Keywords
cone-beam computed tomography; diagnostic reference levels; dose-area product; effective dose; radiation protection; dose optimization

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Establishment of National Diagnostic Reference Levels and Effective Dose Estimation for Cone-Beam Computed Tomography Examinations in Jordan: A Multicenter Retrospective Study

Abstract
Background/Objectives: Cone-beam computed tomography (CBCT) is widely used in dental and maxillofacial imaging; however, radiation dose optimisation remains essential because radiosensitive organs such as the salivary glands, thyroid, extrathoracic airway, and eye lens may be partially irradiated during CBCT. Diagnostic reference levels (DRLs) provide practical benchmarks for dose optimisation at local and national levels. Methods: A multicenter retrospective study was conducted on 1098 adult CBCT examinations performed between February 2025 and August 2025. Dose-area product (DAP; mGy·cm²) and exposure parameters were extracted from DICOM headers. The national DRL was defined as the 75th percentile of the DAP distribution. Effective dose and selected organ equivalent doses were estimated using field-of-view (FOV)-specific published conversion coefficients. Results: The mean patient age was 39.2 ± 15.9 years, and 55.1% were female (n = 605). The overall DAP was 946.2 ± 513.3 mGy·cm² (median 690.0 mGy·cm²), and the national DRL was 1153.0 mGy·cm². The estimated effective dose was 75.0 ± 44.0 µSv (median 57.0 µSv; DRL 97.0 µSv). Median equivalent doses were 1933 µSv for the salivary glands, 229 µSv for the thyroid, 1409 µSv for the extrathoracic airway, and 1412 µSv for the eye lens. Conclusions: Jordan's first national DRLs for CBCT examinations were established, together with DAP-based effective-dose and organ-dose estimates. These benchmarks support protocol harmonisation, continuous audit, and targeted optimisation across Jordanian CBCT services.

1. Introduction

Cone-beam computed tomography (CBCT) has become an essential imaging modality in contemporary dentistry and maxillofacial practice because it provides high-resolution three-dimensional information with short scan times and wide clinical applicability, including implant planning, assessment of impacted teeth, orthodontic evaluation, temporomandibular joint imaging, endodontic diagnosis, and maxillofacial trauma or pathology work-up [1,2]. Over the past two decades, wider availability of CBCT units and increasing demand for three-dimensional imaging have contributed to a rise in population exposure from dental imaging, which now represents a relevant component of medical radiation exposure in many countries [3,4]. Although CBCT generally delivers lower doses than conventional multislice computed tomography (CT), dose levels remain highly variable and can approach those of low-dose CT protocols when large fields of view (FOVs) or high-resolution settings are used [4-6].

For CBCT, dose characterisation is commonly performed using dose-area product (DAP, mGy·cm²) because DAP is available on many modern systems, reflects both beam output and irradiated area, and enables multicentre surveys across different manufacturers and protocols [7-9]. However, DAP alone does not directly communicate biological risk [10]. Effective dose (E, µSv), which combines organ equivalent doses using International Commission on Radiological Protection (ICRP) tissue weighting factors, is frequently reported to facilitate benchmarking and risk communication at the population level, while acknowledging that it is not intended for individual patient risk estimation [4,6,11]. Organ-specific equivalent doses are also clinically relevant because radiosensitive tissues in the head and neck—particularly the salivary glands, thyroid, extrathoracic airway, and eye lens—may receive non-negligible exposure depending on the selected FOV, collimation, and scan geometry [12]. International surveys show that protocol and FOV choices can change DAP and organ doses several-fold, highlighting the need for indication-based optimisation and local auditing [4,5,12].

Radiation protection in dental CBCT therefore requires a balanced approach that maintains diagnostic image quality while ensuring adherence to justification and optimisation principles [13]. International recommendations emphasise selecting CBCT only when it is expected to add diagnostic value beyond two-dimensional radiography and tailoring exposure parameters to the clinical task according to the as-low-as-reasonably-achievable (ALARA) principle [14,15]. Diagnostic reference levels (DRLs) are widely endorsed as a practical optimisation tool for identifying unusually high exposures and prompting protocol review, staff feedback, or equipment performance checks [16]. DRLs are not dose limits; rather, they represent typical values for standard examinations and are commonly set at the 75th percentile of a dose distribution for a defined procedure and patient group, with periodic updating as technology and practice evolve [17].

Despite the increasing use of CBCT in Jordanian dental and maxillofacial practice, national benchmark dose data and DRLs have not been formally established. In the absence of national DRLs, dose optimisation efforts may be inconsistent between facilities, and opportunities to reduce unnecessary variation can be missed [18]. Establishing a national diagnostic reference level (NDRL) based on representative multicentre data provides a practical reference for quality improvement, staff training, and regulatory oversight [19]. Therefore, the present study aimed to (i) quantify patient dose in routine dental CBCT examinations across multiple centres in Jordan using DAP as the primary metric, (ii) propose a national DRL (75th percentile) and typical value (median) for current practice, (iii) estimate effective dose and selected organ equivalent doses using published DAP-based conversion coefficients, and (iv) explore dose distributions by FOV category and adult age group to support targeted optimisation strategies and future periodic DRL updates.

2. Materials and Methods

2.1 Study design and setting

This multicenter retrospective dose survey included CBCT examinations performed in Jordanian dental and maxillofacial imaging centres between February 2025 and August 2025. The study population comprised adult patients (18 years and older) who underwent clinically indicated CBCT examinations as part of routine care. Data were collected from public, private, university, and royal medical services facilities to provide a representative national overview. Based on the available equipment metadata, the pooled dataset included examinations acquired on Kodak 9500, Carestream CS 8100 3D, Carestream CS 8200 3D, Carestream CS 9600 3D, Planmeca ProMax 3D, and Vatech PaX-Duo3D systems. These data were analysed at examination level rather than stratified by scanner model because the purpose of the survey was to derive national benchmark values across current routine practice. Patient identifiers were removed before analysis. A total of 1098 CBCT examinations were included. Ethical approval was obtained from the Institutional Review Board, and all data were fully anonymised.

2.2 Data collection

For each examination, dose and technical parameters were extracted from DICOM headers and PACS records, including patient age and sex, device model, clinical indication, field of view (FOV), voxel size, dose mode, tube voltage (kVp), tube current (mA), exposure time (s), and reported DAP (mGy·cm²). For the present analysis, FOVs were categorised according to vertical scan height as small (≤8 cm), medium (>8 to ≤13 cm), and large (>13 cm). All data were recorded on a standardised collection form. DAP was selected as the primary dose metric for DRL establishment in line with international recommendations for medical imaging DRLs [19]. Examinations with missing or zero DAP values were excluded.

2.3 Statistical Analysis

Statistical analysis was performed using SPSS software (Version 25.0, IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean ± standard

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deviation (SD) and median with interquartile range (IQR), while categorical variables are presented as frequencies and percentages. The study objective was descriptive benchmark establishment; therefore, subgroup results by age, sex, and FOV are presented descriptively and no formal hypothesis-testing comparisons were planned.

2.3.1 Establishment of Diagnostic Reference Levels

Following ICRP recommendations, the national DRL for CBCT was defined as the 75th percentile (third quartile) of the observed DAP distribution across all included examinations. Additional descriptive DRLs were calculated for subgroups defined by sex, adult age category, and FOV size to support targeted optimisation.

2.3.2 Effective Dose Estimation

The effective dose (E) was estimated from DAP using FOV-specific conversion coefficients (k, μSv/mGy·cm²) derived from published CBCT conversion studies [20,31]. The coefficients applied in the present analysis were 0.041 for small FOV, 0.086 for medium FOV, and 0.066 for large FOV (Table 1).

$E\ (\mu Sv) = DAP\ (mGy \cdot cm^2) \times k.$

To account for the influence of irradiated volume, the FOV categories used in the Jordanian dataset were mapped to small-volume, medium-volume, and large-volume conversion groups before effective-dose estimation.

Table 1. FOV-specific conversion coefficients used for effective and organ dose estimation (μSv/mGy·cm²).

FOV category	Vertical scan height	Effective dose k	Salivary glands c_T	Thyroid c_T	Extrathoracic airway c_T	Eye lens c_T
Small	≤8 cm	0.041	2.291	0.269	1.929	2.045
Medium	>8 to ≤13 cm	0.086	2.821	0.334	2.057	2.046
Large	>13 cm	0.066	1.588	0.194	1.170	2.045

2.3.3 Organ Equivalent Dose Estimation

Equivalent doses (H_T, μSv) to selected organs (salivary glands, thyroid, extrathoracic airway, and eye lens) were estimated from DAP using organ-specific published conversion coefficients [12,20,31]. The FOV-specific coefficients used in the present study are summarised in Table 1.

$H_T\ (\mu Sv) = DAP\ (mGy \cdot cm^2) \times c_T.$

where c_T is the organ-specific conversion coefficient (μSv/mGy·cm²).

3. Results

A total of 1098 adult CBCT examinations were included. The mean patient age was 39.2 ± 15.9 years (range: 18–85 years), and 55.1% were female (n = 605). Medium-FOV protocols were most common (n = 879). Exposure parameters showed moderate variability across examinations. Tube voltage ranged from 73 to 91 kVp with a mean of 88.8 ± 4.3 kVp; tube current ranged from 2.0 to 12.0 mA with a mean of 6.2 ± 2.9 mA; and exposure time ranged from 10.8 to 24.1 s with a mean of 14.9 ± 3.7 s (median 14.4 s).

3.1 Dose-Area Product (DAP) and DRLs

The distribution of DAP values for all examinations is summarised in Table 2. The overall mean DAP was 946.2 ± 513.3 mGy·cm² (median 690.0 mGy·cm²; IQR 605.0–1153.0), and the national DRL (75th percentile) was 1153.0 mGy·cm².

Significant variation in DAP was observed across FOV categories. Table 1 shows that DRLs increased with larger FOVs, with the large-FOV DRL (1862.0 mGy·cm²) approximately double the small-FOV DRL (857.0 mGy·cm²).

Table 2. Dose-area product (DAP) by field of view (FOV).

Metric	Overall	Small FOV	Medium FOV	Large FOV
Number of examinations, n	1098	141	879	79
DAP (mGy·cm²), mean ± SD	946.2 ± 513.3	653.0 ± 288.8	964.7 ± 481.2	1263.5 ± 831.5
DAP (mGy·cm²), median (IQR)	690.0 (605.0–1153.0)	532.0 (458.0–857.0)	827.0 (605.0–1274.0)	1467.0 (605.0–1862.0)
DAP DRL (75th percentile), mGy·cm²	1153.0	857.0	1274.0	1862.0

Table 3 summarises DAP by adult age group (≥18 years; n = 1098). Mean DAP values were broadly comparable across age groups (18–30, 31–50, and >50 years), with similar 75th-percentile values.

Table 3. Dose-area product (DAP) by adult age group (≥18 years).

Age group (years)	n	Mean DAP (mGy·cm²)	Median DAP (mGy·cm²)	75th percentile (DRL) (mGy·cm²)
18–30	389	936.3	827	1153
31–50	395	964.4	857	1153
>50	314	919.6	685	1140

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DAP values were slightly higher in males than in females (Figure 1), with males showing higher mean and median DAP as well as a higher 75th percentile.

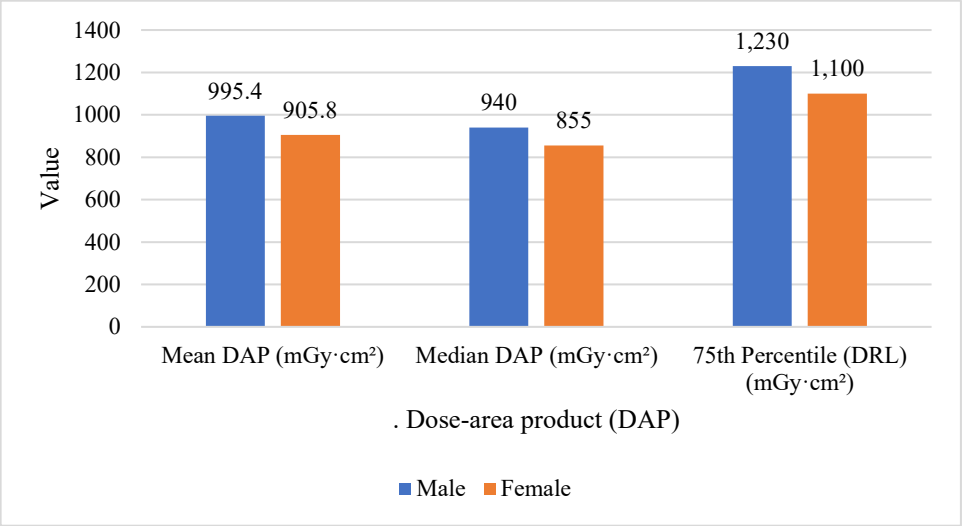

Figure 1. Dose-area product (DAP) by gender group (n = 1098).

3.2 Estimated Effective Dose

The estimated effective dose is summarised in Table 4. Overall, the mean effective dose was 75.0 ± 44.0 µSv (median 57.0 µSv; IQR 52.0–97.0 µSv), and the corresponding effective-dose DRL was 97.0 µSv. By FOV, the median effective dose was 22.0 µSv for small FOV, 71.0 µSv for medium FOV, and 97.0 µSv for large FOV.

Table 4. Estimated effective dose by field of view (FOV).

Metric	Overall	Small FOV	Medium FOV	Large FOV
Number of examinations, n	1098	141	879	79
Estimated effective dose (µSv), mean ± SD	75.0 ± 44.0	27.0 ± 12.0	82.8 ± 41.3	83.4 ± 55.0
Estimated effective dose (µSv), median (IQR)	57.0 (52.0–97.0)	22.0 (19.0–35.0)	71.0 (52.0–109.0)	97.0 (40.0–123.0)
Effective dose DRL (75th percentile), µSv	97.0	35.0	109.0	123.0

3.3 Selected Organ Equivalent Doses

Estimated equivalent doses varied across organs. Overall, the highest organ dose was observed in the salivary glands, with a median (75th percentile) of 1.933 mSv (3.216 mSv), followed by the eye lens at 1.412 mSv (2.359 mSv) and the extrathoracic airway at 1.409 mSv (2.344 mSv), while the thyroid received the lowest dose at 0.229 mSv (0.381 mSv).

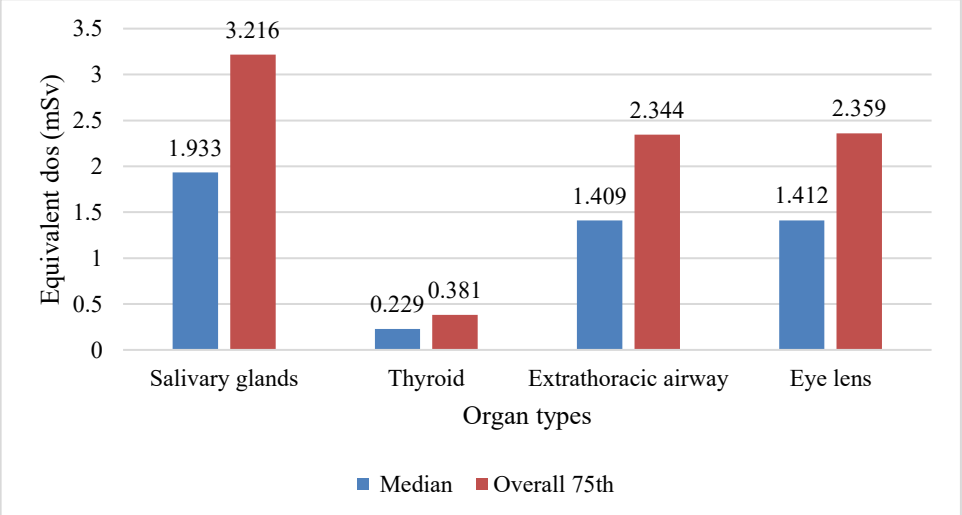

Figure 2. Median equivalent doses across selected organs during CBCT procedures.

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Organ doses in Table 5 generally increased with larger FOVs, with the eye lens showing the most pronounced increase from 1.088 (1.753) mSv in small FOV to 3.001 (3.810) mSv in large FOV.

Table 5. Estimated equivalent doses to selected organs by FOV (mSv).

Organ	Small FOV (median; 75th)	Medium FOV (median; 75th)	Large FOV (median; 75th)
Salivary glands	1.219; 1.964	2.333; 3.594	2.329; 2.956
Thyroid	0.143; 0.230	0.276; 0.425	0.284; 0.360
Extrathoracic airway	1.026; 1.653	1.701; 2.620	1.716; 2.178
Eye lens	1.088; 1.753	1.692; 2.607	3.001; 3.810

4. Discussion

Internationally, the Jordanian typical value and DRL (690 and 1153 mGy·cm², respectively) are broadly comparable with CBCT dose surveys published between 2017 and 2022 (Table 6) [7,9,21,23]. However, these values are lower than those reported in the United Arab Emirates (1000 and 1434 mGy·cm²) [9] and the IAEA multi-country survey (1000 mGy·cm²) [21], likely reflecting differences in case mix, scanner technology, exposure settings, reconstruction resolution, and the proportion of larger scan volumes [2,11,22]. In contrast, national data from the United Kingdom (265 mGy·cm²) [23] and Switzerland (638 mGy·cm²) [7] indicate lower typical doses, potentially reflecting more mature optimisation strategies and wider implementation of indication-based protocols. International comparisons should therefore be interpreted as contextual benchmarking rather than direct performance ranking. Adoption of the proposed NDRL can nevertheless support local audits, facilitate identification of outliers, and prompt targeted protocol review at facilities exceeding the 75th percentile, while periodic reassessment will be important to ensure that benchmarks remain current and clinically appropriate [24].

Table 6. Comparison of the current study's typical dose (median DAP) with published CBCT dose surveys.

Study / Country	Year	Dose metric	DAP (mGy·cm²)
Jordan (current study)	2025	Median (typical value); DRL (75th percentile)	690; 1153
United Arab Emirates [9]	2022	Median (typical value); 75th percentile	1000; 1434
IAEA multi-country survey [21]	2020	Median (typical value)	1000
United Kingdom [23]	2017	Median (typical value)	265
Switzerland [7]	2020	Median (typical value)	638

Age-stratified analysis (Table 3) demonstrated broadly similar DRL values across adult age groups, indicating that protocol selection and FOV size are stronger determinants of DAP than age in routine dental CBCT. Slightly lower mean and median DAP values among older adults may reflect differences in referral patterns and the use of smaller or more localised scan volumes. These findings support the use of standardised, indication-based adult protocols rather than age-dependent modifications, while maintaining case-by-case justification and optimisation [11,19].

Gender-stratified results (Figure 1) showed modest differences in radiation output, with males exhibiting slightly higher DAP values than females. Similar demographic and indication-related variability in CBCT dose metrics has been reported previously and is largely explained by differences in scan protocol selection, FOV characteristics, and exposure settings rather than sex alone [17,25]. Since patient dose is strongly influenced by FOV size and scan geometry, and can also be affected by patient positioning, small sex-based differences may reflect differences in habitus, positioning, or selection of higher-output protocols for specific indications [12,26].

Analysis by FOV size (Table 2) confirmed that larger FOVs are associated with higher DAP, consistent with prior evidence identifying irradiated volume and scan geometry as primary determinants of patient dose in a\ CBCT [5,12]. From a radiation-protection perspective, careful indication-based FOV selection remains one of the most effective optimisation strategies, as many routine dental indications can be addressed using limited-volume acquisitions [27,28]. Harmonising default protocols across centres—such as preferential use of low-dose modes for follow-up imaging and reserving high-resolution settings for specific endodontic or surgical tasks—may further reduce unwarranted variability while preserving diagnostic adequacy [29].

Organ-specific analysis reinforced the importance of optimisation in head and neck imaging. The salivary glands received the highest estimated doses, followed by the eye lens and extrathoracic airway, while the thyroid consistently received the lowest dose. This distribution aligns with the anatomical proximity of these tissues to the primary beam in typical dental CBCT examinations [9]. Eye-lens exposure is of particular relevance because of the radiosensitivity of the lens and the potential for cumulative exposure in patients undergoing repeated imaging [30]. Where clinically feasible, avoiding unnecessary cranial coverage, optimising beam collimation, and careful positioning to exclude the orbits can help minimise lens dose [12]. When the thyroid is within or near the primary beam, shielding and collimation strategies should also be considered [26].

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Comparison with published CBCT studies shows that Jordanian organ-dose estimates fall within reported ranges, although absolute values differ across surveys (Table 7). For example, mean organ doses reported in the UAE were higher for the thyroid but lower for the eye lens than in the present study [9], whereas phantom-based studies have reported higher salivary-gland and extrathoracic-airway doses under reference protocols [12,20]. Such variability is expected and reflects heterogeneity in scanner models, spectra and filtration, protocol settings, and FOV distribution [31]. Importantly, the present study relied on published DAP-to-dose conversion coefficients rather than patient-specific Monte Carlo simulations, which may yield different absolute values even for similar DAP levels because of modelling assumptions and scanner-specific characteristics [12,20,31].

Reporting estimated effective dose alongside DAP and organ doses provides complementary information for benchmarking and communication with clinicians. In line with ICRP guidance, effective dose should be interpreted as a population-averaged metric for comparing imaging strategies rather than an individual patient-risk estimate [11,32]. In settings where full Monte Carlo tools are not routinely available, the use of validated DAP-to-dose coefficients enables harmonised national audits and supports optimisation initiatives while preserving practicality in routine clinical workflows [20,31].

This national multicentre survey provides the first baseline for CBCT dose levels in Jordan and proposes an NDRL for routine dental CBCT examinations using DAP as the primary metric. The overall median DAP (typical value) and 75th percentile (DRL) reflect current practice across multiple facilities and protocol selections. Because data from several scanner models (including Kodak, Carestream, Planmeca, and Vatech systems) were pooled for a national benchmark analysis, scanner-specific sources of variability could not be assessed in detail and should be explored in future work.

Table 7. Comparison of organ equivalent doses in the current study with published CBCT studies.

Study / Country	Year	Dose metric	Salivary glands	Eye lens	Extrathoracic air-way	Thyroid
Jordan (current study)	2025	Median (75th), µSv	1933 (3216)	1412 (2359)	1409 (2344)	229 (381)
United Arab Emir-ates [9]	2022	Mean, mGy (≈µSv)	2.71 (≈2710)	0.61 (≈610)	1.64 (≈1640)	1.24 (≈1240)
Korea (Kim et al.)	2014	Reference organ dose, µSv*	4089.7	NR	2982.1	533.1
Japan (Pauwels et al.)	2014	Eye lens range, µGy (≈µSv)	NR	95–6861	NR	NR

* Phantom-based conversion study (C-mode). NR, not reported.

5. Limitations

Several limitations should be considered when interpreting the NDRL and dose estimates. First, the survey used console-reported DAP values; differences in calibration, reporting methods, and beam geometry may introduce inter-scanner variability [8]. Second, examinations were pooled across different clinical indications, patient anatomies, and scanner models, preventing protocol-specific or manufacturer-specific DRLs that may better support optimisation [19]. Third, effective and organ doses were estimated using published DAP-to-dose coefficients rather than patient-specific Monte Carlo simulations, which may not capture variation in patient size, positioning, or scanner design [5,12,31].

6. Conclusions

Jordan's first national diagnostic reference level for adult CBCT examinations was established at 1153 mGy·cm² (DAP). The corresponding estimated effective-dose DRL was 97.0 µSv. These benchmarks provide a practical foundation for dose audit, protocol optimisation, and quality assurance across Jordanian CBCT imaging centres.

Supplementary Materials: Not applicable.

Author Contributions: Conceptualization, M.A. and N.M.A.; methodology, M.A. and N.M.A.; validation, a\ M.A. and N.M.A.; formal analysis, M.A. and N.M.A.; investigation, M.A. and N.M.A.; data curation, M.A. and N.M.A.; writing-original draft preparation, M.A.; writing-review and editing, M.A. and N.M.A.; supervision, M.A.; project administration, M.A.; funding acquisition, M.A. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: This retrospective study received approval from the IRB at Jordan University of Science and Technology (Approval No. 31/171/2025, dated 2/2/2025), confirming adherence to ethical standards. Data management followed stringent confidentiality protocols, ensuring patient privacy and upholding the ethical principles of the Declaration of Helsinki.

Informed Consent Statement: Patient consent was waived by the IRB due to the absence of patient interaction and identifiable information.

Data Availability Statement: The data that supports the findings of this study is available from the corresponding author upon reasonable request.

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Conflicts of Interest: The authors declare that they have no conflicts of interest.

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