Evaluation of Combined Ultrasonography and Cone Beam Computed Tomography for Clinical Imaging: A Negative Results Study

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Abstract

The combination of ultrasonography (US) and cone beam computed tomography (CBCT) has been proposed as a multimodal imaging strategy capable of uniting real-time soft-tissue assessment with high-resolution three-dimensional visualization of osseous structures. This study critically evaluated whether such integration provides measurable diagnostic or workflow advantages in mandibular imaging. Despite strong theoretical justification, the combined use of US and CBCT failed to demonstrate clinically meaningful improvements in diagnostic accuracy, confidence, or efficiency when compared with CBCT alone. Fundamental physical mismatches, hardware incompatibilities, geometric constraints, and operator-dependent variability limited the anticipated synergistic benefits. These negative findings underscore the importance of reporting unsuccessful integration attempts to guide future research and prevent premature clinical adoption of technically incompatible imaging paradigms.

Introduction

Accurate imaging of the jaws is essential in dentistry, oral and maxillofacial surgery, orthodontics, and periodontology. (1,2) Cone beam computed tomography has become the standard three-dimensional imaging modality for evaluating dentoalveolar structures, implant planning, and temporomandibular joint (TMJ) morphology, while ultrasonography remains a valuable tool for real-time assessment of superficial soft tissues, salivary glands, and vascular structures. Previous literature has suggested that combining these modalities could yield a more comprehensive diagnostic approach by compensating for the limitations inherent to each technique individually.

However, CBCT and US are based on fundamentally different physical principles, acquisition geometries, and reconstruction assumptions. While hybrid use at the workflow level, via sequential acquisition and software-based image fusion, is feasible, the development of a truly integrated or synergistic CBCT–US system remains technically and clinically challenging. This study evaluates the practical outcomes of combining US and CBCT for mandibular imaging and reports predominantly negative results.

Ultrasonography

Ultrasonography is a non-invasive imaging modality that employs high-frequency acoustic waves to generate real-time images of soft tissues. In maxillofacial applications, US has been used to assess salivary gland pathology, superficial infections, vascular lesions, and soft-tissue masses. (3,4,5,6)

Ultrasonography Principles

Ultrasound imaging relies on the emission and reception of sound waves that reflect and scatter at interfaces with differing acoustic impedance. Image formation depends on time-of-flight and amplitude of returning echoes, assuming relatively uniform sound speed and limited scattering along the propagation path. These assumptions are frequently violated in regions containing bone, air, or complex interfaces.

Ultrasonography Advantages

- Real-time dynamic imaging of soft tissues
- Absence of ionizing radiation
- Portability and cost-effectiveness
- Ability to differentiate cystic and solid lesions
- Utility for image-guided aspiration or biopsy

Ultrasonography Limitations

Despite its advantages, ultrasonography is severely limited in osseous imaging by poor penetration through cortical and trabecular bone, strong reflection at bone–air interfaces, and high operator dependence. Lack of standardized osseous protocols, susceptibility to motion, geometric distortion, and challenges in reproducible image registration further reduce its reliability when integrated with tomographic modalities.

Cone Beam Computerized Tomography (CBCT)

CBCT is a three-dimensional radiographic technique widely used in dental and maxillofacial imaging. It provides high-resolution visualization of osseous structures with lower radiation dose than conventional medical CT.

CBCT Principles

CBCT systems acquire multiple two-dimensional projections using a cone-shaped X-ray beam during gantry rotation. Reconstruction algorithms assume straight-line photon propagation and stable voxel attenuation values, enabling volumetric reconstruction through filtered back-projection or iterative techniques.

CBCT Advantages

- High spatial resolution for bony anatomy
- Accurate three-dimensional representation
- Essential for implant planning and surgical guidance
- Lower radiation dose relative to conventional CT

CBCT Limitations

CBCT exhibits poor intrinsic soft-tissue contrast, susceptibility to scatter and beam-hardening artifacts, and limited ability to characterize non-mineralized tissues. These limitations have motivated interest in complementary modalities such as ultrasonography. (7)

Integration of Ultrasonography and CBCT

The proposed integration of US and CBCT aims to combine soft-tissue and hard-tissue information into a unified diagnostic framework. In practice, integration was limited to sequential acquisition and software-based fusion rather than simultaneous hardware integration. (3,8)

Integration of Ultrasonography and CBCT: Advantages and Limitations

While theoretical advantages include comprehensive tissue assessment and improved diagnostic confidence, practical implementation revealed significant limitations. Increased acquisition time, registration errors, operator variability, and minimal incremental diagnostic value outweighed any perceived benefit. (8)

Integration of Ultrasonography and CBCT: Clinical Applications

Clinical scenarios evaluated included salivary gland disease, TMJ disorders, vascular lesions, and mixed soft- and hard-tissue pathologies. In most cases, ultrasonography provided limited additional information beyond CBCT findings, except for superficial soft-tissue abnormalities.

Mismatches

Fundamental mismatches between X-ray attenuation-based tomography and acoustic wave-based imaging prevent true synergy. CBCT assumes static geometry and linear attenuation, whereas ultrasonography depends on dynamic probe positioning, tissue compression, and heterogeneous sound propagation.

Hardware and Geometric Limitations

CBCT requires rigid gantry rotation with fixed source–detector geometry, while ultrasonography demands direct tissue contact and free probe manipulation. These requirements are mutually incompatible within a single acquisition system, precluding true hardware integration.

Negative Findings

The study demonstrated that:

- Ultrasonography rarely added clinically relevant information beyond CBCT
- Bone interference prevented consistent anatomical correlation
- Combined workflows increased procedure time
- Inter-operator variability reduced reproducibility

Collectively, these findings indicate that US does not meaningfully enhance CBCT-based mandibular imaging under current technological constraints.

Future Considerations

Future progress may depend on advances in artificial intelligence-assisted registration, improved a coustic penetration techniques, standardized imaging protocols, and novel hybrid physics approaches such as X-ray-induced acoustic imaging. Until such developments mature, routine integration remains unjustified. (9,10,11,12,13,14)

Conclusions

Despite strong theoretical appeal, the integration of ultrasonography and CBCT for mandibular imaging failed to demonstrate measurable clinical benefit in this negative results study. Fundamental physical, geometric, and operational incompatibilities limit meaningful synergy between these modalities. Reporting these negative findings contributes to scientific transparency and provides realistic guidance for future research in multimodal imaging.

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