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ABSTRACT
The success of autologous tooth transplantation depends on the activity of the periodontal ligament of the donor tooth. Its activity decreases with a longer exposure time. In order to reduce the exposure time of the donor tooth and quickly prepare the alveolar fossa highly matching with the donor tooth root, the clinical data of cone-beam CT (CBCT) was imported into Mimics 21.0 software in this study to obtain three-dimensional (3D) images of the jaw tissue structure. The images were used to extract the target area and select the target tooth. By analysing the information of the recipient region and the donor region, 3-Matic 13.0 software was used to implant the donor virtual into the target region, and restrictive personalised guidance was designed. Subsequently, the surgical guide template was printed by 3D printing technology, and the alveolar fossa was rapidly prepared in vitro. After the operation, the donor tooth was matched with the complete alveolar cavity using 3-Matic13.0 software. The depth deviation of the prepared alveolar cavity was measured within 2.0 mm, and the width deviation was about 1.0 mm. The maximum width deviation is 2.88 mm due to the tilt of the roots. With a high matching degree to the donor tooth root, it needs further and larger clinical studies.

Key Words: CBCT, Tooth autotransplantation, 3D printing technology, Computer-aided imaging, Periodontal ligament.


INTRODUCTION
Autotransplantation is a time-honored technique that remains a valuable treatment for patients with missing teeth.¹² It has the advantages of low cost, good histocompatibility, and high physiological reducibility. Since the root is not fully mature, the tooth transplanted in adolescent age can continue to grow after surgery until the tip closes. Periodontal ligament cells in the roots of fresh teeth can induce the growth of periodontal fibers,³ and promote bone wall growth and reattach adherent epithelium,⁴ thereby forming natural gingival sulcus and achieving natural aesthetic effects.⁵ The reconstructed periodontal membrane can restore the proprioceptive function of the tooth, and the chewing sensation is similar to that of the original tooth.⁶ However, the clinical success rate of autotransplantation is not high due to the negative effects of surgical trauma, the long-term loss of donor teeth, and the number of implant trials.

In the past few years, 3D printing technology has become more mature. In the process of tooth transplantation, the 3D printed prefabricated donor teeth were used to be made fit into the alveolar socket. Root damage of the original donor teeth was avoided by repeated friction. The activity of periodontal cells was preserved as much as possible to further improve the success rate of transplantation.⁷-¹⁰

In the current study, computer-aided imaging and 3D printing technology were used for the planning of transplantation, and the custom 3D design surgical guide plates were designed to guide the preparation of new alveolar fossa. The objective of this study was to evaluate the feasibility and accuracy of preparing the alveolar fossa morphology highly consistent with the root morphology by 3D printing personalised guide plate in vitro, and further verify it in vivo to improve the success rate of clinical treatment.

TECHNIQUE
The study was conducted in the Stomatology Department of Sichuan Academy of Medical Sciences, Sichuan Provincial People's Hospital. Informed consent was obtained from a patient who had completed autogenous tooth transplantation. The original maxillofacial CBCT was obtained, and the scan data were stored in DICOM format and imported into Mimics21.0 software. The 3D image of the jaw tissue structure was obtained and the target tooth was extracted (Figure 1a and 1b). At the same
time, the whole target alveolar bone anatomical structure was reconstructed by the threshold segmentation method.

The tooth was rotated 90 degrees into the alveolar bone because of the large mesiodistal inclination angle of the two roots of the donor tooth. The height and width of the donor tooth were analyzed by distributing the two roots along the buccal-lingual direction and transferring them to the recipient area to adjust the direction and depth of placement (Figure 1 a-e). Finally, image reconstruction and arbitrary rotation image observation were performed from multiple directions of the sagittal plane, coronal plane, and cross-section. Then the donor tooth and alveolar bone files were exported in STL format.

The STL file was imported into 3-Matic13.0 software, and the target tooth was divided into upper and lower alveolar parts in the 3D model. In this research, the shear function was used to cut the teeth along the maximum root circumference (Figure 2 a-d), and the shear direction was determined by preserving as much alveolar bone as possible (Figure 2 e and f). In order to grind precisely, three guides were designed: The guide plate 1 (Figure 2g), which was fitted with two maximum peripheral diameters, accurately limited, and guided the work of drill needles with diameters of 2.2 mm; the guide plate 2 (Figure 2h), which was used to remove the root column part; and the guide plate 3 (Figure 2i), which was used to trim the remaining alveolar partition. These three virtual guide plates were generated to restrict and guide the work of the drilling needle, selectively, and precisely removing bone so that the shape of the prepared cavity most closely approximated the root shape.

Exported data were inputted to Magic 21.0 software, imported to a 3D printer for printing, and finally obtained limited personalized resin guide plates, alveolar bone in the graft area, and donor tooth model (Figure 3 a-c).

In order to reduce the loss of alveolar bone, the minimum diameter of the existing implant drill needle (diameter 2.2 mm) was selected to simulate the operation in vitro through the model made of photosensitive resin, and the above guide plate system was used to prepare the hole. Firstly, guide plate 1 was placed in the alveolar model (Figure 4a), and two rough shapes were ground out according to the movement angle of the drilling needle limited by the guide plate and the pre-planned depth. Then, guide plate 2 was used to remove the part of the root column above the bifurcation (Figure 4b). Finally, guide plate 3 was used to remove the remaining alveolar ridge in the alveolar socket (Figure 4c). The previously printed donor model was then placed into the alveolar socket to check the position.

The prepared alveolar cavity was scanned to obtain the data. The statistical analysis values of the data were expressed as mean ± standard deviation (X±S), and the t-test was used. When p<0.05, the difference was statistically significant.

The alveolar fossa prepared by the guide plate scan be directly placed the donor tooth inside, without further installation, and had good stability. Because of the restriction of the guide plates, there was no rotation in the transverse plane (Figure 5 a and b).

The three-dimensional image of the alveolar fossa was obtained by scanning after spraying the developer, and the data were prepared for analysis (Figure 5c). The drilling process was unremarkable, the depth deviation could be controlled within 2.0mm, and the width deviation could be controlled around
1.0mm (Figure 6 a and b). Due to the inclination of the root, the widest point at the root tip was about 2.88mm (Figure 6c). The deviation of the proximal-distal buccal root and the width deviation of the palatal root and buccal root had statistical significance (p <0.05), while the deviation of proximal-distal palate root and the two root tips had no statistical significance (Figure 7). There was still room for improvement.

The reason for the large apical offset is still related to the change of the root angle. The root tips of molars are usually curved, which will bring difficulties to the preparation of alveolar fossa. Surprisingly, the use of intentional replantation, another technique used in the clinic, will remove about 3 mm of the tip length and then backfill, which may just solve the difficulty of preparing the root tip curve.\(^\text{[17,18]}\) After the partial removal of the curved part, the depth of the alveolar preparation decreased, and the angle of the needle deviation decreased correspondingly, which not only increased the amount of alveolar bone retention in the apical region but also reduced the preparation difficulty.

What needs to be improved is that only one alveolar bone with dentition defect was selected for study in this study. In future, in-depth studies can be conducted on alveolar bone and teeth with different dental positions and anatomical morphology to enrich experimental data. Although the smallest diameter drilling needle (2.2 mm) in the existing implant surgical toolbox was used in this experiment, the whole process did not require replacement of the drilling needle and the operation was simple, but due to the shape and size of the needle, the efficiency of alveolar preparation needed to be further improved. In the future, research can also focus on increasing the path restriction of guide plate to drill

**DISCUSSION**

Dental grafts have existed for hundreds of years, and successful autotransplantation can survive up to 45 years.\(^\text{[11]}\) The preservation of healthy periodontal ligament of donor teeth and the fit of the alveolar socket between donor and recipient site are crucial considerations in autotransplantation. Excellent periodontal healing is the crux of successful grafting.\(^\text{[12]}\) Therefore, the surgical technique, the time of donor tooth isolation, the number of donor tooth implantation tests, and the size of the gap between the donor tooth root and the new alveolar socket will significantly affect the results of tooth transplantation. Studies have shown that compared with traditional methods, CBCT-based autologous tooth transplantation significantly reduced the operation time, less trauma, and less failure rate.\(^\text{[13]}\) Tong et al. used CBCT and computer-aided molding technology to print the donor teeth in advance before surgery, which significantly shortened the operation time and made the immature premolar continue to develop successfully after transplantation, and achieved good clinical results.\(^\text{[14]}\)

This experiment is based on CBCT, applying computer-aided imaging combined with 3D printing technology to reversely design and produce personalised guide plates, and printed the donor tooth before the experiment began.\(^\text{[15,16]}\) In order to simplify and improve the success rate of autologous transplantation, this experiment directly selected the smallest diameter drill needle (2.2 mm) in the existing implantation surgical toolbox, used the personalised guide plate to limit the surgical path, and operated freely by hand, completed the expectation of rapid and accurate in vitro preparation for height matching of the donor tooth root alveolar fossa. In the scanning results, there was a large difference in the proximal and distal offsets of the palatine roots, which was related to the anatomical structure of the palatine roots. One-third of the apical tips were narrowed rapidly. Compared with the relatively smooth curve of the buccal roots, the angle offsets of the palatine roots were larger, which reduced the accuracy of alveolar fossa preparation. In terms of width, except for about one-third of the root tip, the rest of the parts were almost uniformly and gently narrowed, which had very little influence on the preparation of alveolar fossa.

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needle and making personalised drill needle, to reduce the preparation time of alveolar socket, further promote the in vivo research, promote the clinical application of transplanted teeth, and improve the success rate of transplantation.

CONCLUSION

Computer-aided imaging technology can simulate the position of the donor tooth, design the template, and guide the accurate preparation of the alveolar fossa. And 3D printing technology can print the donor tooth model and guide plate in advance, so that the alveolar socket matching the donor root can be fully prepared. Computer-aided imaging technology combined with 3D printing technology can improve the efficiency and accuracy of alveolar preparation, and provide technical support for the improvement of the success rate of autologous tooth transplantation.

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COMPETING INTEREST:

The authors declared no competing interest.

AUTHORS’ CONTRIBUTION:

MZ: Designed the work and wrote the main manuscript.
YC: Participated in the design of work.
JC, JR: Performed the procedure and took the images.
JL: Collected and analysed processing data.
KT: Reviewed the manuscript and made corrections before submission.

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