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The impact of study design on the efficacy of cone-beam computed tomography in detecting vertical root fractures: Why are the results conflicting?

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Dear Editors,

I am writing to address the conflicting results and limitations observed in cone-beam computed tomography (CBCT) studies concerning the diagnosis of vertical root fractures (VRFs). This issue has sparked considerable debate in recent dental research. Although systematic reviews have sought to synthesize data on the accuracy, sensitivity, and specificity of CBCT for diagnosing VRFs, the inclusion of both *in vitro* and *in vivo* studies introduces significant challenges that could skew the results. To date, there remains no consensus on the effectiveness of CBCT in detecting VRFs. While its use appears justified, attempts to establish optimal conditions for the radiographic identification of these fractures have yet to yield successful outcomes. In this letter, the authors aim to explore the design factors contributing to these conflicting results and to offer recommendations for future research.

Recent research has identified several factors related to study designs that influence outcomes:

In vitro versus *in vivo* nature of the study

In vitro studies are essential as they directly evaluate the capability of CBCT to detect VRFs, often demonstrating that the detectability is significantly influenced by the width of the fracture, a factor not assessed in all *in vitro* studies.[1] These studies, however, employ varying methodologies to simulate fractures, resulting in differences in fracture width that must be meticulously documented (including mean and range) to maintain the validity of systematic reviews.[2] Conversely, *in vitro* studies readily address ethical concerns associated with study designs, whereas *in vivo* studies may conflict with the "as low as reasonably achievable" (ALARA) principle of radiation safety.[3,4]

Contrastingly, *in vivo* studies introduce variables that are absent in controlled environments, such as patient movement, breathing, and the presence of surrounding tissues, which can obscure fracture lines.[1] Furthermore, in clinical settings, radiologists may diagnose VRFs based on indirect signs such as vertical bone resorption, which can be confounded with other periapical or endodontic lesions.[5] Moreover, the diagnostic process *in vivo* can sometimes identify VRFs without directly visualizing the fracture. Such scenarios demonstrate the limitations of *in vitro* CBCT studies and highlight the potential utility of including bone resorption as a diagnostic criterion in future research.[5]

Tooth-related factors

The mandibular molars and maxillary premolars are the teeth most commonly affected by VRFs.[6] Tooth shape can also influence the patterns of artifacts. Bi- or multi-rooted teeth treated with various intracanal materials tend to exhibit more artifacts than single-rooted teeth, complicating the diagnosis, particularly when assessing root fractures and perforations.[7] However, the authors' research indicates that the most frequently studied teeth are single-rooted, including mandibular premolars. Artifacts in imaging primarily result from high-density materials such as metal implants, intracanal posts, metallic crowns, and amalgam restorations. The impact of these artifacts varies depending on the type and location of the material.[8]

CBCT-related factors

The factors influencing the quality of CBCT images include voxel size, field of view (FOV), exposure settings (kV, mA, and number of base images), receptor technology (flat panels, complementary metal oxide semiconductors, and charge-coupled devices), and the reconstruction algo-

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rithm.[9] Voxel size is a more critical determinant of image resolution than FOV size.[10] Recent meta-analysis findings indicate that smaller voxel sizes enhance fracture detection.[11] However, it is important to consider that smaller voxel sizes may increase radiation exposure, potentially violating the ALARA principle. Additionally, the relationship between voxel size and fracture width should be noted, as fractures smaller than the voxel size may not be detected.[12]

Several studies have explored whether the placement of an object within the FOV influences diagnostic accuracy, given that radiation scattering and noise are not uniformly distributed across the FOV. It has been found that positioning the object at the center of the FOV provides the best results for accurately detecting vertical root fractures in teeth with intracanal posts.[13]

FOV sizes are typically classified into 4 categories: large (>15 cm), medium (10-15 cm), small (8-10 cm), and dentoalveolar (4-6 cm). The dentoalveolar FOV is preferred for diagnosing cracked teeth. In the absence of a dentoalveolar FOV, small FOVs may occasionally be used. Using a smaller field aligns with the ALARA principle.[12]

Observers' expertise and diagnosis method

Advanced training in interpreting CBCT images and providing CBCT imaging and reporting services is essential. An experienced radiologist may achieve greater diagnostic accuracy than a less experienced one.[14] Diagnosing cracked teeth with significant displacement of fracture fragments is usually straightforward, with minimal influence from the evaluator. However, for early or subtle fractures, diagnostic accuracy can vary significantly between evaluators.[15]

Fracture-related factors

Brady et al.[16] reported that CBCT is highly accurate in detecting vertical root fractures of 50 μm or larger in teeth that have not undergone endodontic treatment. Additional studies, both *in vitro* and *in vivo*, have demonstrated that the ability of CBCT to detect VRFs depends on the fracture's width. Recently, Gao et al.[12] proposed a classification system for VRFs based on CBCT imaging. They identified 3 types of CBCT appearances for VRFs: (a) displaced, (b) subtle, and (c) hidden. While displaced VRFs are easily detectable, subtle and hidden VRFs remain significant areas for further investigation.

Conclusion

Exploratory surgery remains the gold standard for detecting VRFs, although it does not always ensure that the fracture is visible. Additionally, the presence of root canal materials may cause false positives in CBCT scans, which adds complexity to the diagnosis.[17] Given these challenges, it is essential for future studies to clearly distinguish between the detection of fracture lines and bone resorption in their methodologies, and to compare these aspects when diagnosing VRF. This consideration is particularly important for *in vivo* studies and should be incorporated into advanced training programs for VRF diagnosis. Similar training should also be provided to calibrate observers before VRF studies, thereby improving their consensus. Furthermore, the methods used for diagnosing VRF should be clearly described.

As previously mentioned, artificially created VRFs for *in vitro* studies can differ from their natural counterparts. Designing *in vivo* studies remains problematic due to ethical concerns, making *in vitro* studies the preferable option. The authors propose that researchers exclusively incorporate naturally derived VRFs into *in vitro* study designs going forward. Although collecting the appropriate samples is time-consuming, this approach is essential for accuracy.

Collecting the VRF width of these teeth, along with the type of tooth in terms of the treatments received, can provide an approximate but more realistic average of VRF widths. This average may serve as a criterion for selecting the optimal voxel size in accordance with ALARA principles. Additionally, including more mandibular molars and maxillary premolars will modify the effect of tooth shape on artifacts.

Another suggestion is to integrate *in vitro* and *in vivo* studies. By collecting teeth from subjects participating in an *in vivo* study and subsequently including them in an *in vitro* study under similar controlled conditions, researchers can assess the compatibility of *in vivo* and *in vitro* data.

Classifying VRFs may be helpful. Although Gao et al.[12] classified VRFs in terms of CBCT appearance, it appears that the visibility of a VRF is highly dependent on the properties of the specific CBCT unit used. Consequently, a VRF that is not visible in one CBCT unit might be only subtly visible in another unit with a smaller voxel size.

In conclusion, studying the diagnosis of VRFs using CBCT has remained challenging. Without standardization and consistent measurement of the variables discussed, results may remain inconsistent, potentially impacting subsequent research and yielding evidence that does not accurately reflect reality.

Conflicts of Interest: None

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ChatGPT 4.0 artificial intelligence has been used only to paraphrase the contents of this Letter to the Editor and then was checked for accuracy by authors.

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