Tooth Transplantation Using Computer-Aided Rapid Prototyping Model Compared to Conventional Technique (A Pilot Study)

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Abstract

Objective: This research study aimed to compare the efficiency between tooth transplantation using the Computer-aided rapid prototyping model (CARP model) and a conventional tooth transplantation technique.

Materials & Methods: Ten patients were enrolled in this study. Patients were randomly divided into 2 groups. Five patients were performed tooth transplantation using the CARP technique (study group) and other five patients were performed antotransplantation using the conventional technique (controlled group). During transplantation, operation time, extra-alveolar time, and attempt of fitting donor tooth to recipient site were evaluated. Moreover, after 3 months post-operation, PDL space, tooth mobility, and pocket depth were examined.

Result: During transplantation, the study group consumed lower operating time and extra-alveolar time compared to the control group although no statistic significance was found ($p = 0.086$ and $p = 0.05$ respectively). In addition, the study group showed significantly fewer attempts to fit the donor tooth to the recipient socket compared to the control group ($p = 0.019$). After 3 months post-transplantation, average PDL width shows a narrower significant difference in the study group compared to the control group ($p = 0.014$). Moreover, the study group showed significantly better pocket depth reduction compared to the control group ($p = 0.024$). No significant difference found in tooth mobility after tooth transplantation in both groups ($p = 0.074$).

Conclusion: CARP technique reduced attempt to fitting donor tooth and improved PDL healing of donor tooth in tooth transplantation compared to conventional technique.

Keywords: Tooth transplantation, Computer-aided Rapid prototyping, CARP model

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Introduction

Autogenous tooth transplantation or tooth autotransplantation is defined as the surgical transplantation of a tooth from its original site to another site in the same patient (1). Unlike other prosthetic restorations, tooth autotransplantation provides autogenic compatibility and has the ability to restore proprioceptive perception during function (2) and is viable for further orthodontic treatment (3). The outcome of this procedure depends on specific case selection and an understanding of the biological principles (4). The successful outcome of autotransplanted tooth is influenced by preoperative planning, perioperative procedure, and postoperative care, which could be categorized as prognostic factors (5). The extra–alveolar time, defined as duration after the donor tooth is extracted out of the socket until replaced into the recipient site, influences the prognosis of tooth transplantation of the tooth, which strongly affects the viability of the periodontal ligament (PDL) cells of the donor tooth (6). Andreasen reported that, in order to achieve the normal PDL healing after tooth transplantation, the extra-oral time of the donor tooth should be limited to 18 minutes (7). Moreover, Nethander reported that increasing the number of attempts when fitting the donor tooth into the recipient site socket wound prolong extra-oral time and each attempt carried an increased risk of contamination with saliva-borne bacteria. This would compromise both the pulp and periodontal survival (8).

Nowadays, the fabrication of a three-dimensional (3D) tooth replica for assisting tooth tooth transplantation was first reported by Lee et al 2001 (9) and Verweij, et al (10). Three-dimensional (3D) planning has improved modern tooth transplantation techniques (3). Cone-beam computed tomography (CBCT) and rapid prototyping enable preoperative planning and the manufacturing of a replica for donor tooth preparation. This replica for the donor tooth generated by a computer-aided rapid prototyping model (CARP model) is subsequently used to prepare the newly formed tooth socket (recipient socket) before extracting the donor tooth in order to minimize the extra-alveolar time and facilitate the fit of the donor tooth (4). These innovations improve the predictability of the tooth transplantation technique and consequently increase the usefulness of tooth transplantation as a treatment option to avoid donor tooth damage and reduce the failure rate (10).

The CARP model improves the success of tooth transplantation by reducing operating time. The use of surgical templates allows the clinician to shape the recipient site as planned preoperatively to have maximal bony adaptation to the donor tooth resulting in decreased extra-alveolar and operation time. Adopting this technology might improve the clinical outcome in tooth transplantation surgery. However, no study provides the information on tooth transplantation with the CARP model which is made from an open-source software recently. Therefore, the aim of this study is to investigate operating time, extra-alveolar time and number of attempts of fitting the donor tooth to the recipient site of tooth transplantation using CARP model developed from an open-source software compared to conventional technique. Moreover, we evaluated the success of the CARP model in tooth transplantation (in radiographic and clinical aspects) using PDL space, tooth mobility, and pocket depth.

Materials and Methods

Study design and population

This study was a randomized controlled trial study performed at the department of oral and maxillofacial surgery, Faculty of Dentistry, Chulalongkorn University from 2018–2020. The study was approved by the Human Research Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (HREC-DCU-P 2019-010). Due to the lack of information from the previous study, we designed this pilot study with 5 samples per group. Therefore, ten patients were divided randomly into two groups. Five patients underwent a conventional technique (control group) and the other five patients were assigned to the experimental group using the CARP model (study group) as a surgical template for tooth transplantation. The participants were assigned a running number. The research examiner was blinded to avoid any bias during the investigation.

Sample

The participants were enrolled into the study as following criteria shown in table 1.

Table 1. Criteria for enrollment of the participants.

Inclusion criteria	Exclusion criteria
1. Healthy patient age 18–40 years old, Classified as ASA Physical status type I – II. 2. Patients who had one single edentulous area (at least 3 months post extraction) that needed dental substitution and present adjacent teeth at the mesial and distal site and had one possible candidate donor tooth that could be harvested without odontectomy. 3. No ridge preservation or guided bone regeneration (GBR) procedure at the recipient site. 4. No pathology or infection at the recipient site.	1. Patient who was a heavy smoker. 2. Patients with heavy consumption of alcohol 3. Intraoperative complications such as the root of donor tooth fracture, alveolar bone fracture at the recipient site, severe bleeding 4. Severe periodontitis of adjacent teeth 5. Poor Oral hygiene patient. 6. Conditions that make adjacent teeth unable to be used for stabilization.

Preoperative Planning

The donor teeth were evaluated using computer tomography and periapical radiographs to analyze the root morphology, angulation, and the position of the donor tooth. CBCT was performed for preoperative planning of the tooth transplantation procedure. The width (bucco-lingual and mesio-distal directions) and the length of the donor tooth were measured to assess the adaptability of the donor tooth to the recipient area (Fig 1A-C).

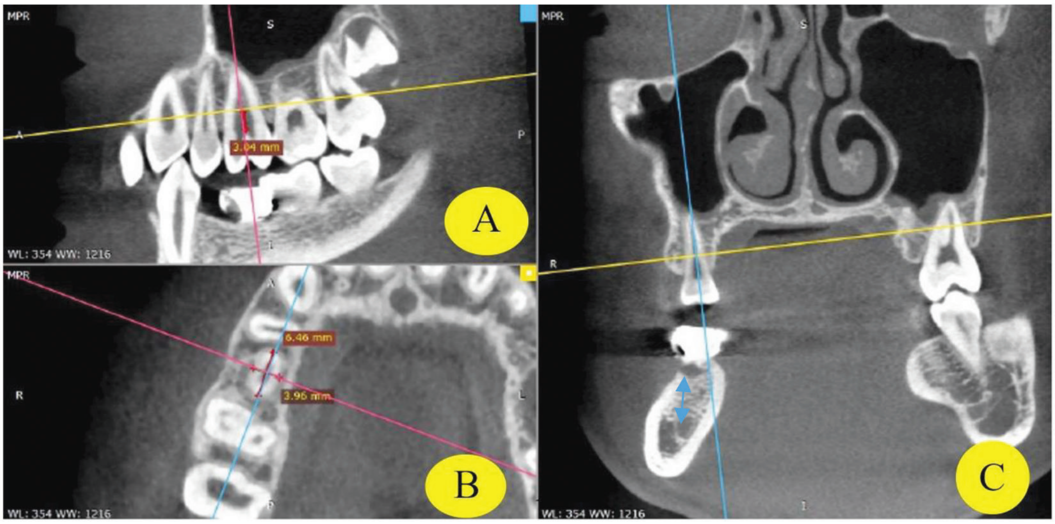

Fig 1. Preoperative planning of the tooth transplantation procedure in CBCT in the study group and controlled group.

A: Measurement mesio-distal, apically-coronal length of donor tooth in CBCT in sagittal view.

B: Measurement mesio-distal, bucco-lingual length of donor tooth in CBCT in axial view.

C: Measurement mesio-distal , bucco-lingual aspects and apically-coronal length of recipient area (in picture present only coronally view) and nearly vital structure in CBCT (on blue arrow mark).

Manufacturing 3d Printed Replicas of Donor Teeth

In the study group, a selective cone-beam computed tomographic (CBCT) scanning of the donor tooth was performed before tooth trans-plantation. The scan position was in the occlusal plane that paralleled the floor according to the manufacturer's recommendations. The data were imported into the 3D reconstruction software to obtain a 3D model. The scan volumes were exported from Digital Imaging and Communications in Medicine (DICOM) (Fig 2A) and imported to open source free software InVesalius 3.1.1(Moraes 2011) image analysis software (11-13) (Fig 2B). Subsequently, a 3D surface model of the donor tooth was created (Fig. 2C). Segmentation of the donor teeth was performed in a standardized manner (12) (Fig 2D).

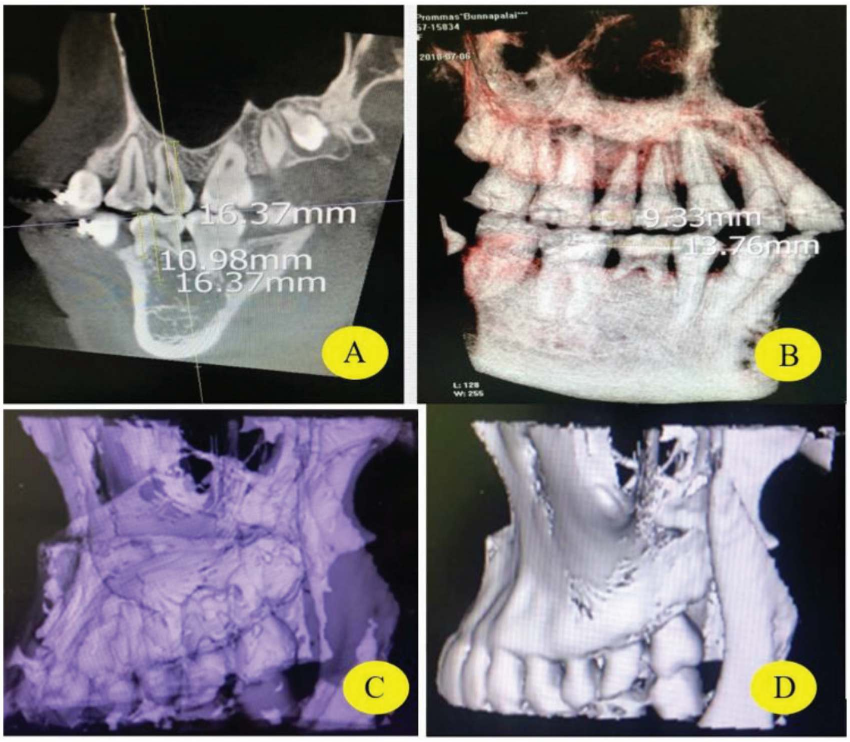

Fig 2. Segmentation of the donor teeth is performed in a standardized manner with open source software (Invesalius 3.1)

A. DICOM file was exported to scan volume.

B. Open source software (Invesalius 3.1) for analyzing and generating data for the 3D surface model.

C. 3D surface model of maxilla and mandible was created from a field of views (FOV) using CBCT.

D. Segmentation and separated area of donor tooth to create a replica of donor tooth.

A region of interest for the donor tooth and surrounding periodontium was selected. The root and crown of the donor tooth were separated from the surrounding bone based on a threshold value that was determined from histographic analysis, local gray level, and image gradient. Based on the sagittal views, manual selection is subsequently applied for the most apical part of the root to complete the segmentation of the tooth. Images were prepared using interactive processing tools in order to remove any remaining artifacts. A 3D surface mesh of the donor tooth was created and stored as a Standard Triangulation Language (STL) file ans reprocessed by an open source free software Meshlab version 2016 to create a printable mesh (13) (Fig 3).

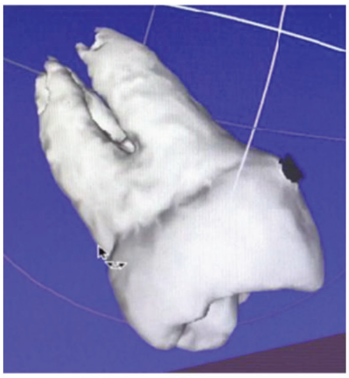

Fig 3. Images were processed using interactive processing tools to remove any remaining artifacts. A 3D surface mesh of the donor tooth was created and stored as a Standard Triangulation Language (STL) file that was reprocessed by an open-source free software Meshlab version 2016 to create a printable mesh.

Fabrication of the replica of the donor tooth was created using DLP-based 3D with 385 UV wavelength producing a 4M-pixel projector. Artificial Intelligence (AI) in pixel tuning was applied to achieve a high-quality surface finish to fabricate copies of the donor teeth from the STL files. This technology was an additive manufacturing technique that can be used to build complex-shaped 3D objects by successively depositing and melting resin layers. The replicas of the donor teeth were produced using biocompatible resin, E-Guide Tint. E-Guide Tint (EnvisionTEC's) is a biocompatible certified Class I material which is developed to produce high precision surgical drill guides for use in implant surgery. The material is resistant to disinfectants and can be sterilized using gamma rays and autoclave without affecting dimensional stability (Fig 4A-B).

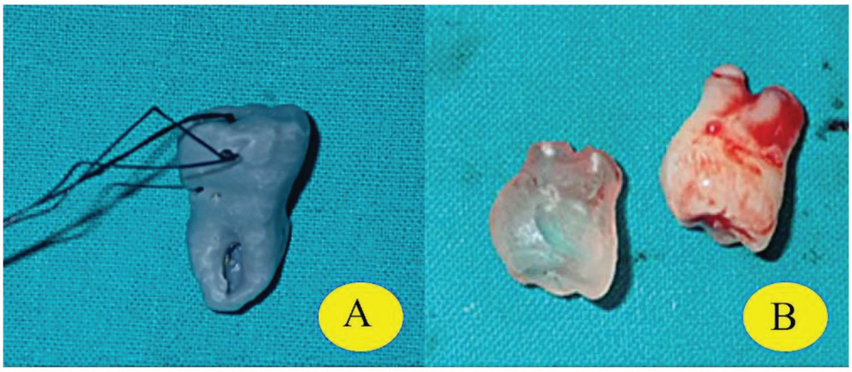

Fig 4. A. The replica of the donor teeth is produced in a biocompatible resin B. The replica of the donor teeth compared to the real donor tooth.

Surgical procedure

All patients underwent tooth transplantation by a single experienced surgeon with the same surgical technique. The standard procedure was performed under local anesthesia. Local anesthesia (2% Mepivacaine with epinephrine 1:100,000 1.8ml) was administered prior to the surgical procedure, A full-thickness mucoperiosteal flap was raised at the recipient site to provide good access. The recipient site was prepared with dental implant surgical drill (Fig 5A-B).

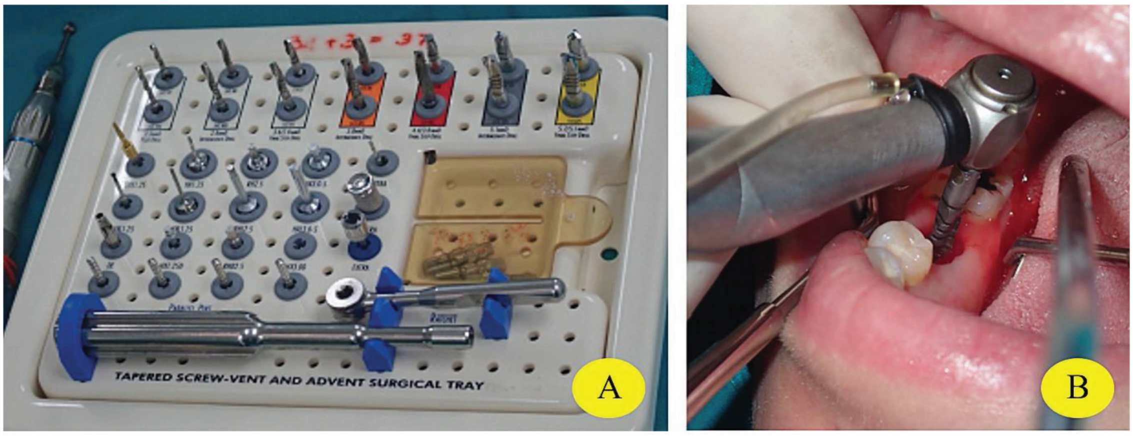

Fig 5. A: Surgical drill set for dental implant placement
B: Alveolus at the recipient site will be prepared with dental implant surgical drills.

In the study group, the 3D-printed replica was fitted in recipient socket in order to prepare a proper socket for donor tooth prior to donor tooth fixation (Fig 6A-B).

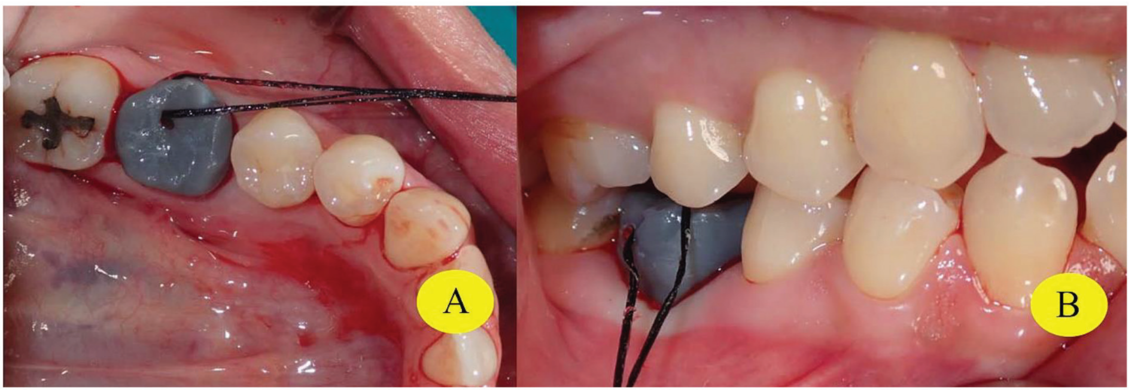

Fig 6. A. The 3D-printed replica was fitted to ensure that the donor tooth would fit exactly in recipient site socket.
B.Occlusal adjustment of the replica or opposing tooth to avoid traumatic occlusion

Then, the donor tooth was extracted in the atraumatic technique. During the procedure, the time record was started when the edentulous ridge was prepared until the operation was finished. Moreover, the extra-alveolar time of the donor tooth and the number of attempts to fit the donor tooth in the recipient socket were recorded. After fitting the donor tooth, fixation of the donor tooth was performed using suture (Fig 7A). Stainless steel wire No.26 was fixed to mesial and distal adjacent teeth using composite resin fixation in case clinical tooth mobility was over than 1st degree mobility (Fig 7B).

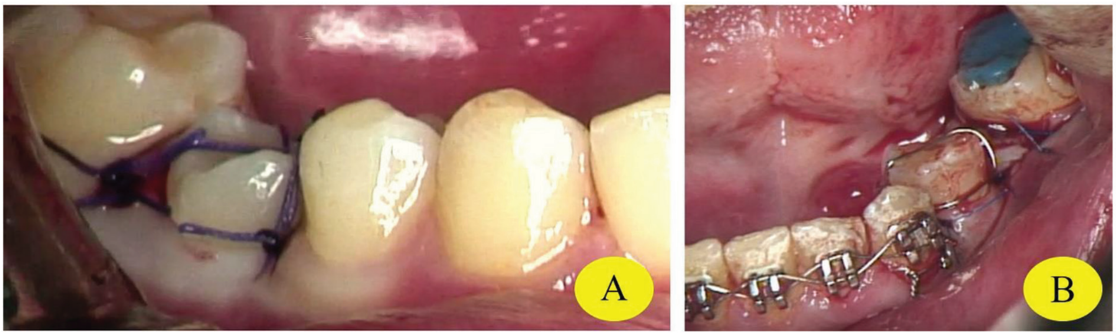

Fig 7. A. Fixation donor tooth with suture.
B. Fixation donor tooth with SSW No.26 if movable than 1-degree mobility of fit to the socket.

The donor tooth was placed in slight infraocclusion to prevent excessive occlusal force postoperatively. The periapical film was performed immediately after the operation and 3 months after tooth transplantation in order to examine PDL space reduction (Fig 8A-D). For clinical stability(mobility), the distance of tooth movement from the central groove as a reference line was evaluated. The distance of tooth movement in the bucco-lingual axis from its static position was recorded. Probing depth was measured using periodontal probe (15-mm scale). 0.12% chlorhexidine mouthwash and an analgesic drug were prescribed (paracetamol). After 7-14 days of operation, all patients in both groups were referred for endodontic treatment.

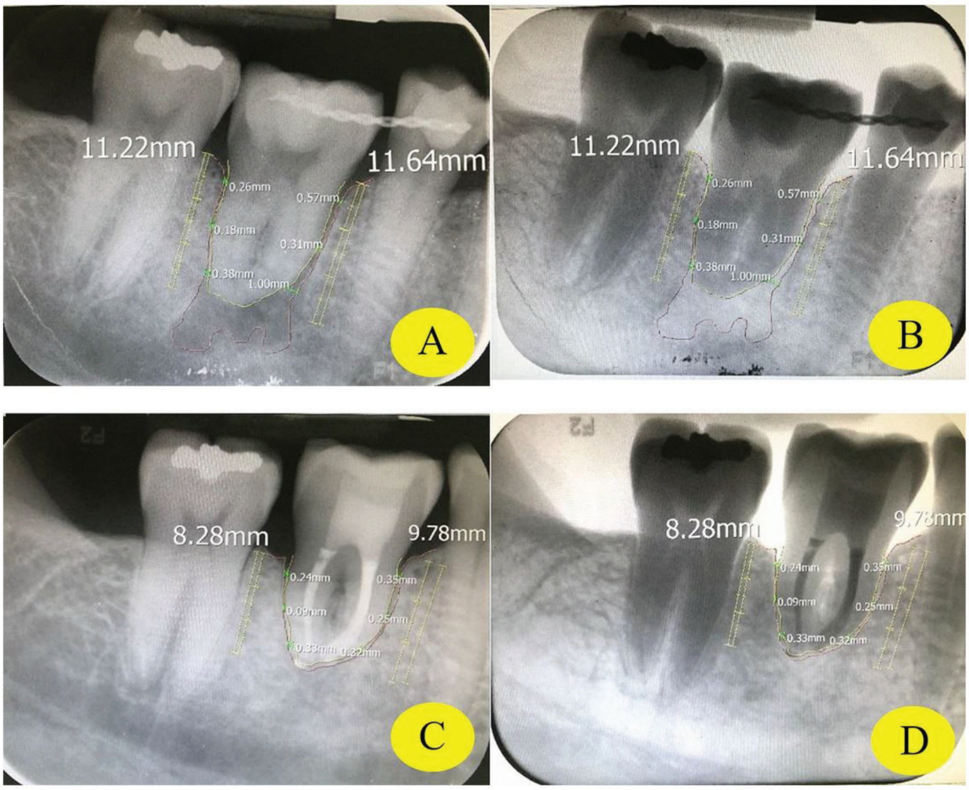

Fig 8. A. Immediate post-operation measurement of PDL space in the periapical film.
B. Immediate post-operation measurement of PDL space in the periapical film with alternative contrast to ensure the area of measurement.
C. After 3 months of tooth transplantation measurement of PDL space in the periapical film compared to 1 week of operation.
D. After 3 months of tooth transplantation measurement of PDL space in the periapical film with alternative contrast to ensure the area of measurement compared to 1 week of operation.

Data Analysis

During operation, operation time, extra-alveolar time of the donor tooth, and number of attempts were recorded. Moreover, the outcomes to be evaluated clinically and radiographically were described below;

1. Clinical aspects
   1.1 Pocket depth and bleeding on probing
   1.2 Mobility of donor tooth
2. Radiographic aspects
   2.1 PDL space

Outcomes related to the success of the CARP model are shown in Table 3 in the appendix. At 3 months, the pocket depth, tooth mobility, and PDL space in the periapical radiographs were evaluated. The reduction of PDL space in percentage was calculated at the mesial and distal average of PDL space.

$$\text{Percentage reduction of PDL space} = \frac{(\text{Immediate PDL space} - \text{3 months follow up PDL space})}{\text{Immediate PDL space}} \times 100$$

Pocket depth was recorded at six points; mesiobuccal, midbuccal, distobuccal, mesiolingual, midlingual, and distolingual sites. Then the average pocket depth was calculated.

Statistical Analysis

Statistical analysis was performed using SPSS version 22.0 (SPSS Inc., Chicago, IL). Operating time, extra-alveolar time, attempt times, a distance of PDL space, clinical stability (mobility), and pocket depth were tested for normal distribution using the Kolmogorov-Smirnov test, and the data was calculated statistically using the two-sample Mann Whitney U test. P-values less than 0.05 were considered significant.

Results

One patient was excluded from the study due to loss of follow-up. Therefore, a total of nine patients were enrolled in this study. Four patients were in the study group and five patients were in the control group. The demographic data of nine patients were shown in table 2. The data were tested and defined as normal distribution using the Kolmogorov-Smirnov test. However, we performed the Mann-Whitney U test due to the small sample size.

Demographic data

Table 2. Demographic data in study and control group.

	Study (n = 4)	Control (n = 5)
Age	Mean = 29 SD = 10.87	Mean = 15 SD = 2.17
Sex		
- Male	0	4
- Female	4	1
Apex of donor tooth		
- Closed	3	1
- Open	1	4

CARP = Computer-aided rapid prototyping model

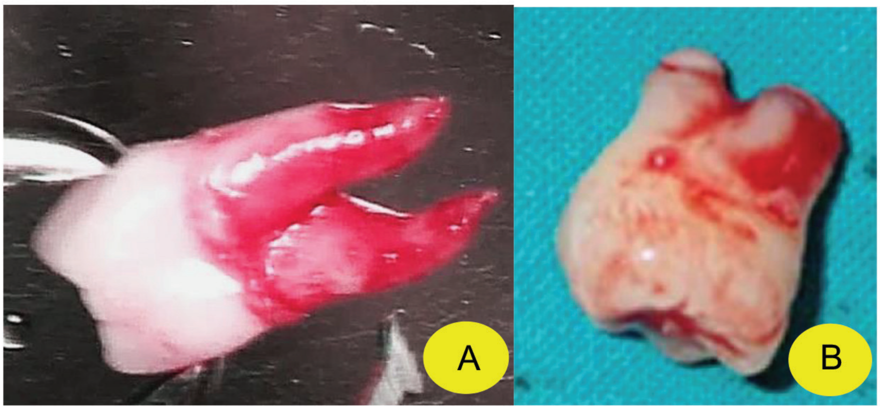

Fig 9. A. Donor tooth with closed root apex.
B. Show tooth with the distinct open root apex of donor tooth surrounded by dental papilla.

Operating time

Our data showed that the CARP group provided less operating time compared with the control group (20.25 mins vs 39.37 mins, respectively) without a statistically significant difference shown in table 3.

Extra-alveolar time

The extra-alveolar time of the study group was 3.10 mins, which was 2.6-fold less compared with the control group (8.17 mins) with $p = 0.05$ shown in table 3.

Number of attempts

Study group showed significantly fewer attempts than the control group significantly with $p = 0.019$ (2.63 vs 6.9 attempts, respectively) shown in table 3.

Table 3. Time consumption and attempt.

	Operation time (min) Group			Extra-alveolar time (min) Group			Number of attempts(times) Group		
	Mean	SD	p-value	Mean	SD	p-value	Median	IQR (P25, P75)	p-value
Control	39.37	4.93	0.086	8.17	3.67	0.05	5	6 (0.5,2.5)	0.019*
Study (CARP)	20.25	12.36		3.10	2.53		2	2 (3.5,9.5)	

*Statistic: significance at $p < 0.05$

CARP = Computer-aided rapid prototyping model

Radiographic and clinical outcome

Average PDL width percentage reduction

The average of percentage in reduction of PDL space was reduced significantly in the Study group compared to the control group (35.29% and 48.6%, respectively) with p = 0.027 after 3 months post-transplantation shown in table 4.

Clinical stability (mobility)

There was no significant difference in the study group compared with the control group regarding clinical stability (mobility) (0 vs 0.6 mm, respectively) shown in table 4.

Average pocket depth

Average pocket depth at 3 months showed the study group was significantly less than that of the control group (1.43 vs 2.2 mm, respectively) with p = 0.024 shown in table 4.

Table 4. Radiographic and clinical outcome

	Average PDL width percentage reduction Group			Clinical mobility (mm) Group			Pocket Depth Group 3 month		
	Mean	**SD**	**p-value**	**Median**	**IQR (P25, P75)**	**p-value**	**Mean**	**SD**	**p-value**
Control	48.6%	24.10	0.027*	1	1(0,1)	0.074	2.2	0.54	0.024*
Study (CARP)	35.29%	17.05		0	0(0,0)		1.43	0.31	

*Statistic significance at $p < 0.05$

CARP = Computer-aided rapid prototyping model

Discussion

This pilot study was the first randomized clinical trial that evaluated clinical and radiographic outcomes between conventional technique and CARP-assisted technique for tooth transplantation. We performed the CARP model created by an open-source software that has not been reported elsewhere. We evaluated factors directly related to tooth transplantation success rate, including operating time, extra-alveolar time, and the number of attempts. In addition, we investigated the clinical parameters (PDL space, mobility, and pocket depth) to strengthen the benefit of using CARP assisted technique for tooth transplantation.

Tooth transplantation seems to be advantageous in the growing patients compared to other prosthetic management for numerous reasons (14,15). Tooth transplantation can provide an aesthetically superior emergence profile and gingival contour when compared to its prosthetic alternatives, with less of a burden on oral hygiene (16). The highest survival rates cited in the literature regarding tooth transplantation, ranging from 93%–100% have been reported, with follow-up periods in the range of nine months to 22 years. However, there appears to be a lack of consensus on the definition of success (17). High success rates of tooth transplantation have been reported over the past decade varying from 74% to 100% (18). These can be increased by following some simple biological principles. The data from the previous study showed a strong correlation between the incidence of root resorption, extra-alveolar period, and storage medium (14). One major factor related to the survival of autotransplanted teeth is the extra-alveolar time. The recommended extra-oral time should be minimized as possible, ideally in the range of 3–16 min. During that time, the donor tooth should be kept moist (19).

Extra-alveolar time is the main factor related to the periodontal health of the donor tooth and resulting in better PDL healing. However, overall operation time showed no significant difference between groups. This might result from the surgeon's limited experience with relatively new technology.

In order to improve the normal PDL healing after tooth transplantation, the extra-alveolar time of the donor tooth should be limited to 18 minutes (6). While in the control group the total mean of extra-alveolar time in our study was 8.17 minutes (497 seconds), the extra-alveolar time in the Study group was 3.10 minutes (190 seconds), which was much shorter than the critical time duration mentioned above. Compared to the multicenter study of Verweij, et al (20), our extra-alveolar time was lower than their reported range of extra alveolar time (1-600 seconds). A three-dimensional replica for autotransplant provides shorter extra-alveolar time and improves the survival of PDLs which is one of the key successes (21). The surgeon should consciously prevent mechanical or chemical damage to the PDL (21,22). Furthermore, the number of attempt of fitting donor teeth is one of the important factors to ensure a greater chance of successful implantation of the donor tooth. In our study, the number of attempts of fitting donor teeth in the recipient site in the Study group was lower than that of the control group with a statistically significant difference (mean 1.75 vs 6.2 times). Consistent to our study, less number of attempt provided better periodontal tissue healing due to reduced risk of iatrogenic injury (20).

Average probing depth usually represents reattachment between the connective tissues of the root surface and the recipient socket walls. Within 2 weeks after tooth transplantation, the probing depth returns to normal (18). Complete healing occurs within 8 weeks, which appears radiographically as a continuous space around the root and presence of lamina dura (2). The probing depth more than 4 mm is considered a plaque accumulation-related risk which limits self-cleansing and could lead to surrounding the alveolar bone loss. At 1- and 3-months periods of study, probing depth over 4 mm. was not found in both groups. In 1 month, there was no statistically significant difference in probing depth of the Study group compared to the control group. However, there was a significant difference in the average probing depth between the Study group compared to the control group (1.43 vs 2.2 mm) at 3 months. At late stage follow-up (3 months), the teeth in the Study group showed better PDL healing than those in the control group. This data strengthened the hypothesis that a lesser attempt to fit in the donor tooth resulted in an improvement in PDL healing. Lee et al., (23) reported 251 clinical cases where the average distance between the transplanted root surface and the alveolar bone was 1.17 mm at the mesial cervix, and 1.35 mm at the mesial apex, 0.98 mm at the distal cervix, and 1.26 mm at the distal apex. Consistently, the CARP method improved PDL width significantly at 3 months after tooth transplantation. In our study, the average PDL space was narrower compared to the previous study. Our average PDL space presents a decrease in the percentage of the change in PDL space in the Study group compared to those of the control group with statistical significance.

Economic consideration could be one of the important factors in patient decision-making. In many studies, the cost of the CARP model was not mentioned in the literature. There was no study that compared the cost of using CARP printed with titanium (20) and biocompatibility resin as we used in our study. Moreover, the biocompatible resin can be easily manipulated. For example, holes can be created on the surface for applied safety silk to the replica. Further studies comparing different material of 3D replica and long-term follow-up is recommended.

Conclusion

Our study presents a novel technique for tooth transplantation based on computerized 3D simulation for planning and assisting in recipient site preparation. Using CARP reduced number of attempt to fit the donor tooth compared to conventional technique. This technique may significantly simplify the tooth transplantation procedure and will probably also increase the success rate related to PDL healing from an attempt at fitting the recipient site which causes catastrophic failure of PDL cells around the root of the donor tooth.

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