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Richa Wadhawan
Professor, Oral Medicine, Diagnosis & Radiology, PDM Dental College and Research Institute, Bahadurgarh, Haryana, India

Tanmay Kumar Bagchi
Private Practitioner, Jharna Dental Clinic, Rajdhanwar, Jharkhand, India

Gopal Krishna
Post Graduate, Master of Public Health, Combined (P.G.) Institute of Medical Sciences and Research, Dehradun, Uttarakhand, India

Ritesh Gupta
Dental Surgeon, Three Star Eye and Dental Hospital, Birgunj, Nepal

Suranjana Bora
Consultant Dental Surgeon, Aditya Multispeciality Hospital, Nagaon, Assam, India

Sandana Borah
Dental Surgeon, IKS Health, Navi Mumbai, Maharashtra, India

Shahanaz Parvin
Dental Surgeon, Mediassist Health Care, Bengaluru, Karnataka, India

Corresponding Author:
Richa Wadhawan
Professor, Oral Medicine, Diagnosis & Radiology, PDM Dental College and Research Institute, Bahadurgarh, Haryana, India

Elastography meets dentistry: A novel synergy for better oral health

Richa Wadhawan, Tanmay Kumar Bagchi, Gopal Krishna, Ritesh Gupta, Suranjana Bora, Sandana Borah and Shahanaz Parvin

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Abstract
Elastography, or elasticity imaging, is a non-invasive modality that assesses tissue stiffness by measuring elasticity in normal and pathological tissues. When tissues are compressed, they produce strain, causing displacement that allows estimation of tissue hardness. This resulting tissue elasticity is displayed as an elastography. Elastography is particularly useful in preoperative evaluations, as pathological tissues are typically harder than normal ones. This review highlights elastography's principles, applications, and future prospects in the oral and maxillofacial region, emphasizing its transformative impact on dentistry. By detecting and imaging changes in tissue elasticity, elastography represents a significant advancement in dental diagnostics.

Keywords: Elastography, elasticity imaging, elastography, ultrasonography, dentistry

Introduction
Tissue elasticity, crucially tied to microscopic structure, function, and pathology, depends on the extracellular matrix composition, influenced by aging and disease. Pathological changes in tissue structure and composition affect elasticity, underpinning the significance of palpation in disease detection during physical exams. While traditional imaging can't directly measure elasticity, several techniques provide indirect quantitative estimates [1]. Ultrasound elastography, a non-invasive method, evaluates tissue elasticity using ultrasound principles, aiding diagnosis. This state-of-the-art imaging assesses tissue stiffness, providing valuable diagnostic enhancements to traditional methods. For over a millennium, palpation has gauged stiffness and identified malignancies [2]. Ultrasound elastography, pioneered by Ophir *et al*. in 1991, mimics clinical palpation by objectively assessing tissue stiffness. It quantifies lesion hardness, replacing subjective evaluations. With a specificity of around 93% and sensitivity up to 90%, it's a powerful diagnostic tool. Ophir termed it a means of quantifying tissue strain and elastic modulus. Tissue elasticity changes often correlate with pathology [3]. Integrating artificial intelligence enhances accuracy, reducing operator dependency, and improving specificity and sensitivity. This synergy facilitates quicker diagnosis, real-time analysis, and personalized treatment strategies [4].

Principles of Elastography: The equipment includes an ultrasound machine and probe. When the transducer compresses the area of interest, the tissue strain reflects its elasticity. Harder tissues produce less strain compared to softer tissues. Typically, pathological tissues like tumors are 5 to 28 times stiffer than normal soft tissue. The echo patterns generated before and after compression are processed into an image called an elastography. There are two main types of elastography: grayscale and color. In grayscale elastography, hard (malignant) tissues appear darker, while softer tissues appear brighter [5].
In color elastography, the image uses red, yellow, green, and blue to represent increasing tissue stiffness. In certain machine configurations the color sequence order is exactly reversed. Elastography measures tissue displacement in response to mechanical force, creating a visual map of tissue stiffness. The two main types are strain elastography and shear wave elastography. Strain elastography produces images based on tissue response to displacement

forces from an external transducer, acoustic radiation force impulse, or internal sources like breathing or heartbeat. It allows for a qualitative comparison of lesion stiffness relative to surrounding tissues but does not provide exact stiffness measurements. In contrast, shear wave elastography uses an acoustic radiation force impulse, or "push pulse," to generate shear waves, offering a precise assessment of tissue stiffness [6]. The speed of shear waves is measured with conventional B-mode imaging to determine tissue displacement, providing a precise assessment of stiffness. Shear wave speed varies with tissue stiffness, being slower in softer tissue and faster in stiffer tissue. Shear wave elastography quantitatively measures this speed to assess tissue stiffness. Strain elastography evaluates tissue deformation under compression, offering qualitative data on stiffness. It's particularly useful for detecting lesions or anomalies that conventional ultrasound may miss, such as tumors, which typically have different stiffness than surrounding healthy tissue [7]. Shear wave elastography can be further classified into: Transient elastography utilizes a mechanical vibrator to generate shear waves. Point Shear Wave Elastography focuses acoustic impulses to a specific point. 2D shear wave eastography covers a broader area, providing a comprehensive stiffness map. Transient elastography most often refers to a type of elastography which relies on a mechanical pulse generated by an external probe. The principle is similar to shear wave elastography, in that the elastic modulus is generated from shear wave velocity, but the application of the pulse from an external probe is different than calculations of the liver stiffness from an ultrasound pulse, an "acoustic radiation force impulse". MR elastography refers to the use of magnetic resonance imaging to evaluate tissue stiffness. It employs shear waves to measure tissue displacement in all directions, offering greater precision than sonoelastography [8].

Discussion

In orthodontics, elastography offers significant potential for improving diagnosis, treatment planning, and monitoring of conditions affecting the oral and maxillofacial regions. For cleft palate, a congenital condition with an opening in the palate extending into the nose that causes feeding, speech, and ear infection issues, elastography can be particularly useful. Although traditionally used to evaluate internal organs and soft tissue diseases, elastography could assess tissue stiffness and quality around the cleft palate before or after surgery, aiding surgical planning and healing evaluation. In research, it can study the biomechanical properties of tissues in individuals with cleft palate, leading to better surgical techniques and materials [9]. Comparative studies using elastography might reveal differences between normal and cleft-affected tissues, offering insights into etiology and treatment optimization. Elastography also serves as a valuable tool in monitoring tissue responses to orthodontic forces, tracking changes in periodontal tissue stiffness to optimize force application, potentially reducing treatment durations and improving outcomes [10]. Additionally, it guides surgical procedures in orthodontics by assessing the elasticity of soft tissues like the masseter muscle, essential for diagnosing and managing conditions such as bruxism and temporomandibular joint disorders. It has proven effective in evaluating muscle stiffness changes post-orthognathic surgery, facilitating long-term treatment monitoring [11]. For orthognathic surgery, elastography aids in pre-surgical planning by providing detailed information on tissue stiffness, ensuring more precise and effective surgical interventions. Toker *et al*. investigated the use of shear wave elastography for diagnosing bruxism in ten individuals with confirmed bruxism and a matched control group.

They measured the masseter muscles under three conditions: relaxed jaw, 50% of perceived maximum bite force, and maximal jaw opening. The study showed that shear wave elastography has potential for bruxism diagnosis and monitoring but also identified significant limitations and methodological issues that need addressing in future research [12]. Transient elastography can be adapted to evaluate the mechanical properties of oral tissues, such as periodontal ligaments and alveolar bone, essential for orthodontic treatment planning and monitoring. Applications in orthodontics include periodontal ligament assessment. It measures stiffness to understand tooth movement under orthodontic forces, leading to more personalized and efficient treatment plans. It also evaluates alveolar bone properties to predict post-treatment tooth stability, especially in patients with conditions like osteoporosis. It helps in tracking changes in oral tissues to enhance treatment outcomes and adjust plans as needed [13]. It represents a promising advancement in periodontics, providing an innovative method to evaluate and monitor periodontal health and disease. It measures the mechanical properties of the periodontal ligament, detecting changes associated with periodontal conditions. Healthy ligaments exhibit specific elasticity, while diseased or inflamed ones show altered stiffness. It non-invasively identifies these changes, potentially catching early stages of periodontal disease before significant clinical symptoms appear. It can also monitor periodontal treatment effectiveness by measuring changes in tissue stiffness over time, providing a quantitative approach to evaluate healing and therapy response. Additionally, it aids in assessing bone density in the alveolar bone, useful for planning and monitoring treatments for conditions like periodontitis [14]. The advantages of elastography in periodontics are significant. Unlike traditional methods requiring biopsies or invasive techniques, elastography offers a non-invasive alternative with immediate feedback for prompt clinical decisions.

It detects subtle tissue changes not visible through conventional imaging. Integrating elastography into routine periodontal practice necessitates advanced equipment, specialized training, standardized protocols, and calibration methods to ensure consistent and accurate measurements [15]. Ongoing research, including large-scale studies, is essential to fully validate elastography's clinical utility in periodontics and correlate its findings with clinical outcomes. It is an innovative imaging technique gaining momentum in various medical fields, including Oral Surgery, Oral Medicine & Oral Pathology [16]. It measures tissue elasticity or stiffness, enhancing diagnostic accuracy, surgical planning, and postoperative monitoring. It assists in preoperative assessment and tumor characterization by distinguishing benign from malignant lesions, as malignant tumors typically exhibit higher stiffness. It can identify fibrosis or scar tissue, impacting surgical planning, especially in reconstructive surgery or re-operations. By providing detailed tissue stiffness maps, elastography helps surgeons accurately locate abnormal tissues, improving the precision of excisions [17]. It helps identify and preserve vital structures like nerves and blood vessels by distinguishing them from pathological tissues. It monitors postoperative tissue elasticity to assess healing; with abnormal stiffness indicating complications such as fibrosis or incomplete healing [18]. Regular elastographic evaluations can detect tissue properties, tumor recurrences, and other pathological conditions earlier than conventional methods. Its applications include detecting and characterizing oral lesions, monitoring inflammatory conditions, and assessing bone pathologies [19]. It differentiates between benign and malignant lesions based on tissue stiffness, with malignant tissues typically exhibiting higher stiffness. It monitors conditions like leukoplakia and erythroplakia for malignant transformation and assesses inflammatory and autoimmune diseases. For oral lichen planus, it evaluates mucosal tissue stiffness to monitor disease progression and treatment response [20].

It is valuable for distinguishing between benign and malignant salivary gland tumors by analyzing elasticity patterns. It's useful for monitoring oral carcinomas, assessing tumor margins, and detecting changes in tissue stiffness during and after treatment. Regular elastographic assessments can track treatment progress effectively and spot early signs of recurrence [21]. In Sjogren's syndrome, elastography assess salivary gland stiffness for diagnosis and monitoring. It also evaluates salivary gland pathologies like sialadenitis or sialolithiasis by detecting inflammation or obstructions [22]. Reichel CA *et al*. found that individuals with sialolithiasis, one of the most common non-malignant salivary gland conditions, can be effectively monitored during therapy using acoustic radiation force impulse imaging [23]. Sasaki *et al*. used shear wave elastography to distinguish between benign and malignant cervical lymph nodes in oral carcinoma patients, confirming its effectiveness for objectively diagnosing oral carcinoma metastases [24]. Akatsuka *et al*. utilized ultrasonography to track changes in tongue hardness among 60 children aged 6 to 11, shedding light on tongue development during growth. They highlighted the effectiveness of ultrasound SWE and SE in measuring tongue elasticity [25]. Shingaki *et al*. assessed the clinical utility of intraoral strain elastography for early diagnosis of tongue cancer, suggesting its potential as a non-invasive substitute for identifying the disease [26]. Ogura *et al*. examined quantitative strain elastography for tongue carcinoma using intraoral ultrasound. They found that in a 50-year-old male, the average strain for normal tissue was 1.468%, while for tongue cancer it was 0.000%. Similarly, in a 59-year-old male, normal tissue had a strain of 1.007%, while tongue cancer showed 0.000% strain [27]. It extends its utility to assessing soft tissue elasticity around the temporomandibular joint, aiding in conditions like synovitis or disc displacement. Ariji *et al*. in 2012 explored masseter muscle inflexibility in temporomandibular disorders, correlating elasticity index ratios from sonographic elastography with toughness measured by a firmness meter in healthy volunteers [28]. In oral medicine, elastography offers a non-invasive substitute for biopsies, minimizing patient discomfort and risk. Its real-time imaging capability facilitates immediate clinical decision-making during examinations. Integrating elastography with additional imaging modalities like conventional radiography, cone-beam computed tomography, or magnetic resonance imaging can offer a more holistic diagnostic approach, enriching patient care. With advancing technology and increased accessibility, elastography may become a standard part of routine oral medicine practice, improving standard diagnostic procedures. Continuous research and clinical trials will confirm the efficacy of elastography across various oral conditions, solidifying its role as a standard diagnostic tool [29]. Elastography, an imaging method gauging tissue stiffness and elasticity, holds promise in Endodontics, the dental field focusing on dental pulp and root tissues. By furnishing detailed mechanical insights into these tissues, elastography significantly improves the diagnosis, treatment, and monitoring of endodontic conditions. Its applications in Endodontics encompass evaluating pulpal health and aiding in diagnosing pulpitis. Elastography assists in distinguishing reversible from irreversible pulpitis by detecting changes in dental pulp stiffness. Altered elasticity in inflamed pulp tissue aids in early, precise diagnosis. Additionally, it aids in detecting pulp necrosis by identifying differences in stiffness, facilitating the assessment of pulp vitality. It aids in evaluating periapical conditions by detecting periapical abscesses through stiffness changes in surrounding bone and soft tissues. It assists in distinguishing between periapical granulomas and cysts, enhancing diagnostic precision by assessing tissue stiffness. It facilitates monitoring treatment outcomes, indicating healing progress post-endodontic procedures like root canal therapy. It assesses newly formed dental pulp tissue quality in regenerative treatments, ensuring treatment success [30]. Additionally, it aids in detecting root fractures. Elastography aids in root crack and fracture detection by evaluating tooth structure integrity, often undetectable in traditional radiographs. Its advantages in Endodontics include non-invasive tissue property assessment, reducing the need for exploratory surgery. Providing real-time feedback during clinical procedures enables immediate decisions. It enhances diagnostic precision by revealing tissue characteristics not visible in conventional imaging. Challenges include the need for specialized training to interpret images accurately. Ongoing technological advancements may enhance accessibility and ease of use, making it more applicable in routine endodontic practice. With the progression of technology and continued research, elastography is poised to become a fundamental component of Endodontics, enriching diagnostic precision, treatment strategizing, and patient results [31]. This non-invasive imaging method, measuring tissue stiffness and elasticity, holds significant promise in prosthodontics, the dental field focused on creating artificial replacements for teeth and oral structures. By providing detailed insights into tissue mechanics, elastography enhances various aspects of prosthodontic care, including diagnosis, treatment planning, and outcome monitoring. In prosthodontics, elastography aids in assessing soft tissue health by evaluating gingival tissue elasticity, facilitating the detection and monitoring of conditions like gingivitis and periodontitis [32]. Healthy gingiva typically exhibits specific elastic properties, while diseased tissues show altered stiffness. Additionally, it assists in evaluating bone quality for dental implant placement. Elastography evaluates alveolar bone density and quality before implantation, crucial for determining optimal implant locations and ensuring long-term stability. Post-implantation, it monitors osseointegration by assessing changes in bone stiffness around the implant, confirming successful integration. Elastography is pivotal in early peri-implantitis detection, identifying tissue stiffness changes indicating inflammation and bone loss for timely intervention. It assesses soft tissue adaptation to prosthetic devices, improving fit and lowering complication risks [33].

Monitoring prosthetic effects on the Temporomandibular Joint ensures joint function isn't compromised. Detailed tissue resilience maps aid in personalized prosthetic device development, matching patient tissue properties. Its non-invasive nature reduces invasive procedure needs, like biopsies. Real-time imaging offers immediate feedback during clinical procedures, streamlining decision-making. It boosts diagnostic precision by revealing tissue characteristics beyond traditional imaging. However, challenges include the need for technical expertise to interpret images and integrate them into prosthodontic practice. Ongoing advancements may enhance accessibility and usability. Combining elastography with other imaging techniques such as cone beam computed tomography, magnetic resonance imaging, or digital impression systems could offer more comprehensive diagnostic information and enhance patient care. Equipment costs may limit availability. Standardized protocols are crucial for reliable measurements. Further research is needed to validate elastography's clinical utility and establish it as a standard diagnostic tool [34].

Conclusion

Elastography represents a significant advancement in diagnostics and treatment. By providing detailed insights into tissue elasticity, it enhances dentists' ability to diagnose conditions, plan treatments, and monitor progress with greater accuracy and minimal invasiveness. As technology continues to advance, the integration of elastography with artificial intelligence and other imaging modalities will likely lead to even more sophisticated and effective dental care.

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