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Ultrasonography as a Definitive Diagnostic Tool Soft Tissue Imaging in Dentistry - A Review

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Abstract: Ultrasonography is increasingly recognized as a safe, non-invasive, and dynamic imaging modality in dentistry, utilizing high-frequency sound waves to visualize soft tissues, vascular structures, and pathological lesions in real time. Its applications span diagnostic, therapeutic, and surgical domains, including evaluation of salivary glands, tongue, palate, periodontal structures, periapical lesions, TMJ disorders, implant planning, and oral and maxillofacial masses. Ultrasound-guided interventions enhance precision in procedures such as cyst aspiration, nerve blocks, implant placement, and biopsies, while Low-Intensity Pulsed Ultrasound (LIPUS) supports bone regeneration and tissue healing. Advantages include radiation-free imaging, portability, cost-effectiveness, and excellent soft tissue differentiation, with Doppler modes enabling vascular assessment. Limitations involve operator dependence, restricted bone penetration, and limited availability of dental-specific intraoral probes. Future trends emphasize high-frequency, 3D imaging, elastography, contrast enhancement, AI integration, and workflow digitalization, positioning ultrasonography as a complementary tool alongside conventional radiography and CBCT for modern, precision-driven dental practice.

Keywords: Ultrasonography, Dentistry, Doppler, Intraoral Imaging, TMJ

I. INTRODUCTION

Ultrasonography, based on the application of ultrasound, utilizes sound waves at frequencies greater than 20 kHz beyond the upper limit of human hearing to visualize internal structures. The phenomenon of ultrasound was first described by Jacques and Pierre Curie in 1880, while its diagnostic use in dentistry was first reported by Baum et al. in 1963.[1] In ultrasonography, electrical impulses generated by the scanner are converted into high-frequency sound waves through a transducer containing piezoelectric materials, most commonly lead zirconate titanate (PZT). These waves propagate through tissues, producing echoes that are recorded and displayed as real-time images. The image quality depends on the frequency of the sound waves lower frequencies offer greater tissue penetration but lower resolution, whereas higher frequencies yield finer detail with reduced depth. As ultrasound waves are blocked by bone and air, their dental application is limited to areas with bony defects or soft-tissue access.[2] Nevertheless, modern high-frequency linear probes (7.5–12 MHz) now enable high-resolution imaging of the head and neck region. Compared to other imaging modalities such as radiography, CBCT, and MRI, ultrasonography offers several advantages: it is non-invasive, radiation-free, inexpensive, portable, and unaffected by metal artifacts from restorations, while also allowing real-time assessment of lesion vascularity through power and color Doppler modes. It can distinguish cystic from solid or benign from malignant masses, making it highly valuable in diagnostic evaluation.[3] However, its limitations include a restricted field of view, difficulty in imaging behind bone or air, and dependency on operator skill. In dentistry, ultrasonography is increasingly applied for evaluating maxillofacial fractures, cervical lymphadenopathy, soft-tissue masses, salivary gland disorders, periapical lesions, masticatory muscles, and temporomandibular joint (TMJ) conditions. Despite its potential, the lack of intraoral probe designs tailored for dental ergonomics limits widespread use, often requiring adaptation of small-footprint transducers intended for other purposes.[4] During intraoral scans, topical anesthesia and coupling gel are used to minimize discomfort and gag reflex, while buccal mucosa is preferred as the starting point for access. Transcutaneous ultrasonography, though feasible, often produces lower-quality images than intraoral approaches, which allow direct evaluation of lesion size, thickness, echogenicity, and vascularity, especially for tumors of the tongue, floor of the mouth, and buccal mucosa.[5]

II. PRINCIPLES, IMAGING MODES, AND TECHNICAL PARAMETERS OF ULTRASOUND

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Ultrasound is a mechanical, longitudinal wave that propagates through matter unlike electromagnetic radiation by creating alternating compressions and rarefactions within tissues, typically at frequencies exceeding 20 kHz. In soft tissue, ultrasound travels at approximately 1,540 m/s, with its velocity determined by tissue density and elasticity.

Central to ultrasound generation is the piezoelectric effect, wherein piezoelectric crystals, such as lead zirconate titanate (PZT), convert electrical energy into mechanical vibrations and vice versa. When an electrical current is applied, these crystals deform to emit ultrasonic waves; the returning echoes are then reconverted into electrical signals to produce images. The behavior of ultrasound within tissues is influenced by reflection, refraction, attenuation, and acoustic impedance.[6] Reflection occurs when waves encounter interfaces between tissues of differing acoustic impedance (a product of density and sound speed), forming the echoes that create diagnostic images. Refraction, the bending of sound waves when entering tissues at an angle, can displace structures from their true location, while attenuation refers to the gradual loss of signal intensity due to absorption, scattering, and reflection, with higher frequencies attenuating more rapidly. Acoustic impedance differences determine how strongly echoes are reflected at boundaries. Various imaging modes are employed in ultrasonography: A-mode (Amplitude mode) produces a one-dimensional graph of echo amplitude versus depth, historically used to differentiate cystic and solid structures; B-mode (Brightness mode), the most widely used, provides two-dimensional grayscale images where brightness corresponds to echo intensity, allowing real-time imaging at 15–60 frames per second; and M-mode (Motion mode) captures the movement of tissues over time, primarily for dynamic evaluations such as cardiac valve motion.[7] The Doppler mode, based on the Doppler effect, measures frequency shifts in reflected sound to evaluate the direction and velocity of moving structures, particularly blood flow visualized using color scales (red for flow toward and blue for flow away from the transducer) while Power Doppler enhances sensitivity to detect even low-velocity flows or vascular density in lesions. In dental imaging, frequency selection is crucial: intraoral applications typically use 5–20 MHz for optimal balance between resolution and penetration, while superficial structures may require high-resolution probes operating at 30–50 MHz. Transducer types linear or convex arrays affect field of view and image geometry, while coupling media such as ultrasound gel are essential to eliminate air interfaces that impede sound transmission. [Figure 1] A fundamental trade-off exists between resolution and penetration: higher frequencies yield superior image clarity but reduced depth, whereas lower frequencies allow deeper imaging with less detail.[8]

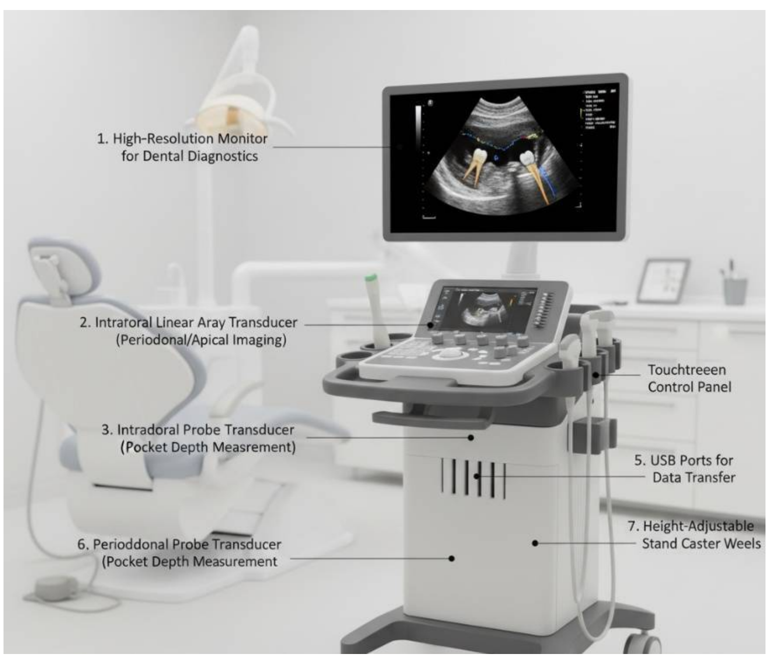

Figure 1: Ultrasound Machine and Parts

III. THERAPEUTIC AND SURGICAL APPLICATIONS OF ULTRASOUND IN DENTISTRY

Ultrasound has emerged as a valuable tool not only for diagnostic imaging but also for therapeutic and surgical applications in dentistry, enhancing precision, safety, and tissue healing outcomes. In ultrasound-guided procedures, real-time visualization allows clinicians to perform minimally invasive interventions with greater accuracy and reduced risk. During cyst aspiration or abscess drainage, ultrasound enables precise localization of lesions and adjacent anatomical structures, ensuring safe needle placement while minimizing neurovascular injury.[7]

Similarly, ultrasound-guided local anesthesia and nerve blocks, such as inferior alveolar or maxillary nerve blocks, facilitate direct visualization of neural pathways and surrounding soft tissues, leading to higher success rates, fewer complications, and improved analgesic effectiveness compared to traditional blind techniques.[8] Moreover, ultrasound can assist in real-time implant or mini-screw placement, allowing clinicians to assess bone contours, soft tissue thickness, and implant angulation without radiation exposure; when integrated with digital workflows, its accuracy approaches that of CBCT-based navigation systems. Beyond its surgical guidance role, ultrasound offers therapeutic benefits through Low-Intensity Pulsed Ultrasound (LIPUS), which delivers gentle mechanical stimulation that promotes bone regeneration by enhancing osteoblastic activity, stimulating growth factor expression, and accelerating bone remodeling at fracture or osteotomy sites.[9] Clinical studies have shown that LIPUS shortens healing time and improves bone density following jaw fractures, orthognathic surgeries, and dental implant procedures. Additionally, therapeutic ultrasound plays a beneficial role in managing temporomandibular joint (TMJ) dysfunction, where its deep-tissue micromassage and mild thermal effects enhance local circulation, reduce inflammation, relieve muscle spasms, and improve joint mobility.[10]

IV. APPLICATIONS OF ULTRASONOGRAPHY IN ORAL AND MAXILLOFACIAL REGIONS

Ultrasonography has emerged as a valuable, non-invasive diagnostic modality in dentistry for the evaluation of various soft-tissue structures and pathological conditions of the oral and maxillofacial region. It offers real-time, dynamic visualization of salivary glands, ductal systems, vascular and neural pathways, mucosal tissues, tongue, palate, and periodontal structures with minimal patient discomfort. In the assessment of major salivary glands, particularly the submandibular and sublingual glands, ultrasonography enables accurate localization and characterization of inflammatory lesions, cysts, and neoplasms.[11] The examination begins from the orifice of Wharton's duct toward the floor of the mouth, with intraoral ultrasound providing superior visualization and detection of even minute calculi. Sialolithiasis is identified as hyperechoic foci with distal acoustic shadowing, and ultrasonography can distinguish stones within the glandular parenchyma or ductal lumen information vital for treatment planning.[12] In addition, high-frequency hockey-stick transducers facilitate the examination of the lingual nerve and artery, which aids in preoperative localization to prevent surgical injuries during third molar extraction or implant placement. The minor salivary glands of the lips and buccal mucosa can also be clearly visualized, allowing precise assessment of mucoceles, soft tissue lesions, and the depth of ulcerations. Examination of the tongue using high-resolution (7–15 MHz) linear or hockey-stick probes allows for detailed imaging of its muscular architecture and has become particularly useful in determining tumor thickness in cases of oral tongue carcinoma an important prognostic indicator influencing surgical management.[13] Intraoral ultrasonography is also beneficial in detecting recurrent tumors or post-treatment changes following radiotherapy, while Doppler imaging helps assess vascular and lymphatic involvement. Evaluation of the hard and soft palates by ultrasonography provides valuable preoperative information on palatal masses, donor site thickness for grafting procedures, and orthodontic anchorage planning, although limitations exist due to the dome-shaped contour of the palate and restricted access for linear probes.[14] Furthermore, intraoral ultrasonography serves as a useful adjunct in differentiating periapical granulomas from cysts based on echogenic characteristics, providing a dynamic, radiation-free diagnostic alternative where CT or MRI may be impractical.[15]

V. APPLICATIONS OF ULTRASONOGRAPHY IN PERIODONTOLOGY AND ENDODONTICS

Ultrasonography has become a versatile, non-invasive diagnostic and monitoring tool in both periodontology and endodontics, offering real-time visualization of soft and hard tissue structures with remarkable precision. In periodontology, ultrasound imaging enables the detection of subgingival calculus by identifying acoustic impedance differences between calculus deposits and tooth surfaces. The integration of computerized calculus detection (CCD) technology into modern ultrasonic scalers facilitates precise, real-time identification and removal of calculus during clinical procedures.[16] High-frequency intraoral ultrasound (20–30 MHz) allows accurate measurement of soft tissue thickness, mucogingival dimensions, and assessment of alveolar bone contours and defects, which are critical for presurgical mapping in periodontal and regenerative procedures. Ultrasonography also provides a highly accurate and patient-friendly method for assessing gingival biotype, keratinized tissue width, and periodontal attachment levels, measuring distances from the cemento-enamel junction to the epithelial attachment without causing discomfort or bleeding.[17] The addition of Doppler functionality enhances this by enabling evaluation of gingival vascularization, offering insights into healing potential, graft viability, and tissue perfusion. Furthermore, ultrasound serves as an invaluable monitoring tool for postoperative healing, allowing clinicians to track soft tissue remodeling, new attachment formation, and bone density changes following regenerative or surgical interventions.[18] Advanced modalities like elastographic ultrasound further aid in assessing tissue elasticity and graft or membrane integration during guided tissue regeneration, reflecting the progress of wound healing.

In endodontics, ultrasonography plays a significant role in localizing periapical lesions and cysts, providing superior sensitivity in detecting early periapical radiolucencies that may not yet be visible on conventional radiographs. [Figure 2] Its capacity to image both soft and hard tissue components allows differentiation between periapical abscesses, cysts, and granulomas an essential step in determining the appropriate therapeutic approach, especially for patients for whom ionizing radiation must be minimized.[19] Color and pulsed Doppler ultrasound add diagnostic depth by assessing vascularity within lesions: cysts typically lack vascular flow, while granulomas or tumors show distinct perfusion patterns, allowing reliable differentiation between cystic and solid lesions before surgical intervention. [Figure 3] Moreover, high-resolution ultrasound (≥30 MHz) enables detailed evaluation of root fractures, cortical bone discontinuities, sinus tracts, and soft-tissue extensions associated with chronic infections, often surpassing conventional radiography in diagnostic accuracy.[20] When combined with CBCT, ultrasound further refines the localization and characterization of periapical pathology, enhancing clinical decision-making and optimizing outcomes in endodontic diagnosis and surgical planning.[21]

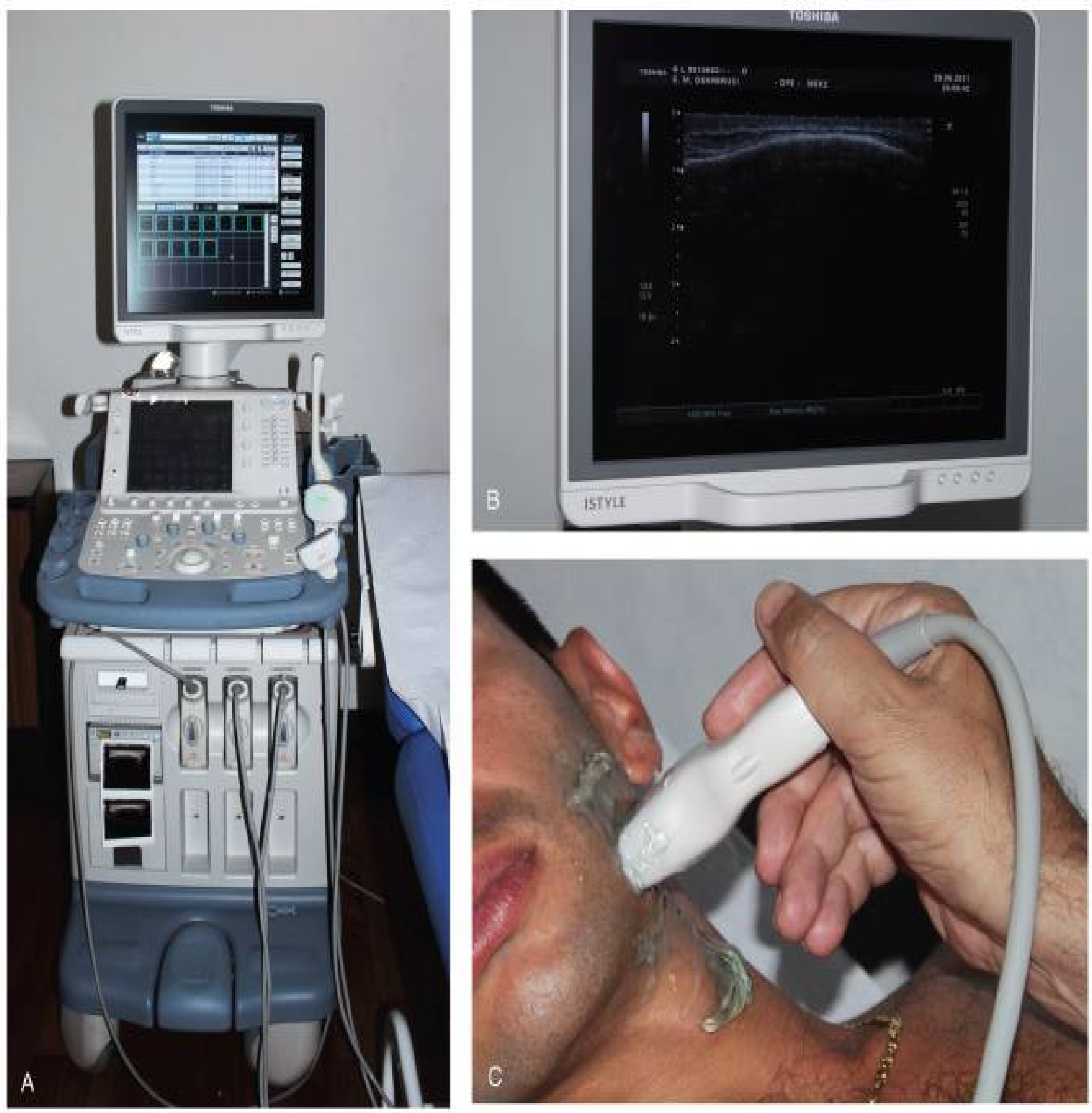

Figure 2: Ultrasound in Endodontics

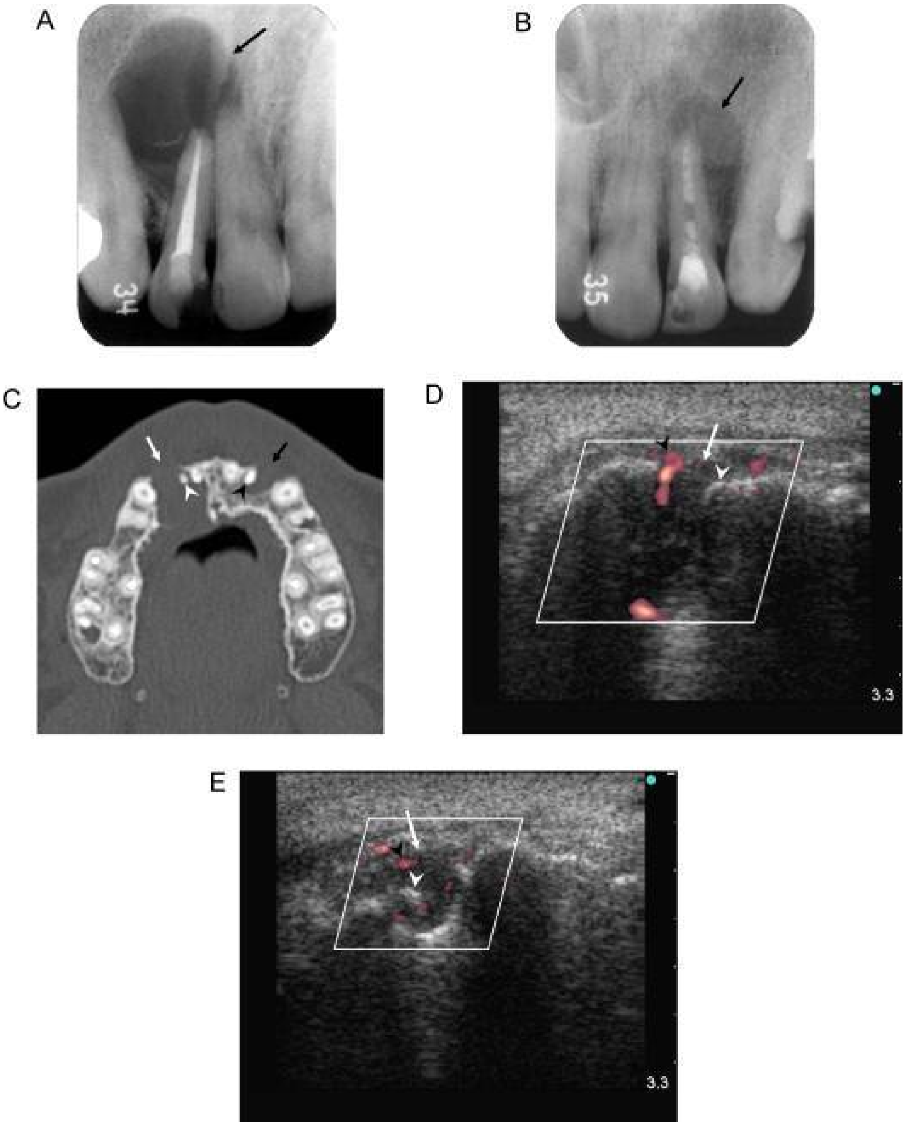

Figure 3: Ultrasound in Cyst Detection

VI. APPLICATIONS OF ULTRASONOGRAPHY IN ORAL AND MAXILLOFACIAL SURGERY, IMPLANTOLOGY, AND TMJ ASSESSMENT

Ultrasonography has become an invaluable, non-invasive tool in oral and maxillofacial surgery, implantology, and temporomandibular joint (TMJ) evaluation, providing real-time visualization of soft tissue, bone, and vascular structures. In oral and maxillofacial surgery, ultrasound effectively characterizes cystic and solid masses, tumors, and soft tissue swellings by delineating lesion borders, internal architecture, and extension into adjacent tissues, which facilitates accurate preoperative assessment and postoperative monitoring.[22] It also plays a critical role in guiding fine-needle aspiration cytology (FNAC) or core biopsies, enabling precise needle placement within lesions, reducing injury to surrounding structures, and improving diagnostic yield, particularly in deep or poorly palpable lesions. Doppler modes allow evaluation of lesion vascularity, distinguishing avascular cysts from hypervascular tumors, mapping vascular networks for flap planning, and assessing bleeding risk before surgical interventions.[23] In implantology, high-resolution ultrasound permits non-invasive measurement of alveolar ridge dimensions and soft tissue thickness, supporting accurate planning of implant diameter, surgical flap design, and prediction of esthetic outcomes, sometimes serving as a complement or alternative to CBCT. [Figure 4] During implant or mini-screw placement, ultrasound provides real-time intraoperative guidance to avoid vital structures, optimize alignment, and ensure precise positioning, while serial scans enable longitudinal monitoring of osseointegration, peri-implant soft tissue health, and early detection of peri-implantitis or bone loss without radiation exposure.[24]

[Figure 5] For TMJ assessment, ultrasonography offers visualization of articular disc position, joint effusions, synovitis, and osteoarthritic changes, serving as a practical alternative to MRI for superficial structures. Dynamic imaging can record jaw movements, condylar translation, and disc behavior during mouth opening and closure, aiding in the diagnosis and follow-up of internal derangements and functional joint disorders.[25] [Figure 6]

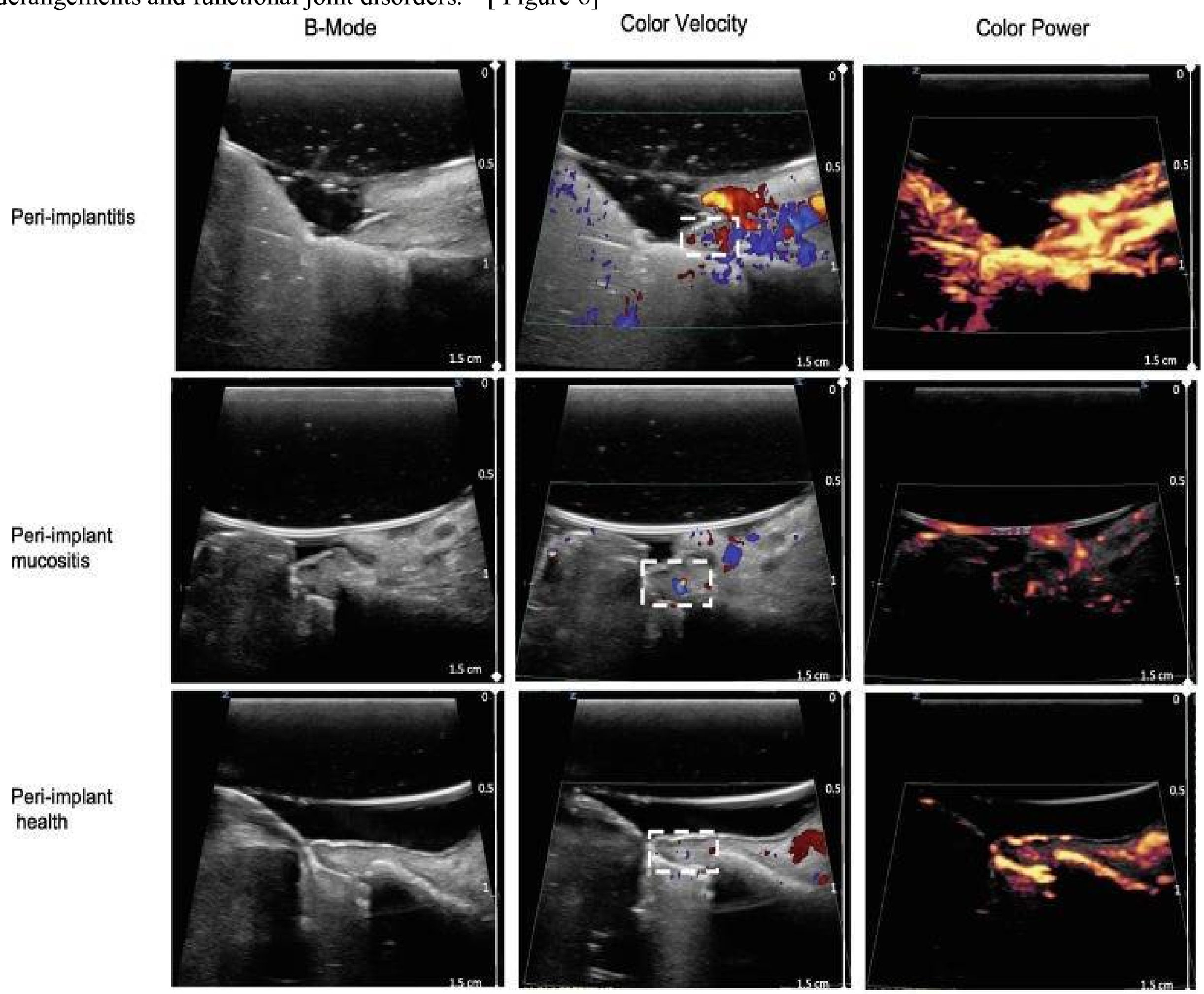

Figure 4: Ultrasound in Peri –Implantitis

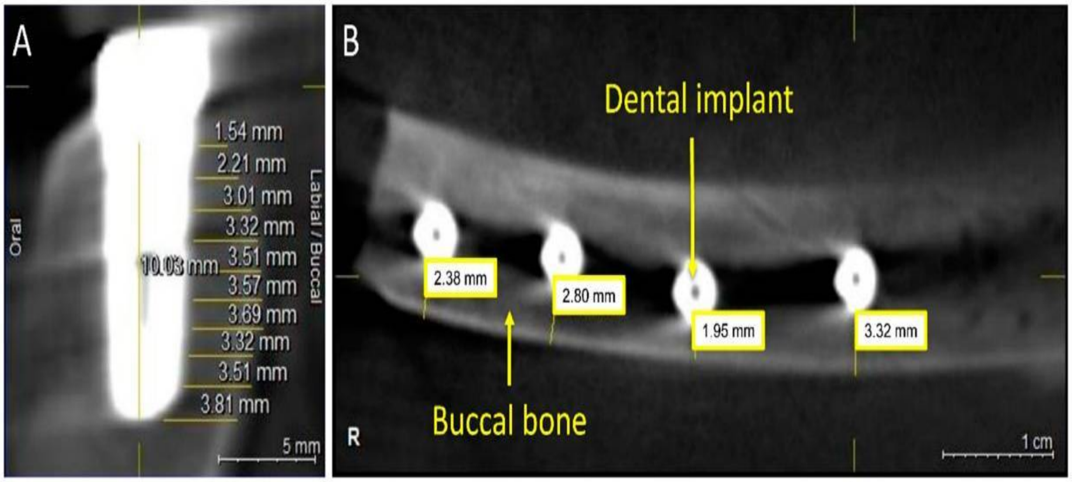

Figure 5: Ultrasound in implantology

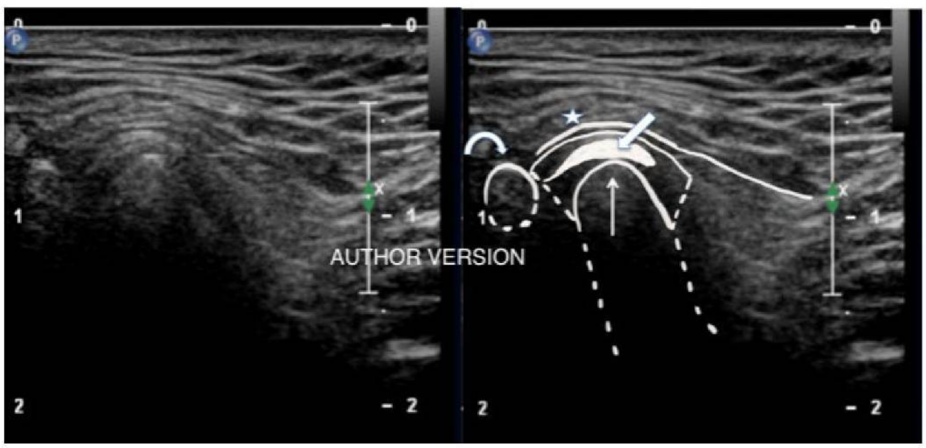

Figure 6: Ultrasound in TMJ Assessment

VII. ADVANTAGES, LIMITATIONS, AND FUTURE PERSPECTIVES OF ULTRASOUND IN DENTISTRY

Ultrasound offers numerous advantages in dentistry, making it a safe, versatile, and increasingly valuable imaging modality. Being non-invasive and radiation-free, it is suitable for repeated use in all patient populations, including children and pregnant patients, while providing real-time visualization for dynamic assessment and procedural guidance. Its portability and cost-effectiveness compared to MRI or CBCT facilitate rapid bedside evaluations and adoption in varied clinical settings.[26] Ultrasound excels in soft tissue differentiation, enabling precise imaging of gingiva, mucosa, muscles, salivary glands, and vascular structures, with Doppler modes allowing functional assessment of blood flow. Procedures are generally painless and well-tolerated, and repeated imaging can be performed without risk, enhancing patient comfort and longitudinal monitoring. Despite these advantages, ultrasound has notable limitations.[27] Dense cortical bone impedes penetration, restricting evaluation of deep bone or structures shielded by bone. Imaging and interpretation are highly operator-dependent, necessitating specialized training for reliable and reproducible results. Currently, dedicated intraoral probes with ergonomic designs optimized for dental structures are limited, and compact, dental-specific ultrasound devices are not yet widely available, constraining broader clinical implementation.[28] Looking forward, emerging trends are poised to expand the clinical utility of ultrasound in dentistry. High-frequency (30–50 MHz) and three-dimensional ultrasonography provide detailed anatomical reconstructions with superior spatial resolution. Elastography allows assessment of tissue stiffness, aiding differentiation of tumors, fibrosis, or inflammatory changes. Contrast-enhanced ultrasound (CEUS) improves visualization of vascular lesions and microcirculation, enhancing detection of tumors and inflammatory processes. Integration of artificial intelligence (AI) and machine learning algorithms holds promise for automated image segmentation, lesion detection, and diagnostic support, potentially reducing operator dependence.[29] Development of compact, flexible intraoral probes will improve ergonomics and accessibility in confined oral spaces. Finally, integration of ultrasound with digital workflows, including

CAD/CAM systems and surgical navigation platforms, can enhance implant planning, guided surgery, and patient-specific treatments, positioning ultrasonography as a key modality in modern, precision-driven dental care.[30]

VIII. CONCLUSION

Ultrasound in dentistry is emerging as a safe, versatile, and dynamic imaging tool that complements traditional radiography and advanced modalities. It enables real-time, radiation-free assessment of soft tissues, lesions, and vascularity. To fully harness its potential, standardized protocols, dedicated intraoral probes, and comprehensive operator training are essential. Continued device innovation and integration with digital workflows will expand its clinical and research applications.

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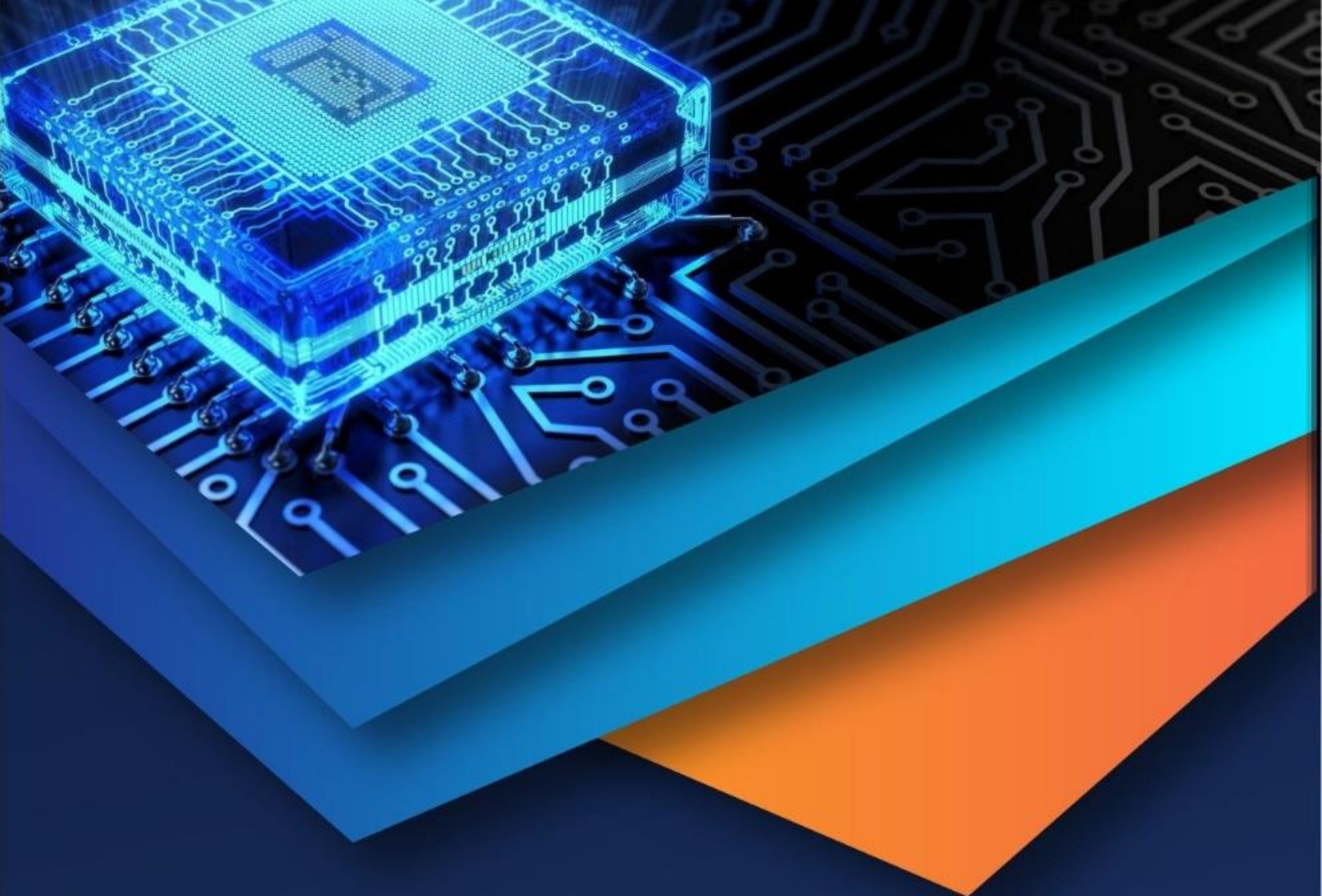

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