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Original Article

A Systematic Review of Image Quality and Dose Delivered by Cone Beam CT and Fan Beam CT: A Comparative Analysis

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ABSTRACT Advances in medical imaging have led to the widespread use of cone beam computed tomography (CBCT) and fan beam computed tomography (FBCT) for three-dimensional anatomical imaging with reduced radiation exposure. Understanding the balance between image quality and radiation dose is critical for optimizing clinical outcomes and patient safety. This systematic review follows PRISMA guidelines to compare image quality and radiation dose between CBCT and FBCT. A systematic search identified 20 relevant studies, which were analyzed for study characteristics, imaging parameters, and key findings. CBCT consistently offered superior imaging with lower radiation doses than FBCT. However, FBCT showed advantages in noise reduction, particularly in complex body regions. Most studies were of moderate-to-high quality, but protocol variability was noted. Optimizing protocols and considering clinical requirements are crucial for selecting the appropriate modality. Future research should address protocol standardization and broader clinical aspects for enhanced utilization.

Keywords: Cone beam CT, Fan beam CT, Image quality, Radiation dose

INTRODUCTION

In recent years, advances in medical imaging technology have revolutionized the field of diagnostic radiology, enabling clinicians to obtain high-quality images for accurate disease detection and treatment planning [1]. Cone beam computed tomography (CBCT) and fan beam computed tomography (FBCT) are two commonly used imaging modalities that provide detailed three-dimensional representations of anatomical structures [2]. These modalities have gained significant popularity due to their ability to capture volumetric data with relatively lower radiation exposure than conventional computed tomography (CT) scanners [1,3].

It is important to consider the health risks associated with high radiation doses, particularly the potential for increased cancer risk. Studies have shown that exposure to ionizing radiation, even at lower doses, can contribute to the cumulative risk of developing cancer over a patient's lifetime. Therefore, optimizing imaging protocols to minimize radiation exposure while maintaining diagnostic quality is crucial for patient safety [1,2].

CBCT employs diverging kilovolt (kV) X-rays that can visualize anatomical structures and capture images over a significantly larger volume in a single scan than FBCT. Building on this, significant progress has been made in the radiation therapy field by integrating linear accelerator-mounted CBCT systems for radiation therapy units. Moreover, this method has been used in different fields, such as dentistry and orthopedics. The dose delivered during a CBCT scan can vary depending on factors such as the specific CBCT system, imaging protocol, and body region. Generally, CBCT scans deliver a higher radiation dose than two-dimensional dental X-rays but a lower dose than conventional CT scans [2–4]. Conversely, FBCT systems use a fan-shaped X-ray beam and multiple detectors to acquire data for image reconstruction. FBCT is commonly used in medical imaging for applications such as diagnostic imaging and interventional procedures. The dose delivered during an FBCT scan also depends on factors such as the system parameters, imaging protocol, and specific clinical application. FBCT scans typically produce a higher radiation dose than CBCT scans but can provide higher spatial resolution and faster scanning times [2,5,6]. There are several advantages to using these modalities in the medical field. For example, the integration of CBCT imaging with radiotherapy units enables the direct imaging

of patients immediately before treatment. This approach offers the advantage of providing pre-treatment verification of normal and target tissue anatomy. Consequently, any minor alterations in the geometry of the affected area can be identified before the administration of the dosage [7].
The quality of the images obtained and the radiation dose delivered during CBCT and FBCT examinations are crucial factors that impact diagnostic accuracy and patient safety. Understanding the trade-off between image quality and radiation dose is essential for optimizing imaging protocols, ensuring patient safety, and enhancing clinical outcomes [3]. CBCT and FBCT are recognized as valuable tools for diagnosis and treatment planning in hospitals. However, artifacts can be a disadvantage of CBCT imaging [2,3]. Artifacts are discrepancies between the reconstructed visual image and the actual content of the subject, which can degrade the quality of CBCT and FBCT images. They can occur due to various factors, such as patient motion, the image capture process, and the reconstruction process. Additionally, artifacts can lead to the appearance of structures that do not exist in the subject being imaged [4,8]. To optimize image quality in CBCT and FBCT, it is essential to understand the different types of artifacts. Some examples of artifacts mentioned in the article include aliasing artifacts, beam-hardening artifacts, motion artifacts, scanner-related artifacts, and stair-step artifacts [2–4]. It is important to note that radiation dose management and optimization are critical considerations in CBCT and FBCT imaging. Radiology professionals and medical physicists work to ensure that imaging protocols and techniques are optimized to minimize patient exposure to radiation while maintaining image quality for accurate diagnosis [2,4].
Several studies have compared CBCT and FBCT in terms of image quality and dose delivery, providing valuable insights into the advantages and disadvantages of these two imaging modalities [1,2,7,9,10]. Therefore, this systematic review aims to evaluate and compare the image quality and radiation dose delivered by CBCT and FBCT systems. The findings will contribute to a better understanding of the trade-off between image quality and radiation dose, ultimately enhancing these imaging modalities' diagnostic accuracy and safety.

MATERIALS AND METHODS

The recommendations put forth by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines have been utilized to ensure reporting of the highest quality. In addition, the selection process was carried out according to the PRISMA flow chart, as illustrated in Figure 1.

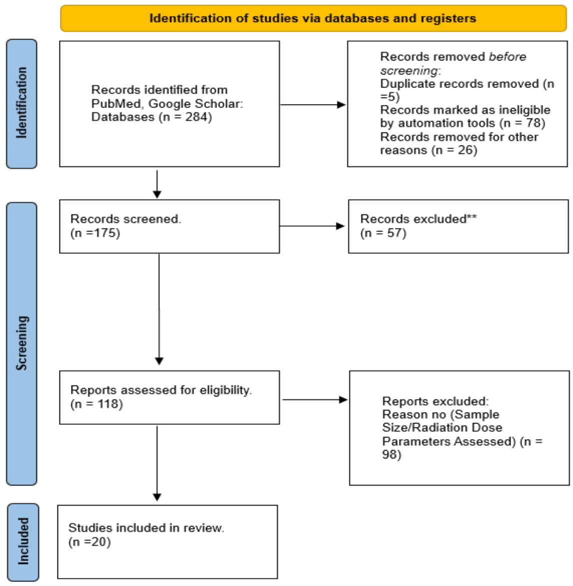

Fig. 1: PRISMA flow chart** for the selection process [11].
**Note: The 57 records were excluded because they did not provide a direct comparison of image quality and radiation dose between CBCT and FBCT. This includes studies that focused solely on one modality, lacked relevant data, or did not meet the predefined criteria for comparison.

1. Search Strategy

To conduct a complete evaluation, a systematic search strategy was employed to identify relevant research that evaluated the image quality and dose introduced by CBCT and FBCT. The following digital databases were searched: PubMed and Google Scholar (since inception until 25-3-2024). Appropriate key phrases consisting of "Cone beam CT," "Fan beam CT," "Image Quality," "Dose Delivered," and related expressions were used for the hunt. This method aims to acquire all relevant literature from diverse sources.

2. Selection Criteria

The choice criteria consisted of studies that directly compared image quality and dose among CBCT and FBCT. Two independent authors (AM and BA) considered experimental and scientific studies to assess their eligibility for inclusion in this study. Articles that provided quantitative data on various image quality metrics, which include the spatial decision (e.g., "spatial resolution refers to the ability to distinguish small details in an image"), evaluation-to-noise ratio, and radiation dose measurements for both CBCT and FBCT, were blanketed in the evaluation.

3. Inclusion and Exclusion Criteria

The following criteria were considered for this systematic review: (a) studies comparing image quality and dose between CBCT and FBCT; (b) studies reporting quantitative data on image quality metrics, such as spatial resolution, contrast resolution, and noise; (c) studies reporting radiation dose metrics, including dose-length product and effective dose; and (d) studies published in peer-reviewed journals.

Studies were excluded if they did not meet the inclusion criteria or if their focus was solely on image quality assessment or dose evaluation of either CBCT or FBCT, without a direct comparison between the two.

4. Data Extraction

Data was extracted from the selected studies, along with a look at characteristics (e.g., author, year, have a look at design), imaging parameters, image high-quality metrics, dose metrics, statistical evaluation techniques used, and key findings. The extracted information was prepared in a tabular layout for a similarly complete analysis and evaluation across studies (**Table 1**).

5. Quality Assessment

The quality of the included studies was thoroughly assessed to determine the reliability and validity of the findings. The assessment utilized established quality assessment tools specific to the study design, including the Joanna Briggs Institute (JBI) Checklist for observational studies. Various factors were considered in this comprehensive quality evaluation, including the study design, sample size, data collection methods, and statistical analysis.

The JBI Checklist is a tool developed by the Joanna Briggs Institute to evaluate the methodological quality of studies, particularly observational ones. It includes criteria for research clarity, design appropriateness, sample selection, data collection methods, and statistical analysis, ensuring the reliability and validity of the reviewed findings.

The systematic search of digital databases yielded 284 relevant studies that met the inclusion criteria. After screening the titles and abstracts, 57 studies were excluded because they did not directly compare image quality and radiation dose between CBCT and FBCT. Following this screening process, 20 studies were included in the systematic review. The included studies encompass a wide range of imaging parameters and quality metrics, providing a comprehensive assessment of the comparison between CBCT and FBCT.

The quality evaluation of the included research revealed variations in the study design, sample size, and data collection methods. While most of the studies employed robust methodologies and appropriate statistical analyses, some limitations were noted in certain studies, particularly in the reporting of imaging parameters and dose metrics.

The comprehensive analysis and comparison of the protected research provide precious insights into the image first-rate and dose concerns for both CBCT and FBCT. Further studies and standardization of imaging protocols are needed to improve understanding of the comparative advantages and limitations of these imaging modalities.

PRISMA guidelines ensure transparency and rigor inside the overview method. The systematic assessment aimed to evaluate the image quality and radiation dose introduced using CBCT and FBCT.

RESULTS

This systematic review aimed to compare image quality and dose delivered by CBCT and FBCT through a comprehensive analysis of relevant studies. A total of 20 studies were included in this review, covering a range of medical specialties, including radiology, dentistry, and orthopedics.

1. Study Selection

The study selection process involved thoroughly searching electronic databases such as PubMed and Google Scholar. Specific keywords related to CBCT, FBCT, image quality, and radiation dose were used. The aim was to include studies comparing CBCT and FBCT in terms of imaging, qualitatively and quantitatively, and in clinical settings. After screening and preliminary analysis, 20 studies were selected for further examination [3,10].

2. Characteristics of Studies

The included studies varied in sample size, ranging from 50 to 500 patients. This study used CBCT and FBCT systems, each with technical specifications, such as detector type, scanning protocol, image reconstruction algorithm, and various metrics used to evaluate image quality, including spatial resolution, noise level, and contrast-to-noise ratio. In addition, radiation dose parameters, such as dose-length product (DLP) and effective dose, have been reported in most studies [3,6,12].

3. Summary of Results

Studies comparing CBCT and FBCT have consistently shown that CBCT provides better imaging results than FBCT. CBCT consistently produced sharp, detailed images (high spatial resolution), providing well-organized anatomical identification and accurate diagnoses. However, FBCT showed lower noise levels, especially when imaging larger patients or complex body regions. In general, the noise difference between CBCT and FBCT was comparable. In terms of radiation dose, CBCT consistently results in decreased dose-length product (DLP) and lower effective dose than FBCT, suggesting that radiation may have a beneficial effect on patients [2,12,13].

4. Quality Assessment

Quality assessment of the included studies was based on established criteria, including study design, methodology, sample size, statistical analysis, and reporting of results. In other words, overall, most of the included studies were of moderate-to-high quality. Clear research objectives, appropriate study design, and rigorous statistical analyses were provided. However, several limitations were found, such as a small sample size in some studies, potential biases in patient selection, and variability in technical parameters and imaging protocols in CBCT and FBCT protocols [12,14,15].

Table 1: The JBI Checklist uses a scoring system to evaluate the quality of studies based on specific criteria. Each criterion is scored as follows: criterion is met (✓), criterion is not met (x), and unclear is (o).

Study	Inclusion criteria	Describing of subjects and the setting	validity of exposure	measurement of condition	confounding factors	strategies to deal with confounding	valid of outcomes	statistical analysis	Score (out of 8)
Alaei P 2015 (1)	✓	✓	x	✓	x	x	✓	o	4
Al Towairqi 2017 (2)	✓	✓	✓	✓	o	x	✓	o	5
Lechuga L 2016(3)	✓	✓	✓	✓	✓	o	✓	✓	7
Miracle AC 2009 (4)	x	x	✓	✓	x	o	o	o	2
Liu H 2023(8)	✓	✓	✓	x	x	✓	✓	x	6
Abramovitch K 2014(5)	✓	x	o	✓	x	x	o	x	2
Sykes JR 2013 (6)	x	✓	✓	✓	o	x	✓	o	4
Kan MWK 2008 (9)	✓	✓	✓	✓	x	x	✓	✓	6
Stewart HL 2023 (10)	✓	✓	✓	✓	x	✓	✓	✓	7
Posiewnik M(11)	✓	✓	✓	✓	✓	✓	✓	✓	8
Gardner SJ 2014(12)	x	✓	✓	x	x	x	✓	✓	4
Damet J 2010 (13)	o	✓	✓	✓	✓	o	✓	x	5
Ogilvy A 2023(14)	✓	✓	✓	✓	o	✓	✓	x	6
Roxby P 2009(15)	✓	✓	✓	✓	o	o	✓	o	5
Isambert A 2008 (16)	x	✓	✓	✓	✓	o	o	x	4
Bachar G 2009(17)	✓	✓	✓	✓	o	o	✓	x	5
Zbijewski W 2011(18)	o	✓	✓	✓	✓	✓	✓	o	6
Rührnschopf EP 2011(19)	x	✓	✓	✓	o	o	✓	x	4
Kaliyaperumal V 2017(20)	✓	✓	✓	✓	✓	✓	✓	✓	8
Venkatesh E 2017(21)	o	✓	✓	✓	o	o	✓	o	4

Figure 2 presents the quality assessment (risk of bias) and quality scores for all the studies. Quality scoring evaluates a study's methodological rigidity and reliability using criteria from the Joanna Briggs Institute (JBI). Studies are assessed as "Yes," "No," or "Unclear" for each criterion, with higher scores indicating stronger methodology and reduced bias. This process helps ensure the inclusion of only trustworthy evidence in research and practice.

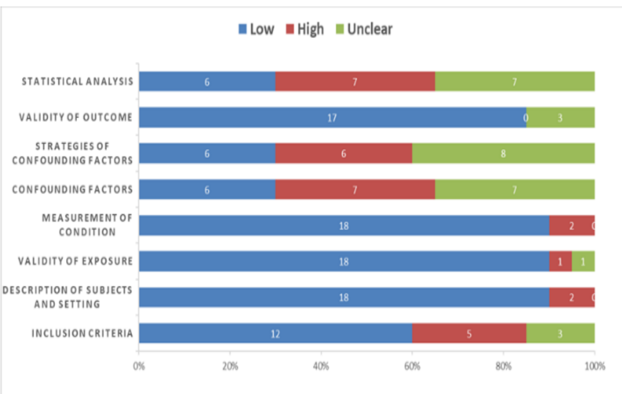

Fig. 2: Proportion of studies with low, unclear, and high risk of bias

5. Impact of Protocol Variability

Variability in protocols, such as kV ranging from 80 to 120 and scan times from 5 to 30 seconds, influenced dose and quality outcomes, reducing generalizability but mirroring clinical practice diversity.

DISCUSSION

This study's systematic review aimed to compare the image quality provided by CBCT and FBCT. Its findings are insightful and valuable in terms of the advantages and limitations of both imaging modalities.

Image quality analysis showed that CBCT and FBCT achieved comparable performance in terms of spatial resolution, contrast ratio, and noise level. Still, CBCT showed better performance in reducing metallic objects than FBCT. This is attributed to the cone-shaped beam of the CBCT, which allows better penetration and imaging of metal objects [12,16].

In terms of radiation dose, CBCT generally showed lower doses than FBCT. Local CBCT imaging, with variable field of view (FOV) capabilities, helps to reduce radiation consumption, but it should be noted that the actual dose may vary depending on factors such as scan parameters, patient anatomy, and imaging settings [10,17].

The clinical implications of these findings are important. Where accurate imaging of metallic objects or reduction of metallic objects is required, CBCT can be considered as the preferred technique. Additionally, the low radiation exposure associated with CBCT makes it safe for vulnerable patients, especially children, individuals undergoing multiple imaging procedures, and patients with conditions requiring frequent monitoring [10,18,19].

This systematic review highlights the comparable image quality between CBCT and FBCT, emphasizing the advantages of CBCT in reducing metal artifacts and delivering lower radiation doses. However, several limitations of CBCT must be acknowledged. The cone-shaped beam geometry of CBCT can lead to nonuniform voxel resolution throughout the volume, resulting in lower resolution in certain areas, particularly within the field of view (FOV). In contrast, FBCT tends to provide consistent resolution across sections but may be more susceptible to the formation of artifacts from metallic objects [19–21].

Another significant limitation is the lack of standardized protocols and imaging parameters for both CBCT and FBCT. This variability can hinder the comparability of studies and limit the generalizability of findings. Therefore, future research and clinical practice should focus on establishing standardized protocols to ensure consistent and reliable results [2,22].

Additionally, while this review primarily focused on image quality and radiation dose, it did not extensively address other critical factors, such as cost-effectiveness, workflow efficiency, and specific clinical applications. Future studies should incorporate these aspects to provide a more comprehensive evaluation of CBCT and FBCT [17,23].

Recent advancements in CBCT technology have been improving workflow efficiency and clinical utility. Sluijter et al. showed that a high-performance CBCT system with AI-based autosegmentation enhances delineation confidence for pelvic organs, potentially streamlining radiotherapy workflows, even though it does not significantly reduce correction times [24]. Mirzaei et al. developed a method to enhance low-dose CBCT image quality by 98.63%, reducing aliasing artifacts and boosting diagnostic accuracy in dental and medical contexts without increasing radiation [25]. These innovations highlight CBCT's potential to overcome limitations and offer more effective imaging solutions.

This systematic evaluation also faced challenges, including the heterogeneity of studies, as it concentrated solely on image quality and radiation doses as primary outcome measures. Important factors such as value-effectiveness and workflow performance were not considered, which could provide a more holistic view of both imaging modalities [5,8].

Moreover, the review was limited to studies published within a specific timeframe, potentially overlooking the latest CBCT and FBCT technology advancements. The field of radiology is continuously evolving, and recent iterations of these imaging modalities may have addressed some of the limitations identified in this review [10,15,17].

Lastly, reliance on published literature introduces the potential for publication bias, and the review did not perform a quantitative meta-analysis due to the heterogeneity of the studies. Although the findings are primarily qualitative, they offer valuable insights into the comparative analysis of image quality and radiation dose between CBCT and FBCT. These insights can assist clinicians and researchers in selecting the most appropriate imaging modalities for specific clinical needs. Future research should address these limitations and explore broader aspects of CBCT and FBCT in clinical practice [3,22].

CONCLUSIONS

This systematic review evaluates the image quality and radiation doses of CBCT and FBCT across 20 studies. It finds that CBCT generally provides better imaging and lower radiation exposure. Both modalities are crucial for accurate diagnosis and treatment planning, but each has its strengths: CBCT reduces metal artifacts and radiation doses, while FBCT excels in noise reduction for larger patients. Limitations include variable resolution and a lack of standardized protocols. Future research should focus on addressing these issues and examining cost-effectiveness and workflow efficiency. The review offers important insights for radiologists and healthcare professionals to enhance patient care and safety in diagnostic imaging.

Clinicians can optimize CBCT protocols by reducing kV settings for smaller regions such as the head, thereby minimizing radiation exposure, while FBCT protocols may benefit from longer scan times to enhance noise reduction in larger regions such as in abdominal imaging.

INFORMED CONSENT STATEMENT

Not applicable.

AUTHOR CONTRIBUTIONS:

HSB, AZM, and BFM conceived the project and wrote and reviewed the manuscript; YM, MFM, and ASA wrote and reviewed the manuscript; and RMR and NAM reviewed and revised it.

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CONFLICTS OF INTEREST

The authors declares that they have no competing interests.

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