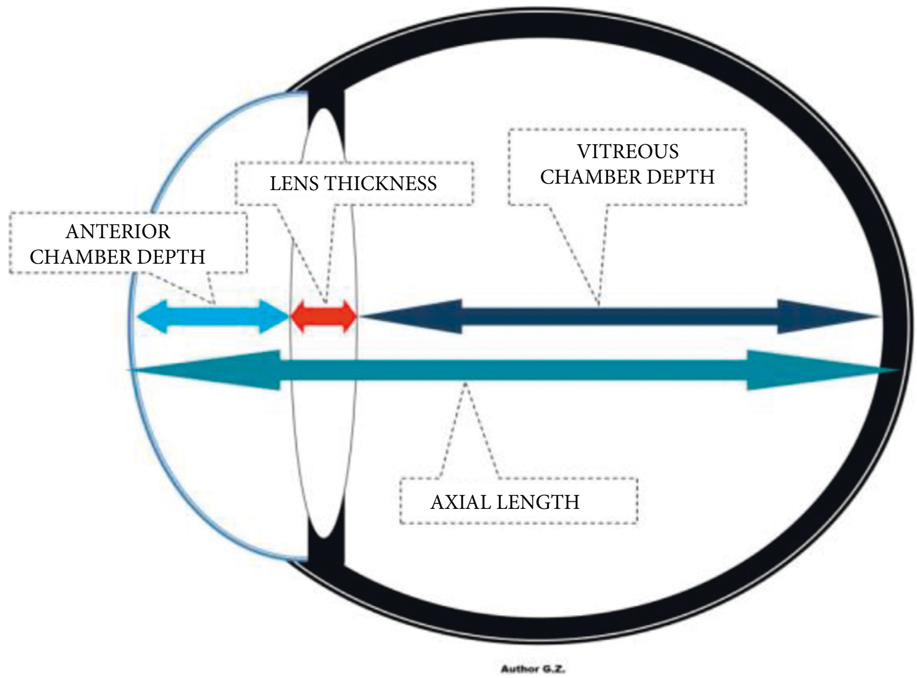

Figure 1: The axial length of the eyeball.

Figure 2: The axial length eyeball measurement during the study.

optically smooth tear film over the cornea. Five separate tests were performed to assess the average axial length [27].

2.2.2. Electromyographic Examination. Surface electromyographic examinations (sEMG) were performed between 8 and 12 a.m. The sEMG tests were conducted in the dental chair. The subjects assumed a perpendicular position, with the head resting on the armchair headrest and the lower limbs positioned horizontally and parallelly.

Before placing surface electrodes, the skin was cleansed with 90% alcohol solution. sEMG electrodes (Ag/AgCl) with a conductive surface of 16 mm (SORIMEX, Torun, Poland) were placed bilaterally on the skin, covering the examined muscle groups. Four pairs of masticatory and neck muscles were analyzed: temporalis muscle (the anterior part-TA), the masseter muscle (the superficial part-MM), the digastric muscle (the anterior belly-DA), and the sternocleidomastoid muscle (the middle part-SCM), according to the SENIAM (surface EMG for noninvasive assessment of muscles) standards and our previous work [28, 29]. The reference sEMG electrode was put on the forehead in the middle of the frontal bone [30] (Figure 3).

Bioelectric muscle activity was measured during the resting mandibular position (10 seconds), maximal voluntary clenching in the intercuspal position (as hard as possible; 3×3 seconds, 2 seconds break), maximal voluntary clenching on dental cotton rollers (as hard as possible; 3×3 seconds, 2 seconds break), and maximal mouth opening (as wide as possible; 3×3 seconds, 2 seconds break). The averaged results from three measurements were used in the statistical calculations [16, 29]. An open eye and closed-eye test were conducted with a 5-minute break between tests. A random choice of the pretest was made. sEMG measurements were performed without visual correction [13, 16].

The reproducibility of the sEMG examination was confirmed by repeated sEMG tests on 10 participants. Two independent sEMG measurements were separated by 5 minutes of rest between the above-mentioned masticatory activities. There were no significant differences ($p > 0.05$) between repeated sEMG results at rest, during maximal voluntary clenching in the intercuspal position, during maximal voluntary clenching on dental cotton rollers, and during maximal mouth opening [3].

The sEMG signal was processed using the BioPAK Measurement System software (BioResearch Associates, Inc. Milwaukee, WI, USA). The microvolt sEMG potentials were amplified with minimal noise to 5000 times their original level. The sEMG noise was reduced by 40 dB using the digital

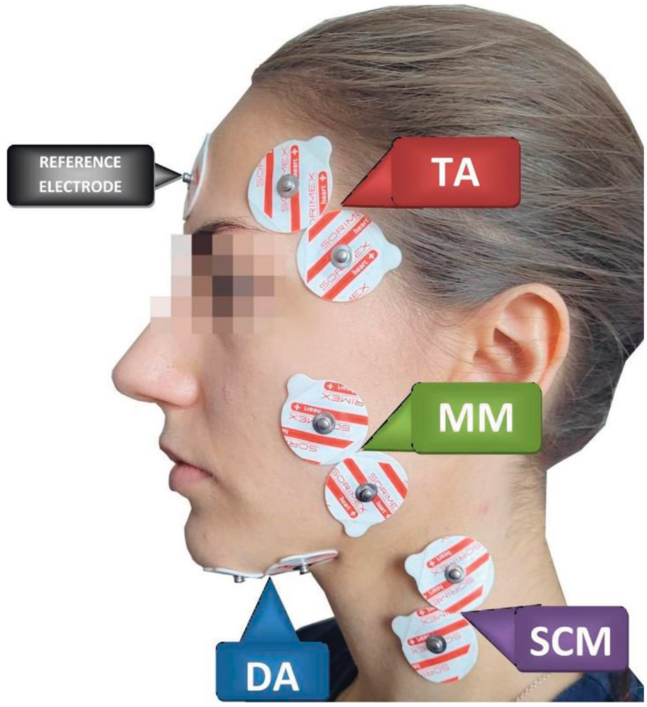

Figure 3: Electrodes placement during the electromyographic examination. TA: temporalis muscle (the anterior part), MM: the masseter muscle (the superficial part), DA: the digastric muscle (the anterior belly), and SCM: the sternocleidomastoid muscle (the middle part).

Table 1: Comparison of age between groups.

Variable	Group	Mean	95% CI	95% CI	Median	Minimum	Maximum	SD	z	p
Age (year)	Myopia	23.52	22.60	24.45	24.00	20.00	30.00	2.04	0.18	0.86
	Control	23.76	22.49	25.03	23.00	19.00	31.00	2.79		

Noise Buster BioPAK measurement system. The electromyography signal processing based on root means square (RMS) calculations produced average bioelectrical values, which were then used for statistical analyses [29]. The strengthening the reporting of observational studies in epidemiology (STROBE) checklist was used to assess the procedural quality of the research [31].

2.2.3. Statistical Analysis. The statistical analysis was performed using the Statistica™ 14.0 (TIBCO Software Inc., Palo Alto, CA, USA). The normal distribution of the data was verified with the Shapiro-Wilk test. The Wilcoxon matched-pairs test for paired samples was used for data, which showed no compatibility with normal distribution. To compare groups, the Mann–Whitney U test and T-test were used. We compared muscle activity and the axial eye length on the same side in the statistical analysis. The Spearman rank correlation coefficient (R, rho) was used to test the relationship between the axial eye length and the electromyographic activity of the selected muscles. Spearman rho varies between −1 (perfect negative monotonic association) and +1 (perfect positive monotonic association). A correlation was considered large for results greater than 0.5 and moderate for results between 0.3 and 0.5 [32]. Effect sizes were determined for the t-test using the Cohen d method as small (0.2), medium (0.5), and large (0.8). Statistical significance was set at $p \leq 0.05$.

3. Results

Statistical analysis showed no significant differences between subjects' ages (Table 1) and mandibular mobility ranges (Table 2). Statistically significant differences were shown in the right and left eye axial length between groups (Table 2).

The statistical analysis showed a significant positive correlation between the left axial length and left-sided digastric muscle activity during clenching in the intercuspal position and clenching on dental cotton rollers, both in open and closed eye measurements. The significance of the correlation increased with eyes closed (Table 3).

The statistical analysis revealed a significant positive correlation between axial length and MM-L, DA-L, MM-R, DA-R muscles during maximum mouth opening within both open and closed eye measurements. The significance of the correlation increased with eyes closed (Table 4). In addition, a significant positive correlation was observed during maximum mouth opening within SCM-L muscles (open eyes measurement) and within TA-R (closed eyes measurement). The statistical analysis showed a significant

Table 2: Comparison of eye axial length and mandibular range of motion between groups.

	Myopia group							Control group								
	Mean	95% CI	95% CI	Median	Minimum	Maximum	SD	Mean	95% CI	95% CI	Median	Minimum	Maximum	SD	Z/t	p
Eye axial length (right eye)	24.46	24.16	24.75	24.47	23.23	25.49	0.65	23.53	23.26	23.80	23.47	22.74	24.79	0.59	$T = 4.84$	**<0.001 ES = 1.50***
Eye axial length (left eye)	24.49	24.14	24.85	24.58	23.04	26.08	0.78	23.53	23.26	23.80	23.49	22.74	24.73	0.59	$T = 4.50$	**<0.001 ES = 1.40***
Active maximum mouth opening	48.05	45.35	50.75	48.00	35.00	59.00	5.76	48.86	46.77	50.94	48.00	42.00	58.00	4.59	$T = -0.50$	0.62
Passive maximum mouth opening	51.00	48.42	53.58	51.50	42.00	62.00	5.51	51.62	49.62	53.62	50.00	46.00	60.00	4.39	$T = -0.40$	0.69
Right lateral movement	10.00	9.32	10.68	10.00	8.00	12.00	1.45	9.52	8.23	10.82	10.00	0.00	13.00	2.84	$Z = 0.20$	0.84
Left lateral movement	10.10	9.17	11.03	10.50	6.00	14.00	2.00	9.71	8.39	11.03	10.00	0.00	14.00	2.90	$Z = 0.36$	0.72
Protrusion	8.80	7.70	9.90	9.50	4.00	13.00	2.35	8.90	7.72	10.09	9.00	3.00	13.00	2.61	$T = -0.13$	0.89

Table 3: Pooled correlation results in subjects with myopia.

			Eyes open			Eyes closed		
			Spearman R	t (N-2)	p value	Spearman R	t (N-2)	p value
			Myopia group					
Left axial length	Rest	TA-L	−0.14	−0.59	0.56	0.03	0.12	0.90
		MM-L	−0.14	−0.62	0.54	−0.15	−0.66	0.52
		SCM-L	−0.08	−0.33	0.74	0.07	0.33	0.75
		DA-L	0.13	0.55	0.59	0.04	0.18	0.86
	Clenching in the intercuspal position	TA-L	0.19	0.85	0.40	−0.01	−0.05	0.96
		MM-L	0.22	1.01	0.33	0.21	0.93	0.37
		SCM-L	0.25	1.12	0.28	0.26	1.18	0.25
		DA-L	0.56	2.98	**0.01***	0.62	3.45	**<0.001***
	Clenching on dental cotton rollers	TA-L	0.22	0.98	0.34	0.18	0.79	0.44
		MM-L	0.18	0.80	0.43	0.14	0.60	0.56
		SCM-L	0.22	1.00	0.33	0.18	0.80	0.43
		DA-L	0.48	2.35	**0.03***	0.50	2.53	**0.02***
	Maximum mouth opening	TA-L	−0.22	−1.01	0.33	−0.12	−0.51	0.61
		MM-L	−0.12	−0.51	0.61	−0.11	−0.48	0.64
		SCM-L	0.00	−0.01	0.99	0.02	0.09	0.93
		DA-L	−0.05	−0.23	0.82	−0.13	−0.57	0.57
Right axial length	Rest	TA-R	−0.24	−1.06	0.30	−0.26	−1.15	0.26
		MM-R	−0.07	−0.29	0.78	0.06	0.25	0.81
		SCM-R	0.07	0.32	0.76	−0.01	−0.03	0.98
		DA-R	−0.06	−0.28	0.78	−0.13	−0.56	0.58
	Clenching in the intercuspal position	TA-R	0.15	0.67	0.51	0.22	0.99	0.33
		MM-R	0.25	1.11	0.28	0.23	1.03	0.32
		SCM-R	0.02	0.11	0.92	0.07	0.31	0.76
		DA-R	0.21	0.91	0.37	0.30	1.35	0.19
	Clenching on dental cotton rollers	TA-R	0.24	1.06	0.30	0.22	0.99	0.33
		MM-R	0.25	1.13	0.27	0.42	2.03	0.06
		SCM-R	0.03	0.14	0.89	0.03	0.13	0.90
		DA-R	−0.01	−0.03	0.98	0.22	0.97	0.35
	Maximum mouth opening	TA-R	−0.32	−1.46	0.16	−0.25	−1.11	0.28
		MM-R	−0.29	−1.32	0.20	−0.30	−1.36	0.19
		SCM-R	−0.02	−0.10	0.92	−0.01	−0.06	0.95
		DA-R	−0.25	−1.12	0.28	−0.27	−1.23	0.23

negative correlation within DA-R during rest and during open eyes measurement, as presented in Table 4.

4. Discussion

The present study investigated the correlation between the axial length of the eyeball and the bioelectric activity of the masticatory and neck muscles in women with myopia compared to healthy women. In the myopic group, two positive correlations were found between the left axial length and left-sided digastric muscle activity while clenching in the intercuspal position and while clenching on dental cotton rollers, both in open and closed eye measurements. Moreover, the significance of the correlation increased with the eyes closed. Surprisingly, we observed more correlations between the analyzed variables in healthy women without visual impairment. In almost all cases, the longer axial eye parameter was associated with an increase in the bioelectrical activity of the analyzed muscles. Significant correlations were most often observed within the masseter and digastric muscles during the maximum mouth opening and at rest. Therefore, it can be assumed that the activity of these muscles is related to the axial length of the eyeball on the same side, which is most manifested during mandibular abduction and at rest.

An increase in correlation strength during closed eyes measurement may indicate the suppression of the vestibulo-ocular reflex (VOR) [33]. VOR stabilizes retinal image, keeping the eye fixed in space and focused on the object [33, 34]. The information along the VOR pathway is processed by three sources: the visual system through the eyes, proprioceptive receptors, and vestibular receptors in the inner ear. For the brain to perceive the activity of the vestibular system, it must receive information via the afferent pathway from different parts of the vestibular structure [35]. Closing eyes may decrease both VOR and masticatory muscle activity [33].

The hypothetical connection for the presented relationship may be as follows: instead of neurological connections, biomechanical connections in the form of a muscle-fascial network will be important [33]. The link between the organ of vision and the masticatory muscles occurs through the Tenon's fascia, connecting with the deep

Table 4: Pooled correlation results in healthy subjects.

			Eyes open			Eyes closed		
			Spearman R	t (N-2)	p value	Spearman R	t (N-2)	p value
			Control group					
Left axial length	Rest	TA-L	−0.11	−0.48	0.64	0.07	0.31	0.76
		MM-L	−0.22	−0.99	0.34	0.05	0.24	0.81
		SCM-L	−0.09	−0.40	0.69	0.26	1.19	0.25
		DA-L	−0.33	−1.52	0.14	−0.01	−0.04	0.97
	Clenching in the intercuspal position	TA-L	0.40	1.92	0.07	0.36	1.69	0.11
		MM-L	0.16	0.71	0.49	0.19	0.83	0.42
		SCM-L	0.14	0.60	0.56	0.19	0.83	0.41
		DA-L	−0.14	−0.63	0.54	−0.15	−0.67	0.51
	Clenching on Dental cotton rollers	TA-L	0.08	0.34	0.74	−0.06	−0.26	0.80
		MM-L	0.20	0.87	0.39	0.09	0.39	0.70
		SCM-L	0.08	0.36	0.72	0.00	0.00	0.99
		DA-L	−0.01	−0.05	0.96	−0.16	−0.69	0.50
	Maximum mouth opening	TA-L	0.16	0.71	0.48	0.41	1.97	0.06
		MM-L	0.46	2.23	**0.04***	0.43	2.07	**0.05***
		SCM-L	0.47	2.33	**0.03***	0.41	1.97	0.06
		DA-L	0.50	2.54	**0.02***	0.44	2.15	**0.05***
Right axial length	Rest	TA-R	−0.11	−0.48	0.64	−0.15	−0.68	0.51
		MM-R	0.14	0.60	0.56	0.38	1.80	0.09
		SCM-R	0.15	0.67	0.51	0.14	0.62	0.54
		DA-R	−0.47	−2.32	**0.03***	−0.30	−1.39	0.18
	Clenching in the intercuspal position	TA-R	0.31	1.43	0.17	0.33	1.52	0.14
		MM-R	0.00	0.02	0.99	−0.22	−0.98	0.34
		SCM-R	0.08	0.34	0.74	0.09	0.38	0.71
		DA-R	−0.21	−0.92	0.37	−0.27	−1.21	0.24
	Clenching on dental cotton rollers	TA-R	0.11	0.47	0.65	0.02	0.08	0.94
		MM-R	0.02	0.09	0.93	−0.09	−0.40	0.69
		SCM-R	0.09	0.39	0.70	−0.08	−0.33	0.74
		DA-R	−0.11	−0.48	0.63	−0.05	−0.22	0.83
	Maximum mouth opening	TA-R	0.26	1.19	0.25	0.44	2.16	**0.04***
		MM-R	0.54	2.78	**0.01***	0.45	2.17	**0.04***
		SCM-R	0.40	1.89	0.07	0.38	1.81	0.08
		DA-R	0.67	3.96	**0.001***	0.68	4.02	**<0.001***

fascia of the skull, and through it, with the temporal subseries and the deep fascia of the neck [36, 37]. The temporal fascia is a dense fibrous layer covering the temporalis muscle. Its surface provides an attachment site for the superficial fibers of the temporalis muscle. Through the deep cervical fascia, it connects to the quadrilateral and sternoclavicular muscles [36, 37].

In contrast, Tenon's fascia surrounds the eyeball from the edge of the ciliary body to the optic nerve entrance. In the middle part, it attaches to the back of the conjunctiva of the eye. It connects with the eye muscles and the fatty lining of the orbit and forms continuity with the sheath of the optic nerve [36]. The presented correlations were evident, especially while opening the mouth when the fascial network is stretched the most.

The greater number of correlations in healthy/emmetropic versus myopic subjects may be explained precisely by the hypothesized changes associated with it in the fascial network. People with nearsightedness are likely to have changed in the fascial network related to the reduced mobility of the eyeball-glasses limit the field of vision. Hypothetically, a longer knob also interferes with a fascial glide through decreased mobility [33]. All this can lead to fascial disorders called the densification of fascia [38]. It is a thickening of loose connective tissue and its extracellular matrix corresponding to a reduction or loss of gliding ability of the fascia [39]. If loose connective tissue is lost or its density is altered, the behavior of the fascia and underlying muscles is disrupted. The function of the entire muscle-tendon chain is also disrupted [40]. The alteration of the fascial glide can affect mandibular mobility and ocular motility [41]. Hypothetically, changes in the fascia structure can also affect the eye structures, leading, for example, to changes in the sclera observed in axial myopia [42]. The absence of the discussed changes in healthy subjects may explain the higher number of obtained correlations.

Our results revealed a relationship between the bioelectrical activity of the masticatory muscles and the axial length of the eyeball on the same side. In our opinion, the presented phenomenon is related to the biomechanical parameters of the Tenon's fascia. The assessment of these relationships may contribute to a better understanding of the coexistence of dysfunctions within the stomatognathic system and the organ of vision. Further research is necessary to clarify the mechanisms of these connections. The limitation of this study concerned a homogeneous research group. Therefore, it would be desirable to compare the results with the male population in future studies.

5. Conclusions

There is a relationship between the bioelectrical activity of the masticatory muscles and the axial length of the eyeball on the same side. Further studies are required to clarify the mechanism of the presented phenomenon.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors acknowledge support from the Medical University of Lublin for open access publishing. The authors acknowledge Julia Różycka for help with preparing the final version of the manuscript.

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Hindawi
Pain Research and Management
Volume 2022, Article ID 9344028, 11 pages
https://doi.org/10.1155/2022/9344028

Research Article

Craniofacial Morphology of Orthodontic Patients with and without Temporomandibular Disorders: A Cross-Sectional Study

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Received 6 January 2022; Revised 6 February 2022; Accepted 17 February 2022; Published 22 March 2022

Academic Editor: Aneta Wieczorek

Purpose. We aimed to explore the relationship between temporomandibular disorders (TMDs) and craniofacial morphology in orthodontic patients. *Methods*. Altogether, 262 orthodontic patients were included and divided into two groups according to their Fonseca Anamnestic Index (FAI) scores: a no-TMD group (control group, FAI < 20) and a TMD group (FAI ≥ 20). Cephalometric parameters including cranial, maxillary, mandibular, and dental parameters were traced on cephalograms. Craniofacial morphology was compared between TMD and control groups, followed by subgroup analyses based on TMD severity, gender, age, and temporomandibular joint (TMJ) symptoms. *Results*. The prevalence of TMDs was 52.7% among included patients (138/262). The mean age of TMD patients was higher than that of the control group. No significant difference in gender distribution between the groups was observed. The most commonly reported FAI items were misaligned teeth, neck pain, and emotional tension. The Frankfort-mandibular plane angle (FMA) was larger in the TMD patients than in the control group, whereas no significant differences in other parameters were observed. Subgroup analysis based on TMD severity revealed that FMA and anterior facial height of moderate/severe TMD patients were significantly larger than those of mild or no-TMD patients. Among male patients, the anterior cranial base length was smaller, and the anterior facial height was larger in the TMD group. Among female patients, no significant differences in craniofacial morphology between the groups were observed. In juvenile patients, overjet and overbite were smaller in the TMD group. In adult patients, SNA, ANB, FMA, and gonial angle were larger in the TMD group. Within the TMD group, patients with TMJ pain or noises exhibited characteristic craniofacial features compared to patients without these symptoms. *Conclusions*. Orthodontic patients with TMDs have specific craniofacial morphology, suggesting a relationship between TMDs and particular craniofacial features in orthodontic patients.

1. Introduction

Temporomandibular disorders (TMDs) are a group of disorders involving pain and dysfunction of the temporomandibular joint (TMJ) and masticatory muscles [1]. The prevalence of TMDs is approximately 40% [2], with higher rates in individuals aged 20–40 years and in women [1, 3, 4]. The main symptoms of TMDs include pain in the face and TMJ area, the difficulty of mandibular movement, and TMJ noises during mandibular movement [1], which affects the quality of life for many patients. Currently, TMDs are considered multi-etiological disorders. The main risk factors include biological factors such as anatomical morphology, trauma, occlusion, and sex hormones alongside psychological factors such as anxiety and depression [5–8]. Since the etiology and pathogenesis of TMDs have not been fully clarified, more research on risk factors for TMDs is warranted.

Over the years, various methods of diagnosing TMDs have been proposed, including the Research Diagnostic

Criteria for TMDs (RDC/TMD) [9] and the Diagnostic Criteria for TMDs (DC/TMD) [10], an improved version of the RDC/TMD. However, these instruments are procedurally complicated and require professional judgment, limiting their scope of application. A simplified and easier-to-use questionnaire is required to screen for TMDs in a larger population. A case in point is the Fonseca Anamnestic Index (FAI), which was proposed in 1994 and has shown high sensitivity in the diagnosis of TMDs [11–13]. The FAI consists of only ten questions pertaining to symptoms and risk factors related to TMDs. By calculating the total score, clinicians can diagnose the presence and severity of TMDs efficiently and at a low cost. In studies involving large sample populations and epidemiological surveys, the FAI would be superior to the RDC/TMD and DC/TMD for these reasons.

Nowadays, the clinical symptoms and signs of TMDs are relatively straightforward. Hence, other features of TMD patients, such as craniofacial morphology, are attracting growing academic attention. Patients with TMDs are reported to have specific craniofacial features such as a skeletal Class II profile, hyperdivergent growth pattern, and others [14, 15]. Some studies found differences in cervical posture and hyoid bone position between TMD patients and normal individuals, with an elevation of the hyoid bone and cervical lordosis observed in TMD patients [16, 17]. However, other studies have shown no differences in craniofacial morphology between TMD patients and individuals without TMDs [18–20]. The relationship between craniofacial morphology and TMDs remains controversial, especially in the orthodontic population. Therefore, the current study aimed to explore the relationship between the occurrence of TMDs and specific craniofacial morphological features among orthodontic patients. The null hypothesis was that there would be no relationship between them.

2. Materials and Methods

2.1. Subjects. The current observational cross-sectional study was performed at the Department of Orthodontics, West China Hospital of Stomatology, Sichuan University, during June 2021–August 2021. The study was approved by the Ethics Committee of West China School of Stomatology of Sichuan University (Ethics number: WCHSIRB-2020-418) and was conducted in accordance with the Declaration of Helsinki. All adult patients themselves and parents or legal guardians of patients aged under 18 years provided informed consent. The study was performed in compliance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) research guidelines [21].

Every orthodontic patient visiting the Department of Orthodontics for the first time was recruited consecutively and requested to fill out a questionnaire, including age, gender, medical history, and FAI scale. Angle's classification of malocclusion was determined by clinical examination. Lateral cephalograms were obtained in the Department of Imaging following routine procedures. The inclusion criteria were as follows: (1) patients seeking treatment in our department for the first time; (2) patients with qualified lateral cephalograms; and (3) patients aged 12 years or above. The exclusion criteria were as follows: (1) patients with orthodontic or orthognathic treatment history; (2) patients with maxillofacial trauma, cleft lip, or cleft palate; (3) patients with craniomaxillofacial deformities caused by systemic diseases such as rheumatoid arthritis; and (4) patients with mental disorders such as depression.

2.2. TMD Diagnosis and Severity Assessment. The Chinese version of the FAI [22] was utilized to assess whether a subject had TMD and to assess its severity. The scale consisted of ten questions, which in English are as follows: (1) Do you have difficulty opening your mouth wide? (2) Do you have difficulty moving your jaw to the sides? (3) Do you feel fatigued or muscle pain when you chew? (4) Do you have frequent headaches? (5) Do you have neck pain or a stiff neck? (6) Do you have ear pain or pain in the TMJ area? (7) Have you ever noticed any noise in your TMJ while chewing or opening your mouth? (8) Do you have any habits, such as clenching or grinding your teeth? (9) Do you feel that your teeth do not come together well? (10) Do you consider yourself a tense (nervous) person? Thus, the FAI allowed researchers to measure the degree of symptoms (questions 1–7) and risk factors (questions 8–10) related to TMDs of subjects. Each question had three possible answers, and each answer had a corresponding score (yes = 10, sometimes = 5, and no = 0). The severity of TMD of each patient could be assessed using the total FAI score (no-TMD = total score of 0–15, mild TMD = total score of 20–40, moderate TMD = total score of 45–65, and severe TMD = total score of 70–100) [11].

2.3. Cephalometric Analysis. The lateral cephalograms of all patients were obtained by the same radiologist. Patients were required to maintain the natural head position [23] with the mandible in the maximum intercuspal position. After obtaining the lateral cephalograms, Uceph software (version 780, Yacent, Chengdu, Sichuan, China) was used for cephalometric analysis. The cephalometric landmarks used in the study are shown in Figure 1.

The eighteen cephalometric parameters used in the study are presented as follows. Cranial parameters: (1) Saddle angle (N-S-Ar angle); (2) Articular angle (S-Ar-Go angle); (3) Anterior cranial base length (S-N distance); (4) Posterior cranial base length (S-Ar distance). Maxillary and mandibular parameters: (1) SNA (S-N-A angle); (2) SNB (S-N-B angle); (3) ANB (A-N-B angle); (4) FMA (Frankfort horizontal plane-mandibular plane angle); (5) Gonial angle (Ar-Go-Me angle); (6) Ramus height (Ar-Go distance); (7) Mandibular Body length (Go-Me distance). Dental parameters: (1) Interincisal angle (U1E-U1R-L1E-L1R angle); (2) Cant of occlusal plane (Frankfort horizontal plane-occlusal plane angle); (3) Overjet (U1E-L1E horizontal distance); (4) Overbite (U1E-L1E vertical distance). Other parameters: (1) Anterior facial height (N-Me distance); (2) Posterior facial height (S-Go distance); (3) Wits appraisal (A' (the intersection between the perpendicular of occlusal plane through A and occlusal plane)-B' (the intersection

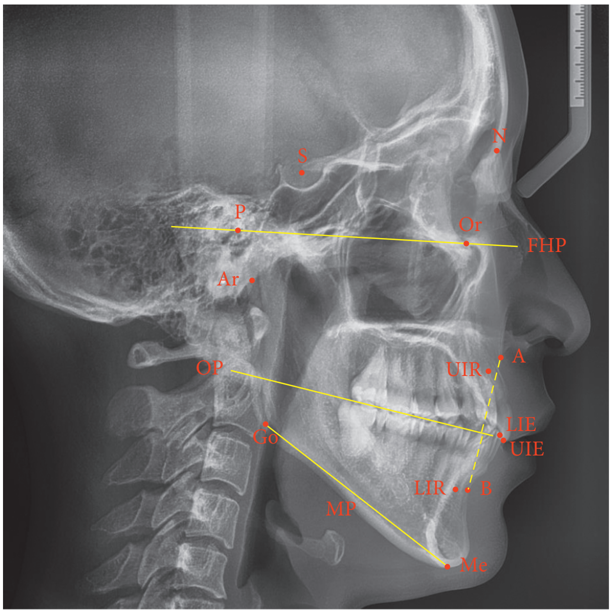

Figure 1: Cephalometric landmarks used in the study. N, Nasion; S, Sella; P, Porion; Or, Orbitale; Ar, Articulare; A, Subspinale; UIR, Upper incisor root; UIE, Upper incisor edge; LIR, Lower incisor root; LIE, Lower incisor edge; B, Supramentale; Me, Menton; Go, Gonion; FHP, Frankfort horizontal plane; OP, Occlusal plane; MP, Mandibular plane.

between the perpendicular of occlusal plane through B and occlusal plane) distance).

Two researchers blinded to the patient details performed the measurements. Inter-observer and intra-observer reliability were tested according to the method described by Xiong et al. [24] to ensure the accuracy of the measurements. For inter-observer reliability, 20 lateral cephalograms were randomly selected for initial measurement by the researchers before the formal measurement, and the repeat measurement was performed 2 weeks later. The intra-class correlation coefficient (ICC) was used to test the repeatability of the results from the two measurements. If ICC was ≥ 0.75, formal measurement was performed. If ICC was < 0.75, 20 cephalograms were randomly selected for repeatability testing again. Formal measurement was not completed until an ICC value of ≥ 0.75 was obtained.

2.4. Statistical Analysis. The demographic, occlusal, and craniofacial morphological characteristics were compared between the control group (FAI < 20) and TMD group (FAI ≥ 20), followed by subgroup analyses based on TMD severity, gender, and age. According to the results of item 6 in the FAI scale, the TMD group was divided into subgroups of patients with TMJ pain (item 6 score = 5 or 10) and without TMJ pain (item 6 score = 0). According to the results of item 7, the TMD group was divided into subgroups of patients with TMJ noises (item 7 score = 5 or 10) and without TMJ noises (item 7 score = 0). The demographic and occlusal characteristics as well as cephalometric parameters were compared between patients with and without TMJ pain, as well as between patients with and without TMJ noises.

All data were analyzed using IBM SPSS Statistics (version 20.0, IBM Corp., Armonk, NY, USA). Quantitative data were expressed as mean and standard deviation (SD), and qualitative data were expressed as quantity and frequency. The Shapiro-Wilk test was used to analyze the normality of data distribution. To compare the differences in ages and cephalometric parameters between the groups, an independent samples *t*-test or one-way analysis of variance was used when the data showed a normal distribution. Mann-Whitney *U* test or Kruskal-Wallis *H*-test was used when the data did not show a normal distribution. A chi-squared test was used to analyze the differences in sex distribution and occlusal characteristics between the groups. The test level was $\alpha = 0.05$, and $P < 0.05$ was taken to indicate statistically significant differences.

3. Results

3.1. Demographic and Occlusal Characteristics. Altogether, 262 orthodontic patients were included in this study. The mean age was 21.20 ± 7.11 years, and the proportion of women was 65.3%. According to the FAI classification criteria, patients were divided into two groups: a no-TMD group (control group, 124 patients [47.3%]) and a TMD group (138 patients [52.7%]). The mean age of the TMD group was significantly higher than that of the no-TMD group ($P < 0.001$). However, no significant difference in gender distribution between the groups was observed ($P = 0.307$). The proportions of females were higher than those of males in both groups. The proportion of patients with Angle Class III in the TMD group was significantly higher than that in the no-TMD group ($P = 0.019$, Table 1).

3.2. FAI Scale Survey. Among the included patients, the most commonly reported TMD symptoms were neck pain (48.9%) and TMJ noises (37.8%), followed by headache (32.4%) and muscle pain (27.5%). The frequencies of all three TMD risk factors were high, with the prevalence of misaligned teeth (67.9%) the highest. The frequencies of various clinical manifestations were low in the no-TMD group, with only the presence of misaligned teeth (45.2%) exhibiting a frequency above 20%. However, a variety of widespread symptoms and risk factors were present in the TMD group. Misaligned teeth (88.4%) and neck pain (76.8%) were observed in most of the patients (Figure 2).

3.3. Relationship between TMDs and Craniofacial Morphology. Table 2 compares craniofacial morphological parameters between the no-TMD group and the TMD group. A significant difference in FMA between the groups was observed. The average FMA in the TMD group was larger than that in the control group ($P = 0.039$).

After stratifying the TMD patients according to severity, the demographic, occlusal, and craniofacial morphological characteristics were compared among patients without TMDs, with mild TMDs, and with moderate/severe TMDs

Table 1: Demographic and occlusal characteristics of patients with and without TMDs.

		Total	No TMD	TMD	*P*-value
Number	(*n* (%))	262 (100.0)	124 (47.3)	138 (52.7)	
Age	(years, mean ± SD)	21.20 ± 7.11	19.46 ± 7.44	22.76 ± 6.44	<0.001*
Age stratification	<18 years (*n* (%))	90 (34.4)	60 (48.4)	30 (21.7)	
	≥18 years (*n* (%))	172 (65.6)	64 (51.6)	108 (78.3)	
Gender	Male (*n* (%))	91 (34.7)	47 (37.9)	44 (31.9)	0.307
	Female (*n* (%))	171 (65.3)	77 (62.1)	94 (68.1)	
Angle's classification	Angle class I (*n* (%))	103 (39.3)	51 (41.2)	52 (37.7)	0.019*
	Angle class II (*n* (%))	97 (37.0)	53 (42.7)	44 (31.9)	
	Angle class III (*n* (%))	62 (23.7)	20 (16.1)	42 (30.4)	

Independent samples *t*-test and chi-squared test were used. $^*P < 0.05$. TMD: temporomandibular disorder, SD: standard deviation.

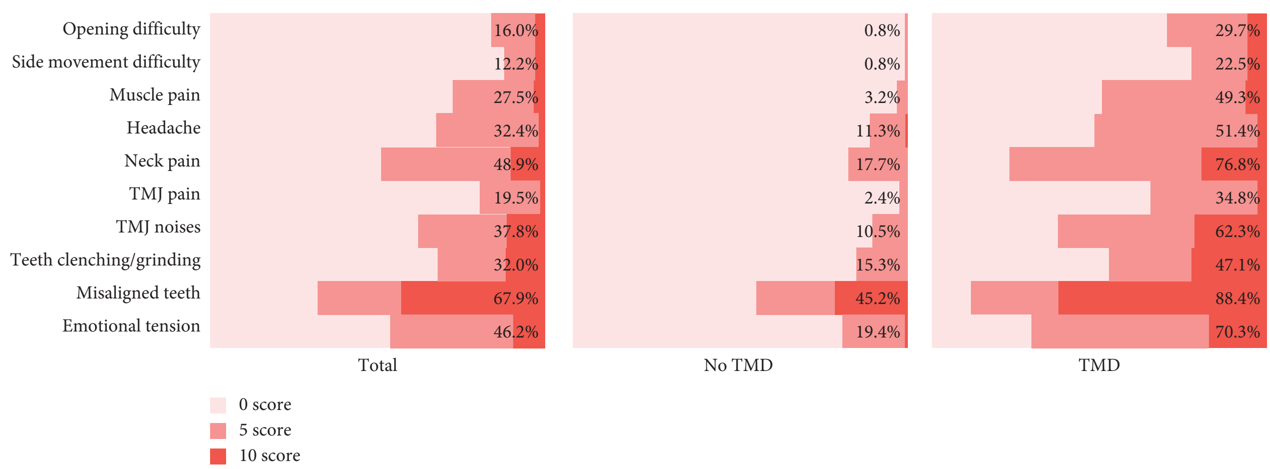

Figure 2: Results of the Fonseca anamnestic index (FAI) scale survey. Left panel, all included patients; center panel, patients with no TMDs; and right panel, patients with TMDs. Each bar shows the answer distribution of an item on the FAI survey. The percentage in each row represents the proportion of patients with a score of 5 or 10, indicating the prevalence rate of the TMD-related symptom or risk factor reflected by every question. TMJ: temporomandibular joint, TMD: temporomandibular disorder.

Table 2: Comparison of craniofacial morphological parameters between patients with and without TMDs.

	Total 262 (100.0%) Mean ± SD	No TMD 124 (47.3%) Mean ± SD	TMD 138 (52.7%) Mean ± SD	*P*-value
Saddle angle (°)	122.91 ± 5.10	123.26 ± 4.41	122.59 ± 5.64	0.378
Articular angle (°)	151.47 ± 6.83	151.04 ± 6.31	151.86 ± 7.26	0.330
Anterior cranial base length (mm)	64.18 ± 3.69	64.38 ± 3.87	63.99 ± 3.53	0.657
Posterior cranial base length (mm)	34.67 ± 3.50	34.71 ± 3.24	34.64 ± 3.73	0.873
SNA (°)	82.04 ± 3.27	81.73 ± 3.23	82.31 ± 3.30	0.156
SNB (°)	79.00 ± 4.24	79.02 ± 3.96	78.98 ± 4.49	0.953
ANB (°)	3.04 ± 3.54	2.72 ± 3.46	3.32 ± 3.59	0.176
FMA (°)	24.08 ± 6.77	23.17 ± 5.95	24.89 ± 7.35	0.039 *
Gonial angle (°)	118.20 ± 7.60	117.49 ± 6.57	118.83 ± 8.40	0.150
Ramus height (mm)	47.17 ± 5.96	47.20 ± 5.74	47.15 ± 6.17	0.934
Mandibular body length (mm)	70.73 ± 5.24	70.70 ± 5.22	70.76 ± 5.27	0.919
Interincisal angle (°)	124.73 ± 13.99	124.34 ± 13.28	125.08 ± 14.64	0.993
Cant of occlusal plane (°)	7.06 ± 4.78	6.65 ± 4.92	7.44 ± 4.63	0.180
Overjet (mm)	3.75 ± 3.46	3.97 ± 3.42	3.55 ± 3.50	0.227
Overbite (mm)	2.68 ± 2.20	2.83 ± 2.03	2.54 ± 2.34	0.244
Anterior facial height (mm)	116.90 ± 8.29	116.07 ± 7.84	117.65 ± 8.63	0.124
Posterior facial height (mm)	79.23 ± 7.80	79.24 ± 7.37	79.22 ± 8.20	0.982
Wits appraisal (mm)	−0.05 ± 5.15	−0.14 ± 4.63	0.03 ± 5.59	0.473

Independent samples *t*-test and Mann–Whitney *U*-test were used. $^*P < 0.05$. TMD: temporomandibular disorder, SD: standard deviation.

(Table 3). Patients with mild and moderate/severe TMDs were older on average than those without TMDs ($P < 0.001$). No differences were observed in gender or Angle's classification distribution among the three groups ($P > 0.05$). Significant differences were observed in FMA and anterior facial height among the three groups. FMA and anterior facial height were significantly larger in patients with more severe TMDs ($P < 0.05$).

After stratifying the patients by sex, no difference was observed in age between the no-TMD group and the TMD group among male patients (Table 4, $P = 0.120$). However, female patients in the TMD group were significantly older on average than those in the control group (Supplement Table 1, $P = 0.001$). No significant differences in occlusal characteristics were noted between the control and TMD groups of the same sex ($P > 0.05$). In male patients, the anterior cranial base length of the TMD group was shorter than that of the control group, while the anterior facial height of the TMD group was longer ($P < 0.05$). Nevertheless, in female patients, no significant differences were observed in craniofacial morphology between the TMD and control groups ($P > 0.05$).

After stratifying the patients by age (stratification boundary: 18 years), both in juvenile (aged under 18 years) and adult patients (aged 18 years or above), no statistical differences existed in gender or Angle's classification distribution between the groups (Table 5 and Supplement Table 2, $P > 0.05$). Among juveniles, TMD patients were older than those without TMDs ($P = 0.001$). Among adults, no significant difference was observed in age between the groups ($P = 0.917$). Among juvenile patients, the overjet and overbite were significantly smaller in TMD patients than in the control group ($P < 0.05$). Among adults, SNA, ANB, FMA, and gonial angle were significantly larger in TMD patients than in the control group ($P < 0.05$).

Within the TMD group, the proportion of males with TMJ pain was significantly higher than that of males without TMJ pain (Table 6, $P = 0.010$). No significant differences were observed in age or occlusal characteristics between patients with and without TMJ pain ($P > 0.05$). Within the TMD group, the posterior cranial base length and Wits appraisal value of patients with TMJ pain were larger than those of patients without TMJ pain ($P < 0.05$).

No significant differences were noticed in demographic or occlusal characteristics between TMD patients with and without TMJ noises (Table 7, $P > 0.05$). The gonial angle of patients with TMJ noises was significantly greater than that of patients without TMJ noises ($P = 0.047$).

4. Discussion

In the present study, we observed differences in craniofacial morphology between individuals with TMDs and controls without TMDs among a population of orthodontic patients. Especially in male patients, the anterior cranial base length in the TMD group was shorter on average than in the control group, while the anterior facial height of the TMD group was larger; in adult patients, the SNA, ANB, FMA, and gonial angle were larger in TMD patients than in controls. Therefore, the null hypothesis—that there would be no relationship between specific craniofacial morphology and TMDs in this population—was rejected.

The mean age of TMD patients was significantly higher than that of patients without TMDs, which was consistent with the results reported by Yap et al. [25]. This may be attributed to the high incidence of TMD symptoms in populations of middle age [26] or the pathological changes in the TMJ and masticatory muscles, which are easily affected by internal and external environmental factors after the period of growth. However, since only orthodontic patients were included in the present study, all patients (with and without TMDs) were younger than the population studied by Yap et al. [25]. No difference was observed in gender distribution between the TMD group and the control group in the present study. The proportions of women in the study-enrolled group overall, the control group, and the TMD group were similar and higher than those of men, in agreement with the findings reported by Almasan et al. [27]. Biological factors such as genes, hormones, pain perception, psychosocial factors, environmental factors, and others may be associated with the higher prevalence of TMDs in women [4]. The high level of estrogen in women's bodies may be one reason for the higher incidence of TMDs. However, there is no consensus about the relationship between estrogen level and prevalence of TMDs [28]. It is suggested to further explore the specific role of estrogen in the occurrence and development of TMDs. Additionally, the percentage of patients categorized as Angle Class III in the TMD group was significantly higher than in the control group. However, no statistical differences in Angle's classification distribution were noted in subgroup analyses. These results may indicate that the relationship between occlusal factors and the occurrence of TMDs is weak. This implies that other factors such as social, psychological, and environmental influences should be emphasized in the etiology of TMDs [29].

Before stratification, the FMA of TMD patients was significantly larger than that of patients without TMDs. Subgroup analysis based on the severity of TMDs showed that patients with more severe TMDs had greater FMA. Thus, the facial shape of TMD patients tended towards a hyperdivergent growth pattern. Similar trends have been reported by Hwang et al. in their work [15]. After stratification, the anterior facial height of patients with moderate/severe TMDs was significantly greater than that of patients with no or mild TMDs. No such difference was observed before stratification. Similar results were obtained in the experiment by Ramirez-Caro and Espinosa de Santillana [20], who reported that adolescent patients with TMDs exhibited a greater lower facial height. In contrast, Joy et al. [30] found that patients with more severe TMDs exhibited decreased anterior and posterior facial heights. This contradiction between Joy et al. and our results could be attributed to the fact that the former study included patients with a reduced vertical dimension of occlusion (VDO). VDO can be measured using the Shimbashi number—the distance between the cementoenamel junctions of the upper and lower incisors [30]. Decreased VDO may be one of the risk factors for TMDs. It also affects the shape of the face directly,

Table 3: Comparison of demographic, occlusal, and craniofacial morphological characteristics among patients with no, mild, and moderate/severe TMDs.

		No TMD 124 (47.3%)	Mild TMD 100 (38.2%)	Moderate/severe TMD 38 (14.5%)	P value
Age (years, mean ± SD)		19.46 ± 7.44[a]	22.57 ± 6.73[b]	23.24 ± 5.66[b]	<0.001*
Gender	Male (n (%))	47 (37.9)	30 (30.0)	14 (36.8)	0.447
	Female (n (%))	77 (62.1)	70 (70.0)	24 (63.2)	
Angle's classification	Angle class I (n (%))	51 (41.2)	39 (39.0)	13 (34.2)	0.078
	Angle class II (n (%))	53 (42.7)	32 (32.0)	12 (31.6)	
	Angle class III (n (%))	20 (16.1)	29 (29.0)	13 (34.2)	
Craniofacial morphological parameters (mean ± SD)					
Saddle angle (°)		123.26 ± 4.41	123.05 ± 5.09	121.38 ± 6.82	0.566
Articular angle (°)		151.04 ± 6.31	151.53 ± 7.62	152.74 ± 6.20	0.406
Anterior cranial base length (mm)		64.38 ± 3.87	64.06 ± 3.50	63.80 ± 3.64	0.894
Posterior cranial base length (mm)		34.71 ± 3.24	34.45 ± 3.61	35.13 ± 4.05	0.594
SNA (°)		81.73 ± 3.23	82.12 ± 3.22	82.82 ± 3.50	0.207
SNB (°)		79.02 ± 3.96	78.88 ± 4.20	79.27 ± 5.21	0.886
ANB (°)		2.72 ± 3.46	3.24 ± 3.32	3.55 ± 4.26	0.334
FMA (°)		23.17 ± 5.95[a]	24.29 ± 7.28[ab]	26.47 ± 7.39[b]	0.028*
Gonial angle (°)		117.49 ± 6.57	118.15 ± 8.37	120.63 ± 8.32	0.083
Ramus height (mm)		47.20 ± 5.74	47.10 ± 6.16	47.28 ± 6.28	0.662
Mandibular Body length (mm)		70.70 ± 5.22	70.77 ± 5.11	70.75 ± 5.73	0.995
Interincisal angle (°)		124.3 4± 13.28	126.63 ± 14.56	121.00 ± 14.24	0.140
Cant of occlusal plane (°)		6.65 ± 4.92	7.62 ± 4.69	6.97 ± 4.49	0.315
Overjet (mm)		3.97 ± 3.42	3.36 ± 3.44	4.04 ± 3.65	0.346
Overbite (mm)		2.83 ± 2.03	2.73 ± 2.32	2.05 ± 2.35	0.200
Anterior facial height (mm)		116.07 ± 7.84[a]	116.72 ± 8.38[a]	120.10 ± 8.92[b]	0.031*
Posterior facial height (mm)		79.24 ± 7.37	78.92 ± 8.12	80.01 ± 8.48	0.434
Wits appraisal (mm)		−0.14 ± 4.63	−0.09 ± 5.21	0.35 ± 6.56	0.661

One-way analysis of variance, Kruskal–Wallis H-test, and chi-squared test were used. [a, b]The same letters indicate no statistically significant difference, while different letters indicate a statistically significant difference between the groups. $^*P < 0.05$ TMD: temporomandibular disorder, SD: standard deviation.

Table 4: Comparison of demographic, occlusal, and craniofacial morphological characteristics between male patients with and without TMDs.

		Males with no TMD 47 (51.6%)	Males with TMD 44 (48.4%)	P value
Age (years, mean ± SD)		19.06 ± 6.37	21.13 ± 6.20	0.120
Angle's classification	Angle class I (n (%))	20 (42.6)	16 (36.4)	0.165
	Angle class II (n (%))	19 (40.4)	13 (29.5)	
	Angle class III (n (%))	8 (17.0)	15 (34.1)	
Craniofacial morphological parameters (mean ± SD)				
Saddle angle (°)		123.54 ± 3.74	122.58 ± 6.28	0.924
Articular angle (°)		149.26 ± 5.85	151.51 ± 7.46	0.111
Anterior cranial base length (mm)		67.17 ± 3.79	65.50 ± 3.70	0.035*
Posterior cranial base length (mm)		36.57 ± 2.82	37.52 ± 3.29	0.069
SNA (°)		81.85 ± 2.71	82.63 ± 3.27	0.116
SNB (°)		79.67 ± 3.91	79.64 ± 4.76	0.973
ANB (°)		2.18 ± 3.43	3.00 ± 4.27	0.189
FMA (°)		21.09 ± 6.23	23.65 ± 7.59	0.204
Gonial angle (°)		116.57 ± 6.80	117.31 ± 9.16	0.662
Ramus height (mm)		51.20 ± 5.66	51.43 ± 5.58	0.848
Mandibular body length (mm)		73.17 ± 5.69	73.29 ± 5.59	0.915
Interincisal angle (°)		122.73 ± 14.24	123.78 ± 14.07	0.724
Cant of occlusal plane (°)		5.54 ± 5.28	7.59 ± 4.73	0.056
Overjet (mm)		3.77 ± 4.04	3.31 ± 4.52	0.413
Overbite (mm)		3.00 ± 1.99	2.49 ± 2.47	0.275
Anterior facial height (mm)		120.00 ± 7.11	123.49 ± 8.69	0.038*
Posterior facial height (mm)		84.60 ± 6.75	86.09 ± 7.06	0.335
Wits appraisal (mm)		−0.21 ± 4.67	−0.44 ± 7.03	0.715

Independent samples t-test and Mann-Whitney U-test were used. $^*P < 0.05$. TMD: temporomandibular disorder, SD: standard deviation.

Table 5: Comparison of demographic, occlusal, and craniofacial morphological characteristics between adult patients (aged 18 years or above) with and without TMDs.

		Adults with no TMD 64 (37.2%)	Adults with TMD 108 (62.8%)	P value
Age (years, mean ± SD)		24.74 ± 6.81	24.84 ± 5.66	0.917
Gender	Male (n (%))	26 (40.6)	31 (28.7)	0.108
	Female (n (%))	38 (59.4)	77 (71.3)	
Angle's classification	Angle class I (n (%))	28 (43.7)	41 (38.0)	0.189
	Angle class II (n (%))	25 (39.1)	35 (32.4)	
	Angle class III (n (%))	11 (17.2)	32 (29.6)	
Craniofacial morphological parameters (mean ± SD)				
Saddle angle (°)		123.74 ± 4.52	122.51 ± 5.82	0.178
Articular angle (°)		150.98 ± 6.54	152.27 ± 7.10	0.237
Anterior cranial base length (mm)		65.20 ± 3.77	64.34 ± 3.54	0.278
Posterior cranial base length (mm)		34.98 ± 3.54	34.71 ± 3.78	0.645
SNA (°)		81.24 ± 3.23	82.28 ± 3.35	0.048*
SNB (°)		79.23 ± 3.98	78.95 ± 4.59	0.689
ANB (°)		2.02 ± 3.57	3.33 ± 3.77	0.023*
FMA (°)		21.95 ± 6.43	24.68 ± 7.33	0.015*
Gonial angle (°)		116.00 ± 6.14	118.24 ± 8.09	0.042*
Ramus height (mm)		49.24 ± 5.83	47.67 ± 6.29	0.107
Mandibular Body length (mm)		72.09 ± 5.00	71.13 ± 5.13	0.233
Interincisal angle (°)		124.72 ± 12.44	125.76 ± 15.31	0.646
Cant of occlusal plane (°)		5.91 ± 5.39	7.24 ± 4.68	0.093
Overjet (mm)		3.09 ± 3.03	3.52 ± 3.59	0.218
Overbite (mm)		2.47 ± 2.17	2.60 ± 2.42	0.730
Anterior facial height (mm)		117.60 ± 7.51	118.21 ± 8.52	0.635
Posterior facial height (mm)		81.48 ± 7.66	79.88 ± 8.19	0.207
Wits appraisal (mm)		−0.60 ± 4.30	0.22 ± 5.76	0.173

Independent samples t-test, Mann-Whitney U-test, and chi-squared test were used. * $P < 0.05$. TMD: temporomandibular disorder, SD: standard deviation.

Table 6: Comparison of demographic, occlusal, and craniofacial morphological characteristics between TMD patients with and without TMJ pain.

		TMD without TMJ pain 90 (65.2%)	TMD with TMJ pain 48 (34.8%)	P value
Age (years, mean ± SD)		23.29 ± 6.80	21.76 ± 5.66	0.187
Gender	Male (n (%))	22 (24.4)	22 (45.8)	0.010*
	Female (n (%))	68 (75.6)	26 (54.2)	
Angle's classification	Angle class I (n (%))	37 (41.1)	15 (31.2)	0.193
	Angle class II (n (%))	24 (26.7)	20 (41.7)	
	Angle class III (n (%))	29 (32.2)	13 (27.1)	
Craniofacial morphological parameters (mean ± SD)				
Saddle angle (°)		122.46 ± 5.05	122.83 ± 6.67	0.324
Articular angle (°)		152.12 ± 7.52	151.37 ± 6.79	0.566
Anterior cranial base length (mm)		63.86 ± 3.55	64.23 ± 3.50	0.278
Posterior cranial base length (mm)		34.00 ± 3.68	35.84 ± 3.56	0.005*
SNA (°)		82.29 ± 3.26	82.35 ± 3.42	0.914
SNB (°)		79.20 ± 4.41	78.58 ± 4.64	0.441
ANB (°)		3.09 ± 3.87	3.77 ± 2.97	0.291
FMA (°)		24.81 ± 7.89	25.04 ± 6.30	0.852
Gonial angle (°)		118.77 ± 8.90	118.94 ± 7.44	0.909
Ramus height (mm)		47.13 ± 6.20	47.18 ± 6.19	0.969
Mandibular Body length (mm)		70.89 ± 5.32	70.53 ± 5.21	0.705
Interincisal angle (°)		126.25 ± 14.10	122.89 ± 15.51	0.160
Cant of occlusal plane (°)		7.77 ± 4.79	6.83 ± 4.31	0.259
Overjet (mm)		3.16 ± 3.69	4.27 ± 3.02	0.498
Overbite (mm)		2.42 ± 2.19	2.76 ± 2.60	0.417
Anterior facial height (mm)		117.12 ± 8.74	118.65 ± 8.43	0.323
Posterior facial height (mm)		78.62 ± 8.19	80.34 ± 8.19	0.244
Wits appraisal (mm)		−0.70 ± 5.72	1.41 ± 5.12	0.027*

Independent samples t-test, Mann–Whitney U-test, and chi-squared test were used. * $P < 0.05$. TMD: temporomandibular disorder, TMJ: temporomandibular joint, SD: standard deviation.

Table 7: Comparison of demographic, occlusal, and craniofacial morphological characteristics between TMD patients with and without TMJ noises.

		TMD without TMJ noises 52 (37.7%)	TMD with TMJ noises 86 (62.3%)	P-value
Age (years, mean ± SD)		23.37 ± 7.20	22.38 ± 5.95	0.385
Gender	Male (*n* (%))	18 (34.6)	26 (30.2)	0.592
	Female (*n* (%))	34 (65.4)	60 (69.8)	
Angle's classification	Angle class I (*n* (%))	25 (48.1)	27 (31.4)	0.128
	Angle class II (*n* (%))	15 (28.8)	29 (33.7)	
	Angle class III (*n* (%))	12 (23.1)	30 (34.9)	
Craniofacial morphological parameters (mean ± SD)				
Saddle angle (°)		123.21 ± 5.24	122.22 ± 5.86	0.322
Articular angle (°)		151.41 ± 7.10	152.14 ± 7.38	0.572
Anterior cranial base length (mm)		64.28 ± 3.34	63.82 ± 3.64	0.660
Posterior cranial base length (mm)		34.72 ± 3.33	34.59 ± 3.97	0.839
SNA (°)		82.50 ± 3.21	82.19 ± 3.37	0.598
SNB (°)		78.95 ± 3.58	79.01 ± 4.98	0.941
ANB (°)		3.55 ± 2.88	3.19 ± 3.96	0.874
FMA (°)		23.48 ± 7.08	25.75 ± 7.42	0.080
Gonial angle (°)		117.01 ± 8.34	119.93 ± 8.28	0.047*
Ramus height (mm)		47.68 ± 5.55	46.83 ± 6.53	0.438
Mandibular body length (mm)		70.98 ± 5.00	70.63 ± 5.45	0.623
Interincisal angle (°)		126.89 ± 14.52	123.99 ± 14.69	0.160
Cant of occlusal plane (°)		7.42 ± 4.69	7.45 ± 4.62	0.966
Overjet (mm)		3.40 ± 2.91	3.64 ± 3.82	0.363
Overbite (mm)		2.91 ± 2.30	2.32 ± 2.34	0.316
Anterior facial height (mm)		116.44 ± 8.84	118.38 ± 8.47	0.201
Posterior facial height (mm)		79.75 ± 7.76	78.90 ± 8.49	0.738
Wits appraisal (mm)		0.51 ± 4.33	−0.26 ± 6.24	0.816

Independent samples t-test, Mann-Whitney U-test, and chi-squared test were used. $^*P < 0.05$. TMD: temporomandibular disorder, TMJ: temporomandibular joint, SD: standard deviation.

especially that of the lower face, which might explain the results in the study mentioned above. Therefore, we postulate that the orthodontic patients with TMDs exhibit trends towards a hyperdivergent growth and characteristically long faces.

Subgroup analysis based on gender showed that among male patients, the anterior facial height of the TMD group was larger, which was similar to the results before stratification. The anterior cranial base length of the TMD group was shorter than that of the control group. Nevertheless, no significant differences were observed in any of the cephalometric parameters between the TMD and control groups in female patients. Kwon et al. [31] found that in both men and women, patients with TMJ disc displacement showed different dentofacial morphology compared with the normal population. In a study by Chen et al. [32] involving female patients with skeletal Class II deformity, the craniofacial morphology of osteoarthrosis patients was different from that of the control group. In contrast to these earlier findings, our results did not note any special craniofacial features of female patients with TMDs. This might be partially attributed to the insufficient sample size. In the present study, although no significant differences in any parameters between TMD and control groups were observed among female patients, the P-values obtained from statistical analyses of the anterior facial height, anterior cranial base length, and other parameters were still close to the test level. Significant differences might be observed in these parameters if the sample size were expanded. Moreover, images were analyzed to diagnose TMDs in these previous studies, while a symptom-based scale was utilized in our study. This suggests that objective imaging data can accurately diagnose TMDs and may be more conducive to finding the specific characteristics of craniofacial morphology in female patients with TMDs.

Subgroup analysis based on age revealed statistically significant differences in overjet and overbite between the TMD and control groups among juvenile patients. Venere et al. [18] found that the proportion of deep bites in patients with craniomandibular disorders was higher than in their control group, but the difference was not statistically significant. Pereira et al. [19] found that larger overjet was associated with higher Dysfunction Index scores in patients with TMDs. Sonnesen et al. [33] found that larger overjet and smaller overbite were associated with a high prevalence of TMD-related symptoms. However, these studies could not confirm significant differences in craniofacial morphology between adolescents and children with TMDs and those without. In contrast, significant differences were observed in SNA, ANB, FMA, and gonial angle between the groups in adult patients. In the current study, adult patients with TMDs exhibited more protruding maxilla, steeper mandible, and larger gonial angle, which reinforced the conclusions of previous studies [15, 34]. The relationships between TMDs and craniofacial morphology were inconsistent among different age groups. This may be explained by the fact that children and adolescents are still in the growth phase, with their bone structures still affected by age and nutrition. Thus, the craniofacial morphology of these TMD patients may not exhibit unique characteristics. In comparison to youngsters, the craniofacial bones in adults, who have passed the peak of growth, tend to be more stable. The occurrence and development of TMDs may be associated with significant remodeling of bones, which may result in more apparent differences in craniofacial morphological parameters between the TMD and control groups.

In the TMD group, both the posterior cranial base length and Wits appraisal value of patients with TMJ pain were greater than controls, suggesting that patients with a longer posterior cranial base and Angle Class II malocclusion may have overloaded TMJs and be more prone to pain. The gonial angle of patients with TMJ noises was larger than those without, which may indicate its relationship with pathophysiological changes in the TMJ, resulting in TMJ complaints. Colonna et al. [34] found that patients with TMJ pain had a larger gonial angle. Dibbets and van der Weele [35] also found that orthodontic patients with TMJ clicking or crepitations had smaller maxilla, mandible, and cranial base lengths. These findings suggest that patients with local TMJ symptoms exhibit characteristic craniofacial morphology, which is in line with our results. The occurrence of some potential TMJ symptoms may be predicted using these unique parameters, but more studies are required to determine the specific craniofacial morphological characteristics among these patients.

Several previous studies were carried out with limited sample sizes and mainly focused on female or adult patients. The sample size in the present study was relatively larger, and subgroup analyses based on sex, age, and TMJ symptoms were conducted. The characteristic craniofacial features of TMD patients were mainly discovered in men and adults, while in women, no differences were observed in cephalometric parameters between control and TMD groups. In addition, some craniofacial morphological features were observed in patients with TMJ pain or noises within the TMD group. These findings suggest that craniofacial morphology could be used as a screening and diagnostic tool for TMDs and indicate a new direction for applying lateral cephalograms in the future [15]. However, because several factors such as social background, periodontal, and mucosal status were not controlled in this study, further research is required to explore the specific craniofacial morphology of TMD patients and verify this conjecture.

The present study has some limitations. Initially, the duration of TMD symptoms was not considered. TMD patients who have long experienced symptoms might have undergone evident bone remodeling and thus may exhibit unique craniofacial morphology. Failure to stratify TMD patients according to the duration of the illness might miss some parameters with significant differences. Furthermore, due to the large sample population this study recruited, the FAI scale was utilized to diagnose TMDs due to its simplicity and convenience. However, because of its low specificity [13], some false-positive TMD patients might have been included. Therefore, in future studies, both FAI and DC/TMD could be used together to screen and diagnose TMDs. Moreover, the cone beam computed tomography and magnetic resonance imaging of the TMJ, which are helpful for the diagnosis of TMD subtypes such as TMJ degenerative joint diseases and disc displacement, should be evaluated. In addition, the present study included only orthodontic patients, some of whom were so young that they may have not developed TMDs yet, but could in the future. This may lead to a different prevalence rate of TMDs in this study compared to others, making it difficult to detect special craniofacial morphology of TMD patients. Thus, further studies involving other populations, such as patients from the Department of TMJ, are needed.

5. Conclusions

We observed a significant difference in FMA between individuals with and without TMDs among the studied population of orthodontic patients. In male patients and adult patients, significant differences in craniofacial morphology between the control and TMD groups were present in more parameters, including anterior facial height, anterior cranial base length, ANB, and gonial angle. In female patients and juvenile patients, the differences in craniofacial morphology between the groups were not significant. Orthodontic patients with TMDs have a particular type of craniofacial morphology, especially in male and adult patients. A specific relationship between TMDs and craniofacial features exists. In patients with TMDs, differences in posterior cranial base length, Wits appraisal, and gonial angle were observed between patients with and without TMJ pain or noises, suggesting possible relationships between TMJ symptoms and craniofacial morphology in TMD patients.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

The authors thank TopEdit (http://www.topeditsci.com) for its linguistic assistance during the preparation of this manuscript. This work was supported by the Innovative Entrepreneurship Training Program for College Students in Sichuan University (grant numbers: 202110611384).

Supplementary Materials

Supplementary 1. Supplement Table 1: Comparison of demographic, occlusal, and craniofacial morphological characteristics between female patients with and without TMDs. *Supplementary 2*. Supplement Table 2: Comparison of demographic, occlusal, and craniofacial morphological characteristics between juvenile patients (aged under 18 years) with and without TMDs. (*Supplementary Materials*)

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Hindawi
Pain Research and Management
Volume 2022, Article ID 1429932, 14 pages
https://doi.org/10.1155/2022/1429932

Research Article

Cause-Effect Relationships between Painful TMD and Postural and Functional Changes in the Musculoskeletal System: A Preliminary Report

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Received 18 November 2021; Revised 4 January 2022; Accepted 28 January 2022; Published 28 February 2022

Academic Editor: Tomasz Kaczmarzyk

Introduction. Temporomandibular disease (TMD) is a general term including a group of conditions that cause pain and dysfunction in the masticatory muscles, the temporomandibular joint (TMJ), and their related structures. The painful forms of these dysfunctions have become an increasing phenomenon among dental patients. A number of scientific publications indicated the relationship between the presence of postural dysfunctions and functional disorders of the masticatory system in humans. Nevertheless, dental procedures still very rarely include comprehensive diagnostics and procedures aimed at the normalization of the locomotor system related to TMD. Scientific literature usually refers to and describes the coexistence of postural disorders in patients with TMD in the context of anatomical connections, the so-called biokinematic chains, indicating specific types of postures that correlate with different positions of the mandible and/or teeth. *Objective.* The aim of the study was to investigate the effect of painless positioning of the mandibular head in the articular fossa on postural and functional changes in the musculoskeletal system. *Materials and Methods.* The study was conducted on a group of 30 randomly selected patients who reported to the Department of Propaedeutic, Physical Diagnostics and Dental Physiotherapy of the Pomeranian Medical University in Szczecin (Poland). Before the examination, the dentists and the physiotherapist were calibrated by an examiner who had previously been calibrated and had three years of experience in the management of patients with TMD. Training of the appropriate palpation strength was performed, and then the results were discussed. In the study group, painful disorders in the temporomandibular joint with an abnormal position of the mandibular head in the articular fossa and individual posture defects were found. The patients complained of pain in the area of the TMJ, episodes of locked joints, and difficulty biting. None of them was treated for these disorders, previously rehabilitated or participated in any body posture examination. The patients were examined by an interdisciplinary team who also performed a preliminary test. The inclusion criterion for the study group was the presence of TMD symptoms in the past. Myofascial pain was diagnosed on the basis of diagnostic criteria for temporomandibular disorders (RDC/TMD Ia and Ib). On the other hand, the displacement of the articular disc was diagnosed on the basis of the diagnostic criteria of temporomandibular disorders (RDC/TMD IIa)—displacement of the articular disc without reduction. At the same time, the body posture was assessed by inspection and using computer techniques while standing and during motion. The examinations were repeated after positioning the mandibular heads in the articular fossa and stabilizing the condylar process using a temporary silicone occlusal splint. Since there is no DC/TMD protocol in Polish to date, RDC/TMD was used in the study. *Results.* Initial pilot studies and the authors' observations indicated that the positioning of the mandibular heads in the articular pits and stabilization of the condylar process by providing the oral cavity with a temporary, silicone occlusive splint significantly influenced the posture of the examined patients, both while standing and during locomotion. This correlation also applies to the corrective effect on the foot architecture during standing and patient gait. *Conclusions.* Diagnostic and therapeutic management in the course of TMD should be holistic. Nevertheless, the observed changes are often varied and largely dependent on individual posture defects, which is an important postulate for further research on a larger study group.

1. Introduction

TMDs such as occlusion disorders, displacement of the articular disc, increased tension of the masticatory muscles, bruxism, and acoustic phenomena in the temporomandibular joint affect an increasing number of patients [1]. Often, these problems coexist with other musculoskeletal disorders such as protraction head, abnormal position of the pelvis, and the angle of lumbar lordosis, within the knee joints or the architecture of the feet [2, 3]. Patients with any type of TMD may have several symptoms otological symptoms such as tinnitus, ear fullness, ear pain, hearing loss, hyperacusis, and vertigo, which may be due to the anatomical proximity between the temporomandibular joint, muscles innervated by the trigeminal nerve, and ear structures [4]. The relationship between dental occlusion and ophthalmology attracts less attention, and yet, it is also important [5, 6].

TMJ connecting the mandible with the temporal bone, with articular surfaces between which the articular disc is located, is one of the most important parts of the masticatory and speech organs. This joint is made of hard and soft tissues and is considered to be one of the most complicated joints in the human body. Its proper operation is responsible for the basic, physiological activities such as speaking, swallowing, and eating [7–9]. The dysfunctions within it are manifested through crackling, pain, headache, and mobility disorders [10–15]. Under normal conditions, without disturbances in the TMJ mandibular, the patient does not feel pain, discomfort, acoustic phenomena, locks, and problems in the mobility of the mandible. Pain is a problem with mandibular abduction, temporary or permanent locks, and acoustic phenomena such as crackles or clicks. In the case of disorders of muscle origin, the intra-articular situation is correct, but there is a difference in speed and the range of individual movements of the mandible, which are most often accelerated, i.e., acceleration compared to healthy patients [16–20]. Similar conclusions were formulated by Yokoyama et al., additionally pointing out that an increase of speed caused acoustic phenomena having a tendency to be heard in a closed position of the condylar process [21]. The purpose of the preliminary test is to check for the existence of a musculofascial, according to the concept of Anatomy Trains, and examine whether the temporomandibular disorder can linearly affect distant tissues [22]. According to the tensegration theory, the damaging stimulus caused by excessive voltage, it is transmitted linearly in the human body [23–26]. For this reason, ailment pain and mobility limitations may appear in a place distant from the primary stimulus. According to the concept of Anatomy Trains, there is a network of visual connections in the human body [27]. TMJ through the myofascial and ligamentous connections with the cervical segment forms a functional relationship. Therefore, patients with disorders in the TMJ are people who automatically position their heads in protection, which results in deepening cervical lordosis and the presence of pelvic dysfunction [28–34]. Clinical studies have shown a direct link between the abnormal setting of the shoulder and pelvic girdles to the incorrect position of the mandible [35]. Relationships between disorders in the temporomandibular joint and existing dysfunctions in the cervical spine have been confirmed by clinical tests [36–39]. The presented pattern of a posture of a human body with disturbances present in the TMJ through anatomical tapes could linearly influence other human body segments, e.g., through the trapezius and levator scapula deepen the lumbar lordosis, which, by way of compensation, is involved in increased hip flexion and pelvic anterior tilt, which directly affects the curvature of the spine. Studies have been carried out describing the impact of disorders within the pelvis on the TMJ and the relationships in the reverse order [40–43]. A properly constructed and functional pelvis with undisturbed sacroiliac joints is found to be a key region in static balance [44]. Disorders of the pelvis, its components and sacroiliac joints, cause a static imbalance manifested as disorders of other remote parts of the body, including the TMD [44]. The sacroiliac joint is a gliding joint, formed by the iliac and sacrum bone, strengthened by the interosseous sacroiliac ligaments, abdominal sacroiliac ligaments, and dorsal sacroiliac ligaments. Iliolumbar, sacrospinous, and sacrotuberous ligaments indirectly strengthen the sacroiliac joint. The range of motion in the sacroiliac joint is minimal. Therefore, any disorder of this joint and its connections with the structures mentioned above leads to dysfunction [45]. Additionally, the feet and toes play a key role in static balance and proper gait.

These relevant reports indicate the need to combine dental diagnostic procedures of TMD with a posture examination. In particular, taking into account the anatomical and, above all, biomechanical complexity of the locomotor system. Given the above, it is an important task of interdisciplinary teams dealing with dental therapy to conduct a detailed dental diagnostic in almost every procedure combined with a posture examination (while standing and in motion-free walking).

2. Objectives

The aim of the study was to investigate the effect of painless positioning of the mandibular head in the articular fossa on postural and functional changes in the musculoskeletal system.

2.1. Materials and Methods. The study was conducted on a group of 30 randomly selected patients who reported to the Department of Propaedeutic, Physical Diagnostics and Dental Physiotherapy of the Pomeranian Medical University in Szczecin (Poland). Before the examination, the dentists and the physiotherapist were calibrated by an examiner who had previously been calibrated and had three years of experience in the management of patients with TMD. Training of the appropriate palpation strength was performed, and then the results were discussed. The RDC/TMD protocol was modified with acoustic phenomena because the vast majority of patients reporting to the clinic report the presence of sounds during the abduction and adduction movements of the mandible. The inclusion criterion for the study group was the presence of TMD symptoms in the past. The study population suffered from TMD with improper positioning of the mandibular head and individual postural defects. The subjects had no prior diagnosis of TMD. The study population did not experience systematic diseases, including craniofacial, spine, and pelvic injuries, nor neurological and psychiatric disorders. The patients complained of TMJ soreness, episodes of locked joints, and difficulty biting. None of them was treated for these disorders, previously rehabilitated or participated in any body posture examination. Individuals undergoing a regular drug therapy and those with mental illness, coagulopathy, diabetes, and chronic infections were excluded from the study. The subjects were not addicted to nicotine, alcohol, or illegal substances.

The research protocol was approved by the Bioethics Committee of the Pomeranian Medical University in Szczecin (Poland) (KB-0012/126/17). The study complied with the ethical standards. All participants signed a written informed consent form and were instructed on the technique and course of the research. The patients were examined by an interdisciplinary group who also performed a preliminary test. The subjects completed a personal questionnaire. A full general and dental medical history was collected, with particular emphasis on TMD.

2.2. Dental Examination Methodology. The dental analysis was conducted on the basis of the modified Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD Ia, Ib, and IIa). The analysis also included acoustic phenomena within the joint and heard during jaw movements. The phenomena were evaluated using the following criteria: 0-no sound, 1-click, 2-cracking, pain during movements (0-no pain; 1-the presence of pain), and pain on palpation of the posterior and lateral regions of the TMJ (0-no pain; 1-the presence of pain). Palpation of the lateral and posterior parts of the joints was conducted in order to diagnose painful areas. Acoustic phenomena were examined using a stethoscope, with the chest piece applied to the lateral and posterior surfaces of the TMJ.

The examination of TMD was performed in a supine position, as it provides the most accurate sightline into the oral cavity and the best ergonomics of the examination. The examination started with correct positioning of the head on the headrest, the Camper line was perpendicular to the ground, the orbital plane was parallel to the ground, and the head was set at the height of the knees. Maintaining the supine position allowed the examination to be repeated in the same patient, as well as on the entire group of subjects.

Direct inspection of the facial features allowed for a visual assessment of the facial symmetry, and for checking the absence or presence of lesions or swelling. The correct sequence of the actions was important for the repetition and reliability of the results. The examinations started at the shoulder girdle muscle, then the examiners moved toward the temporal muscles. Muscle palpation was performed in order to detect trigger points and to assess tension in the temporal muscles, medial pterygoid, lateral pterygoid, masseter, suprahyoid, deltoid, sternocleidomastoid, and rhomboid muscles.

An intraoral examination was also performed in order to determine the condition of the teeth (DMF) and the presence of occlusion defects and to examine the periodontal tissues (CPITN) (Figures 1(a)–1(c)).

After the dental examination, the patient was referred to a physiotherapist who performed the postural examination.

2.3. Methodology of the Physiotherapeutic Examination. Each patient underwent the following subjective and objective physiotherapeutic examinations: visual assessment of the posture, positioning asymmetry in the patient's body, and comparisons of individual body sequences in three planes: frontal, sagittal, and transverse performed using a podoscope, goniometer, and ruler (Figures 2(a) and 2(b)). Next, functional tests of the sacroiliac joints were carried out (asymmetry of the lower limbs length and excessive joint mobility were excluded in each patient-spring test II). The iliac spine test and the standing flexion test were carried out. A pedobarographic examination was also performed along with the assessment of standing and gait, as well as pelvic function testing using the Wiva Science sensor, equipped with a sensomotor magnetometer system and a gyroscope. The results of the pelvic range of motion were obtained during walking in 3 planes: forward/backward inclination, lowering and lifting the iliac alae, and rotation.

The subjects had a negative history of spine and temporomandibular joint injuries; they also had not undergone any surgery and did not have scoliosis or other postural defects diagnosed in childhood.

The following structures and body segments were assessed:

(i) Head position and head-to-shoulder ratio
(ii) Position of the lower jaw and its relation to the scalp
(iii) Position and protrusion of the arms, their relationship to each other, and the lumbar spine
(iv) Position of the shoulder blades, their relationship to each other, and the spine
(v) The ratio of the cervical segment to the thoracic and lumbar segment
(vi) The ratio of the thoracic segment to the lumbar segment
(vii) Waist indentation line
(viii) Navel position
(ix) Posterior superior and inferior iliac spine and their relationship
(x) The pelvis and its position relative to the upper and lower segment of the body
(xi) Iliac alae and their relationship

(a) (b) (c)

Figure 1: (a–c) An intraoral examination in order to determine the condition of the teeth and the presence of occlusion defects and to examine the periodontal tissues. (a) The assessment of the patient's occlusion-overbite. (b) The bite assessment according to Angle's classification and canine classification-left side. (c) The bite assessment according to Angle's classification and canine classification-right side.

(xii) Symmetry of the buttock line
(xiii) Popliteal pits line
(xiv) Position of the patella and the knee to medial ankle ratio
(xv) Feet: tarsus, metatarsus, toes, and vault (Figure 3)

During the podoscopic examination, the following anthropometric measurements were taken: arch of the foot, the position of the tarsus, fingers, knees, etc. During the examination, functional tests of the sacroiliac joints were performed along with the evaluation of the length of the lower limbs (joint mobility-spring test II). A differentiation test, also known as the iliac spine test, was carried out in order to assess the function of the sacroiliac joints. Postural and functional diagnostics were conducted using computer methods. A pedobarographic test (EPS R1 pedobarograph, BIOMECH Studio v2 software) was conducted to evaluate the arch of the foot and the distribution of pressure on the feet. The examination was performed during standing and walking (motion), which allowed for the assessment of the relationship between the feet based on the deviation angle COP (Figures 4(a) and 4(b)) and the AI (Arch Index; Figures 5(a), 5(b), 6(a), and 6(b)).

The described physiotherapeutic examination was performed before and after changing the position of the mandibular head in the articular fossa, which was stabilized by the correction of the stomatognathic system using a temporary silicone occlusal splint (Figures 7(a) and 7(b)).

The functional assessment of the pelvic complex was performed using computer techniques of postural diagnostics and functional evaluation (Wiva Science biokinetic sensor, BIOMECH Studio software) (Figures 8(a) and 8(b)). The angle of lordosis, measured while standing, and the range of motion were determined in three planes during walking:

(i) Frontal plane: the range of motion assessed by lifting/lowering the iliac alae
(ii) Sagittal plane: the range of motion of the pelvis tilted forward and backward
(iii) Transverse plane: the range of motion of the pelvis relative to the lumbar region and rotation associated with alternating movements of the lower limbs

The next stage of the diagnosis included a dental intervention by placing the head of the mandible in the center, the elimination of the acoustic phenomena in all patients during the adduction and abduction movements of the mandible, and stabilization of this position by means of a temporary silicone occlusal splint. Then, postural tests using computer techniques were carried out again while standing and during motion.

After the examinations, the patients were treated for a period of 1 to 3 months with a bimangled reposition brace and were subjected to intensive physiotherapy. After this time, patients were presented with orthodontic, prosthetic, and conservative treatment plans depending on their needs.

3. Results

The paired *t*-test was used in statistical analysis to compare the characteristics before and after therapy. The normality of the distribution of quantitative features was checked using the Shapiro–Wilk test. The results were considered statistically significant at $p < 0.05$. The R statistical package was used for the calculations.

The use of a temporary silicone occlusal splint to change the position and the correct positioning of the mandibular head in the articular fossa had a positive effect on the acoustic phenomena within the temporomandibular joint, eliminating the sounds in 100% of patients. The results of measurements of acoustic abnormalities were digitized as follows:

(i) 0: absence of sound
(ii) 1: click
(iii) 2: crackling

The general level of acoustic abnormalities was calculated as the sum of the results of four measurements of mandibular movements. The distribution of acoustic abnormalities is presented in the histogram in Figure 9(a). The histogram of acoustic abnormalities with division into the left and right sides is shown in Figure 9(b).

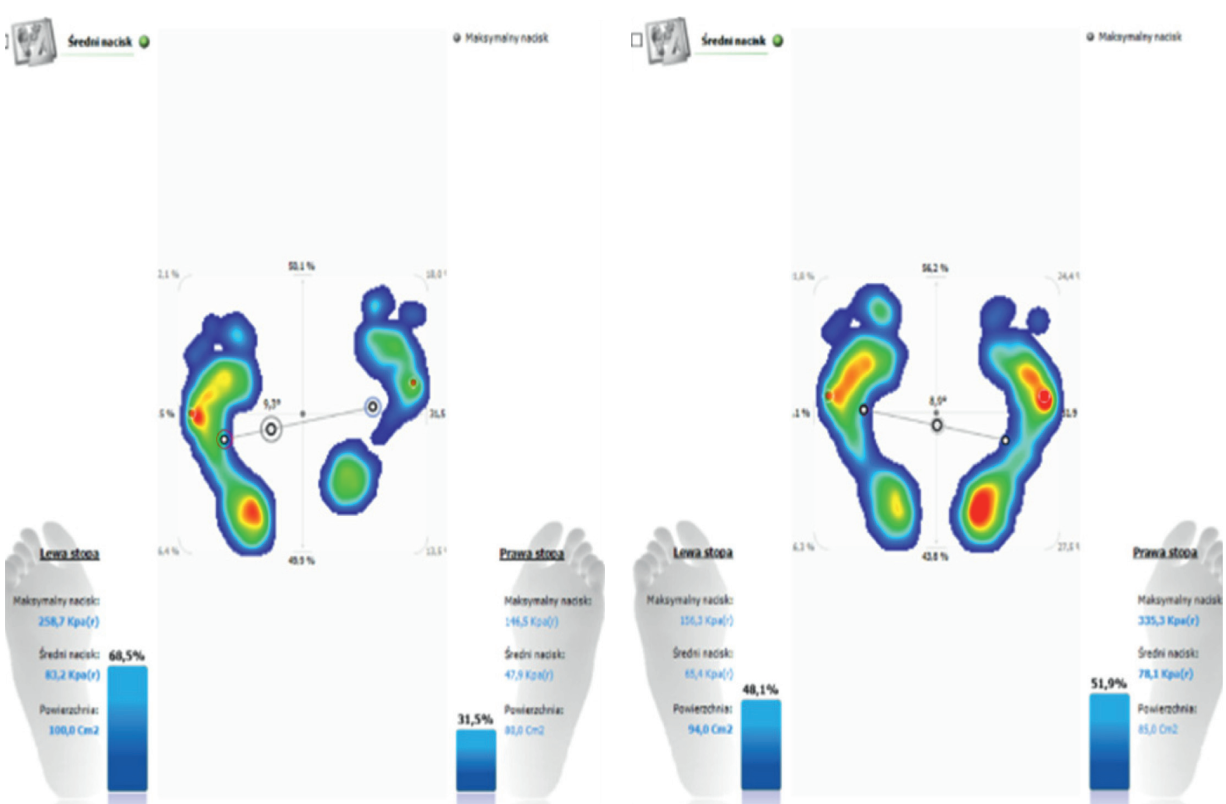
Next, the presence of TMJ pain was examined during the abduction and adduction of the mandible. After stabilizing the position of the mandibular head in the articular fossa using a temporary silicone occlusal splint, TMJ pain was absent in 100% of the patients. Then, the pain in the lateral

(a)

(b)

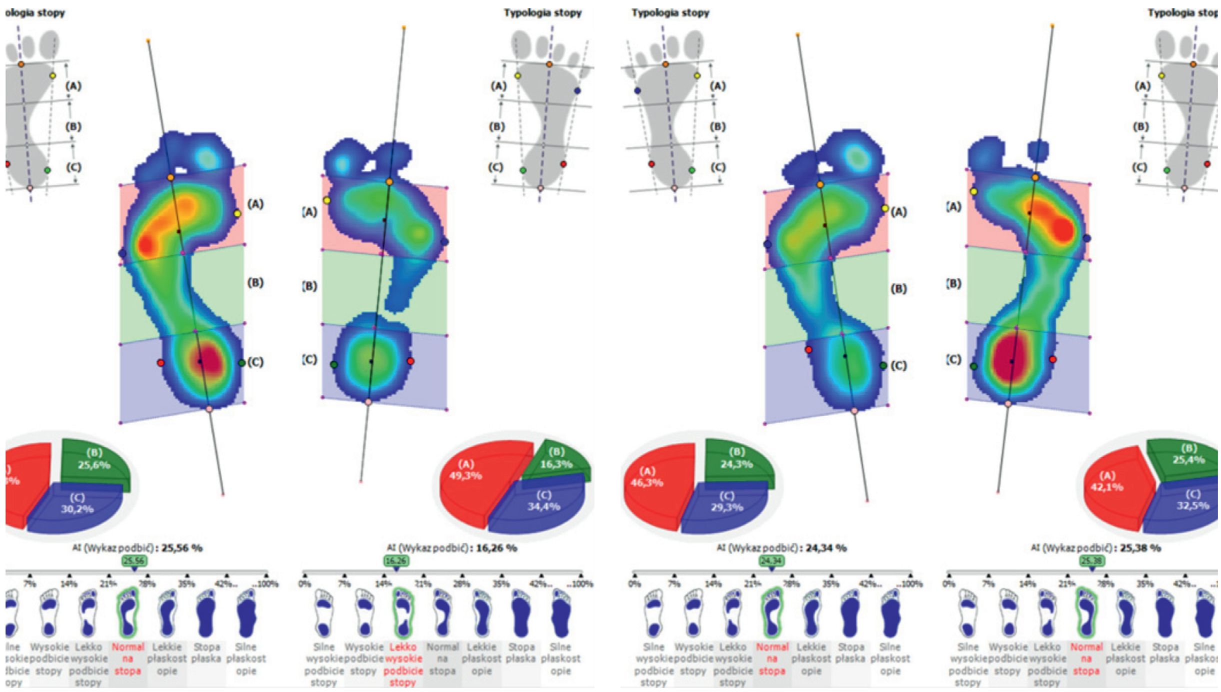
Figure 2: (a) A visual examination of an exemplary patient. (b) A visual examination of an exemplary patient.

Figure 3: A visual examination of an exemplary patient using a podoscope.



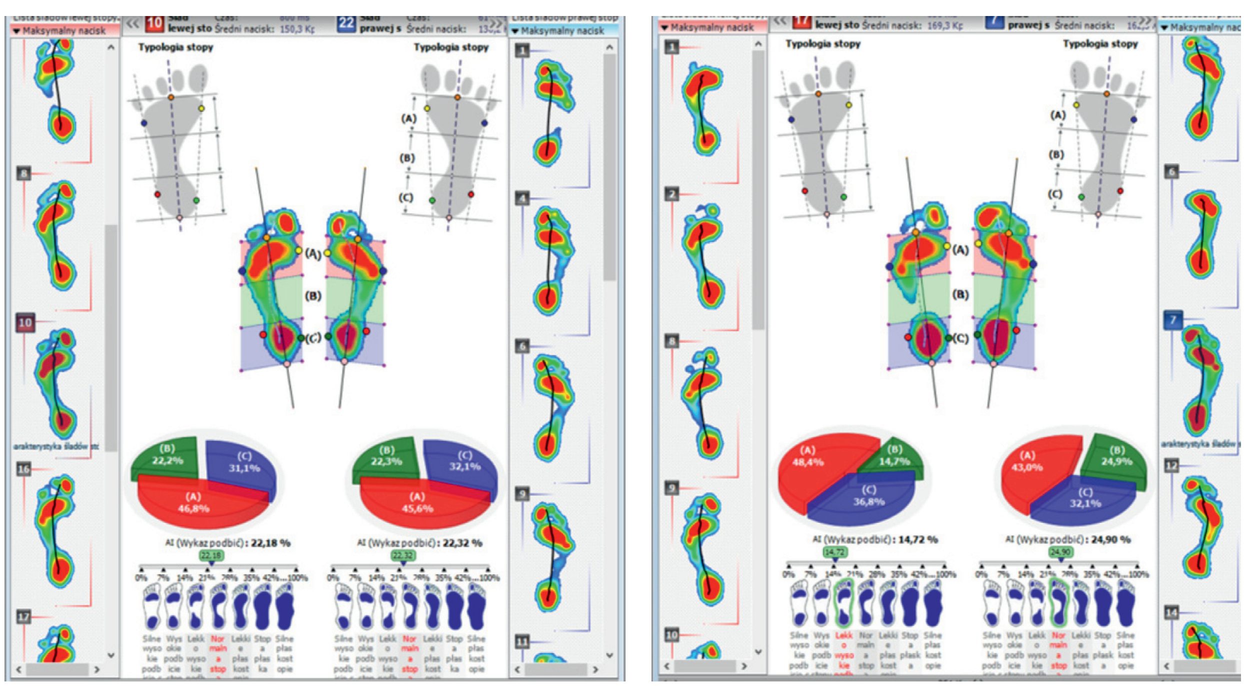
(a) (b)

Figure 4: (a) Distribution of pressure in the anterior/posterior and lateral view and the angle of the relation of the feet before repositioning the mandibular head in the articular fossa and stabilizing the position of the condylar process with a temporary silicone occlusive splint. (b) Distribution of pressure in the anterior/posterior and lateral view and the angle of the relation of the feet after repositioning the mandibular head in the articular fossa and stabilizing the position of the condylar process with a temporary silicone occlusive splint.



(a) (b)

Figure 5: (a) The results of the AI test before repositioning the mandibular head in the articular fossa and stabilizing the position of the condylar process with a temporary silicone occlusal splint, in an exemplary patient. (b) The results of the AI test after repositioning the mandibular head in the articular fossa and stabilizing the position of the condylar process with a temporary silicone occlusal splint, in an exemplary patient.

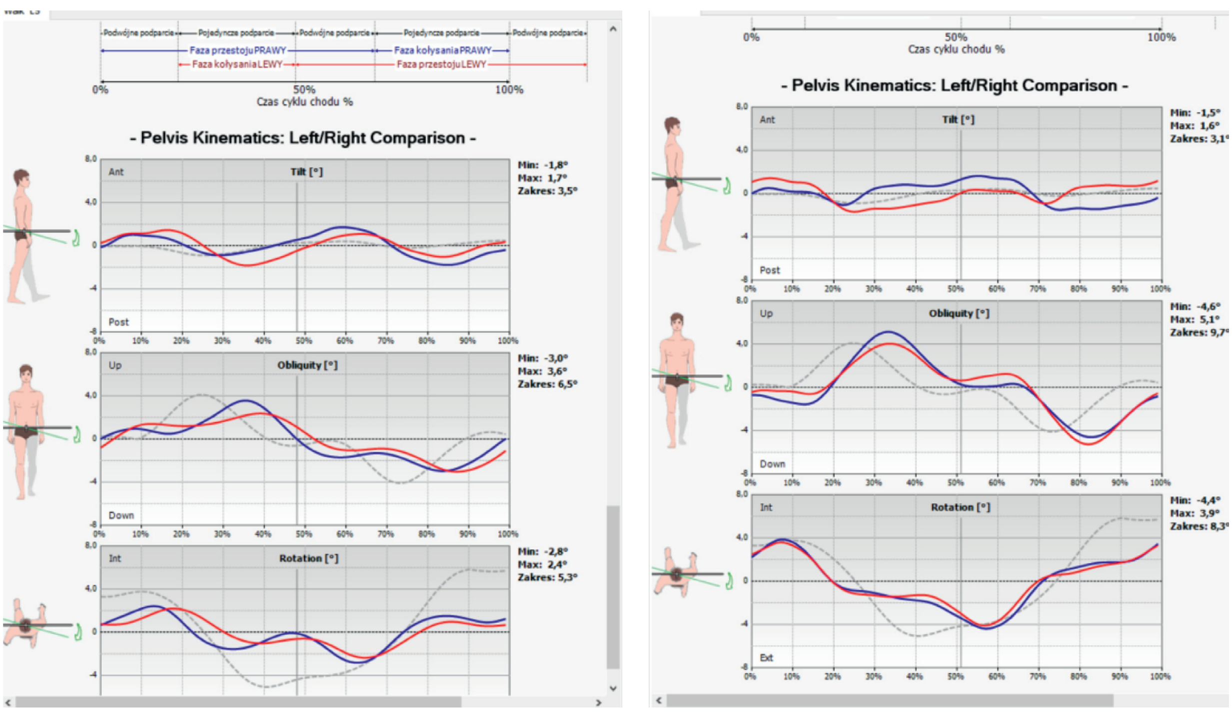


(a) (b)

Figure 6: (a) The results of the AI test before repositioning the mandibular head in the articular fossa and stabilizing the position of the condylar process with a temporary silicone occlusal splint, in an exemplary patient, during walking. (b) The results of the AI test after repositioning the mandibular head in the articular fossa and stabilizing the position of the condylar process with a temporary silicone occlusal splint, in an exemplary patient, during walking.

(a) (b)

Figure 7: (a, b) Stabilization of the mandibular head position in the center using a temporary silicone occlusal splint (CyberTech silicone putty; DE Healthcare Products Gillingham ME8 OSB U.K.).

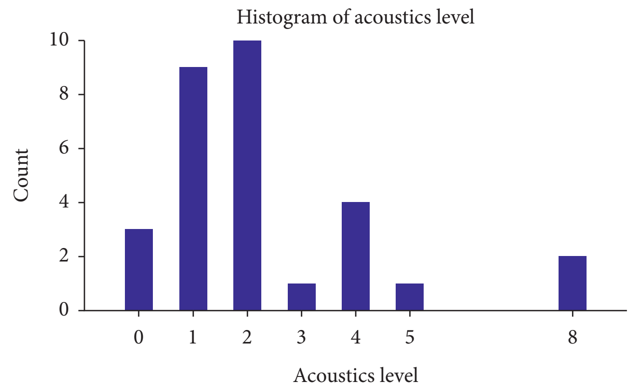


(a) (b)

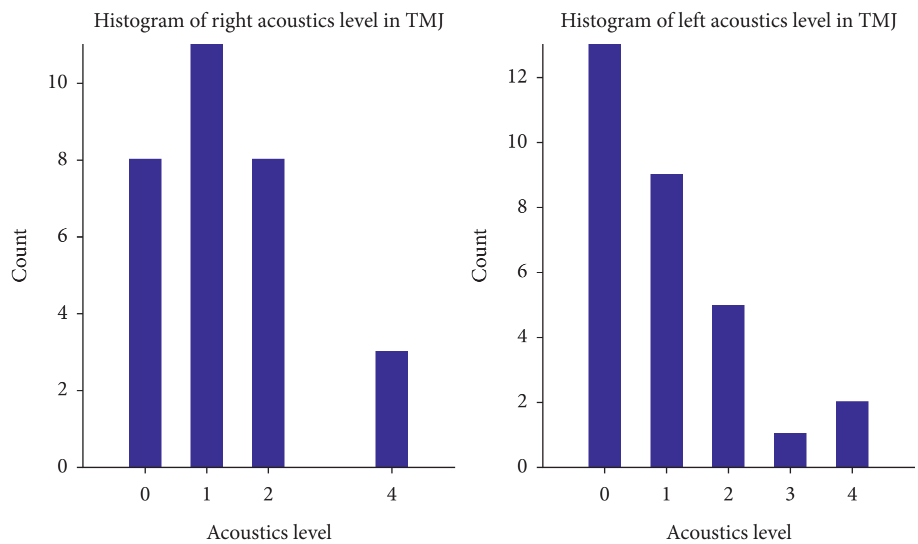
Figure 8: (a) The result of the pelvic mobility test and angle of lordosis (while standing) before repositioning the mandibular head in the articular fossa and stabilizing the condylar process with a temporary silicone occlusive splint in an exemplary patient. (b) The result of the pelvic mobility test and angle of lordosis (while standing) after repositioning the mandibular head in the articular fossa and stabilizing the condylar process with a temporary silicone occlusive splint in an exemplary patient.

and posterior part of the temporomandibular joint was evaluated twice: in a preliminary examination and after stabilizing the position of the mandibular head in the articular fossa using a temporary silicone occlusal splint. The functional tests were performed to assess the locks of the sacroiliac joints, with the presence of locks coded with number 1 and the physiological condition (no locks) coded with number 0. Locks of both joints were reported in 13 patients, locks of the right joint occurred in 5 subjects, locks of the left joint were observed in 11 individuals, and one patient had no locks at all. The general level of locks was accepted as the sum of these two variables (it was 2 in 13 patients, 1 in 16 patients, and 0 in 1 patient). The correlation between the level of TMJ acoustic abnormalities and the sacroiliac joint locks was also analyzed (Table 1).

There is a statistically significant positive correlation between the level of TMJ acoustic abnormalities and the sacroiliac joint locks, both on one side and in the general level of locks. Statistical analysis of changes in the arch of the foot showed that after removing outliers, there are significant differences in the mean values of the AI, except for the result obtained for the right feet, during walking (Table 2). The distribution of the results of the AI before and after stabilizing the mandibular head in the articular fossa using a temporary silicone occlusal splint is shown in Figures 10(a) and 10(b).



(a)



(b)

Figure 9: (a) Histogram of general acoustic abnormalities. (b) Histogram of acoustic abnormalities with division into the left and right TMJ.

Table 1: Correlation coefficients between the level of TMJ acoustic abnormalities and the sacroiliac joint locks by sides and jointly.

Variables	Correlation coefficient	p value
Right acoustics and right locks	0.412	0.024
Left acoustics and left locks	0.489	0.006
General acoustics and the number of locked joints	0.562	0.001

Table 2: Differences in mean values of the AI before and after stabilizing the mandible in a new position using a temporary silicone occlusal splint.

	Mean before	SD before	Mean after	SD after	p value
Left, during standing	22.72	3.118	23.80	2.642	0.019
Right, during standing	22.01	3.117	23.36	3.152	0.045
Left, during walking	20.25	3.974	17.75	5.477	0.019
Right, during walking	19.34	4.423	20.40	3.927	0.294

The last examination of the study was aimed at assessing pelvic mobility in 3 planes. The distribution of the pelvic range of motion relative to the lumbar segment is as follows: in the sagittal plane (anterior-posterior tilt) (Figure 11), in the frontal plane (lowering-lifting of the iliac alae) (Figure 12), and in the transverse plane (rotation) (Figure 13). No statistically significant differences in the mean levels of deviations were found, which may

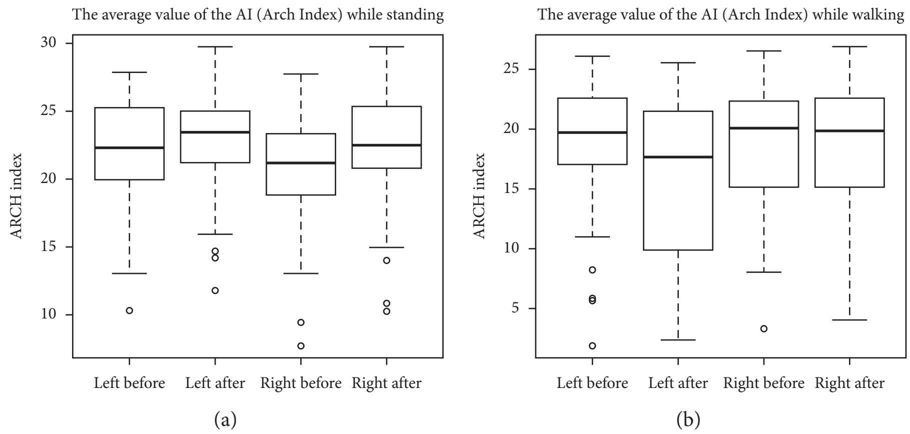


Figure 10: (a) Distribution of the AI before and after stabilizing the mandible in a new position using a temporary silicone occlusal splint; the examination was performed in the standing position. (b) Distribution of the AI before and after stabilizing the mandible with a temporary silicone occlusal splint; the examination was performed during walking.

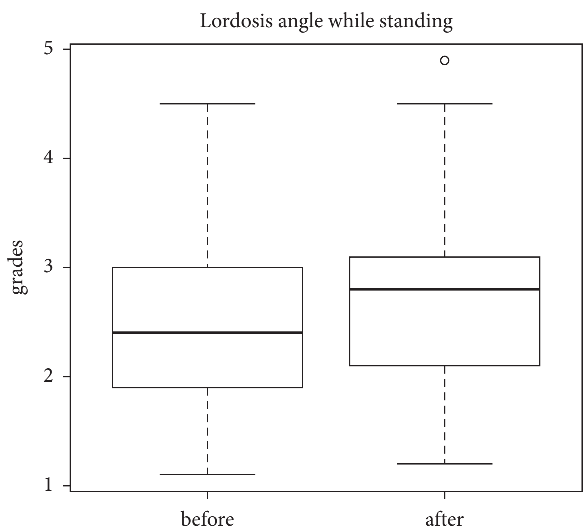


Figure 11: Distribution of the pelvic range of motion relative to the lumbar region (anterior-posterior tilt of the iliac alae) during walking.

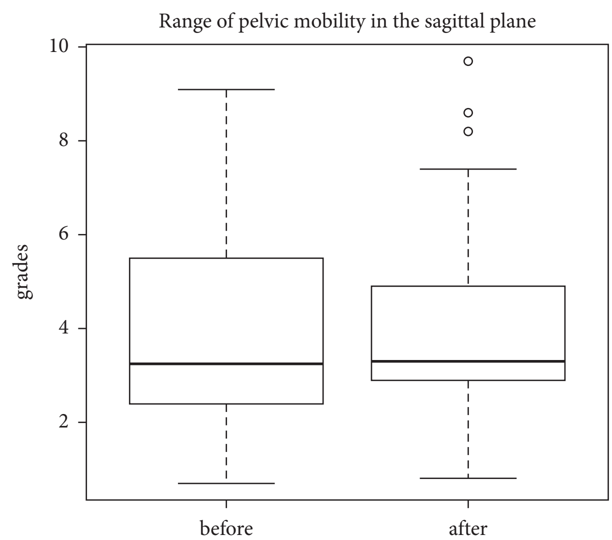


Figure 12: Distribution of the pelvic range of motion relative to the lumbar region (lowering-lifting of the iliac alae) during walking.

correlate with the presence of sacroiliac joint locks in 29 out of 30 patients.

4. Discussion

The relationship between TMD dysfunction and pain in the other TMJ disorders of the human locomotor system is still an important aspect of scientific investigations. However, cross-sectional studies in postural diagnostics, which is used to assess the relationship between TMD and body posture, have not brought any explicit recommendations in this regard. Scientific reports focus on postural diagnostics in the course of TMD assessment and treatment. The approach to the problems of posture is selective, which is largely due to the complexity and multifaceted character of posture diagnosis and functional assessment of the body.

Saito et al. analyzed the effect of TMD on postural dysfunctions, denying any connection in this regard. The conclusions of these authors were based on the research conducted in a group of 10 patients with displacement of the articular disc in the TMJ and in a control group of 16 individuals with no TMD. The postural examination included photogrammetry, where control points were determined on the body by palpation and inspection. The study showed no difference in the measurement of the trace (longitudinal arches) in patients with TMD and those from the control group. Nonetheless, it was shown that the position of the pelvis, head, and spine significantly differed in the sagittal and frontal plane between the groups. However, given the important biokinematic and structural connections between the pelvis and lower limb, the lack of a relationship between these structures is puzzling. According to the authors, this could have been associated with the use of a plantograph for assessing the feet, the so-called Harris mat [46]. This device can produce a significant measurement error, mainly due to the fact that in order to imprint the footprint by the use of

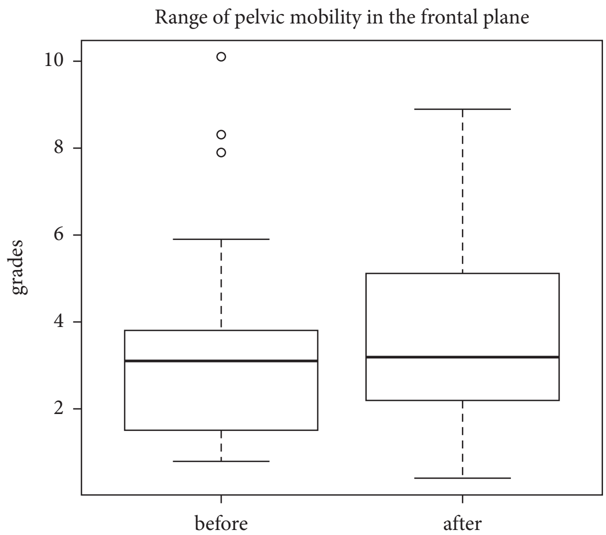


Figure 13: Distribution of the pelvic range of motion relative to the lumbar region during rotation.

ink, the patient needs to reach a very small diagnostic area, and therefore, his/her position is forced. The study conducted using EMG by Valentino et al. on a group of 10 young patients without stomatognathic system disorders demonstrated that stimulation of the foot increases tension within the masseter and the temporal muscle [47]. Examining a group of 40 women, Kittel-Ries and Berzin noticed that people with TMD showed greater postural asymmetry and pain of the uterine cervix, which was potentially associated with the increased postural stability [48]. Cuccia, who analyzed the relationship between the mandibular position and posture on a much larger group of subjects, showed differences in the arches of the feet between TMD patients and those without TMJ problems. A pedobarograph was used to assess the plantar part of the foot only while standing. This repeatable method of computer foot diagnostics largely eliminated the measurement error resulting from the forced position. However, gait evaluation was omitted in the study. The analysis included the measurements taken in the resting position of the mandible, during teeth clenching and occlusion forced by cotton rollers [49]. Similarly, Souza et al. assessed the relationship between TMD and locomotor system disorders. The tests were repeated at various positions of the mandible, taking into account the TMJ alignment correction. In patients with TMD, the evaluation of the association with the feet included measurements of the distribution of plantar pressure using a pedobarograph. In addition, photogrammetric methods were used to evaluate posture. A significant relationship between the position of the feet and TMD was found [50]. In their research, Walczyńska-Dragon et al. evaluated a group of 60 individuals with TMD for the effects of the stomatognathic system correction. The study included the functioning of the TMJ (mandibular movements and acoustic phenomena), pain, and the range of motion of the cervical spine. The results of the research showed an improvement in the condition of patients in both research areas, which indirectly suggests the need for expanded diagnostics when providing reposition splints [51]. Bonato et al. assessed the relationship between the pain of the TMJ and pain in other distant joints. The study was conducted on a much larger population group (338 people). In the first stage, the clinical evaluation of TMD (Research Diagnostic Criteria for Temporomandibular Disorders) was performed; in the second part of the study, pain in other joints of the body was assessed. The relationship was found between these two features [52]. Studying postural stability, Nota et al. has demonstrated that patients with TMD had statistically significant greater acceleration and surface area of body oscillation in maximal occlusion (intercuspidation) and in the resting position with the eyes open. The study was conducted using a stabilometric platform [53]. Due to the close functional and neurological relationship (the results of foot stimulation examinations), most studies indicate the need to analyze the feet both while standing and walking. Logical inference indicates that these relationships shown in the foot-TMJ system have a huge impact on therapeutic management in broadly understood rehabilitation of the musculoskeletal system. In particular, a close relationship was observed between the treatment of the stomatognathic system and changes in posture and functionality of the body after using the splints. It can be concluded that the application of the methods of posture diagnostic screening seems to be necessary during the dental examination and therapeutic activities. These findings might give rise to issues of competency and logistics, hence the need for standardized and common methods of posture diagnostics to observe global patterns, which include posture assessment in the standing position, body balance, and gait assessment (from the position of the feet and pelvis). These examinations, supplemented with photogrammetric anthropometric methods aimed at examining the entire posture, performed before, during, and after treatment, can be used as complementary methods ensuring the effectiveness of the therapeutic methods. It should be noted that the results of this research showed a discrepancy between patients, with no improvement regularity or the lack of improvement, which was perhaps associated with individual features (for instance weight, gender, age of the patient, systemic diseases). The need for individualized diagnosis of body posture was an important conclusion.

The analysis of acoustic phenomena and pain of the TMJ revealed a direct, positive impact of stabilization of the mandibular head in the articular fossa using a temporary silicone occlusal splint. A significant impact of this supply was demonstrated on mean values of the AI describing the foot arch and its functionality in terms of supination and pronation during walking. The results varied and were directly related to the co-existence of defects of the feet and lower limbs, which is an important argument for further research in this regard. Another global pattern observed during standing and walking was the position of the pelvis in relation to the lumbar region and its mobility when standing and walking in all planes of postural assessment. No significant deviations of comparable variables from standard deviation were found. Noteworthily, however, there was a coexistence of sacroiliac joint locks in most patients (29 patients out of 30). Locks of the sacroiliac joints significantly correlate with TMD. A positive correlation between a degree of acoustic abnormalities and locks of the sacroiliac joints was identified on one side and for the general locks. This paper indicated few aspects of postural diagnostics. The results suggest a relationship between the position of the mandibular head in the TMJ articular fossa and individual posture defects. Despite the lack of an evident direction and repeatability of the changes, they were observed and depended on individual posture defects. Despite our knowledge on postural patterns describing the relationship between the position of the head and pelvis, the results of studies are divergent. Given the abovementioned observations, we should rather focus on the influence of individual determinants, posture defects, and the impact of previous surgeries and treatment. Therefore, an individual and interdisciplinary approach to each patient seems to be important. Based on this information and the results of pilot studies, we can conclude on the relationship between TMD and posture defects. However, research conducted on a larger study group of patients is needed. Pedobarography (EPS R1 pedobarograph) and an integrated sensor for postural diagnostics are used in the tests. Both devices use BIOMECH Studio software, which allows for inexpensive, noninvasive easy posture diagnostics without a need for expert knowledge. The examination time was approximately 10 minutes. We collect information on foot defects, functional disorders, body balance, range of motion, etc. The patient can be examined while standing and during motion, the examination also gives an opportunity to assess the needs of the individual locomotor system. The chief limitation of the study is a lack of a control group, therefore is a potential risk of data interpretation bias. Conclusions on statistical population tendencies will be implemented by a research team in a much larger population group.

5. Conclusions

(1) Diagnostic and therapeutic management in the course of TMD should be holistic. It is reasonable to use postural diagnostics in the dental therapy of TMD.

(2) The observed changes are often varied and largely dependent on individual posture defects, which is an important postulate for further research on a large research group.

(3) Pedobarography and computer methods of postural diagnostics are valuable diagnostic tools in TMD therapy.

Data Availability

The datasets used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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Hindawi
Pain Research and Management
Volume 2022, Article ID 3115154, 8 pages
https://doi.org/10.1155/2022/3115154

Research Article

Physiotherapeutic Reduction of Orofacial Pain Using Extremely Low-Frequency Electromagnetic Field and Light-Emitting Diode Therapy—A Pilot Study

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Received 16 November 2021; Accepted 12 January 2022; Published 8 February 2022

Academic Editor: Tomasz Kaczmarzyk

Introduction. Pain is a natural response of the body to injury and one of the symptoms defining an inflammatory reaction. It is almost always present after orthognathic surgeries (OGS), but its severity is subjective in each patient. Postoperative care of the patient is aimed at minimizing of postoperative pain relief orofacial region. Options of physiotherapy include extremely low-frequency electromagnetic field (ELF EMF) and high-energy light-emitting diode (LED). *Aim of the Study*. The aim of this study was to evaluate the effects of physiotherapy combining ELF EMF and LED to reduce pain of the orofacial region in patients after OGS. *Material and Methods*. The study was conducted in thirty-two patients who underwent OGS to treat morphological defects. The participants were randomly divided into two groups: Physiotherapy group (PT) and Control group (CG). In both groups, patients were prescribed Paracetamol and nonsteroidal analgesics (NSAID—ibuprofen). Patients from the PT group additionally received postoperative physiotherapy immediately after leaving the surgical clinic in the form of ELF EMF and LED therapy. Physiotherapeutic treatments were performed for 10 days, three applications a day, at no cost to the patient. Pain intensity was assessed using the visual analogue scale (VAS), which is a reliable instrument for the measurement of pain intensity self-reported by the patient. *Results*. Faster reduction of pain was the major observation made in patients who received physiotherapy treatments. In all subjects, after 5 days of therapy, the pain intensity was reduced by about 50% or resolved completely. Effects of therapy were measured with the relative changes in the pain intensity score, showing what fraction of the initial pain was eliminated at the first stage and throughout the whole therapy. The analysis of relative changes instead of absolute changes allowed us, among other things, to eliminate the bias of the higher initial pain intensity in the CG group compared to the PT group. *Conclusions*. The conducted research revealed that the combined use of ELF EMF and LED is beneficial in the reduction of pain of patients after OGS. The analgesic effects of physiotherapy in the treatment after OGS are necessary to continue research in this area and analyze the possibility of extending the indications for its use in other surgically treated maxillofacial diseases.

1. Introduction

The correction of orthognathic deformities requires interdisciplinary orthodontic, surgical, and rehabilitation treatment. The preoperative orthodontic preparatory procedure is aimed at aligning the dental arches and lasts for 6 to 24 months, depending on the type and degree of the deformity. It involves the repositioning of teeth, regardless of their occlusal relations to the opposing arch, which leads to the decompensation and aggravation of the existing defect. This procedure enables the proper fusion of osteotomized fragments and correction of malocclusion during surgery. The surgical techniques that have evolved over recent decades now allow for almost any type of repositioning within the facial bone structure. Orthognathic surgeries (OGS) may concern a single jaw, either maxilla (Le Fort I type osteotomy) or mandible (bilateral sagittal split osteotomy—BSSO), or both jaws, when both techniques are combined during one procedure [1, 2]. OGS is frequently used to correct skeletal classes II and III deformities, dentofacial maxillary deformities, mandibular laterognathism, and maxillofacial asymmetry [3, 4]. Each year 234.2 million major surgeries are carried out worldwide [5]. As with any other surgical procedure, various intraoperative and postoperative complications may occur in patients undergoing OGS. Most patients experience mild to severe pain. Postoperative pain management is very important to reduce the stress caused by the onset of pain, to prevent instability of the circulatory system [6], to restore normal respiratory function, and to ensure fast recovery [7]. Postoperative pain is usually controlled with opioids, which are popular in the United States [8]. Major surgeries are associated with the risk of many early and late complications. Early complications, developing within the first 24 hours postoperatively, include orofacial pain, bleeding, ventilation disorders, soft tissue oedema, inflammatory reactions, infections, nausea, and vomiting. Late complications may occur at different times after surgery and include the recurrence of the defect, unfavourable nasolabial aesthetics, nasal septum deformity, temporomandibular joint dysfunction, idiopathic condylar atrophy, oral or vestibulo-nasal fistulas, osteonecrosis, and neurological disorders [9].

Postoperative care of the patient is aimed at minimizing the risk of complications and treatment of existing ones. Directly after the surgery it includes the monitoring of basic vital parameters, preventing the development of infection, reducing pain and oedema, maintaining the proper nutritional status and hydration of the patient, and psychological support. Pharmacotherapy relies on antibiotics and analgesics, usually nonsteroidal and steroidal anti-inflammatory drugs [10–12]. Stimulating treatment includes cold compresses to reduce pain and oedema. Pain is almost always present after OGS, but its severity is subjective in each patient. Incidentally, the lack of, or only minor, pain within the lower facial region may indicate functional disorders of the inferior alveolar nerve [13, 14].

In all diseases and complications of the stomatognathic system, regardless of the severity of pain, its control is among the major tasks in care of the patient. The physical and mental comfort of patients can be restored with physiotherapy and devices with extremely low-frequency electromagnetic field (ELF EMF) and light-emitting diode (LED) or low level laser therapy (LLLT) [15]. This fact inspired the authors to undertake research on the use of physiotherapy in patients after OGS in order to reduce pain of the orofacial region [16, 17].

2. Objective

The aim of this study was to evaluate the effects of physiotherapy combining ELF EMF and LED to reduce pain of the orofacial region in patients after OGS.

3. Materials and Methods

3.1. Patients. The study was conducted in thirty-two patients of both genders (26 female and 6 male), aged 19–24 years (mean 21.2, SD 1.44), who underwent OGS on between October 2015 and June 2017. All subjects qualified for the study underwent the same surgery—BSSO. The participants were randomly divided into two groups. In the PT group (16 patients–14 female and 2 male), mean age was 20.9, SD 1.26 years. In the control group CG (16 patients – 12 females and 4 males), mean age was 21.4, SD 1.59 years. In both groups, patients were prescribed Paracetamol and nonsteroidal analgesics (NSAID—ibuprofen). Paracetamol was used 1000 mg daily in doses four times a day, while Ibuprofen 400 mg three times a day. Patients from the PT group received postoperative physiotherapy immediately after their discharge from the surgical clinic (day 2 after surgery). Patients from the control group CG did not receive physiotherapy but only did receive analgesics. Pain severity was assessed using the visual analogue scale (VAS), which is a reliable instrument for the measurement of pain intensity self-reported by the patient. Pain intensity was measured on days 1, 5, and 10 after the beginning of therapy.

Study participants met the following inclusion criteria: general good health, lack of pre-existing medical conditions, and no medication that would affect their eligibility for surgery or compromise wound healing after surgery. Each patient was operated on by the same maxillofacial surgeon, who used the same surgical technique on both sides of the mandible to minimize differences in the functional performance of the oral tissues. We excluded patients on regular drug therapy, and those with mental illness, coagulopathy, diabetes, and chronic infections. None of the subjects was addicted to nicotine, alcohol, or illegal drugs.

The study registered on clinicaltrials.gov carries the number KB-0012/149/15. The study complied with ethical standards, and all participants signed a written informed consent form and were informed about the technique and course of the research. Participants in the study did not receive any financial incentive and could withdraw from the study at any time.

3.2. Devices and Parameters of Therapy. Physiotherapy was carried out using a VIOFOR JPS device (Med & Life-Poland) that produced the ELF EMF by the method M2, programme P3, and intensity 6. This means that the frequency was within the range of 180–195 Hz for the basic impulse, 12.5 Hz-29 Hz for impulse packets, 2.8–7.6 Hz for groups of packets, and 0.08–0.3 Hz for the series. The intensity of ELF EMF was set at 6, meaning the successful induction of an electromagnetic field equal to 15 μT. Treatments with ELF EMF were each time provided with a ring applicator fitted onto the patient's head and generating a uniform field, and elliptic applicators used topically (Figures 1(a) and 1(b)).

Patients after OGS, in the PT group, were treated with physiotherapy combining ELF EMF and LED therapy. Treatments with LED (Figure 2) were done with a device set at the M1P3 programme, which ensures constant application of the selected light intensity, and uses the highest values of ion cyclotron resonance, stimulated inside the cells. Patients received physiotherapy once a day, and this consisted of three above-described treatments for a period of 10 days.

(a) (b)

Figure 1: (a) and (b). Treatments with an ELF EMF, ring applicator, and elliptic applicators.

Figure 2: Applicators generating an extremely ELF EMF and light energy (830 nm and 640 nm) emitted from the LEDs during the physiotherapy treatment.

4. Results

Faster reduction of pain was the major observation made in patients who received physiotherapy treatments. In most cases, after the first day of physiotherapy, patients discontinued medication with analgesics. It should be noted that in the group receiving physiotherapy only, one patient reported pain score 10 on the VAS scale immediately after OGS. This patient also discontinued pain-controlling medication after the first day of physiotherapy. Measured intensities of pain on days 1, 5, and 10 are marked VAS_1, VAS_5, and VAS_{10}, respectively. Descriptive statistics for the group receiving physiotherapy (PT) and the control group (CG) are presented in Table 1. Distribution of variables is presented in Figure 3.

4.1. Analysis of Effects of Physiotherapy (PT) and Pharmacotherapy (CG). Because of the zero value and lack of variability in the measurement of VAS_{10} in the PT group, the reduction of pain intensity after physiotherapy treatments was analyzed by testing the statistical significance of mean

Table 1: Descriptive statistics for pain intensity.

Variable	Min	Max	Mean ± SD
PT group			
VAS_1	4	10	7.125 ± 1.500
VAS_5	0	5	2.875 ± 1.147
VAS_{10}	0	0	0 ± 0.000
CG group			
VAS_1	6	10	8.062 ± 1.237
VAS_5	4	8	4.812 ± 1.424
VAS_{10}	0	4	1.938 ± 1.289

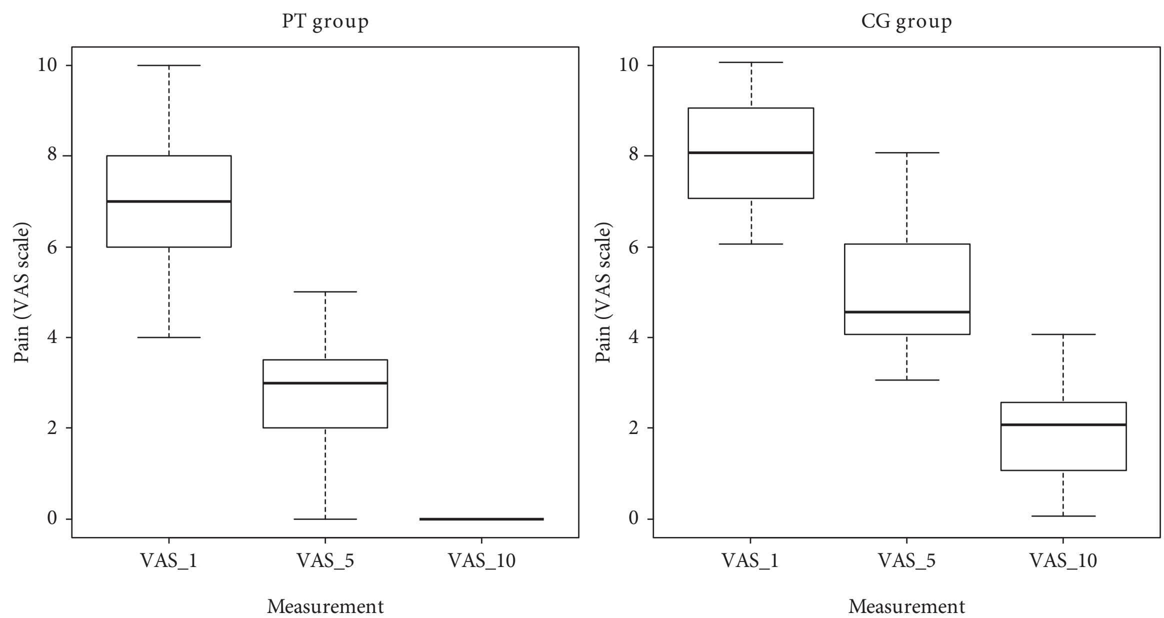

Figure 3: Reduction in pain intensity after physiotherapy treatments with ELF EMF and LED (PT group vs CG group).

variables VAS_1 and VAS_5 and the statistical significance of differences between these means. Results from statistical tests are presented in Table 2.

The study demonstrated reduction in pain intensity after physiotherapy at both stages of therapy (days 1–5, 5–10) and for the whole therapy (days 1–10).

In the CG group (only pharmacotherapy), the reduction of pain intensity was analyzed with repeated measures ANOVA. Measurements did not differ significantly from normal distribution (Shapiro–Wilk test, $p > 0.05$ for all three VAS measurements), and there were no significant differences in the variance of measurements (Levene test, $p > 0.05$).

The study demonstrated reduced pain intensity in the CG. The post hoc analysis of variance (Tukey HSD test) revealed significant differences between all measurements (Table 3).

4.2. Comparison of Effects of Physiotherapy (PT) and Pharmacotherapy (CG). Effects of therapy were measured with the relative changes in the pain intensity score, showing what fraction of the initial pain was eliminated at the first stage and throughout the whole therapy. The analysis of relative changes instead of absolute changes allowed us, among other things, to eliminate the bias of the higher initial pain intensity in the CG group compared to the PT group.

$$\text{Change}_1 = \frac{VAS_5 - VAS_1}{VAS_1},$$
$$\text{Change}_{1,2} = \frac{VAS_{10} - VAS_1}{VAS_1}. \quad (1)$$

The adopted variables showed significantly different variances in both groups, so the mean values of variables were compared with the Welch t-test. Results are presented in Table 4.

The study demonstrated that physiotherapy (PT) provided significantly better outcomes compared to pharmacotherapy in the (CG). This advantage was achieved as early as at the first stage, so physiotherapy reduced pain-related complaints. The distribution of relative changes in pain intensity is presented in Figure 4.

5. Discussion

Pain is one of the symptoms defining inflammatory reaction and also the major symptom for which most patients seek

Table 2: Significance of mean differences in pain intensity for the PT group.

Variable	Mean	t	95% CI	p
PT group				
VAS_1	7.125	19.0	(6.326, 7.924)	≤0.001
VAS_5	2.875	10.0	(2.264, 3.486)	≤0.001
VAS_1–VAS_5	4.25	13.2	(3.562, 4.938)	≤0.001

Table 3: Results of Tukey HSD test for the CG group.

Difference	Mean	95% CI	p
CG group			
VAS_1–VAS_{10}	6.125	(4.995, 7.255)	≤0.001
VAS_5–VAS_{10}	2.875	(1.745, 4.005)	≤0.001
VAS_1 VAS_5	3.250	(2.120, 4.380)	≤0.001

Table 4: Significance of differences in mean changes in pain intensity between groups.

Variable	Mean PT	Mean CG	t	95% CI for difference	p
$Change_1$	−0.597	−0.411	−4.2	(−0.278, −0.094)	≤0.001
$Change_{1,2}$	−1.000	−0.769	−6.8	(−0.304, −0.158)	≤0.001

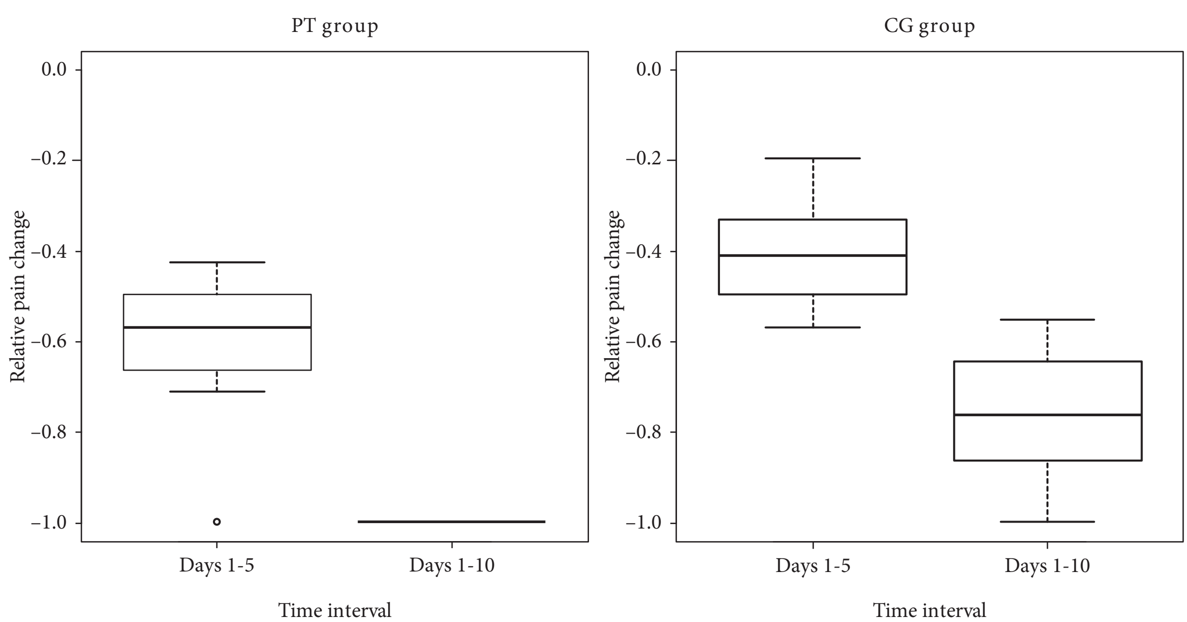

Figure 4: Distribution of relative changes in pain intensity in the PT and CG (lower = greater pain relief).

medical advice [18]. Pain is almost always present after OGS, but its severity is subjective in each patient. Regardless of the severity of pain, its control is among the major tasks in the postoperative care of the patient.

In own research it was proved that reduction of pain was the major observation made in patients who received physiotherapy treatments. The study demonstrated that physiotherapy-PT group provided significantly better outcomes compared to pharmacotherapy in the CG group. This advantage was achieved as early as at the first stage, so physiotherapy reduced pain-related complaints. Effects of therapy were measured with the relative changes in the pain intensity score, showing what fraction of the initial pain was eliminated at the first stage and throughout the whole therapy. The analysis of relative changes instead of absolute changes allowed us, among other things, to eliminate the bias of the higher initial pain intensity in the CG group compared to the PT group.

The limitations of this study concerned a small research group and the inability to divide into male and female subgroups, which would undoubtedly extend the statistical analysis and increase the value of the research. It should be noted that the manuscript presents the research group described as a preliminary report, and the research is continuing.

The analgesic and anti-inflammatory effects of ELF EMF have been well documented. Thomas applied that ELF EMF in the treatment of chronic musculoskeletal pain and proved its analgesic effect [19]. Arneja et al. used ELF EMF in the treatment of chronic lower back pain in patients with degenerative disc disease. His pilot study suggests that the ELF EMF treatment protocol is clinically relevant and can be used as a safe and effective method [20]. Pall concluded that the direct effect of ELF EMF is achieved via the activation of calcium channels, transmembrane transport of ions, and increased the activity of enzymes [21]. The analgesic effect of ELF EMF is mainly due to the increased secretion of endogenous opioid neuropeptides from the class of ß-endorphins, responsible for elevated pain threshold. Regenerative effects primarily come from the intensified use of oxygen and tissue respiration associated with increased diffusion and oxygen uptake by haemoglobin and cytochromes. Increased oxygen uptake stimulates tissue respiration and DNA synthesis and accelerates the mitotic cycle. The anti-inflammatory effect is associated with the stimulation of c-AMP and prostaglandin E synthesis, which affects the accumulation of c-AMP, and reduces the secretion of inflammatory mediators from neutrophils, basophils, mast cells, and lymphocytes. Iannitti conducted a clinical study in elderly people using ELF EMF and reported significant benefit in terms of reduced pain and stiffness of joints and improved physical function [22]. Nelson concluded that noninvasive ELF EMF therapy causes rapid and significant pain reduction in the early stage of knee osteoarthritis [23].

Physiotherapy with ELF EMF and LED used in own research is an innovative method that relies on the combined use of light energy emitted from high-energy diodes and an extremely low-frequency electromagnetic field. This light is monochromatic, i.e., all photons have the same wavelength, and collimated, which means it has parallel rays without divergence. However, this light is not coherent (ordered), i.e., not all the photons have a constant phase, which makes it different from laser light. Calderhead confirmed that the energy of the light generated by LEDs, used predominantly in aesthetic medicine, has a mainly local effect on tissues and can penetrate into their deeper layers, depending on the length of the generated waves and the angle of incidence [24]. Barolet employed LEDs in dermatology and used the reaction of a tissue dependent on energy absorption in specific skin layers. The effects of 830 nm infrared light (IR) are initiated at the level of the cell membrane and the effects of 640 nm red light (R) in the mitochondria. Studies on the mechanisms of action of LEDs indicated many aspects that can be considered to achieve clinical benefits. For example, LEDs influence cell metabolism by stimulating intracellular photobiochemical reactions. Different effects are observed, including increased synthesis of ATP, modification of reactive oxygen species, induction of transcription factors, changes in collagen synthesis, stimulation of angiogenesis, and enhanced blood flow [25]. Other studies demonstrated that red LEDs activate fibroblast growth factor, increase the level of type 1 procollagen, increase the level of matrix-metallo-proteinase-9 (MMP-9), and reduce the level of MMP-1, as confirmed in vitro by Barolet et al. [26]. Other researchers believe that monochromatic near-infrared light stimulates blood circulation by inducing the release of guanylate cyclase and nitrous oxide, which in turn promotes vasodilation and growth, as well as angiogenesis, leading to wound healing [27]. Simpson et al. reported that near-infrared LEDs offer the deepest penetration of the tissues with visible wavelengths and are therefore used for therapies targeted at subcutaneous structures and fibroblasts [28]. Red LEDs have been investigated in a wide range of applications, including wound healing, treatment of precancerous lesions, warts, and the prevention of inflammations of the oral mucosa. IR light emitted by LEDs can penetrate 5 to 10 mm deep into the skin and has been used for the treatment of wounds, ulcerations, and cutaneous scleroderma and was also effective in the treatment of cellulite [29–31]. Studies by Russell et al. demonstrated that the exposure of patients to a combination of different wavelengths emitted by LEDs was more effective compared to monotherapy [32]. A prospective, placebo-controlled, double-blind clinical study on the use of LEDs emitting red (640 nm) and IR light (830 nm) was performed by Lee et al. [33]. A significant smoothing of wrinkles with improved skin elasticity was observed in patients from all study groups. Tissue tests revealed a significant increase in the content of collagen and elastic fibres near highly active fibroblasts. The levels of proinflammatory cytokine, interleukin 1β (IL-1β), and tumour necrosis factor α (TNF-α) were increased, while the level of interleukin 6 (IL-6) was decreased. In another study, Goldberg et al. investigated the effects of combined red LED (633 nm) and IR (830 nm) on the skin and reported smoothing of periorbital wrinkles in 80% of patients. Histological examination showed an increased number and thickness of collagen fibres [34]. Similar studies carried out by Tian et al. in 2012 demonstrated an increased expression of type 1 collagen and the number of viable fibroblasts after treatment with different combinations of 630 nm, 830 nm, and various wavelengths of red and IR light [35].

The effect of ELF EMF in the management of postoperative pain, used in the above studies, can be explained by the cyclotron resonance known from magnetobiology and the influence of electromagnetic fields on the concentration of calcium ions and activation of nitric oxide synthetase. Animal studies have demonstrated that damage to the peripheral nerves and consequent activation of induced nitric oxide synthetase are important in the pathogenesis of neuropathic pain and the development of hyperalgesia. The analgesic effect observed in own research, induced by ELF EMF in cells after the use of the P3 programme, can be explained based on the model of ion cyclotron resonance, described by Brustkern, Graham and Leach et al. [36–38]. According to the theory, using this model in magnetobiology, calcium ions are the main target of the electromagnetic field within cell membranes and cytosol. Studies on the activity of membrane enzymes and transport of calcium ions induced by ELF EMF have indicated changes in intracellular calcium concentrations. Calcium concentration influences changes in the polarization of the cell membrane towards long-term synaptic enhancement or weakening, and thus determines the increase or decrease of cell reactivity. Change in the perception of pain following the treatment with ELF EMF and LED in patients after OGS may be related to this process, but further research is necessary to explain these mechanisms [39].

6. Conclusion

The results of own study on the effects of combined treatment with ELF EMF and LED demonstrated that this method provides benefits in the reduction of pain in orofacial region of patients after OGS. Combined physiotherapy treatments allowed for significantly greater pain relief compared to pharmacotherapy. Patients also resumed their social and professional activity in a shorter time after surgeries. Research in this area should be continued to analyze the possibility of extending the use of this therapeutic modality in other diseases treated by maxillofacial surgery.

Abbreviations

OGS: Orthognathic surgery
BSSO: Bilateral sagittal split osteotomy
ELF EMF: Extremely low-frequency electromagnetic field
LED: Light-emitting diode
IR: Infrared light
R: Red light.

Data Availability

The data sets used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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Hindawi
Pain Research and Management
Volume 2021, Article ID 4852683, 10 pages
https://doi.org/10.1155/2021/4852683

Research Article

Hyoid Bone Position in Patients with and without Temporomandibular Joint Osteoarthrosis: A Cone-Beam Computed Tomography and Cephalometric Analysis

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Received 20 October 2021; Accepted 30 November 2021; Published 11 December 2021

Academic Editor: Aneta Wieczorek

Objective. To assess the differences in hyoid bone position in patients with and without temporomandibular joint osteoarthrosis (TMJOA). *Methods*. The present cross-sectional study was conducted in 427 participants whose osseous status was evaluated using cone-beam computed tomography and classified into normal, indeterminate osteoarthrosis (OA), and OA. The hyoid bone position and craniofacial characteristics were evaluated using cephalograms. Patients were divided into the normal group ($N = 89$), indeterminate OA group ($N = 182$), and OA group ($N = 156$). Descriptive statistics, one-way analysis of variance, and age- and sex-based stratified analyses were performed. $P < 0.05$ was considered statistically significant. *Results*. The differences in Hy to MP, Hy-RGn, Hy to C3-RGn, C3-RGn, and Go-Hy-Me among the three groups were statistically significant. The differences in the Frankfort-mandibular plane angle, saddle angle, articular angle, gonial angle, ramus height, and posterior facial height were statistically significant. After adjusting age and sex, the Hy-RGn and C3-RGn in the normal group were significantly greater than the OA group. No statistical differences were observed in the hyoid measurements in the stratified analyses in males or subjects less than 18 years old. The differences in Hy to MP, Hy to C3-RGn, and Go-Hy-Me in female patients among the three groups were statistically significant. The differences in Hy to SN, Hy to FH, Hy to PP, Hy to MP, Hy-RGn, Hy-C3, Hy to C3-RGn, Go-Hy-Me, Hy-S, and C3-Hy-S in adults were statistically significant. *Conclusion*. The differences in the hyoid bone position, mainly relative to the mandible, were statistically significant in patients with or without TMJOA. The difference pattern varied among different age and sex groups. Clinical evaluation of the hyoid position must consider the age and sex of patients. Longitudinal studies are required to clarify the causal relationship between TMJOA and hyoid bone position.

1. Introduction

Temporomandibular joint osteoarthrosis (TMJOA), a vital subtype of temporomandibular disorders (TMDs), is a degenerative joint disease characterized by cartilage degradation and subchondral remodeling [1, 2]. Around 27–38% of the general population had TMD [3]. And 11% of the TMD patients have symptoms of osteoarthritis [4]. As a primary chief complaint of TMJOA patients, pain and TMJ dysfunction could compromise the quality of life of patients, causing a considerable social and economic burden [5, 6]. However, the etiology of TMJOA is not yet completely understood.

The hyoid bone is a horseshoe-shaped bone attached to the mandible, skull, pharynx, and cervical spine by different ligaments and muscular attachments. The hyoid bone moves during respiration, mastication, swallowing, and phonation, which are functions affected by the temporomandibular joint (TMJ) [7, 8]. The TMJ, mandible, and hyoid bone are crucial for the functions of the stomatognathic system. Abnormalities of the hyoid bone can also cause pain in the neck, temporal region, TMJ, and mandible [9].

Several studies reported the relation between TMJOA and craniofacial morphology [10, 11]. Patients with TMJOA exhibited the retrusion and clockwise rotation of the mandible [12]. Although no study reported the relationship between hyoid bone position and TMJOA, a few studies investigated the relationship between hyoid bone position and TMD [13–15]. However, the results of these studies were inconsistent.

Therefore, the present cross-sectional study attempted to analyze the differences in hyoid bone position in patients with or without TMJOA, which might help understand the etiology of TMJOA and the management of TMJOA pain.

2. Materials and Methods

2.1. Study Population. The present cross-sectional study was conducted on 427 patients visiting the orthodontic department of our hospital between 1 January 2020 and 31 July 2021 after institutional ethics clearance. Written informed consent was obtained from all patients or legal guardians. The personal information of all participants was anonymized. Patients with permanent dentition with clear cephalogram and cone-beam computed tomography (CBCT) images at the first visit to our hospital and with the similar osseous status of the left and right joints were included in the study. Patients with tumor or maxillofacial deformity that could cause joint deformity; those with breathing or swallowing disorders; patients with a history of orthodontic treatment, plastic surgery, or other craniofacial surgeries; those with systematic diseases affecting the orofacial regions; and those with a history of TMJ treatment were excluded from the study.

2.2. CBCT Evaluation. CBCT was used to evaluate condylar osseous conditions. CBCT scans were performed with a 256-slice CT scanner (J Morita Mfg. Corp., Kyoto, Japan) using the following parameters: tube voltage, 90 kVp; tube current, 5 mA; exposure time, 17.5 s; voxel size, 0.25 m; slice thickness, 0.25 mm; and field of view, $140 \times 100\ mm^2$. The condylar images were categorized into the following three groups based on the classification of the osseous diagnosis for TMJ [10, 16]:

2.2.1. Normal. The normal size of the condyle, no deformation, subcortical sclerosis, or articular surface flattening.

2.2.2. Indeterminate for Osteoarthrosis (OA). The normal size of the condyle with subcortical sclerosis or articular surface flattening; no condylar deformation; and condylar hypoplasia with normal condylar morphology but decreased size in all dimensions.

2.2.3. OA. Deformation caused by erosion, osteophyte, subcortical cyst, or generalized sclerosis and short condyles with decreased condylar height but continual cortical bone.

The osseous diagnosis was made by two independent assessors. Any disagreement about the classification was evaluated decisively by a third specialist.

2.3. Cephalometrics. All cephalograms were performed as per the standardized technique with natural head position and teeth in centric occlusion. The patients were instructed not to swallow when taking the cephalograms. The digital cephalograms obtained were traced using Uceph software (version 961, Chengdu, China). An experienced orthodontist, blinded to the diagnoses of the patients, performed the cephalogram tracing. The Frankfort horizontal plane was considered the reference plane, and 13 hyoid-related and 18 craniofacial measurements were performed (Figure 1; Table 1) [15, 17]. The intra- and inter-rater reliability of cephalometric tracing was tested, and the intra-class correlation coefficients were >0.8 [17, 18].

2.4. Statistical Analysis. Descriptive statistics were presented as mean ± standard deviation. All statistical analyses were performed with the *R* package (http://www.R-project.org, The R Foundation) and Empowerstats (http://www.empowerstats.com, X&Y Solutions, Inc., Boston, MA). An α level of 0.05 was considered statistically significant. The differences in the cephalometric measurements among the groups were evaluated through a one-way analysis of variance (ANOVA) when equal variances were assumed. $P > 0.05$ was considered statistically significant. After the ANOVA test, multiple comparisons between the groups were confirmed by using the S–N–K method. Separate stratified analyses were performed based on sex and age (<18 years vs. ≥18 years).

3. Results

3.1. Overall Analysis. Of the 427 subjects included in this study, 89 were classified into the normal group, 182 in the indeterminate group, and 156 in the OA group. Subjects in the indeterminate groups were statistically older than the other two groups ($P < 0.001$). The normal group exhibited a higher proportion of males than the other two groups ($P = 0.016$; Table 2).

The differences in five hyoid measurements, namely, Hy to MP, Hy-RGn, Hy to C3-RGn, C3-RGn, and Go-Hy-Me, were statistically significant. The differences in craniofacial measurements, namely, Frankfort-mandibular plane angle (FMA), saddle angle, articular angle, gonial angle, ramus height, and posterior facial height among the three groups, were statistically significant (Table 3).

After adjusting age and sex using the generalized additive model, the Hy-RGn and C3-RGn in the normal group were significantly greater than those in the OA group. The differences in ANB, FMA, saddle angle, articular angle, gonial angle, ramus height, posterior facial height, and overbite among the three groups were statistically significant (Table 4).

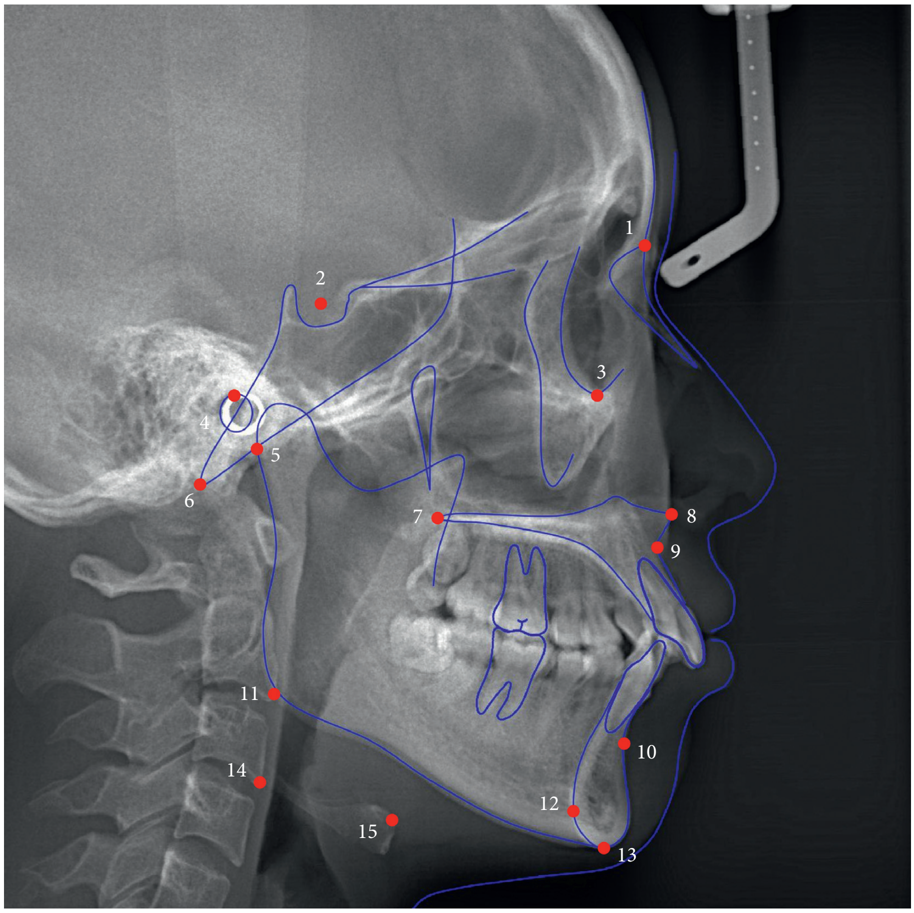

FIGURE 1: Landmarks used in this study. (1) N: nasion; (2) S: sella; (3) Or: orbitale; (4) P: porion; (5) Ar: articulare; (6) Ba: basion; (7) PNS: posterior nasal spine; (8) ANS: anterior nasal spine; (9) A: A point; (10) B: B point; (11) Go: gonion; (12) RGn: most protrusive point of retrognathion; (13) Me: menton; (14) C3: most anterior and inferior point of the third cervical vertebra; and (15) Hy: most anterior and superior point on the body of the hyoid bone.

3.2. Stratified Analysis Based on Sex. The female patients in the indeterminate OA group were older than those in the other two groups. The differences in Hy to MP, Hy to C3-RGn, and Go-Hy-Me among the three groups were statistically significant. The differences in FMA, FH-OP, gonial angle, ramus height, posterior cranial base length, and anterior and posterior facial height among the three groups were statistically significant (Table 5).

The male patients in the indeterminate OA group were older than those in the other two groups. No statistical differences were observed in hyoid measurements among the three groups. The differences in FMA, saddle, articular, and interincisal angles among the three groups were statistically significant (Table 6).

3.3. Stratified Analysis Based on Age. Patients <18 years of age in the normal group exhibited a greater proportion of males than the other two groups ($P = 0.016$). No statistical differences were observed in hyoid measurements. The differences in saddle angle, articular angle, ramus height, posterior cranial base length, posterior facial height, and SNB angle among the three groups were statistically significant (Table 7).

Adults in the indeterminate OA group were significantly older than those in the normal group ($P < 0.05$). The differences in Hy to SN, Hy to FH, Hy to PP, Hy to MP, Hy-RGn, Hy-C3, Hy to C3-RGn, Go-Hy-Me, Hy-S, and C3-Hy-S were statistically significant. The Hy-C3 in the indeterminate group was smaller than that in the normal group. The Go-Hy-Me angle in the indeterminate OA group was greater than that in the other two groups. The differences in the saddle angle, articular angle, ramus height, posterior cranial base length, posterior facial height, and SNB angle were statistically significant. Additionally, the differences among the three groups were statistically significant in ANB, FMA, FH-OP, articular angle, gonial angle, ramus height, and posterior facial height (Table 8).

4. Discussion

The present study investigated the hyoid position in patients with or without TMJOA using cephalograms and CBCT. The patients with condylar flattening or subcortical sclerosis were diagnosed with indeterminate OA as these radiological signs were a physiological phenomenon. The patients with indeterminate OA were attempted to be distinguished from those

Table 1: Hyoid and craniofacial measurements from cephalograms in this study.

Measurements	Definition
Hyoid measurements	
Hy-Ba (mm)	The distance between Hy point and Basion.
Hy to SN (mm)	The distance between the Hy point and the sella-nasion (SN) plane on a line perpendicular to the SN plane through the Hy point.
Hy to FH (mm)	The distance between the Hy point and the Frankfort horizontal (FH) plane on a line perpendicular to the FH plane through the Hy point.
Hy to PP (mm)	The distance between the Hy point and the palatal plane (PP) on a line perpendicular to the palatal plane through the Hy point.
Hy to MP (mm)	The distance between the Hy point and the mandibular plane (MP) on a line perpendicular to the MP plane through the Hy point. If the Hy point is inferior to the MP plane, the measurement is positive.
Hy-RGn (mm)	The distance between Hy point and RGn point.
Hy-C3 (mm)	The distance between Hy point and C3 point.
Hy to C3-RGn (mm)	The distance between the Hy point and the line formed by the C3 and RGn point on a line perpendicular to the C3-RGn line. If the Hy point is inferior to the C3-RGn line, the measurement is positive.
C3-RGN (mm)	The distance between C3 point and RGn point.
Go-Hy-Me	Angle formed by the Gonion-Hy line and the Hy-Menton line.
Hy-S (mm)	The distance between Hy point and sella.
Hy-C3-S (°)	Angle formed by the Hy-C3 line and the C3-sella line.
C3-Hy-S (°)	Angle formed by the Hy-C3 line and the Hy-sella line.
Craniofacial measurements	
SNA (°)	Angle between the SN plane and the nasion-A point line.
SNB (°)	Angle between the SN plane and the nasion-B point line.
ANB (°)	Angle between the nasion-A point line and the nasion-B point line.
Wits (mm)	The distance between vertical lines from A point and B point to the occlusal plane.
FMA (°)	Frankfurt-mandibular plane, formed by the mandibular plane and the FH angle.
FH-OP (°)	Angle formed by the occlusal plane and the FH angle.
Saddle angle (°)	Angle formed by the SN plane and the S-Ar line.
Articular angle (°)	Angle formed by the S-Ar line and the Ar-Go line.
Gonial angle (°)	Angle formed by the Ar-Go line and the mandibular plane.
Interincisal angle (°)	Angle formed the long axis of the upper incisor and low incisor.
Ramus height (mm)	Ar-Go, the distance between articulare and gonion.
Mandibular body length (mm)	Go-Me, the distance between gonion and menton.
Anterior cranial base length (mm)	S-N, the distance between sella and nasion.
Posterior cranial base length (mm)	S-Ar, the distance between sella and articulare.
Anterior facial height (mm)	N-Me, the distance between nasion and menton.
Posterior facial height (mm)	S-Go, the distance between sella and gonion.
Overjet (mm)	The horizontal distance between the upper and lower incisal edge with reference to the occlusal plane.
Overbite (mm)	The vertical overlap between the upper and lower incisal edge.

Table 2: Demographic data among the three groups.

	Normal ($N = 89$)	Indeterminate ($N = 182$)	BOA ($N = 156$)	P-value
Age (years)	20.32 ± 6.91	24.34 ± 7.69	20.90 ± 7.98	<0.001
Age categorical				
<18 years	35 (39.33%)	39 (21.43%)	59 (37.82%)	<0.001
>=18 years	54 (60.67%)	143 (78.57%)	97 (62.18%)	
Sex				
Female	53 (59.55%)	139 (76.37%)	111 (71.15%)	0.016
Male	36 (40.45%)	43 (23.63%)	45 (28.85%)	

with OA or completely normal condyles. Additionally, patients with inconsistent bilateral osseous status were excluded to prevent cephalometric errors. The differences in hyoid position and Hy to MP and Hy-RGn after adjusting age and sex between the three groups were statistically significant.

Although no study reported the relationship between hyoid bone position and TMJOA, a few studies investigated the relationship between hyoid bone position and TMD. A magnetic resonance imaging study observed that disc displacement was not related to hyoid bone position [14].

Table 3: Differences in hyoid and craniofacial measurements among the three groups.

	Normal ($N = 89$)	Indeterminate ($N = 182$)	BOA ($N = 156$)	P-value	
Hyoid measurements					
Hy-Ba (mm)	74.01 ± 8.20	73.18 ± 7.06	73.28 ± 8.42	0.698	
Hy to SN (mm)	102.76 ± 9.63	101.21 ± 8.19	102.01 ± 10.07	0.408	
Hy to FH (mm)	84.54 ± 8.39	82.63 ± 7.14	83.51 ± 8.58	0.171	
Hy to PP (mm)	60.03 ± 7.27	58.12 ± 6.19	58.81 ± 7.28	0.098	
Hy to MP (mm)	14.85 ± 5.33	12.05 ± 5.42	13.58 ± 4.95	<0.001	Indeterminate < normal, OA
Hy-RGn (mm)	35.06 ± 5.51	33.69 ± 5.45	32.68 ± 5.28	0.004	OA < normal
Hy-C3 (mm)	33.15 ± 3.99	32.15 ± 3.74	32.36 ± 3.87	0.128	
Hy to C3-RGn (mm)	3.92 ± 9.20	1.12 ± 8.39	1.37 ± 8.58	0.033	OA, indeterminate < normal
C3-RGN (mm)	65.23 ± 7.86	63.60 ± 6.97	62.64 ± 7.02	0.026	OA < normal
Go-Hy-Me	132.47 ± 15.45	140.71 ± 16.61	135.37 ± 15.31	<0.001	Normal, OA < indeterminate
Hy-S (mm)	103.09 ± 9.68	101.54 ± 8.20	102.33 ± 10.09	0.409	
Hy-C3-S (°)	92.48 ± 11.24	91.62 ± 11.33	91.82 ± 11.57	0.840	
C3-Hy-S (°)	94.54 ± 9.56	93.67 ± 7.28	94.23 ± 8.57	0.684	
Craniofacial measurements					
SNA (°)	81.79 ± 3.18	82.36 ± 3.69	82.21 ± 3.41	0.451	
SNB (°)	78.88 ± 3.56	79.12 ± 3.80	78.37 ± 4.33	0.217	
ANB (°)	2.92 ± 2.78	3.24 ± 3.11	3.84 ± 3.49	0.065	
Wits (mm)	0.52 ± 3.99	0.23 ± 4.52	0.75 ± 5.34	0.598	
FMA (°)	22.82 ± 5.56	23.31 ± 6.07	25.93 ± 6.39	<0.001	Normal, indeterminate < OA
FH-OP (°)	6.04 ± 4.95	6.57 ± 4.33	7.21 ± 4.63	0.141	
Saddle angle (°)	123.76 ± 4.11	122.90 ± 4.78	121.89 ± 4.58	0.007	OA < normal
Articular angle (°)	150.55 ± 5.57	152.19 ± 6.68	153.67 ± 6.70	0.001	Normal < indeterminate, OA
Gonial angle (°)	117.21 ± 6.80	116.99 ± 7.22	119.30 ± 7.67	0.010	Indeterminate, normal < OA
Interincisal angle (°)	124.68 ± 13.34	124.15 ± 13.73	121.96 ± 13.54	0.213	
Ramus height (mm)	46.09 ± 5.74	46.61 ± 4.83	44.29 ± 5.51	<0.001	OA < normal, indeterminate
Mandibular body length (mm)	69.90 ± 5.69	70.07 ± 5.15	69.15 ± 5.57	0.275	
Anterior cranial base length (mm)	63.48 ± 3.67	63.37 ± 3.36	63.14 ± 3.44	0.730	
Posterior cranial base length (mm)	34.32 ± 3.88	33.94 ± 3.14	33.24 ± 3.98	0.056	
Anterior facial height (mm)	113.78 ± 8.10	114.87 ± 7.68	114.89 ± 8.15	0.512	
Posterior facial height (mm)	77.75 ± 8.24	78.12 ± 6.44	75.42 ± 7.63	0.002	OA < indeterminate
Overjet (mm)	3.89 ± 3.02	4.06 ± 2.79	4.33 ± 3.16	0.501	
Overbite (mm)	2.93 ± 1.67	2.72 ± 1.92	2.36 ± 2.51	0.103	

Table 4: Differences in hyoid and craniofacial measurements among the three groups after adjusting age and sex[a].

	Normal ($N = 89$)	Indeterminate ($N = 182$)	OA ($N = 156$)	P-value
Hyoid measurements				<0.001
Hy-RGn (mm)	34.86 (33.74, 35.99)	33.80 (33.01, 34.59)	32.66 (31.82, 33.51)	0.002
C3-RGN (mm)	65.10 (63.60, 66.59)	63.56 (62.51, 64.61)	62.76 (61.64, 63.88)	0.016
Craniofacial measurements				0.016
ANB (°)	2.88 (2.21, 3.55)	3.24 (2.77, 3.72)	3.85 (3.35, 4.36)	0.017
FMA (°)	22.86 (21.59, 24.13)	23.38 (22.49, 24.27)	25.83 (24.87, 26.78)	<0.001
Saddle angle (°)	123.94 (122.99, 124.90)	122.76 (122.09, 123.43)	121.94 (121.23, 122.66)	0.001
Articular angle (°)	150.71 (149.35, 152.06)	152.01 (151.06, 152.96)	153.79 (152.77, 154.81)	<0.001
Gonial angle (°)	117.07 (115.55, 118.58)	117.27 (116.20, 118.33)	119.07 (117.93, 120.20)	0.021
Ramus height (mm)	45.90 (44.88, 46.93)	46.49 (45.77, 47.21)	44.53 (43.76, 45.30)	0.009
Posterior facial height (mm)	77.23 (75.88, 78.59)	78.13 (77.18, 79.08)	75.70 (74.68, 76.72)	0.023
Overbite	2.88 (2.44, 3.32)	2.74 (2.43, 3.05)	2.36 (2.03, 2.70)	0.049

[a]Data in the table: adjust mean (95% confidence interval); only measurements with statistical differences are illustrated.

Câmara-Souza et al. observed no relationship between TMD and hyoid bone position in 80 dental students [19]. Ekici and Camci reported that the hyoid bone in patients with TMD was located closer to the cranium [15]. The inconsistencies in the findings of these studies may be probably due to inconsistent diagnostic criteria, heterogeneity in sample selection, and methodological differences. Although the relationship between hyoid bone position and TMD is debated, the abnormality of the hyoid bone is often related to cervical painful symptomatology that could be claimed by TMD patients [20, 21]. Nathan et al. detected a release of the hyoid bone away from the floor of the mouth in patients resolved of myofascial pain [22]. These not only support that these structures are anatomically and functionally related

Table 5: Differences in hyoid and craniofacial measurements among the three groups in female subjects.

	Normal ($N = 53$)	Indeterminate ($N = 139$)	OA ($N = 111$)	P-value
Age	22.69 ± 7.25	25.78 ± 7.32	21.85 ± 8.41	<0.001
Hyoid measurements				
Hy-Ba (mm)	71.17 ± 7.10	71.28 ± 6.00	70.10 ± 5.80	0.293
Hy to SN (mm)	99.05 ± 7.61	98.81 ± 6.27	97.84 ± 6.62	0.420
Hy to FH (mm)	81.13 ± 6.35	80.67 ± 5.74	80.01 ± 5.96	0.481
Hy to PP (mm)	57.14 ± 5.66	56.58 ± 5.18	55.93 ± 5.06	0.355
Hy to MP (mm)	13.24 ± 4.78	11.14 ± 5.14	12.51 ± 4.61	0.012
Hy-RGn (mm)	34.28 ± 4.76	33.17 ± 4.78	32.49 ± 5.33	0.098
Hy-C3 (mm)	32.28 ± 3.78	31.39 ± 3.19	31.27 ± 3.26	0.170
Hy to C3-RGn (mm)	3.65 ± 7.54	-0.09 ± 7.34	0.23 ± 6.57	0.004
C3-RGN (mm)	64.41 ± 7.11	62.84 ± 5.92	62.34 ± 6.96	0.162
Go-Hy-Me	136.37 ± 15.29	143.20 ± 16.19	137.91 ± 15.02	0.005
Hy-S (mm)	99.34 ± 7.56	99.13 ± 6.30	98.14 ± 6.62	0.407
Hy-C3-S (°)	89.78 ± 11.72	90.83 ± 11.40	89.64 ± 10.39	0.671
C3-Hy-S (°)	92.45 ± 8.50	91.87 ± 6.17	91.92 ± 6.95	0.866
Craniofacial measurements				
SNA (°)	81.67 ± 2.90	81.97 ± 3.68	81.91 ± 3.36	0.868
SNB (°)	79.06 ± 3.35	78.84 ± 3.77	78.09 ± 4.14	0.200
ANB (°)	2.61 ± 2.45	3.13 ± 3.05	3.81 ± 3.55	0.055
Wits (mm)	-0.03 ± 3.97	-0.00 ± 4.35	0.21 ± 5.03	0.922
FMA (°)	22.50 ± 5.37	23.85 ± 6.11	26.36 ± 6.15	<0.001
FH-OP (°)	6.16 ± 4.97	6.73 ± 4.34	7.88 ± 4.37	0.039
Saddle angle (°)	123.71 ± 3.82	123.14 ± 4.74	122.48 ± 4.26	0.217
Articular angle (°)	151.06 ± 5.89	152.55 ± 6.81	153.25 ± 6.87	0.148
Gonial angle (°)	116.53 ± 6.12	117.22 ± 7.42	119.95 ± 7.74	0.004
Interincisal angle (°)	124.32 ± 13.97	124.42 ± 14.08	123.25 ± 14.33	0.793
Ramus height (mm)	45.13 ± 4.93	45.85 ± 4.61	42.87 ± 4.65	<0.001
Mandibular body length (mm)	69.29 ± 5.39	69.46 ± 4.61	68.09 ± 5.46	0.089
Anterior cranial base length (mm)	62.75 ± 3.56	62.64 ± 3.04	62.27 ± 3.05	0.553
Posterior cranial base length (mm)	33.26 ± 3.35	33.10 ± 2.55	32.08 ± 3.07	0.009
Anterior facial height (mm)	111.30 ± 6.91	113.95 ± 6.92	112.64 ± 6.68	0.045
Posterior facial height (mm)	75.87 ± 6.72	76.63 ± 5.54	72.84 ± 5.68	<0.001
Overjet (mm)	4.06 ± 2.59	3.86 ± 2.60	4.01 ± 2.98	0.870
Overbite (mm)	2.82 ± 1.50	2.55 ± 1.84	2.29 ± 2.24	0.248

but also imply that the position of hyoid bone might be an indicator or a contributing factor of painful TMJOA.

A larger proportion of patients in the OA and indeterminate OA group were female. This finding is concurrent with that of other studies [18, 23]. The patients in the indeterminate OA group were older than the other two groups, with a higher percentage of adults, indicating an age-related change in the condyles [24]. This change could be a normal physiological change [25], resulting from condylar remodeling after mild inflammation or a transition stage to OA [26]. In the OA group, 37.82% were aged less than 18 years, indicating that TMJOA can occur early. Studies have reported the mean age of TMJOA patients as 34 years. This finding is in contrast with that of the present study, where patients with OA were younger. This may be because the patients included in the present study were those undergoing preorthodontic examinations, which consists of most adolescents and young adults. Thus, another population in which TMJOA occurs, namely, the climacteric women aged 40–55 years, was not included.

The present study observed that patients with OA exhibited the largest ANB angle, gonial angle, smaller ramus height, and posterior facial height. The differences in the cephalometric persisted even after adjusting for sex and age, suggesting that patients with OA exhibit clockwise-rotated mandibles with low posterior facial height. This finding is concurrent with that of other studies [10, 27, 28]. Stratified analysis exhibited that ramus height and posterior facial height deficiency were more significant in females, whereas no significant differences were observed in males among the three groups. This may be related to the fluctuations in estrogen. Estrogen has multiple effects on TMJ, such as stimulating bone formation and inhibiting bone resorption [29]. Estrogen levels in women may fluctuate during puberty and near menopause, affecting the stability of the intra-articular environment [30]. On the other hand, androgens are a protective factor in TMD, inhibiting the inflammatory response and reducing pain. Overall, the craniofacial characteristics of the present study population were generally consistent with those of other studies, allowing the generalization of our results.

Ekici and Camci investigated 113 adults, with 55 patients with TMD and 58 healthy volunteers. They observed that adult patients with TMD exhibited hyoid bones closer to the cranium and larger Go-Hy-Me angle [31]. In the present study, adult patients with TMJOA

TABLE 6: Differences in hyoid and craniofacial measurements among the three groups in male subjects.

	Normal ($N = 36$)	Indeterminate ($N = 43$)	OA ($N = 45$)	P-value
Age	16.83 ± 4.58	19.69 ± 7.06	18.55 ± 6.31	0.123
Hyoid measurements				
Hy-Ba (mm)	78.19 ± 8.00	79.33 ± 6.78	81.13 ± 8.80	0.242
Hy to SN (mm)	108.22 ± 9.76	108.96 ± 8.90	112.28 ± 9.80	0.116
Hy to FH (mm)	89.57 ± 8.58	88.98 ± 7.57	92.14 ± 7.98	0.153
Hy to PP (mm)	64.30 ± 7.34	63.12 ± 6.60	65.91 ± 7.09	0.176
Hy to MP (mm)	17.21 ± 5.29	15.00 ± 5.34	16.22 ± 4.83	0.164
Hy-RGn (mm)	36.21 ± 6.34	35.37 ± 6.99	33.16 ± 5.19	0.071
Hy-C3 (mm)	34.42 ± 3.99	34.59 ± 4.34	35.03 ± 3.99	0.782
Hy to C3-RGn (mm)	4.31 ± 11.31	5.02 ± 10.30	4.18 ± 11.83	0.932
C3-RGN (mm)	66.43 ± 8.82	66.05 ± 9.28	63.40 ± 7.20	0.202
Go-Hy-Me	126.73 ± 14.02	132.66 ± 15.51	129.12 ± 14.31	0.196
Hy-S (mm)	108.62 ± 9.91	109.31 ± 8.84	112.68 ± 9.76	0.114
Hy-C3-S (°)	96.46 ± 9.29	94.16 ± 10.85	97.19 ± 12.64	0.422
C3-Hy-S (°)	97.62 ± 10.30	99.50 ± 7.62	99.92 ± 9.54	0.504
Craniofacial measurements				
SNA (°)	81.96 ± 3.59	83.62 ± 3.45	82.96 ± 3.43	0.113
SNB (°)	78.60 ± 3.89	80.03 ± 3.81	79.05 ± 4.74	0.298
ANB (°)	3.36 ± 3.18	3.59 ± 3.31	3.91 ± 3.37	0.756
Wits (mm)	1.33 ± 3.93	0.97 ± 5.03	2.09 ± 5.88	0.573
FMA (°)	23.30 ± 5.86	21.57 ± 5.66	24.87 ± 6.91	0.048
FH-OP (°)	5.87 ± 4.98	6.04 ± 4.29	5.57 ± 4.89	0.896
Saddle angle (°)	123.84 ± 4.55	122.09 ± 4.89	120.45 ± 5.05	0.009
Articular angle (°)	149.79 ± 5.05	151.01 ± 6.17	154.71 ± 6.23	<0.001
Gonial angle (°)	118.23 ± 7.68	116.26 ± 6.54	117.71 ± 7.32	0.440
Interincisal angle (°)	125.22 ± 12.51	123.27 ± 12.64	118.77 ± 10.85	0.046
Ramus height (mm)	47.50 ± 6.57	49.04 ± 4.77	47.80 ± 5.93	0.442
Mandibular body length (mm)	70.80 ± 6.06	72.02 ± 6.27	71.76 ± 5.01	0.620
Anterior cranial base length (mm)	64.56 ± 3.59	65.72 ± 3.31	65.30 ± 3.41	0.323
Posterior cranial base length (mm)	35.88 ± 4.13	36.65 ± 3.35	36.10 ± 4.52	0.677
Anterior facial height (mm)	117.43 ± 8.44	117.83 ± 9.21	120.44 ± 8.86	0.241
Posterior facial height (mm)	80.53 ± 9.50	82.92 ± 6.87	81.80 ± 8.11	0.433
Overjet (mm)	3.64 ± 3.58	4.68 ± 3.29	5.13 ± 3.48	0.153
Overbite (mm)	3.08 ± 1.90	3.26 ± 2.07	2.54 ± 3.10	0.359

TABLE 7: Differences in hyoid and craniofacial measurements among the three groups in subjects aged <18 years.

	Normal ($N = 35$)	Indeterminate ($N = 39$)	OA ($N = 59$)	P-value
Age (years)	13.30 ± 1.68	13.76 ± 1.86	13.44 ± 1.71	0.496
Sex				
Female	14 (40.00%)	20 (51.28%)	40 (67.80%)	0.026
Male	21 (60.00%)	19 (48.72%)	19 (32.20%)	
Hyoid measurements				
Hy-Ba (mm)	73.16 ± 8.98	75.77 ± 6.81	71.72 ± 8.81	0.066
Hy to SN (mm)	101.70 ± 10.00	104.43 ± 8.20	100.31 ± 10.27	0.119
Hy to FH (mm)	84.19 ± 8.76	85.06 ± 6.65	82.10 ± 8.73	0.187
Hy to PP (mm)	60.16 ± 7.43	60.09 ± 5.74	57.56 ± 7.53	0.117
Hy to MP (mm)	16.44 ± 4.68	14.85 ± 4.22	14.32 ± 5.08	0.109
Hy-RGn (mm)	34.41 ± 6.29	33.49 ± 5.52	32.96 ± 5.46	0.496
Hy-C3 (mm)	32.42 ± 4.17	32.06 ± 4.79	31.00 ± 3.92	0.240
Hy to C3-RGn (mm)	3.17 ± 10.50	1.85 ± 10.08	0.30 ± 9.55	0.392
C3-RGN (mm)	63.20 ± 9.03	62.20 ± 8.08	61.06 ± 7.26	0.445
Go-Hy-Me	126.17 ± 12.68	131.96 ± 12.49	132.59 ± 15.24	0.079
Hy-S (mm)	102.09 ± 10.11	104.83 ± 8.17	100.67 ± 10.37	0.119
Hy-C3-S (°)	93.83 ± 12.17	96.08 ± 9.68	93.62 ± 11.99	0.547
C3-Hy-S (°)	92.70 ± 9.68	94.79 ± 8.40	91.69 ± 7.50	0.203
Craniofacial measurements				0.573
SNA (°)	81.11 ± 3.39	82.92 ± 4.28	82.32 ± 3.68	0.120
SNB (°)	77.42 ± 3.04	79.69 ± 4.14	78.26 ± 4.38	0.048

Table 7: Continued.

	Normal ($N = 35$)	Indeterminate ($N = 39$)	OA ($N = 59$)	P-value
ANB (°)	3.69 ± 3.03	3.23 ± 2.98	4.05 ± 3.16	0.432
Wits (mm)	1.13 ± 3.86	0.80 ± 4.60	1.40 ± 4.67	0.808
FMA (°)	24.78 ± 5.76	23.81 ± 6.49	25.79 ± 5.59	0.267
FH-OP (°)	7.37 ± 5.48	5.83 ± 4.61	6.70 ± 4.47	0.381
Saddle angle (°)	124.54 ± 4.88	122.18 ± 4.75	121.82 ± 5.25	0.034
Articular angle (°)	149.67 ± 6.19	150.31 ± 5.97	152.61 ± 6.10	0.048
Gonial angle (°)	119.75 ± 6.53	119.23 ± 7.76	120.14 ± 7.45	0.834
Interincisal angle (°)	123.38 ± 13.30	125.45 ± 14.37	121.98 ± 14.79	0.501
Ramus height (mm)	43.35 ± 5.41	45.28 ± 5.03	42.82 ± 3.92	0.038
Mandibular body length (mm)	67.44 ± 5.25	69.62 ± 5.70	67.79 ± 5.79	0.184
Anterior cranial base length (mm)	62.76 ± 3.58	63.31 ± 3.67	62.86 ± 3.57	0.772
Posterior cranial base length (mm)	33.90 ± 3.76	35.05 ± 3.31	33.03 ± 3.90	0.032
Anterior facial height (mm)	112.39 ± 8.64	113.99 ± 8.63	112.23 ± 7.41	0.545
Posterior facial height (mm)	74.50 ± 7.63	77.61 ± 7.12	73.65 ± 6.81	0.026
Overjet (mm)	4.72 ± 2.99	4.64 ± 2.95	5.02 ± 3.10	0.804
Overbite (mm)	3.14 ± 1.80	2.99 ± 2.04	2.67 ± 2.44	0.556

Table 8: Differences in hyoid and craniofacial measurements among the three groups in adults.

	Normal ($N = 54$)	Indeterminate ($N = 143$)	OA ($N = 97$)	P-value
Age (years)	24.87 ± 4.88	27.23 ± 5.94	25.44 ± 6.79	0.017
Sex				
Female	39 (72.22%)	119 (83.22%)	71 (73.20%)	0.100
Male	15 (27.78%)	24 (16.78%)	26 (26.80%)	
Hyoid measurements				
Hy-Ba (mm)	74.56 ± 7.70	72.47 ± 6.99	74.23 ± 8.08	0.099
Hy to SN (mm)	103.45 ± 9.41	100.32 ± 7.99	103.04 ± 9.86	0.023
Hy to FH (mm)	84.77 ± 8.22	81.97 ± 7.14	84.37 ± 8.42	0.020
Hy to PP (mm)	59.95 ± 7.23	57.59 ± 6.22	59.57 ± 7.05	0.025
Hy to MP (mm)	13.81 ± 5.52	11.28 ± 5.48	13.13 ± 4.85	0.003
Hy-RGn (mm)	35.49 ± 4.95	33.74 ± 5.45	32.51 ± 5.20	0.004
Hy-C3 (mm)	33.61 ± 3.83	32.17 ± 3.42	33.18 ± 3.61	0.016
Hy to C3-RGn (mm)	4.40 ± 8.32	0.92 ± 7.90	2.02 ± 7.91	0.025
C3-RGN (mm)	66.54 ± 6.77	63.98 ± 6.61	63.61 ± 6.73	0.026
Go-Hy-Me	136.55 ± 15.82	143.10 ± 16.83	137.06 ± 15.18	0.005
Hy-S (mm)	103.75 ± 9.44	100.64 ± 8.00	103.34 ± 9.83	0.024
Hy-C3-S (°)	91.61 ± 10.62	90.40 ± 11.48	90.73 ± 11.22	0.796
C3-Hy-S (°)	95.74 ± 9.38	93.37 ± 6.95	95.77 ± 8.84	0.042
Craniofacial measurements				0.048
SNA (°)	82.23 ± 2.99	82.21 ± 3.51	82.15 ± 3.24	0.986
SNB (°)	79.82 ± 3.59	78.96 ± 3.71	78.43 ± 4.32	0.113
ANB (°)	2.41 ± 2.51	3.24 ± 3.15	3.71 ± 3.69	0.062
Wits (mm)	0.12 ± 4.06	0.07 ± 4.51	0.36 ± 5.70	0.902
FMA (°)	21.55 ± 5.07	23.18 ± 5.96	26.01 ± 6.87	<0.001
FH-OP (°)	5.18 ± 4.41	6.77 ± 4.24	7.52 ± 4.72	0.009
Saddle angle (°)	123.25 ± 3.48	123.09 ± 4.79	121.93 ± 4.15	0.084
Articular angle (°)	151.12 ± 5.11	152.70 ± 6.79	154.31 ± 7.00	0.015
Gonial angle (°)	115.57 ± 6.51	116.38 ± 6.97	118.80 ± 7.79	0.010
Interincisal angle (°)	125.53 ± 13.42	123.80 ± 13.57	121.95 ± 12.80	0.267
Ramus height (mm)	47.87 ± 5.26	46.97 ± 4.73	45.19 ± 6.13	0.006
Mandibular body length (mm)	71.49 ± 5.43	70.19 ± 5.00	69.97 ± 5.30	0.199
Anterior cranial base length (mm)	63.95 ± 3.68	63.39 ± 3.29	63.32 ± 3.36	0.512
Posterior cranial base length (mm)	34.59 ± 3.97	33.64 ± 3.03	33.37 ± 4.03	0.121
Anterior facial height (mm)	114.69 ± 7.69	115.11 ± 7.41	116.50 ± 8.20	0.273
Posterior facial height (mm)	79.86 ± 7.99	78.26 ± 6.26	76.50 ± 7.92	0.019
Overjet (mm)	3.36 ± 2.94	3.90 ± 2.73	3.91 ± 3.14	0.464
Overbite (mm)	2.79 ± 1.58	2.64 ± 1.88	2.18 ± 2.55	0.138

exhibited hyoid bones closer to the cranium and mandible. In contrast, patients with indeterminate OA exhibited a Go-Hy-Me angle larger than the other two groups. The OA group exhibited a slightly larger Go-Hy-Me angle than the normal group. However, this difference was statistically nonsignificant. Possible reasons for this finding might be the older age of the patients in the indeterminate OA group than that in the other two groups or the muscle compensations for the joints demonstrated in the patients with indeterminate OA, which could affect the hyoid bone position. Andrade et al. evaluated the relative position of the hyoid bone concerning the third cervical vertebra. They observed no difference in hyoid bone position between 17 adult patients with TMD and 17 healthy volunteers [31]. The hyoid bone was closer to the third cervical vertebrae in the indeterminate OA group than normal. However, no difference was observed between the OA and the normal group. The distance between the hyoid bone and third cervical vertebrae was related to the upper airway space [9]. Our results revealed that the relative position of the hyoid bone to the third cervical vertebra in patients with indeterminate OA might be more unique. Further studies are required to clarify the characteristics of the hyoid bone position in patients with indeterminate OA.

In the present study, the differences in more parameters among adults and females were statistically significant than between adolescents and males. Adolescents still have growth potential. Therefore, adolescents have more variability in their cephalometric parameters, which may account for the inability to derive statistical differences. For males, indicators such as Hy-RGn did not yield statistical differences due to the relatively small sample size. Further studies with a larger sample size for males may better evaluate the differences in some hyoid indicators. Different patterns of differences in hyoid bone position in different sexes and age groups may be observed. Thus, future studies subdividing the populations are required. In clinical practice, when evaluating the hyoid position, the age and sex of the patient should be considered to obtain an accurate diagnosis.

The main limitation of this study is its cross-sectional design. Therefore, no causal relationship can be built between the hyoid position and OA. Future longitudinal studies are necessary to clarify the causal relationship. Additionally, the hyoid bone and cranium measurements were two-dimensional, and three-dimensional measurements could be used to explore the relationship between the bilateral TMJ and the position and size of the hyoid bone [32].

5. Conclusion

Hyoid bone position, mainly relative to the mandible, differs in patients with or without TMJOA. The pattern of differences varies in different age and sex groups. Clinicians should be aware that the patients might have with abnormal position. Clinical evaluation of the hyoid position might be required to consider the age and sex of the patients. Longitudinal studies are required to clarify the causal relationship between TMJOA and hyoid bone position.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Xueman Zhou and Xin Xiong contributed equally to this work. Xueman Zhou and Xin Xiong are co-first authors.

Acknowledgments

This work was supported by National Natural Science Foundation of China (nos. 81771114 and 81970967), Sichuan Science and Technology Program (no. 2020YFS0173), and Research and Develop Program, West China Hospital of Stomatology, Sichuan University (RD-03-202101). The authors acknowledge TopEdit LLC for the linguistic editing and proofreading during the preparation of this manuscript.

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