USG Imaging in Orthodontics

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15.1 Introduction

Orthodontics is the art and science that considers harmonizing crowded teeth, jaw relationships, abnormal teeth bites, and circumoral muscles and

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deals with jaw orthopedics in children/adults that may need surgery-assistant prosedures [1].

The understanding of the complex anatomy, correlations, and adjacent structures of the craniofacial skeleton is essential for treatment planning and management. Radiographic scanning is the complementary part of the entire evaluation of the orthodontic cases. In orthodontic practice, the aim of the imaging involves ensuring additional information for the diagnosis of skeletal/dental problems, soft tissues, and their interrelationships [2].

The radiographic findings obtained from conventional diagnostic tools (e.g., panoramic and lateral cephalometric images) have been integrated with clinical data for orthodontic diagnosis and planning, assessment of growth and development, and evaluation of treatment course and outcomes [2].

Every technique has its own advantages, disadvantages, and limitations [3]. However, the potential risks of radiography, some investigators have been directed to the new methodologies [4]. Ultrasonography (USG) has been utilized in the medical field as a diagnostic and therapeutic device [5]. Ultrasound is a recently introduced field of application in dentistry. Since the first study by Baum et al. [6], in dental practice, many different and new usages of Ultrasound imaging have been stated.

The aim of this chapter is to give an overview of the applications of USG in orthodontic clinics and broadening researchers' horizons depending on the recent studies in the literature.

15.2 Evaluation of the Muscles of Mastication

Orthodontic treatment planning is, not to stand completely on biomechanical considerations, but it needs consideration of the maxillofacial muscular component of each case. The craniofacial muscles have assumed to be a great significance in treatment stages, including the etiology and active treatment of occlusal problems and deformation of the jaw, and the stability of treatment [7].

Among imaging modalities, it has been demonstrated that USG has a capability for providing information by displaying muscle structural changing[8] (Fig. 15.1). Ultrasound imaging is usually performed on the superficial tissues in the maxillofacial area, as the hard tissues absorbed the sound waves and the sound beam can not transmit deep tissues [8–10]. Also, the transducer can not always cover the cross-sectional area of the muscle [11, 12]. Despite the disadvantages of the technique, USG offers important advantages, which made it proper for longitudinal researches, especially in children [11–13].

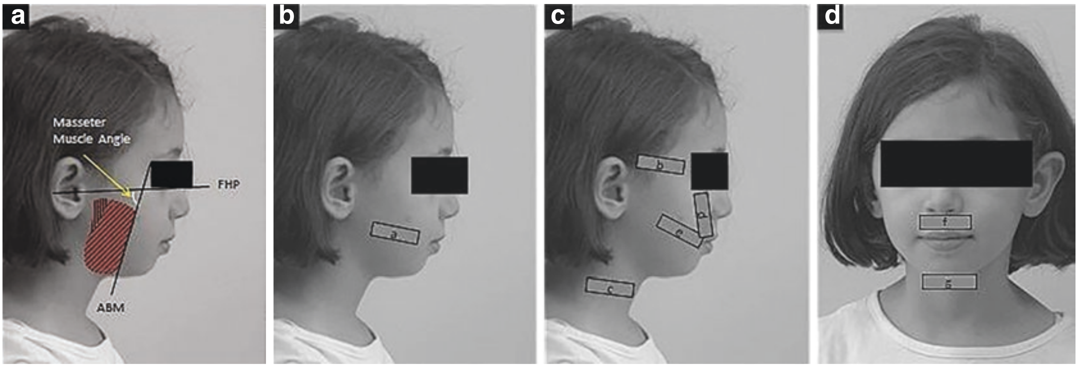


Fig. 15.1 (**a**) Masseter muscle angle is defined as the angle between the FHP (Frankfort Horizontal Plane) and ABM (Anterior Border of Masseter muscle). (**b**–**d**) Schematic representation of the ultrasound transducer placement on volunteer for the (**a**) masseter, (**b**) anterior portion of temporalis, (**c**) sternocleidomastoid muscle, (d) levator labii superioris, (**e**) zygomaticus major, (**f**) orbicularis oris, and (**g**) anterior digastric muscles

Ultrasound has been represented as a reliable imaging method for accurately measuring the thickness and cross-sectional area of the masticatory muscles and for calculating changes in local cross-sectional parameters of the craniofacial muscle groups in vivo [11–21].

The thickness measurement has been utilized commonly in studies that evaluated Ultrasound imaging of masticatory muscles. Also, the crosssections, transversal areas, and the transverse dimensions have been evaluated [13, 22–24]. The images have obtained unilaterally and bilaterally, in the course of relaxation and/or contraction [25].

15.2.1 Masseter

The masseter was the most common masticatory muscle investigated [25]. The muscle's thickness, cross-sectional area, volume, and length have been used for the morphometric analysis of the masseter (Fig. 15.2). It is possible to make comparisons, as it constitutes objective data [26, 27].

Several studies investigated the measurements of the masseter muscle by USG within different conditions, including correlations between the thickness of masseter and facial morphology [15, 19, 20, 28–33], dental arch width [34, 35], thickness of alveolar process, mandibular symphysis, mandibular inclination [20], and integrated orthodontic treatment/functional appliances outcome [36–39].

USG has been utilized for thickness and/or cross-sections to explore the interactions with temporomandibular joint dysfunction (TMD), muscle palpation pain, facial morphology, bite force, and occlusal factors, specifically of the incisors and molars [15].

It has also evaluated the relationships between the masseter muscle volume and selected cephalometric values with USG [40].

In the literature, we determined the significant inhomogeneity in the published studies' data. The measurement of the masseter muscle with ultrasound imaging is offered in different analyzes as an accurate method, reliable, and reproducible. However, in future researches, to increase the value of the methodology and results of the studies, data may need to be exhibited and analyzed in new hypothesis tests, also taking into account the heterogeneity of the studies.

15.2.2 Temporalis

After the masseter muscle, the most second masticatory muscle studied [25].

A study conducted by Rasheed et al. [41], reported that patients with an open or deep bite in the mixed dentition have a statistically thicker anterior temporalis muscle than patients with

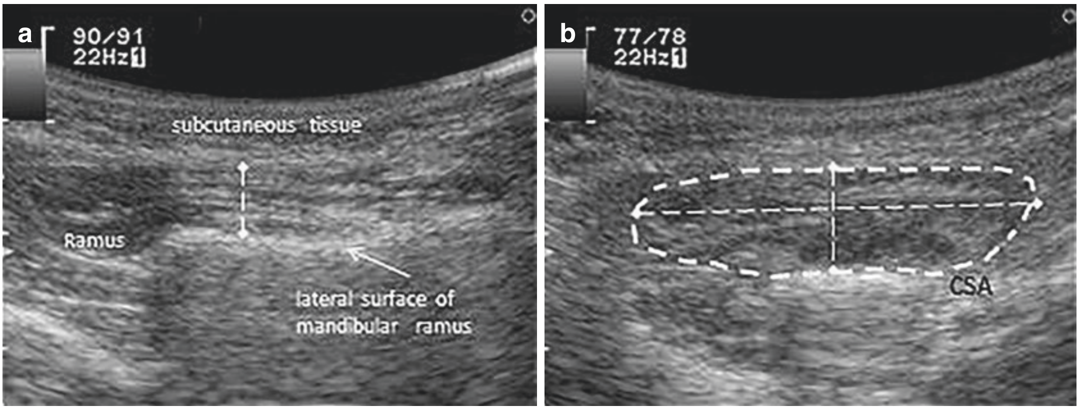


Fig. 15.2 Transverse ultrasound image of (**a**) relaxed and (**b**) contracted left masseter muscle demonstrating the measurement of length (horizontal dotted line), thickness (vertical dotted lines), and cross-sectional area (CSA)

normal occlusion. Castelo et al. [42] compared the normal and crossbite sides, the mixed-crossbite group presented a significantly thicker anterior temporalis muscle at rest for the crossbite side than the normal side.

15.2.3 Other Muscles of the Stomatognathic System

The medial and lateral pterygoid muscles have not been assessed with USG, as they are not superficial muscles, and thus they do not diagnose on the ultrasound imaging, clearly [25].

Raadsheer et al. [43] examined the correlations between bite force (magnitude and directions), facial morphology, and masticatory muscle thickness (masseter, temporalis, and digastric muscle). A preliminary study by Macrae et al. [44] reported that USG is an effective imaging method for the measurement of the anterior belly of the digastric muscle and submental muscle group (Fig. 15.3). In addition, the authors have concluded that on MRI imaging, measuring the cross-sectional area of the geniohyoid muscle and mylohyoid muscle thickness was not possible, as poor border representation.

Şatıroğlu et al. [45] investigated the thickness of the masseter, *levator labii superioris*, and zygomaticus major muscles by USG and evaluated the correlation between facial and masticatory muscle thickness and vertical facial morphology. The authors found that masseter muscle thickness was significantly associated with vertical facial measurements, but the facial muscles were not correlated with the vertical facial morphology.

Several authors explored the relationship between the *orbicularis oris* muscle and malocclusion states [46], treatment outcomes [47, 48], and skeletal and dental variables [49] (Fig. 15.4).

A study by Coclici et al. [50] used ultrasound device for displaying the posttreatment muscular alterations in class II and class III malocclusion patients and measured the length, width, and cross-sectional area of the masseter and suprahyoid muscles (mylohyoid and geniohyoid muscle). Variable adaptive response to orthognathic surgery has been detected in the mandibular muscles.

Impellizzeri et al. [51] aimed to evaluate the association between the masticatory and cervical muscles (temporalis, masseter, and sternocleidomastoid) thickness and facial asymmetries in young individuals (Fig. 15.5). It has been concluded that a significant relationship between facial asymmetries and masticatory and cervical musculature, and there are thinner muscles in the

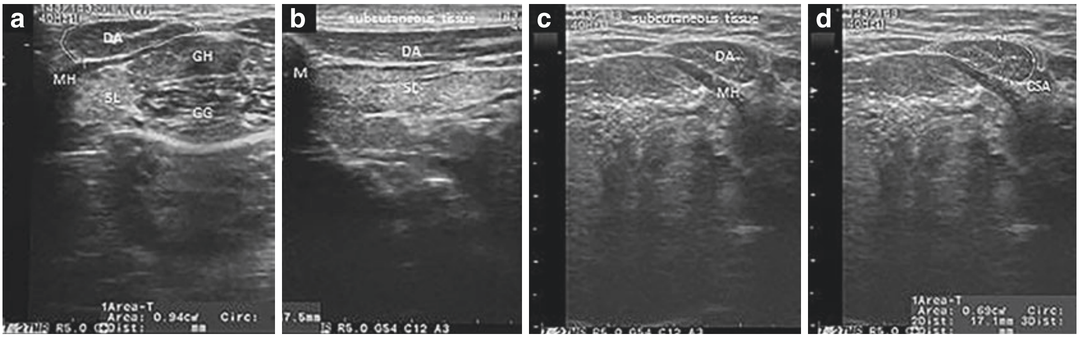


Fig. 15.3 Gray-scale transverse (**a**) and longitudinal (**b**) USG of the right anterior digastric muscle measured using electronic cursors to instantaneously calculate the cross-sectional area. (**a**) Transversal ultrasound image of the left anterior digastric muscle (**c**, **d**). Image demonstrating the measurement of length (horizontal dotted line), thickness (vertical dotted line), and cross-sectional area (CSA) measurement made by manually tracing around the circumference of the muscle with an electronic caliper (**d**). *DA* Anterior belly of Digastrics Muscle, *MH* Mylohyoid Muscle, *GH* Geniohyoid muscle, *GG* Genioglossus muscle, *SL* Sublingual gland, *M* Mandible

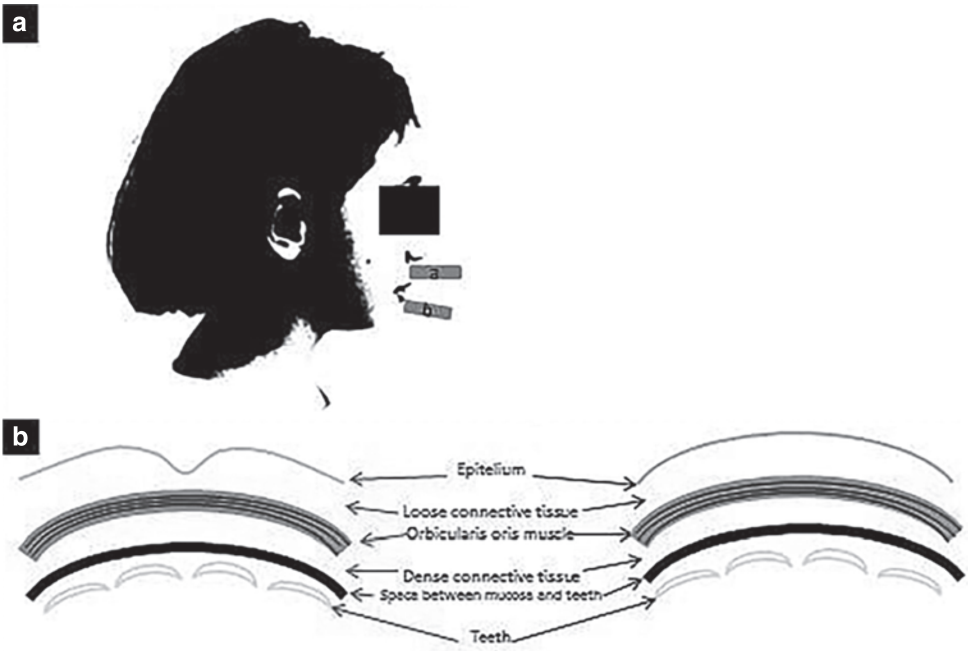


Fig. 15.4 (**a**) Scheme of application of transversal ultrasound transducer on the (a) upper and (b) lower lip. (**b**) Schematic drawing of the transversal image cross-section

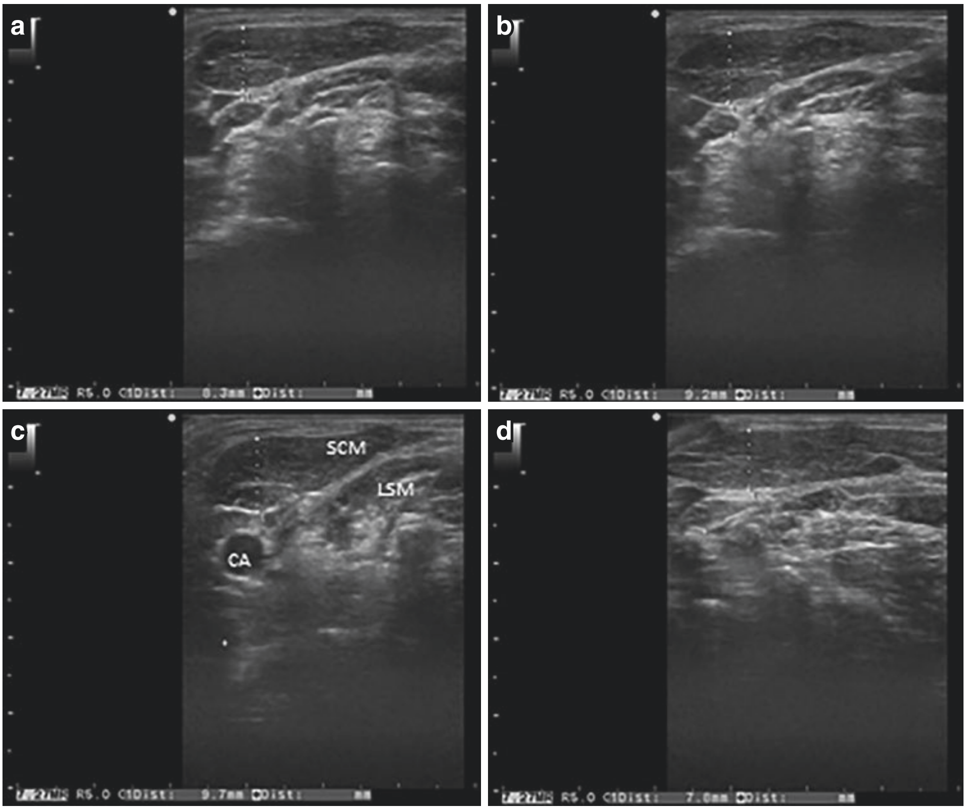


Fig. 15.5 Transverse USG of the left sternocleidomastoid muscle at rest (**a**), during dental clenching (**b**), flexion (**c**), and extension (**d**) of the head; the vertical dotted lines indicate the sites of muscle thickness measurements. *SCM* sternocleidomastoid muscle, *LSM* levator scapulae muscle, *CA* carotid artery

latero-deviation side than in the contralateral normal side, in cases untreated.

Future studies should standardize the methods and parameters for reducing errors and optimizing accuracy with a large-scale population. The use of ultrasound continues a promising option for the study of muscles of mastication.

In addition, Doppler sonography can be helpful for investigating the arteries in and around the masseter muscle and this method has the capability for evaluating pathological alterations in the muscles and arteries [25]. In a study conducted by Ariji et al. [52], the change of muscle thickness immediately after exercise showed a significant correlation with minimum blood-flow velocity.

15.3 Analysis of Tongue, Hyoid, and Swallowing

The tongue is a largely movable muscular organ within the orofacial region and for years, it has been theorized that the tongue size, postures, and functions must have a relationship to the surrounding oral cavity. It is assumed that the tongue size, postures, and functions have great importance for the etiology of malocclusions and dentofacial deformities [53].

Several methods are available for assessment of the tongue's size in vivo: direct measurements [54], different impression techniques [55], and the fluid displacement method [56]. Recently, different imaging methods have been used in tongue volume assessment: cephalometrics [57], computed tomography (CT) [58], cone-beam computed tomography (CBCT) [59], and magnetic resonance imaging (MRI) [60]. However, all techniques have their own clinical indications, advantages, and disadvantages.

Two-dimensional (2D) ultrasound is used for tongue function evaluation such as swallowing [61, 62] and speech [63] as well as for estimating tongue thickness, and tongue volume [64]. Three-dimensional (3D) ultrasound is already performed for the tongue posture assessment [65], as a device for the evaluation of tongue function [66].

15.3.1 Tongue Volume

Wojtczak et al. [64] examined tongue volume that was obtained from the multiplication of the midsagittal cross-sectional images of the tongue by its width in transverse scans, using 2D USG. The correlation between the tongue volume and mandibular arch size [55], vertical facial height, chin position has been demonstrated in clinical studies [67]. Hren ve Barbič [68], aimed to evaluate tongue size and it has been found that tongue volumes are significantly greater in skeletal Class III patients than normal. Also, larger tongues correlate with more severe skeletal Class III malocclusion.

Hren ve Barbic [68] and Barbič et al. [53] have utilized 3D USG for evaluating tongue volume. During USG investigation, each patient sits in upright resting positions and their heads fixed with a strap, so that the Frankfurt horizontal line was parallel to the floor. The 3D convex transducer was positioned on the skin of mouth floor in the midsagittal plane, submentally. The tongue volume evaluation was performed using 4D VIEW program software. The 3D Ultrasound technologies provide a multi-planar image of the region of interest or of certain pathology as well as perform more accurate analyses of them [53].

15.3.2 Tongue Posture

Tongue posture has been described as an etiologic factor in malocclusion development, including anterior open bite and articulation disorders as well as that plays an important role in anterior open bite treatment planning and posttreatment stability [69, 70]. It is believed that the tongue resting posture to be even more important for the dentoalveolar development and dental occlusion than the tongue function during swallowing or speaking [71].In the view of total time, swallowing and speaking is too short to affect the balance of the forces acting on dentoalveolar development.

In the orofacial region, the tone and pressure of the resting tongue is one of the most important long-acting forces on the adjacent structures represented [72, 73]. Clinical evaluation of the tongue dynamics and resting postures are important parts of functional diagnostics [65]. A study by Kravanja et al. [74], who evaluated the tongue posture in children showed that the 3D ultrasound was found to be the most objective method to identify tongue posture in growing children and it could be an important device in functional diagnostics before, during, and after orthodontic treatment.

15.3.3 Tongue Movement

Tongue movement is related to some disorders, such as dysphagia. A better understanding of tongue movement in detail is important for the diagnosis and treatment of such diseases [75]. The tongue posture and function can be evaluated by clinical examination, including observation of tongue movements with lips apart and palpation of the temporalis and masseter muscles during swallowing. Because of anatomical limitations, these methods are not enough for objective evaluation [62]. Additional techniques have been developed and used for tongue movement evaluation, such as videofluoroscopy [76–78], electromyography [79–81], electromagnetic articulography [82], palatography [83], MRI [84], scintigraphy [85], and tongue pressure measurements [86]. Between these methods, the use of videofluoroscopy, which records the dynamic movement of radiopaque barium through the upper digestive tract by conventional X-rays, is considered as the standard criterion for the deglutition and dysphagia evaluation [87–90]. However, especially the disadvantages of irradiation, repeated evaluations are often avoided.

The advantages of ultrasonography for being noninvasive, detailed, repeatable, and real-time soft tissue scanning makes it superior for deglutitive tongue research [91]. The first time, Shawker et al. [92] used B-mode USG to evaluate tongue movements during swallowing. Peng et al. [93, 94] used M-mode sonography for quantitative and qualitative tongue functions assessment. The tongue was viewed by a hyperechoic line in the M-mode traces and that synchronized with the tongue movements during swallowing [75]. Peng et al. [93], divided the swallowing pattern obtained into five phases (phases I, IIa, IIb, IIIa, and IIIb) based on each turn points determined on the M-mode images (Fig. 15.6). This mode allows recording and successful separation of duration, speed, and range of tongue movements in each phase. Peng et al. [95] used the cushion scanning technique (CST) to manage the problems such as the movement of the transducer during examination and compression of the submental region that resulted in abnormal swallowing patterns. However, there is a conflict with using this technique because that increases the distance between the transducer and the floor of the mouth which could decrease the image resolution.

Cheng et al. [96] found that there are significant correlations between tongue movement during swallowing and dentofacial forms using B + M-Mode sonography combined with the CST, especially in the amplitude of the early final phase. They concluded that as the arch length increased, the duration of swallowing prolonged significantly in the late final phase.

Peng et al. [97] stated that the tongue movements of mature swallowing and tongue-thrust swallowing can be differentiated with USG. Based on this study, Tongue-thrust swallowers had a longer late transport phase than mature swallowers, and the tongue speed was

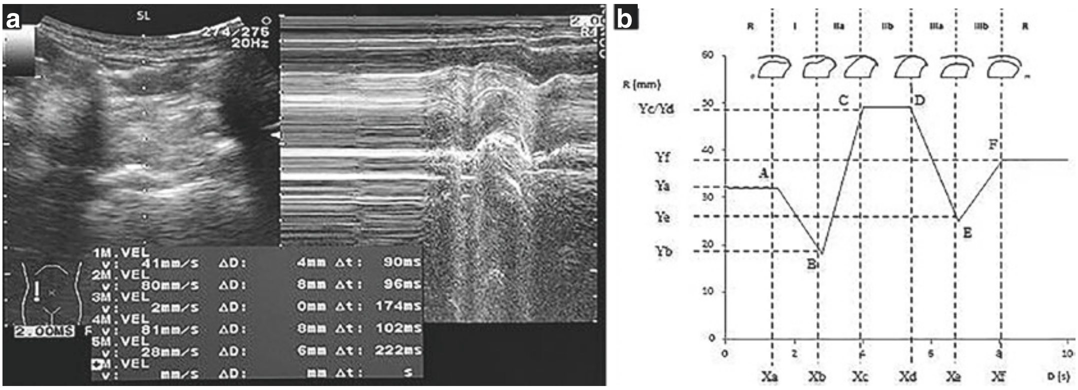


Fig. 15.6 B + M mode ultrasonogram. The left side shows the B-mode image with the scan line (SL) of the ultrasound probe set in the middle of the tongue. The M-mode image (right side) illustrates movements of various anatomic structures along the SL (**a**). Duration and range of tongue movement in each phase were determined graphically. In the rest phase (R), the tongue tip is usually positioned on the lingual surfaces of incisors or is touching the incisive papilla. The swallowing act starts with the shovel phase (I), in which the tongue tip moves cranially, the middle third of the tongue becomes concave and this is reflected in the down-movement of the curve in the M-mode ultrasonogram. In the early transport phase (IIa), the tongue is moving cranially and distally, the middle third of the tongue is approaching the hard palate, and therefore the concavity is disappearing. The late transport phase (IIb) is characterized by minimal vertical movement of the tongue because of the distal transportation of saliva. In the early final phase (IIIa), the curve in the M-mode ultrasonogram drops because of the lowering of the mouth floor. In the late final phase (IIIb), the tongue returns to the rest position and this is reflected as a rise in the M-mode curve [93] (**b**). *R* rest phase; *d* distal, *m* mesial, *D* duration, *R (mm)* Range

faster in the early final phase compared with mature swallowers.

Ardakani et al. [98] investigated the swallowing patterns of the tongue using B-mode Sonography. They concluded that the majority of abnormal or inconsistent swallowing patterns were detected in patients of mandibular prognathism.

Ovsenik et al. [71] compared the swallowing pattern and tongue function during swallowing in children with unilateral posterior crossbite (ULCB) in deciduous dentition by B + M-mode USG. The ultrasound analysis showed that duration, range, and speed of the tongue movements during swallowing significantly differ between children with and without ULCB.

In another study, Vaishnevi et al. [99], investigated the relationship between tongue movement and facial morphology in three types of malocclusion and found that the skeletal class III cases have prolonged duration of tongue movement and greater motion magnitude in the early final phase (III A) of swallowing. Also, there is a decrease in the motion range and duration of swallowing in the skeletal class II individuals.

15.3.4 Hyoid Bone Displacement

The measurements of tongue, hyoid, and laryngeal movements have been used to evaluate swallowing in USG studies [100–107]. The hyoid bone is the point of attachment for muscular and nonmuscular tissues of the floor of the mouth, tongue, and larynx and its movement functions as a marker of the integrity of the hyoid/larynx/epiglottis unit [100]. Under normal physiologic conditions, timely and adequate laryngeal elevation along with hyoid bone movement is an important part of the swallowing movement [108, 109]. The hyoid bone is easily viewed on USG in the sagittal plane as a hyperechoic area with a posterior acoustic.

Shadow (Fig. 15.7). USG allows for detailed evaluation via frame-by-frame images when real-time swallow(s) is acquired. Particularly, the

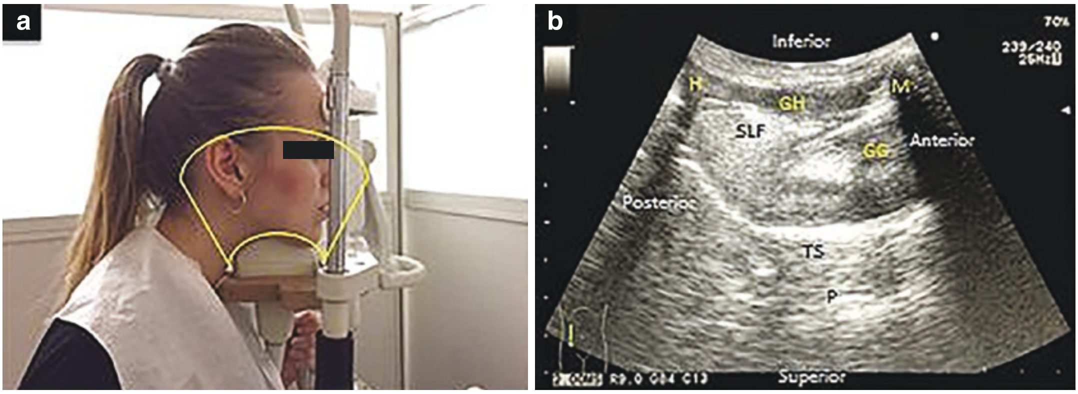


Fig. 15.7 Sagittal view in the submandibular position using a convex transducer between the mentum and the hyoid bone (**a**). The sonogram shows the tongue and the floor of the mouth (**b**). The insets show the transducer position on the skin. *GG* genioglossus, *GH* geniohyoid, *M* Mandible, *H* Hyoid bone, *P* Palate, *SLF* Sublingual fat, and *TS* Tongue surface

hyoid bone displacements during a swallow can be measured [110].

Yabunaka et al. [111] stated that the trajectory of the hyoid bone in the sagittal plane can be a feasible option for detecting some anomalies in swallowing. Similarly, Chen et al. [112] demonstrated that submental USG is a reliable and accurate technique for the hyoid bone movement assessment and that could be an aid in dysphagia screening and evaluation.

Effective bolus flow and pharyngeal clearing need enough hyoid bone movement during swallowing. Feng et al. [113] evaluated the association between the geniohyoid muscle size-function and hyoid bone movement during swallowing. The authors measured the cross-sectional area of the geniohyoid muscle, geniohyoid muscle contraction velocity, and the hyoid bone displacement in healthy young adults. A correlation has been found between the size of the geniohyoid muscle and hyoid bone movement.

15.4 Evaluation of the Airway

Airway obstruction and mouth breathing are among the etiological factors of malocclusion. Therefore, airway evaluation has great importance in clinical practice. The assessment is performed using lateral cephalometric radiography, commonly [114]. Cone-beam Computed Tomography scans can be utilized for assessing the morphology and mechanical behavior of the upper airway bony and soft tissue structures [115]. Also, various methods, including MRI, endoscopic procedures (e.g., fiber-optic, nasopharyngoscopy, fluoroscopy), acoustic reflection, and optical coherence tomography are feasible to display these structures [116–119].

In the literature, there are limited studies with the ultrasound-assisted evaluation of the upper airway. However, it has been demonstrated that USG has great potential for identifying the anatomic structures of the upper airway [120–122]. Bajracharya et al. [123] studied several sonographic parameters (soft tissue thickness at level of hyoid bone, epiglottis and vocal cords, visibility of hyoid bone in sublingual ultrasound, hyomental distance in head-extended position, and hyomental distance ratio) and they suggested the potential use of USG in the airway assessment (Fig. 15.8). Future studies may ensure that the information and understanding of the biomechanics of upper airway structures and their physiology in the different clinical scenarios.

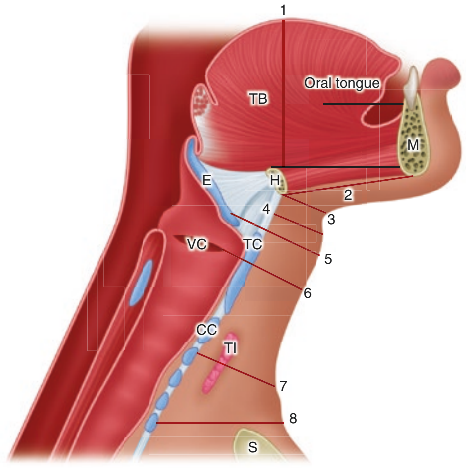


Fig. 15.8 Schematic diagram with USG parameters to evaluate the airway. Ultrasound measurements at various levels, *1* Cross-sectional area at base of tongue. *2* Distance from hyoid bone to mentum. *3* Distance from skin to hyoid bone. *4* Soft tissue thickness at level of thyrohyoid membrane. *5* Distance from skin to epiglottis midway between thyroid cartilage and hyoid bone. *6* Distance from skin to anterior commissure of true vocal cords. *7* Soft tissue thickness at level of thyroid isthmus. *8* Soft tissue thickness at level of suprasternal notch. *TB* Tongue base, *H* Hyoid bone, *M* Mentum, *E* Epiglottis, *TC* Thyroid cartilage, *CC* Cricoid cartilage, *VC* vocal cords, *TI* Thyroid isthmus, *S* manubrium sterni

15.5 The Temporomandibular Joint Evaluation

Temporomandibular joint disorder (TMD) is a general term for disorders affecting the masticatory muscles, temporomandibular joint (TMJ)-related structures, or all [124]. The prevalence of TMD is ranging from 10% to 70%, among the general population [125]. There may be different causes and different specific conditions in the etiology of TMD [126]. The TMDs may cause problems in some of the orthodontic patients, therefore TMJ assessment before, during, and after orthodontic treatment have great significance [127]. There are several methods and techniques used in the diagnosis of TMD, along with the basic clinical examination [126].

Panoramic radiography, conventional (linear or complex motion) tomography, helical or multislice computed tomography (CT), and cone-beam computed tomography (CBCT) are used to view the bony components, and magnetic resonance imaging (MRI) is used to evaluate the soft tissue components (discs) of the TMJ [128]. Bone scintigraphy can help for diagnosis of the osteoarthritis and joint inflammation [129, 130]. However, these methods have advantages and limitations to each.

The diagnosis of TMD can be performed by USG imaging of TMJ and adjacent tissues (Fig. 15.9). A study by Gateno et al. [131], investigated the accuracy of USG to visualize the position of mandibular condylar within the glenoid fossa. They supported that USG can be used as an objective method, during orthognathic surgery for reproducing the condylar position. However, a meta-analysis by Klatkiewicz et al. [126] resulted that there were no standardized procedures for using ultrasound scanning of the temporomandibular joint and further research is needed that should concern both normal and abnormal TMJs.

15.6 Determination of Soft Tissue Thickness at Orthodontic Miniscrew Placement Sites

Loss of anchorage in orthodontic treatments is often an important problem that risks treatment outcomes. Temporary skeletal anchorage instruments have been indicated as a reliable solution for situations where anchorage is critical. The use of orthodontic miniscrews in clinical orthodontics has revolutionized anchorage control, opening a new era [132].

The stability and success of orthodontic miniscrews depend on various factors, including the screw implantation site, the miniscrew angulation, the quality and quantity of cortical bone, the insertion and removal torques, the degree of miniscrew to bone contact, inflammation degree of the peri-orthodontic miniscrew tissues, the soft tissues thickness and mobility,

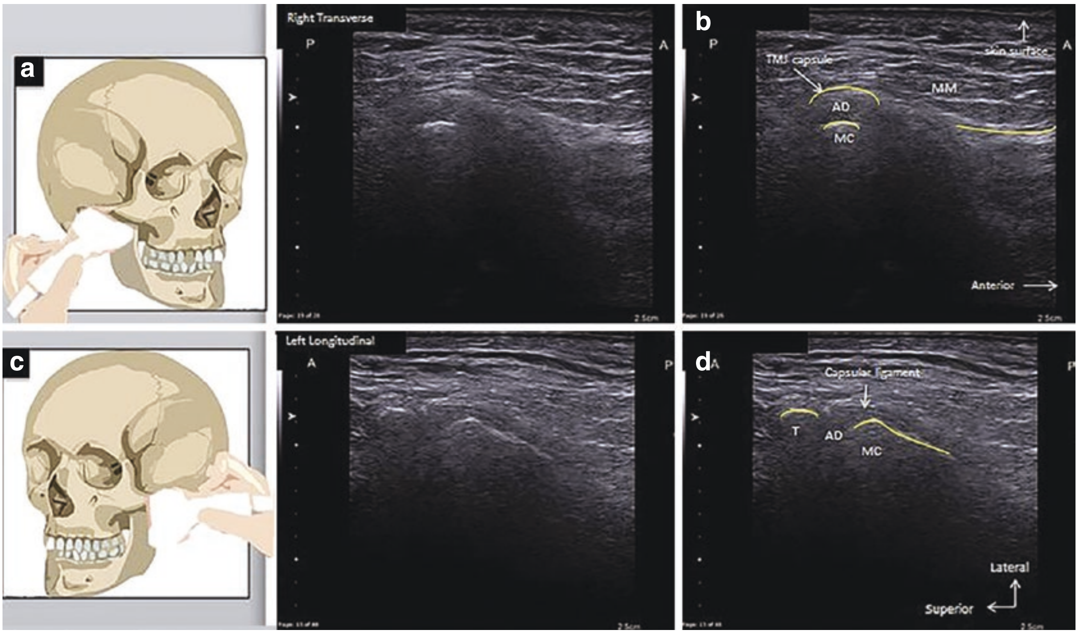


Fig. 15.9 Method of using ultrasound in TMJ. (**a**) *Horizontal positioning*, transverse image of the TMJ, and transverse section of sonography of the right TMJ obtained while the patient was in the closed-mouth position. (**b**) Anatomical landmarks observed in transversal/axial slice. (**c**) *Vertical positioning*, coronal/sagittal image of the TMJ, and coronal section of sonography of the left TMJ obtained while the patient was in the closed-mouth position. (**d**) Anatomical landmarks observed in coronal view. *TMJ* temporomandibular joint, *AD* Articular Disc, *MC* Mandibular condyle, *MM* Masseter muscle, *T* Temporal bone (depending on the angulations of the USG probe)

the patient's craniofacial morphology, and the screw dimensions [133–139].

Risk of failure of orthodontic miniscrews surrounded by nonkeratinized mucosa is higher than for screws surrounded by keratinized mucosa, for the soft tissue component of stability [140]. In the different candidate, areas for screw placement have different soft tissue thicknesses. Therefore, evaluation of the quantitative differences in gingival thickness for miniscrew implantation is one of the significant factors affecting surgical success [141].

Measurements on the thickness of oral mucosa can be acquired by direct methods, such as using a needle or periodontal probe with an endodontic file stopper and biopsy, or indirect measurement using radiographic images. USG is an alternative method that has the potential for providing an evaluation of the soft tissue thickness [142].

Cha et al. [141] evaluated the gingival thickness of potential sites for miniscrew placement in the buccal-attached gingiva and the palatal masticatory mucosa. Mucosal thickness was measured intraorally with an ultrasonic gingival thickness meter (5 MHz).

A study by Parmar et al. [132] aimed to examine the soft tissue thicknesses at potential miniscrew implantation zones and to prescribe a guideline for miniscrew selection in orthodontic clinics. The measurements were performed with A-mode ultrasound device that uses the pulse-echo principle with the frequency was 10 MHz at 10%. The transducer was placed perpendicular to the most gingival surface.

Cha et al. [141] and Parmar et al. [132] concluded that evaluation of the gingival tissues could help in selecting a proper miniscrew in orthodontic practice.

Schulze et al. [142] reported that using B-mode and A-mode ultrasonography is acceptable in various clinical practices for measuring the mucosal thickness accurately. However, B-mode USG is a capable device for soft tissue diagnostics, that needs a small transducer for measurements in the oral cavity.

Although the quantity and quality of cortical bone greatly influenced the stability of mini-screws, also the width of the attached gingiva on the buccal and palatal surfaces in the interdental areas must be considered before surgery [143]. Maximum retention can be obtained when an adequate length of the screw is placed in areas of thin gingival tissue and thick cortical bone [144].

The validity and reliability of USG were shown for measuring soft tissue thickness in different anatomical locations of the oral cavity [145–149], and that offers great potential in pre-surgical assessment for placement of orthodontic miniscrew placement.

15.7 Determining Pubertal Growth and Bone Age

In the human beings, skeletal maturation has a great value for the detection of growth and differentiation processes [150, 151]. Bone age is an important indicator of the skeletal and biological maturity of an individual. The knowledge of the skeletal maturation and the stage of growth can provide useful information for many clinical practices as well as in orthodontic procedures such as treatment planning, the timing of treatment, and selection of the treatment method [152].

Radiological indicators have been used for bone age estimation [153]. For this, several techniques are generally utilized based on hand-wrist radiographs. In clinical practice, the Greulich-Pyle (an atlas method which compares the radiograph of the individual with the nearest standard radiograph in the atlas) and Tanner-Whitehouse (a scoring method which focuses on skeletal maturity for each patient hand and wrist bone) methods are preferred commonly [154–156].

In recent years, because of the possible side effects and damages of ionizing radiation, there is an increasing focus on the establishment of nonionizing imaging methods for age estimation [157]. Some researchers have used USG, which has many advantages and as an ionized radiation-free imaging technique, to estimate bone age [157–160].

The bone age estimation by ultrasonography is not a new method. In children, the hip [158], iliac and radius bones [159], and ossification center of the wrist [160] have been used as sonographic landmarks for determination of the skeletal age previously.

Carpenter and Lester [161] stated that there was a significant difference between chronologic age and bone age in the different regions of hand and genders. Also, in children under age 10 years, the entire hand should be taken to consider for evaluation of bone age, maybe with less interest on the carpal bones, they may cause over- and under-estimated results greatly. They concluded that bone age estimation based on the metacarpals and phalanxes more accurate than wrist and carpal bone age readings.

Nessi et al. [160], Bilgili et al. [157], and Hajalioghli et al. [4] have followed the same protocol for ultrasonographic bone age evaluation. These researchers aimed assessment of the ossification centers, which were viewed as hyperechoic foci with acoustic shadowing, in sonographic images of the radius and ulna distal epiphysis, carpal bones, epiphyses of the first and third metacarpals, and epiphysis of the middle phalanx (Fig. 15.10). Schmidt et al. [151] have targeted examining ossification of the distal radial epiphysis and the ossification stages were categorized. Nessi et al. [160] mentioned that USG is a valuable technique for scanning skeletal maturation of the ossification centers of the hand and wrist (sesamoid bone and DP3). Bilgili et al. [157] who aimed to described hand and wrist ultrasonography charts that present all carpal bones, phalangeal, and metacarpal epiphyses by placing the probe in transverse and longitudinal planes for each finger. They reported significant correlations between radiographic and ultrasonographic results in both genders (71.1% of male cases and 84.4% of female cases) and stated that maturity of carpal bones varies greatly. Daneff et al. [162] concluded that conventional USG has the potential for identifying the ossification centers of the hand and wrist and can be preferred as a harmless follow-up method in cases with

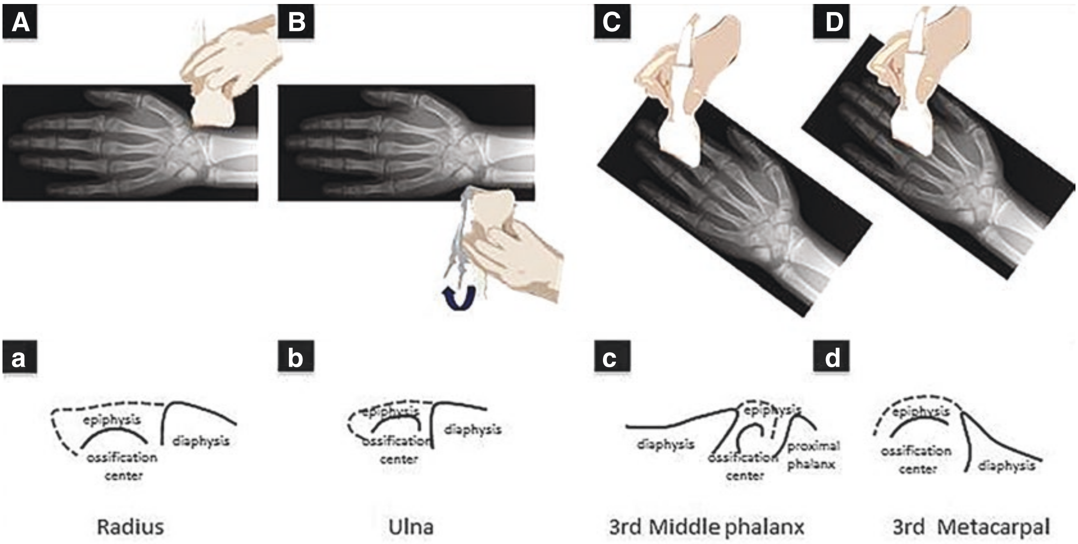


Fig. 15.10 Scanning planes for hand and wrist imaging by ultrasound to examine bone age. (**A**) The probe was set on the radial styloid process in the coronal plane to image the epiphysis of the radius. (**B**) The probe was set on the ulna styloid process in the coronal-to-sagittal plane to image the epiphysis of the ulna. (**C**, **D**) The probe was set on the sagittal plane to image the epiphyses of the third phalanxes and metacarpal. Schematic drawing of the distal radius and ulna, phalanx and metacarpal (**a**–**d**). The *epiphysis* is represented by a dotted line. The hyperechoic surface of the *ossification center* and the *cortex of the diaphysis* are symbolized by solid lines

growth problems. Khan et al. [163], who used an automatic USG device, reported that a low correlation between USG and radiography in their work. In contrast, Hajalioghli et al. [4] reported that conventional radiography can be replaced by USG for bone age estimation. According to a study by Ağırman et al. [152], USG is an alternative method to conventional radiography in the bone age estimation and viewing sesamoid bone and MP3 capping, which is the indicator of pubertal growth.

Although, the reliability of the results of USG examinations largely depends on the experience of each practitioner. It is necessary to study with larger groups to make a standard evaluation of bone age in sonography.

15.8 Evaluation of the Midpalatal Suture

Maxillary transverse constriction is concerning various issues that include posterior crossbite (dental and/or skeletal), occlusal disharmony, dental crowding, pharyngeal airway narrowing, tongue posture alterations, mouth breathing, abnormal muscular function, and esthetic problems [164–166]. The choice of treatment depends on many clinical conditions [167]. Rapid palatal expansion (RPE) is a routine orthodontic treatment that aims to increase the transversal width with the midpalatal suture and the circummaxillary sutural system separation. RPE corrects that by stretching of collagenous fibers and the local formation of a new bone [168]. However, in patients with a midpalatal suture opening, RPE has been recommended, but the surgically assisted rapid maxillary expansion (SARME) has been needed in patients with a full midpalatal suture ossification [167, 169].

The midpalatal suture is one of the critical areas for maxillary expansion as the zygomatic buttress and the pterygomaxillary junction [170]. Oral radiographs and CT are imaging methods used for the evaluation of palatal suture maturation, commonly. However, radiography/CT involves ionizing radiation. In the orthopedic literature, it is reported that USG is accurate and reliable method to assess distraction osteogenesis wounds in long bones [171, 172].

Examination of the midpalatal suture has been performed from outside the mouth on the skin overlying (probe has been placed in the region between the nasal columella–labial junction and the upper lip), and the ultrasound beam was oriented perpendicular to the bone surface [173]. To the best of our knowledge, there are two published studies of sutural expansion with USG in RPE and SARPE patients [170, 173].

Sumer et al. [170] evaluated sutural mineralization at five-time points during the SARME and retention protocol for three patients, scoring each patient's callus formation via semiquantitative bone fill scores (0–3).

Gumussoy et al. [173] utilized the USG examination in 29 RPE patients, and they measured the amount of sutural expansion as mesiodistal length at every stage (immediately after appliance practice, 10 turns, and 20 turns). They reported that the surfaces of the bone segments were easily viewed, and examination in the expansion area could be performed accurately during the active phase of the expansion. The expansion zone was identified by a nonhomogeneous and hyperechoic, sharply demarcated area (Fig. 15.11). Also, they mentioned that the system is not enough for viewing of the whole anatomy, as the field of view depends on the linear probe and scanning angle. Therefore, it was stated that the scoring system used by Sumer et al. [170] is not suitable.

Overall, these studies did not present solid evidence of their validity for the accurate determination of the maturation of the palatal suture. However, when we think about the disadvantages and limitations of other imaging modalities, further evaluations can show the accuracy of ultrasonography examinations for this purpose.

15.9 Ultrasonographic Evaluation of Periodontal Changes During Orthodontic Tooth Movement

The periodontal tissue reaction to tooth movement by orthodontic forces consists of remodeling changes in the periodontal ligament, alveolar bone, and gingiva [174]. Real-time, in vivo visualization of the alterations induced by orthodontic tooth movement in the morphology of the anatomical structures of the periodontium, would be helpful for managing the treatment plan and assessment of the tissue response to orthodontic forces [175]. Previous studies concluded that USG is suitable for evaluating the cortical bone, periodontal space, sulcular depth, the characteris-

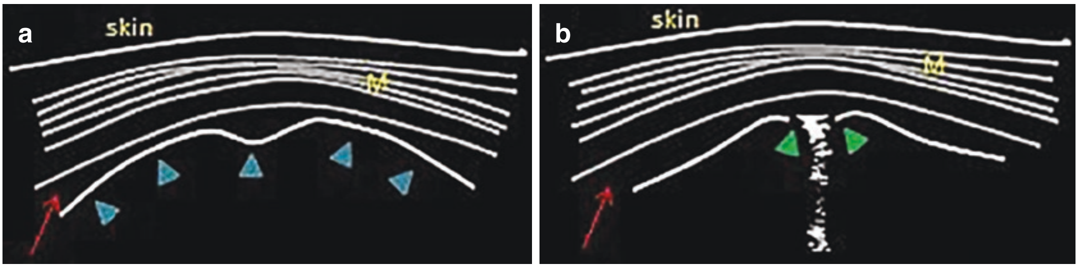


Fig. 15.11 Schematic transverse ultrasound image of normal anatomical structures at (**a**) pre-expansion and (**b**) during treatment. *M* superior orbicularis oris muscle, *red* arrows show vestibulum oris, *blue* arrowheads show border maxillary cortical bone, and *green* arrowheads show sutural expansion

tics of the gingiva, and length of the anatomical crown [176, 177].

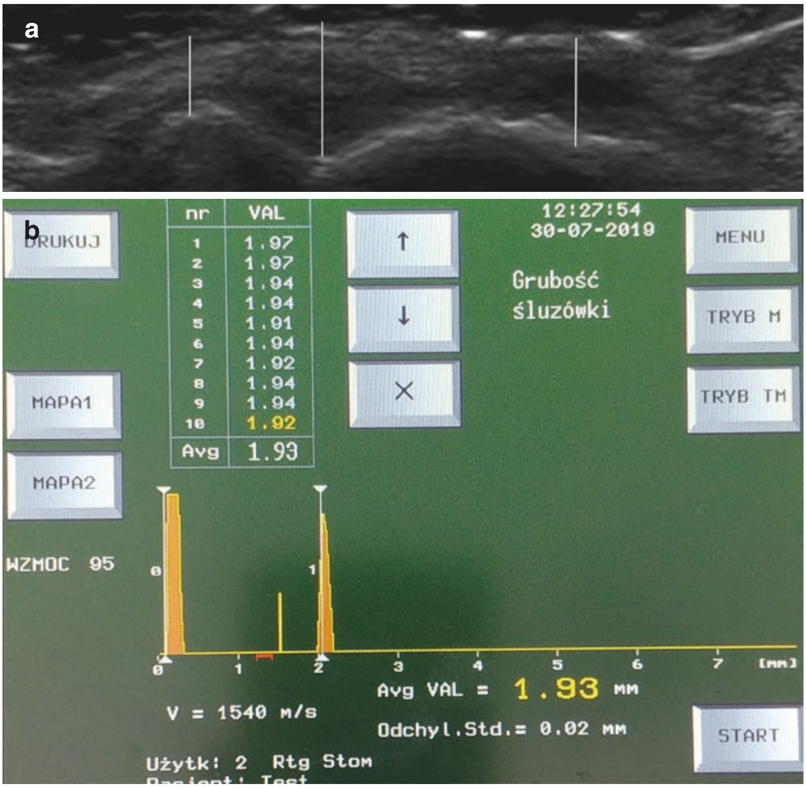
A study by Zimbran et al. [175] aimed to examine whether changes that appear, induced by the orthodontic canine retraction, in periodontal tissues can be diagnosed by USG. Sonographic scans were performed from outside the mouth on the skin overlying, in three different areas of the canines buccal surface (mesial, middle, and distal) and three times (before, during, and after retraction). The transducer (40 MHz frequency pulses) was placed in a longitudinal plane. Four different distances were measured, including depth of the sulcus, thickness of the gingiva, length of the supracrestal fibers, width of periodontal space. The authors found significant results for sulcus depth measurement and distance between marginal gingiva and alveolar crest, immediately after force application on the middle and mesial area of the canine. They concluded that high-resolution USG has the potential to reveal changes in periodontium during orthodontic tooth movement (Fig. 15.12) (Fig. 15.13).

15.10 Effect of Low-Intensity Pulsed Ultrasound (LIPUS) on Tooth Movement and Root Resorption

Orthodontically induced root resorption (OIRR) is an undesirable outcome of orthodontic treatment [178]. The prevalence of OIRR is higher than 90% [179], and from minor to severe, the incidence of OIRR ranges from 94% to 6.6%, respectively [180]. Lund et al. [180] reported that 6.6% of the orthodontic patients had at least one tooth with OIRR more than 4 mm. Mirabella and Artun [181] indicated that about 4% of orthodontic patients with generalized resorption of the six anterior teeth of greater than 3 mm. During treatment, several studies have mentioned that probably about 5% of adults and only 2% of adolescents show at least one tooth with severe resorption of greater than 5 mm.

Several etiologic reasons have been reported that can influence OIRR, including biological (susceptibility, genetics, and systemic factors),

Fig. 15.12 (**a**) An USG device which is dedicated to measure the gingival thickness, (**b**) the image showing the application of the device, note that the high frequency probe for measuring gingival thickness. Courtesy of the Czelej Editorial House in the 3rd Edition of the book "Współczesna Radiologia Stomatologiczna"



nr	VAL
1	1.97
2	1.97
3	1.94
4	1.94
5	1.91
6	1.94
7	1.92
8	1.94
9	1.94
10	1.92
Avg	1.93

12:27:54
30-07-2019

Grubość
śluzówki

Avg VAL = 1.93 mm

V = 1540 m/s

Odchyl.Std.= 0.02 mm

Użytk: 2 Rtg Stom

Fig. 15.13 (**a**) USG image showing the measurement of gingival thickness, (**b**) Note that the device measures the average of the app. 10 measurements. Courtesy of the Czelej Editorial House in the 3rd Edition of the book “Współczesna Radiologia Stomatologiczna”

mechanical, and combined factors [182]. However, the relationship between severe OIRR and the possible etiologic factors is unclear [1]. Sasaki [183] reported that osteoprotegerin (OPG)/RANK/Receptor activator of nuclear factor kappa-B ligand (RANKL) pathway that controls the osteoclastogenesis and odontoclastogenesis exist in physiologic root resorption in deciduous teeth [1]. Some studies indicated that OPG and RANKL levels increase during the application of heavy forces and severe root resorption [182, 184–186]. Also, it has been detected that increased RANKL production and low OPG expression, which stimulated the formation of osteoclast, in PDL cells from severe OIRR patients [186].

Several methods have been used in OIRR treatment, including the bisphosphonate application to rats’ teeth [187]; allowing for self-healing for 70 days [179] or after retention [188]; topical corticosteroid [189]; calcium hydroxide root canal treatment [190]; and recently low-intensity pulsed ultrasound (LIPUS-acoustic pressure waves) in humans [191, 192], and in experimental animals [193–196]. Previous reports concluded that LIPUS modulates the OPG/RANK/RANKL balance, so it minimizes and shows a suppressive effect on osteoclastogenesis. In studies in experimental animals and in humans, it has been detected that LIPUS increased cementum formation and predentine/dentine [191, 195–199].

Accelerated tooth movement has received increasing attention by clinicians for minimizing possible OIRR, shortening treatment duration, saving patient compliance, and reducing side effects of prolonged orthodontic treatment such as enamel decalcification, periodontitis, and psychological impact [1]. Several techniques have been previously reported to reduce treatment periods, including pulsed electromagnetic fields [200], electrical currents [201], corticotomy [202], distraction osteogenesis [203], mechanical vibration [204], photobiomodulation [205], low-level laser therapy [206], and LIPUS.

The 30 mW/cm^2 output signal of LIPUS device (1.5 MHz, pulse 200 µs, delivered at 20% duty cycle, 30 mW/cm2, 20 min daily) has been approved for clinical use [207]. LIPUS device has been used in bone regeneration and fracture healing approved by the U.S. FDA (Food and Drug Administration) for bone regeneration and fracture healing [208].

In addition, a pilot study, within the limitations, reported that LIPUS combined with functional appliances can be used for treating enhancing mandibular growth in children with hemifacial microsomia [197].

However, LIPUS use in these treatments is still controversial because of inconsistency among all trials [209], adverse effects [210], underlying mechanisms remain unclear partly. Therefore, a proper understanding of the complete mechanism of LIPUS stimulation needs further research.

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