As Low Dose as Sufficient Quality: Optimization of Cone-beam Computed Tomographic Scanning Protocol for Tooth Autotransplantation Planning and Follow-up in Children

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Abstract

Introduction: Tooth autotransplantation (TAT) offers a viable biological approach to tooth replacement in children. To enhance the outcome predictability of the TAT procedure, a cone-beam computed tomographic (CBCT)-based surgical planning and transfer technique has been developed. The aim of this study was to optimize the CBCT scanning protocol to achieve a dose as low as possible and to maintain sufficient image quality. **Methods:** A sectional head phantom (SK150; The Phantom Laboratory, Salem, NY) was scanned using 18 exposure protocols in 3 different CBCT machines: 3D Accuitomo 170 (Morita, Kyoto, Japan), ProMax 3D MAX (Planmeca, Helsinki, Finland), and NewTom VGI EVO (QR Verona, Verona, Italy). The effective dose (ED) was calculated using Monte Carlo simulation and pediatric voxel phantoms (5- and 8-year-old males and a 12-year-old female). Image quality was assessed by comparing segmented teeth volumes, evaluation of the visibility of the lamina dura, and morphologic surface analysis of 3-dimensional models. A general linear mixed model was fit to combine image quality parameters and radiation effective dose for each protocol in order to rank and compare the protocols examined in the study. **Results:** The ED for the preoperative scan can be reduced to the range of 74.6–157.9 μSv, with ProMax with ultra–low-dose high-definition reconstruction (Planmeca) 100 × 90 scoring the highest. The ED for the postoperative scan can be reduced to the range of 24.2–41.5 μSv with ProMax with ultra–low-dose normal-dose reconstruction 50 × 55 and NewTom 50 × 50 with the standard mode scoring the highest. **Conclusions:** A considerable reduction in the pediatric ED can be achieved while maintaining sufficient image quality for tooth autotransplantation planning and follow-up using the dose optimization protocols. *(J Endod 2016;■:1–8)*

Key Words

Cone-beam computed tomographic imaging, pediatric radiation effective dose, tooth autotransplantation

Significance

This study provides effective radiation doses for 3 pediatric models. Applying the dose optimization protocols allows considerable dose reduction while maintaining sufficient image quality for CBCT-based 3D planning, 3D printing of tooth replica, and postoperative follow-up.

Permanent tooth loss or agenesis in children is confronting the dentist with challenging therapeutical problems mainly related to ongoing dentoalveolar development. Although implant placement is not a viable option and should be withheld until the completion of dentoalveolar development (1), tooth autotransplantation (TAT) offers a viable biological approach to tooth replacement in children. It enables preservation of the alveolar ridge and allows for periodontal healing and preserving the possibility of function and growth (2–9). To enhance outcome predictability of the TAT procedure, a low-dose cone-beam computed tomographic (CBCT)-based surgical planning and transfer technique has been developed, involving donor tooth selection and stereolithographic tooth replica fabrication (8, 10, 11). CBCT-based surgical planning may aid the clinician seeking answers regarding surgical feasibility and the best new position for the donor tooth while maximizing esthetics and function (8). The use of stereolithographic tooth replica provides individualized bone adaptability and reduces extra-alveolar time for the donor tooth. Thus, it may help to preserve the periodontal ligament and pulp vitality, reducing the risk for necrosis and resorption (8, 9). Moreover, 3-dimensional (3D) planning has been applied in the field of endodontics to treat teeth with pulp canal calcification and apical pathology successfully (12). Furthermore, stereolithographic tooth replicas have been used to plan the endodontic treatment of anomalous anterior teeth (13). The aim of this study

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TABLE 1. Scanning Parameters and Exposure Factors for the Used Protocols

Brand name	Protocol	Rotation (°)	Voxel size (μm)	FOV (mm)	X-ray tube voltage (kV)	X-ray tube loading (mA)	DICOM export parameters (voxel size × slice interval)
Accuitomo 170	High resolution*	360	80	40 × 40	90	154	80 × 80
Accuitomo 170	Standard resolution	360	125	60 × 60†	90	87.5	125 × 125
Accuitomo 170	Standard resolution	360	160	80 × 80‡	90	87.5	160 × 160
ProMax 3D MAX	ULD-LDR	210	400	100 × 90‡	96	6	400 × 400
ProMax 3D MAX	ULD-NDR	210	200	100 × 90‡	96	16	200 × 200
ProMax 3D MAX	ULD-HDR	210	150	100 × 90‡	96	25	150 × 150
ProMax 3D MAX	Normal-dose low-dose reconstruction	210	400	100 × 90‡	96	21.6	400 × 400
ProMax 3D MAX	Normal-dose normal-dose reconstruction	210	200	100 × 90‡	96	67.2	200 × 200
ProMax 3D MAX	ND-HDR	210	150	100 × 90‡	96	105	150 × 150
ProMax 3D MAX	ULD-LDR	210	400	50 × 55†	96	6	400 × 400
ProMax 3D MAX	ULD-NDR	210	200	50 × 55†	96	16	200 × 200
ProMax 3D MAX	ULD-HDR	210	150	50 × 55†	96	25	150 × 150
ProMax 3D MAX	ND-HDR	210	150	50 × 55†	96	105	150 × 150
NewTom VGI evo	Standard mode	360	200	80 × 80‡	110	TCM§	200 × 200
NewTom VGI evo	Eco mode	360	200	80 × 80‡	110	TCM§	200 × 200
NewTom VGI evo	Standard mode	360	200	80 × 50‡	110	TCM§	200 × 200
NewTom VGI evo	Eco mode	360	200	80 × 50‡	110	TCM§	200 × 200
NewTom VGI evo	Standard mode	360	200	50 × 50†	110	TCM§	200 × 200
NewTom VGI evo	Eco mode	360	200	50 × 50†	110	TCM§	200 × 200

FOV, field of view; ND-HDR, normal-dose high-definition reconstruction; ULD-HDR, ultra-low-dose high-definition reconstruction; ULD-LDR, ultra-low-dose low dose reconstruction; ULD-NDR, ultra-low-dose normal-dose reconstruction.

*Reference cone-beam computed tomographic scanning protocol.

†Small field of view for postoperative follow-up.

‡Large field of view for preoperative scanning.

§Tube current modulation.

was to optimize the CBCT scanning protocol to achieve a dose as low as possible and to maintain sufficient image quality for

1. CBCT-based 3D planning and tooth replica fabrication serving TAT and
2. Post-operative follow-up.

Materials and Methods

Image Acquisition and Export

To allow dose optimization while maintaining sufficient image quality for CBCT-based tooth replica fabrication, various CBCT scanning protocols were applied to a sectional head phantom (SK150; The Phantom Laboratory, Salem, NY). This phantom is manufactured with a natural human skull and upper cervical vertebrae. The phantom's natural bones are cast from RANDO material (The Phantom Laboratory) with an internal air cavity representing the oral, pharynx, and trachea anatomy. The opaque RANDO material simulates the x-ray absorbency, atomic number, and specific gravity of soft human tissue.

To determine the clinically optimized scanning protocol serving accurate visualization of tooth morphology, tooth segmentation, replica fabrication, and postoperative follow-up, the head phantom was scanned using 18 exposure protocols in 3 different CBCT machines: 3D Accuitomo 170 (Morita, Kyoto, Japan) (2 protocols), the ProMax 3D MAX with the ultra–low-dose option (Planmeca, Helsinki, Finland) (10 protocols), and the NewTom VGI EVO with the tube current modulation option (QR Verona, Verona, Italy) (6 protocols). Table 1 presents the detailed scanning parameters and the exposure factors for all the protocols. Moreover, the protocols were divided into 2 groups depending on the indication: large field of view protocols for preoperative scanning and small field of view protocols for postoperative follow-up (Table 1).

The image quality of the aforementioned CBCT protocols was compared with a reference CBCT scanning protocol (clinical reference) validated for accurate tooth (14) and bone (15) segmentation. The latter existed of a high-resolution CBCT (80 μm) scan (3D Accuitomo 170, Morita) for maxillary incisors, canines, and mandibular premolars (Table 1).

Dosimetry

Monte Carlo Dose Simulations. A fully validated Monte Carlo (MC) framework developed in our group was used for dosimetric calculations (16, 17). The framework is built in the EGSnrc MC code and is capable of simulating the entire CBCT imaging chain (18, 19). It was customized for the 3 scanners used in this study via creating scanner-specific input files to the source code; these files included scanner-specific technical, geometric, and acquisition details. The x-ray tube modeling was based on the equivalent source models concept (20, 21), consisting of an equivalent energy spectrum for each clinical protocol obtained by half-value layer measurements and the x-ray tube equivalent filter description based on air kerma measurements across the radiation field.

Voxel Models. Organ doses were calculated via our MC framework for 3 pediatric voxel models. We retrieved 3 pediatric head and neck multislice computed tomographic image data sets (5- and 8-year-old males and a 12-year-old female) from the Picture Archiving and Communication System of the University Hospitals Leuven, Leuven, Belgium. It is only multislice computed tomographic data sets that can be used for accurate dose calculations because the resulting voxel models represent a full head. The organs in the head and neck region were fully segmented in Image J (National Institutes of Health, Bethesda, MD) (http://imagej.nih.gov/ij/) leading to voxel models consisting of 23 organs (Table 2). Each organ's density and elemental composition were