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Research Article

Investigating Recent Advancment In CBCT And USG Technology That Enhance Imaging Quality And Diagnostic Capabilities In Tmjs.

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ABSTRACT

Over the past three decades, dentistry has made great advancements in all of its areas. These developments have made the requirement for more accurate diagnostic instruments, particularly imaging techniques, imperative.
Modern dentistry has included sophisticated imaging techniques such as computed tomography, cone beam computed tomography, magnetic resonance imaging, and ultrasound in addition to the basic intra-oral periapical X-rays. In addition to making the procedure quicker and simpler, the switch from analogue to digital radiography has also made it easier to save, manipulate, and retrieve images (adjusting brightness and contrast, cropping them, etc.). The intricate cranio-facial structures are now easier to examine, and deep seated lesions may now be accurately and early diagnosed thanks to three-dimensional imaging. This paper reviews recent developments in USG and CBCT and their applications.

Keywords: CBCT, US imaging, Artificial Inteligance, Deep Learning, Machine Learning

Introduction

The constraints of 2-dimensional (2D) projections, which include structural misrepresentation, distortion, superimposition, and magnification, affect intraoral and conventional radiography operations. Cone-beam computed tomography (CBCT) is a substitute C-arm for conventional computed tomography (CT) that has become widely used in dentistry over the past five years due to its ability to produce three-dimensional (3D) data at a lower cost and radiation dose than CT while also having a higher spatial resolution.[1,2] With CBCT technology developing and becoming more widely available, TMJ treatment appears to have a better future than in the past. Numerous people with TMJ issues have found hope and relief with CBCT imaging, which is a cornerstone of current TMJ care due to its capacity to give extensive anatomical information, guide treatment planning, and monitor treatment success. When it comes to TMJ therapy, CBCT imaging has completely changed how doctors diagnose and treat patients. Practitioners can get new insights into TMJ disorders and develop more effective treatment plans and better patient results by utilizing the capabilities of modern imaging technologies.[2,3]
A versatile imaging technique called ultrasound (US) is employed all over the world as the initial step in a variety of clinical situations as a medical examination. It gains from the ongoing advancements in ultrasonic technology as well as a reputable digital health system centred in the United States.[3] However, because US imaging has intrinsic features including operator reliance and manual operation, its diagnostic performance still faces difficulties. It has been demonstrated that artificial intelligence (AI) can identify complex scan patterns and offer quantitative evaluations for imaging data. As a result, AI technology may be able to assist doctors in producing more consistent and accurate results.[3,4]
The purpose of this review was to provide recent developments on CBCT and USG for the diagnosis of temporomandibular joint disorders. within the rapidly changing context of CBCT and USG applications.[4]

The selection of current and widely accepted evidence-based sources, an organized summary of the data based on an iterative framework, and adherence to ethical, public health, and patient-centered considerations served as the review's guiding principles.

Improving the diagnostic accurecy

In CBCT

There are several research examining the TMJ-specific CBCT's diagnostic accuracy. The first accuracy research, to the best of our knowledge, was published in 2005 and showed that CBCT could reliably and accurately estimate the linear dimensions of the TMJ in dry human skulls. A more recent research concluded that the measures of the joint spaces were remarkably close to the real joint spaces, confirming the accuracy of CBCT in assessing TMJ dimensions.[4]

With macroscopic observations serving as the gold standard, it was demonstrated in 2006 that CBCT had a sensitivity of 0.80 for identifying erosions and osteophytes in postmortem material.CBCT and multislice or multidetector CT, sometimes referred to as CT, were examined in the same study. While the latter had a marginally lower sensitivity (0.70), no discernible differences were discovered between the two modalities.[4,5]

A much decreased sensitivity for identifying cortical abnormalities and osteophytes was discovered in a 2007 comparison of CBCT with conventional (spiral) tomography in a larger cohort of dry human skulls; nonetheless, no significant differences were detected between the modalities. In the same year, another dry skull investigation shown that when it came to condylar cortical erosions, CBCT was more accurate and more reliable than panoramic radiography and traditional (linear) tomography.[6]

The findings of Honda et al. (2011) were supported by a more recent investigation using a dry human skull sample, which found no discernible differences between CBCT and CT in terms of identifying surface osseous alterations. But it was discovered that the sensitivities were lower, in line with Hintze et al.[6,7]

In an experimental research on sheep, it was demonstrated that CBCT offers diagnostic accuracy equivalent to CT11,14 when analyzing condylar fractures.[6]

As shown by Marques et al. and verified by Patel et al. in their studies of simulated condylar lesions, the sensitivity of CBCT for evaluating bone defects depends on the magnitude of the abnormalities.[5,7]

As shown by Marques et al. and verified by Patel et al. in their studies of simulated condylar lesions, the sensitivity of CBCT for evaluating bone defects depends on the magnitude of the abnormalities. The detection of very tiny flaws, less than 2 mm, proved to be challenging, even if the sensitivity for condylar osseous abnormalities was generally very good, ranging from 72.9 to 87.5%.[8] These measures supported the findings of Marques et al. (2016), but they significantly outperformed the findings of Hintze et al. (2012), who looked at morphological alterations including osteophytes and condylar flattening. Thus, it is proposed that, compared to other morphologic changes, erosion of the condylar surface may be simpler to identify from CBCT images.[8,9]

Using the same in vitro material, the same authors conducted another investigation in which they did not find any significant changes, either at normal or high resolution.[9,10] However, they also came to the conclusion that the CBCT unit utilized for the test had a significant impact on the accuracy of detecting condylar abnormalities. When comparing three alternative fields of view—12, 9, and 6 inches—with voxel sizes of 0.4, 0.3, and 0.2 mm, respectively, it was discovered that the smallest field of view had the maximum diagnostic efficiency for representing condylar erosions.18 In a second investigation, the sensitivity of CBCT scans with varying voxel sizes (0.4 and 0.2 mm) for evaluating simulated abnormalities in fresh pig mandibular condyles increased dramatically with increasing scanning resolution, but not for big defects.[7,11]

When utilizing 0.4-mm voxel size CBCT scans, about one out of three minor defects (both diameter and depth <2 mm) may go undetected throughout the diagnostic process. With a 0.2-mm voxel size and a better scan resolution, all faults were identified with >80% sensitivity.[12]

In USG

While a significant number of individuals with TMJ arthritis exhibit neither pain nor impaired function in the early stages of the disease and have a normal TMJ clinical examination, radiographic evidence of TMJ damage can still be detected in the early stages of the disease.[6]

As a result, imaging becomes essential in the early evaluation of TMJ abnormalities in an effort to stop additional TMJ degradation. Furthermore, regular instrumental monitoring is necessary to assess the disease's course and the effectiveness of the treatment strategies.[1,8]

Traditional CT and X-ray scans do not adequately examine soft tissues, articular disc alterations, or early or active symptoms of arthritis; they only show severe damage of TMJ arthropathy. Furthermore, CT has a high radiation dosage and lacks dynamic imaging capacity, even though it is useful in selecting surgical candidates since it offers correct anatomic information.[13,14]

Because MRI has a moderate-to-good reliability and can detect both ongoing arthritis alterations and arthritic sequelae, it is now considered the imaging "gold standard" for the diagnosis of inflammatory processes in TMJ pathologies. MRI has several benefits, but it also has certain disadvantages. More specifically, the test necessitates an open-mouth posture, which can be problematic for patients who are suffering discomfort in their temporomandibular joint (TMJ).[11,13] Image capture takes an average of 20 to 45 minutes. Additionally, MRI is a costly treatment that is not accessible in all centres, and it mostly permits

static picture research.[5] Additionally, it requires patient cooperation, which can be challenging for patients who are claustrophobic or in the juvenile population. Additionally, individuals who have pacemakers, implanted cardiac defibrillators, or metallic foreign substances should not undergo magnetic resonance imaging (MRI).[7,13]
When compared to the gold standard MRI approach, the US diagnosis of effusion has shown promise, particularly in cases when the adult population's capsular width is more than 1.950 mm. [14]Actually, recent research points to a key TMJ capsular width of about 2 mm and emphasizes interobserver reliability as a result. Furthermore, after controlling for other variables, the capsular width has been shown to be a risk factor for TMJ discomfort; as a result, it is an estimate with a corresponding clinical association.[14,15]

Recent Advances in CBCT

Advances in Image Detection

Increasing advances in detector materials and technology have improved CBCT's speed and effectiveness. These days, very few machines have an image intensifier detector and are charge-coupled. Nowadays, flat-panel detectors (FPDs) make up the bulk of detectors.[6] It is well known that FPDs based on amorphous silicon (a-Si), commonly referred to as TFT technology, are more resilient to radiation damage. Nevertheless, with time, they experience instabilities such as "ghosting" or "image lag." FPDs based on complementary metal oxide semiconductors (CMOS) are superior to TFTs in many ways, including reduced costs, smaller pixel pitches, reduced electrical noise, increased readout rates, and reduced picture latency. As a result, while their maximum wafer size and radiation hardness are not as excellent as TFT's, their spatial resolution is greater. Similar to TFT, CMOS-based FPDs are finished by placing a scintillation layer on top of the CMOS pixel array. Commonly, cesium iodine-based scintillators doped with tellurium (CsI:Tl) have been used. Even though this technology could be approaching its limits, efforts are always being made to boost sensitivity while enhancing spatial resolution and lowering the signal-to-noise ratio.[7]

Advances in Volume Reconstruction

The native raw data, which are stored as 2D projection frames, are initially subjected to a number of pre-processing operations (such as offset and gain adjustments), after which they are processed through reconstruction to provide a volumetric dataset. Due to its ease of use and quick reconstruction durations, the Feldkamp-Davis-Kress (FDK) algorithm is used in almost all CBCT machines for filtered back-projection (FBP).[2,9] Even yet, this reconstruction technique is quite susceptible to noise, scatter, and artifacts, especially when the exposure rate and the quantity of x-ray projections are reduced. Higher radiation doses could be necessary in order to get smaller voxels and, thus, better spatial resolution, which runs opposite to the idea of radiation reduction. As a result, a great deal of research is currently being done on alternate approaches such hybrid iterative/analytical reconstruction methods or iterative approaches.[11] To create innovative techniques for low-dose CBCT imaging with an adequate contrast-to-noise ratio, a variety of a priori information is integrated (e.g., modelling of scatter radiation, beam hardening).[6,14] Every iteration usually needs at least one forward and one back projection, but FPB approaches usually only need one back projection operation. The computational load associated with applying iterative methods to high-resolution CBCT imaging can be mitigated by utilizing graphics processing units, or GPUs.[15]

Advances in Image Quality

Every CBCT acquisition and reconstruction adds noise and artifacts unique to each operating mode, which can mask or mimic disease despite continuous increases in picture quality. Artefacts can be caused by unit-, object-, or patient-related variables. In the reconstructed pictures, they typically take the form of double contours, blurring, and black-and-white patterns resembling stripes and rings.[3]
The continual reduction of overall system noise is achieved by the enhancement of sensor and signal transmission system quality. The two most troublesome ones are those connected to patient mobility and metal. Metal artefacts appear because of X-ray beam hardening and the back-projection reconstruction method, which are responsible for areas of hypodense perturbations, black or white radial streaks centered on metal structures, and the presence of a black border near dense structures (e.g. implant, endodontic post, inlay/metal core).[6,9,11] To enhance picture quality, metal artifact removal algorithms and image data processing techniques have been developed. Motion artifacts offset the great spatial resolution that is theoretically present by appearing as a loss of sharpness.[12,15]
Motion compensation algorithms have been created to support mechanical methods (such as biting support and head restraints). In the future, the reconstruction procedure may incorporate accurate data on patient mobility during acquisition (for example, by monitoring marker movements).[1,9]

Recent Advancement of USG

There's a chance that portable ultrasonography will replace stethoscopes. Ultrasound imaging is a unique modality that may be used in a wide range of therapeutic settings due to its affordability, mobility, safety, and non-invasiveness. In reality, ultrasonic imaging has become a significant diagnostic tool for an expanding number and range of clinical conditions, offering a broader diversity of treatment options. This circumstance has prompted the development of several intricate diagnostic techniques and the atomization of their application in medicine.[14]

Still, there are a number of difficulties with ultrasound imaging at the moment:

Operator reliance. Given that US imaging relies on the operator's capacity to It might be challenging to get consistent and trustworthy findings from various operators when positioning the transducer and interpreting the pictures appropriately, necessitating lengthy and specialized instruction.[11,13,14]

Subjectivity in the understanding of images. The US photographs are interpreted in a highly subjective manner. The expertise and competence of the person doing the scan have a major role in the interpretation of US pictures, in contrast to other imaging modalities that yield objective, quantifiable data. This may result in variations in the pictures' accuracy and dependability, especially when utilized for diagnostic reasons.[11]

The Deep-Learning Revolution in Ultrasound Imaging

One of the areas where artificial intelligence has made the most strides is the use of deep learning to medical imaging. In US imaging, it has already produced a number of noteworthy outcomes. Because of the widespread recognition of the enormous potential that exists when clinical and commercial technologies are combined, computer-assisted ultrasonography is a rapidly developing topic of study.[8,13]

Applications of AI in US Imaging

Even with the development of new ultrasonic medical imaging technologies, there is still much room for advancement in the application of machine learning algorithms to ultrasound picture generation in order to produce less hazy and more meaningful images. alterations to hardware components are necessary for new approaches in beamforming, super-resolution, and image enhancement; these alterations are typically more ambitious than simpler software post-processing techniques.[15] Despite the more challenging adoption, several research developments are surpassing conventional and basic reconstruction algorithms, which convert physical measurements of ultrasonic waves into visual representations on a display.[8,12]

The many ultrasonic imaging methods may be enhanced by increasingly complex real-time solutions as computing power in medical devices increases.[6]

Computer-Assisted Ultrasound Scanning

Ultrasound imaging relies heavily on the operator. Thus, in order for sonographers to get clinically valuable pictures, they need to have appropriate training.[14]

Acoustic shadows, attenuation, speckle, and signal dropout all impair noisy ultrasound pictures. Thus, it is not always the case that the operator sees the anatomy as well as one would want. Furthermore, from a clinical perspective, a soft-textured picture free of noise from over-filtering or improper gain settings is meaningless.[11,13]

Computer-assisted scanning is a potential suite of technologies that might democratize ultrasonic medical imaging because of these particular issues. Any advancements in the efficiency and independence of this imaging modality's acquisition workflow would be advantageous to medical professionals. They will be able to streamline their process, cut costs, boost production, and simplify their task with the astute aided scanning assistance.[1]

The Impact of AI on TMJ image Quality

The diagnosis of TMD is largely dependent on imaging. According to the 2014 guidelines for the diagnostic criteria of TMD, a definitive diagnosis of disc displacement (DD) or degenerative joint disease (DJD) requires positive results from an MRI or CT scan, respectively. Diagnostic imaging is a useful tool for the diagnosis and follow-up of a considerable number of TMD patients. JIA, OA, RA, Spondyloarthropathies, and juvenile idiopathic arthritis (JIA) are a diverse collection of illnesses that have comparable radiological TMJ symptoms, and DJD may be one of them. Deterioration of articular cartilage, joint remodelling, and abrasion are the outcomes of the disease course linked to harm to the cartilage, subchondral bone, and synovial membranes.[3,7]

Cone beam computed tomography (CBCT), although being the gold standard for TMD diagnoses, is crucial for assessing alterations in the skeletal structure. MRI is still the modality of choice for patients with difficulty in diagnosis or where the results of imaging might affect the patient's course of therapy or prognosis because of its higher cost and lesser accessibility.[9,11]

When evaluating the morphology of osseous joint components and the integrity of the cortical bone, CBCT has been proven to be more precise and superior to MRI. Because of its excellent spatial resolution and capacity for multiplanar reformation, it continues to be the modality of choice for evaluating the integrity of cortical bone.[1,7,9]

CBCT has emerged as a significant instrument in dental imaging, providing accurate 3D pictures of the dentomaxillofacial region and removing the limitations associated with 2D imaging. Since its commercial release in the 2000s, cone beam computed tomography (CBCT) has been widely utilized for implant planning, periodontics, TMJ imaging, orthodontics, and maxillofacial surgery, with a resolution of less than 100 µm. When it comes to exact diagnosis, CBCT outperforms CT in terms of radiation dosage, exposure duration, and spatial resolution. However, there are drawbacks to CBCT, including noise and artifacts in patient

pictures.[3,5,7] Noise has the ability to obscure low-density tissue distinction, which may result in incorrect diagnosis. Noise-minimizing strategies can reduce radiation exposure and improve the diagnostic accuracy of CBCT since noise and radiation dosage are inversely linked.[6]
Iterative reconstruction (IR) is the method for noise optimization in CT that is most often used. IR has previously demonstrated its diagnostic worth in CBCT and conventional CT. Artificial intelligence (AI) has advanced recently, and as a substitute, deep learning-based image reconstruction algorithms (DLRs) have been developed. DLRs have already shown increased diagnostic precision at lower radiation and noise levels. Nevertheless, its interoperability with other manufacturers' equipment is frequently restricted to particular CT scanner suppliers, such as GE Healthcare's TrueFidelityTM or Canon Medical Systems' AiCE. A vendor-neutral deep learning model (DLM) such as ClariCT.AI, which functions in the image post-processing phase without requiring raw data, is a possible substitute.[10,14]
FDA-approved in 2019, ClariCT.AI has demonstrated the ability to reduce noise while maintaining diagnostic accuracy comparable to vendor-specific DLRs. Over a million CT scans from different vendors and reconstruction settings were used to train the algorithm. ClariCT AI has been shown in studies by Nam et al. and Park et al. to be able to enhance picture quality and spatial resolution even when radiation dosage is reduced by 70%. Subsequent research confirmed the strong diagnostic utility of DLM reconstructions, supporting these findings. Theoretically, they may also have a favourable impact on the TMJ CBCT image quality parameters, which would raise the diagnostic utility of the images in the assessment of lesions linked to DJD.[14]

Even with the development of new ultrasonic medical imaging technologies, there is still much room for advancement in the application of machine learning approaches to ultrasound picture generation in order to produce less hazy and more meaningful images. alterations to hardware components are necessary for new approaches in beamforming, super-resolution, and image enhancement; these alterations are typically more ambitious than simpler software post-processing techniques. Despite the more challenging adoption, several research developments are surpassing conventional and basic reconstruction algorithms, which convert physical measurements of ultrasonic waves into visual representations on a display.
The many ultrasonic imaging methods may be enhanced by increasingly complex real-time solutions as computing power in medical devices increases.[13,15]

Conclusion

Employing AI for DLM reconstruction enhances the objective image quality of TMJ CBCT images. Although readers preferred DLM pictures over regular reconstructions, there was no statistical difference in the subjective image quality or detectability of DJD lesions. The advantages of ultrasound imaging include its relative affordability, non-invasiveness, mobility, and safety. With lightweight and portable equipment, it can dynamically show real-time 2D pictures of the ROI. However, because ultrasonography relies heavily on the operator, adequate training of the sonographer is necessary to fully utilize the technique's diagnostic potential. By facilitating comprehensive evaluations, computer-assisted technologies might lessen the high learning curve associated with ultrasound scanning for medical professionals, nurses, and technicians. Recent studies have demonstrated that AI-based aided US for TMJ is developing into a mature technology that will enable the technique's broad application and usher in a new era of US scanning.

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