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Research article

'Gold' lost in restoration: Evaluation of core morphology of custom metal posts and cores, and analysis of precious metal debris

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A R T I C L E I N F O

Keywords:
Post and core
Precious metal analysis
Precious metal recovery
Crown cores
Deviation analysis

A B S T R A C T

(1) Objectives: To investigate the deviations between the morphological dimensions of finished cores and desired dimensions made by three available fabricating techniques. To assess the precious metal loss in custom precious metal post and core restorative treatment in the dental clinic.

(2) Methods: Titanium posts and cores were fabricated using three different techniques: digital scanning impression technology, digital scanning wax-pattern technology, and the traditional lost-wax casting method. Geomagic Studio was used to fit the scanned model data to the digital design data of the expected preparation and to analyze the 3D deviations between the two. Precious metal debris from the precious metal post and core was collected, processed, weighed and analyzed for precious metal elements by energy-dispersive X-ray spectroscopy layered images.

(3) Results: In all 48 pairs of models, there were positive and negative deviations, with the largest mean positive deviation of (0.752 ± 0.037 mm) for models made by the semi-digital scanning wax-pattern technique. A total of 7001.3 mg of metals was recovered from the waste streams collected, which contained precious metals—mainly gold, silver, and platinum.

(4) Conclusions: There were discrepancies between the custom core and the expected preparation regardless of the fabrication process used. The digital scanning impression technology showed better dimensional rationality of crown cores. Custom precious metal posts and cores can have an average precious metal loss of 129.7 mg per case in the dental clinic.

1. Introduction

Posts and cores are the mainstay of treatment for extensive tooth defects and are the last resort for the preservation of teeth with extensive defects [1–4]. They have been used for nearly a century and a half, and are now commonly used as custom metal posts and prefabricated fiber posts, with the former offering greater retention and a wider range of indications [5–9].

Currently, the most commonly used method for fabricating customized posts and cores is the traditional lost wax casting technique,

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which can be affected by a number of factors (e.g., accuracy of the impressions and plaster, and defects in the metal casting process) and is highly dependent on the technician's manual skill in designing and fabricating the crown core [10]. The inevitable grinding during the fitting process of the working model also reduces the accuracy of the post-and-core dimensions [11].

Despite the widespread use of digitization in the design and fabrication of prostheses [12], the current fully digital design process is limited by scanning technology and cannot be achieved in the tooth root canal. Processes with a reduced degree of digitization have been attempted [13–16]: one method with a lower level of digitization is to take an impression and create a wax pattern following the traditional process, and then optically scan the wax pattern to create three-dimensional (3D) data information of the core and submit it for digitization [17]; another method is to take a partial impression of the root canal and then integrate the canal data to the whole dentition to submit to a subsequent computer-assisted design process [18]. In fact, however, no matter which above-mentioned methods are used, The shaping of the core is particularly dependent on the technician's visual and subjective judgement of the restorative space of the model. The technician's understanding of the standard of the core form and his subjective sense of aesthetics result in the waxed or digital form of the core that he sculpts by hand or designs in computer software [19]. The presence of human intervention factors and the many deviations in the various stages of the processing of the custom post and core create the possibility that the root post must be adjusted in order to be seated in the root canal during the trial placement of the post and core [20–22], as well as ensuring that the core conforms perfectly to the desired shape of the dental preparation after the root post has been seated and cemented.

After the custom post and core have been cemented to the affected tooth, the next step is the preparation of the tooth to provide a reasonable space and an appropriate shape for future external restoration. Within the current state of medical practice, the preparation of the tooth is only possible by hand. The preparation consists of the coronal core and the residual dental tissue exposed in the mouth. The difference in morphological and restorative space requirements between the core processors and the dental preparation operator results in the removal of much metal debris from the core during the preparation. Unfortunately, the current clinical situation of metal debris abraded during chair-side custom metal post and core fitting and tooth preparation operations is neglected; is the debris is usually allowed to enter the waterway of the dental complex with the rinsing action or the aspiration operation and is disposed of with the other waste discharged from the clinic.

Gold, silver and platinum group precious metal alloys are among the main materials used for the fabrication of custom metal pile cores [23,24]. This is due to the excellent physicochemical properties of precious metals, their excellent corrosion resistance at room temperature, their stable thermomechanical properties, their modulus of elasticity being close to that of natural dentin, their good fracture strength, their good biocompatibility and their aesthetic color [25]. Gold is the oldest restorative material used in dentistry, with the earliest clinical use in dentistry as a material for the fabrication of restorations dating back to the ancient Roman period [26]. Gold in clinical dentistry is one of the most important pathways of consuming the precious metal outside of industrial use and ornamentation, as it is used for the fabrication of restorations [24]. According to the current state of technology, gold mining usually only produces a few dozen grams of crude gold from one ton of ore. For this reason, resource recovery and recycling of precious metals is particularly important. At present, precious metal recycling is dominated by the recycling of electronic scrap, mine tailings, used precious metal jewelry, and electrolytic plating waste slag and waste liquid. These recycling processes are often accompanied by the generation of large amounts of waste gas and waste water, resulting in extremely serious environmental pollution and low recycling efficiency [27–29]. It is therefore undoubtedly necessary to avoid precious metal wastage. No literature has been retrieved regarding statistics on the amount of metal debris lost from the above-mentioned chair-side custom metal post and core fitting and tooth preparation operations, but it is certain that precious metal loss in dental clinics is a serious waste of resources.

In the current study, we investigated the deviations between the morphological dimensions of finished cores and their desired dimensions made by three available processes: the semi-digital scanning impression technique, the semi-digital scanning wax-pattern technique, and the traditional lost wax casting technique. Precious metal debris was also collected from dozens of clinical cases during the post and core fitting and tooth preparation to analyze the precious metal content and thus assess the precious metal loss in custom precious metal post and core restorative treatment in dental clinics.

Table 1
Division of groups according to fabrication process and tooth position.

		Fabrication technique
SII	Central incisor	Semi-digital scanning impression technique: A laboratory scanner (D2000 scanner, 3Shape, Denmark) was employed to scan the impression to obtain the digital model of the 3D shape, which was transformed into an inverted counterpart using the Dental System software (3Shape, Denmark). Once the teeth were fitted into the digital model, the Dental Manager module of the Dental System software was applied for post-and-core design. The digital information on virtual shape of the designed 3D post-and-core was transmitted to 3D printing equipment CL-M2150X (Chenglian, China) to manufacture pure titanium posts and cores.
SIM	Molar	
SWI	Central incisor	Semi-digital scanning wax-pattern technique. A plaster cast was made from the impression. A skilled technician made a post investment mold for the root following its orientation and shape, and dropped wax into the root canal and sculptured the crown shape. A laboratory scanner (D2000 scanner, 3Shape, Denmark) was used to scan the wax pattern of the post, and the obtained 3D digital model was transmitted to 3D printing equipment CL-M2150X (Chenglian, China) to manufacture pure titanium posts and cores.
SWM	Molar	
CI	Central incisor	Traditional lost wax casting technique. A plaster cast was made from the impression with a die stone. A skilled technician specially made a post investment mold for the root with the greater incline in teeth with three roots, following its orientation and shape, and dropped wax into the root canal and sculptured the crown shape. Once the wax was solidified, the investment mold was removed, polished, reinserted into root canal, and applied with separating agent. Post investment molds of the residual roots were made in the same way. The wax pattern was embedded and pure titanium posts and cores were cast.
CM	Molar	

2. Materials and methods

2.1. Core size analysis of custom metal pile cores for three processes

One extracted central incisor with a single root canal and one extracted third molars with three root canals, free of lesions and structural developmental abnormalities, were selected. Approval for using the teeth was obtained from the Stomatological College of Nanjing Medical University (PJ2019-095-001). The cervical margin was prepared with a TR-13 diamond bur (MANI, Japan), where the ferrule (height = 1.5 mm) was retained, and the root canal was enlarged sequentially with a #1 P-drill, a #2 P-drill, and a #3 P-drill (MANI, Japan). Post space preparation was done with the required protocols. The post space direction was parallel to the root canal, and its diameter was within 1/4–1/3 of the root diameter. The length of the remnant of gutta-percha filling was 4.00 mm, which served as the apical seal. Teeth with previous root canal therapy and post space preparation were placed into the standard dentition model.

Post-and-core samples were then divided into six groups according to fabrication process (scanning impression, scanning wax-pattern, and traditional method) and tooth position (incisor, and molar). The specific groupings and processes are shown in Table 1.

The specific steps for fabricating posts and cores by the three processes are shown in Fig. 1.

Posts and cores in the aforementioned groups were evaluated in extracted teeth and adjusted as standard to ascertain their successful seating by a skilled technician. Complete seating of cast posts and cores was required.

The temporary crown fabrication module of the Dental System software (3Shape, Denmark) was used to digitally design the intended preparation. According to the requirements of a standard double-layered porcelain structure for zirconia all-ceramic crown restorations, the corresponding tooth position in the standard dental model was cut back with optimal thickness and uniformity. After each post and core was positioned in the root canal of the extracted tooth, the tooth was positioned in a standard dental model and the complete model was scanned using a laboratory bin optical D2000 scanner (3Shape, Denmark). The 48 files (.dcm files) were obtained from the oral scanner, which were converted to STL file format by CrossManager 2021. The datasets were sequentially imported into the reverse engineering software Geomagic Studio (3D Systems, USA) to reconstruct the original images. At the same time, the expected preparation data were imported from the digital design. The best-fit alignment or N-point alignment in the alignment tool was used to select three or more loci to fit the scanning data with the expected preparation data together, which were then analyzed for 3D deviation (Fig. 2).

The results of the 3D deviation analysis include the following two main outputs: (1) Mean and root mean square (RMS) values of positive and negative deviations between the post and core model and the expected preparatory model, where positive deviation is the outward deviation distance of the test model relative to the reference model, and negative deviation is the inward deviation distance, with the expected preparatory model as the reference model; (2) 3D deviation distribution chromatogram, where the software sets the corresponding equivalence interval chromatogram and outputs the deviation distribution chromatogram to further evaluate the 3D deviation distribution.

Data were analyzed with one-way ANOVA tests for comparisons. All data are presented as mean ± SD. Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 26.0 (IBM, Armonk, NY, USA). A p-value of <0.05 was considered

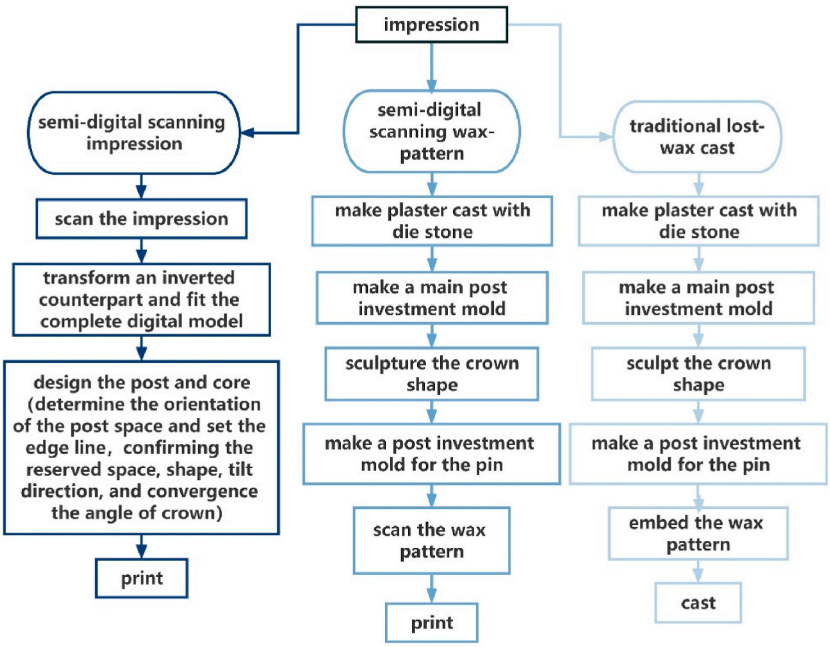

Fig. 1. The production steps of three different fabrication processes.

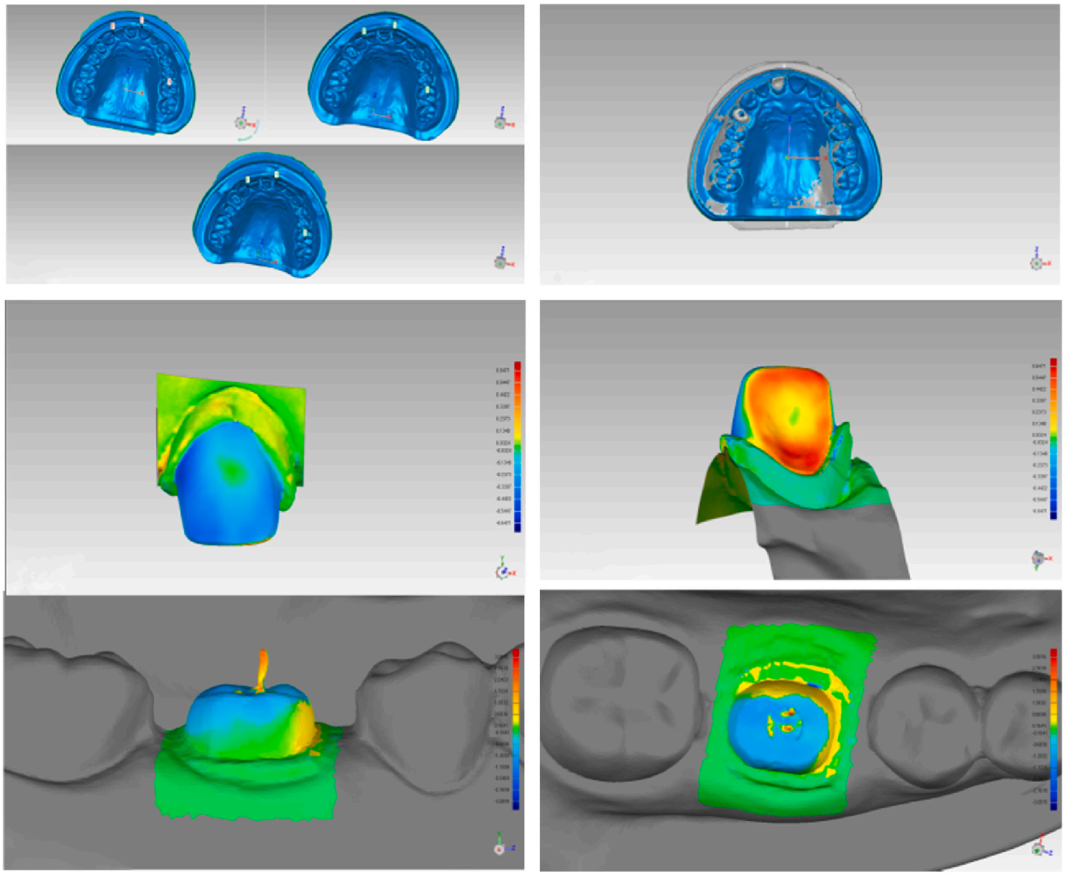

Fig. 2. 3D deviation distribution using Geomagic Studio software.

statistically significant.

Collection and analysis of precious metal debris from the posts and cores fitting and tooth preparation process.

54 patients treated with precious metal (Ardent, China) post and core restorations gave informed consent for the collection of intraoral fluid (no aspiration during this period) during the preparation of the core after cementing (rinsing with water before sample collection). G-power calculation was used to estimate the required sample size for the study in advance. Sample sizes were established using the following parameters: effect size = 0.5 (medium), significance level $\alpha = 0.05$, and power = 0.95. The results showed that a total of 45 specimens (medium effect size) were required for the test. Therefore, the use of 54 samples was considered appropriate.

The liquid collected in each case was autoclaved, and then the solids were collected in the following way: Samples were centrifuged at 1000 r/min for 10 min before taking the bottom sediment. The precipitate (containing precious metal alloy powder and insoluble impurities) was washed alternately with 75 % ethanol and deionized water, and filtered through slow-speed filter paper. The insoluble material was transferred with the filter paper into a 50 mL beaker, to which was added approximately 5 mL of water. Nitric acid (1:1) was slowly added under stirring until no more bubbles appeared in the solution, and then further added in excess. The material was heated and dissolved to remove metals (e.g., copper, lead, and aluminum) and other impurities (e.g., dental hard tissue and cotton wool) that are soluble in nitric acid from the raw material, removed, and cooled before being left to clarify. The upper clear solution was separated from the first part of the precipitate. Concentrated hydrochloric acid was added to the supernatant (containing silver) under stirring until a white, milky silver chloride precipitate no longer precipitated. The supernatant was discarded after the precipitate had settled. The precipitate was washed well with deionized water to remove chloride and other tramp ions, after which 10 g of iron powder (choosing a mesh size greater than 100) was added together with 10 % dilute sulfuric acid and left to stand for 5–8 h. When the reaction was complete, the precipitate was filtered. Dilute sulfuric acid was then added to the filtered precipitate before heating and stirring for 5–10 min to remove any residual iron powder. The solution was then filtered again to obtain the second part of the precipitate. The two portions of the precipitate were washed thoroughly with deionized water and then transferred to an oven for drying. After treatment and drying, the precipitate was weighed using an electronic balance and the data recorded (Fig. 3).

3. Results

As shown in Fig. 4, of all 24 pairs of anterior models, the eight pairs produced using the semi-digital scanning impression technique

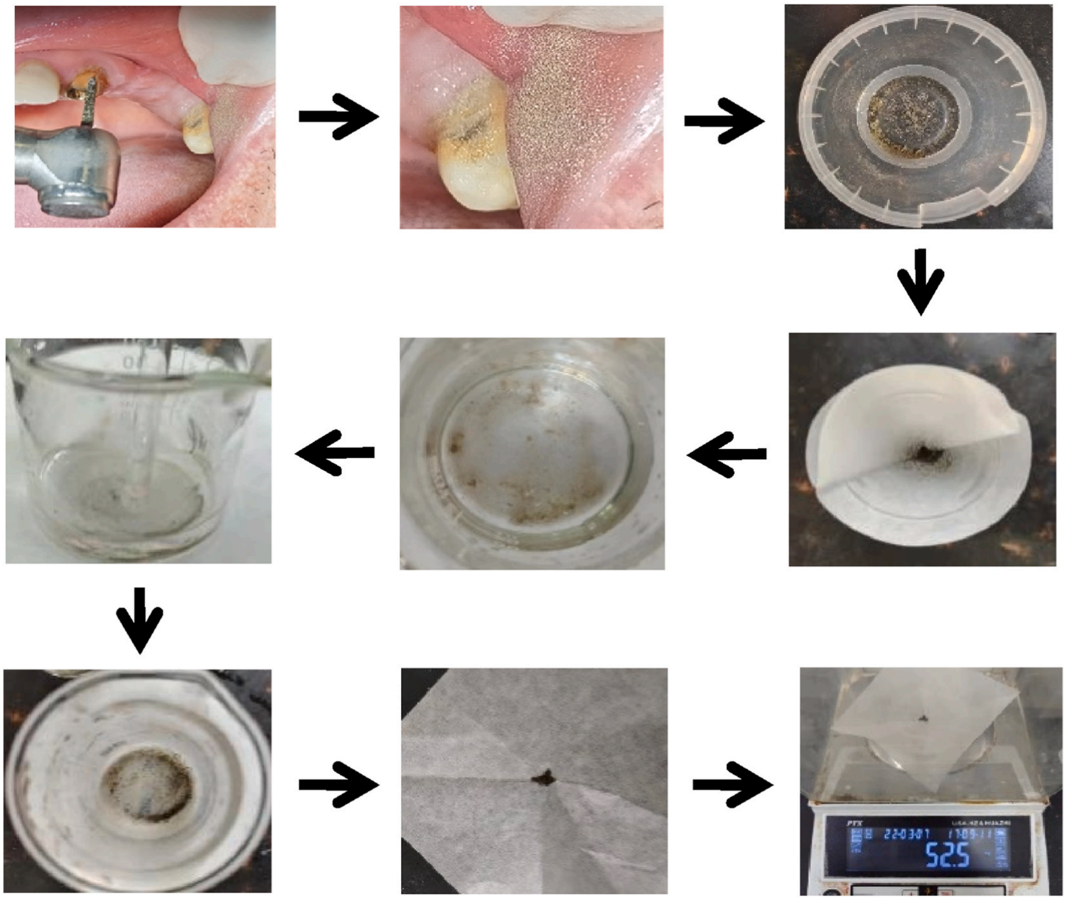

Fig. 3. Collection and processing of scrap containing precious metals for recycling.

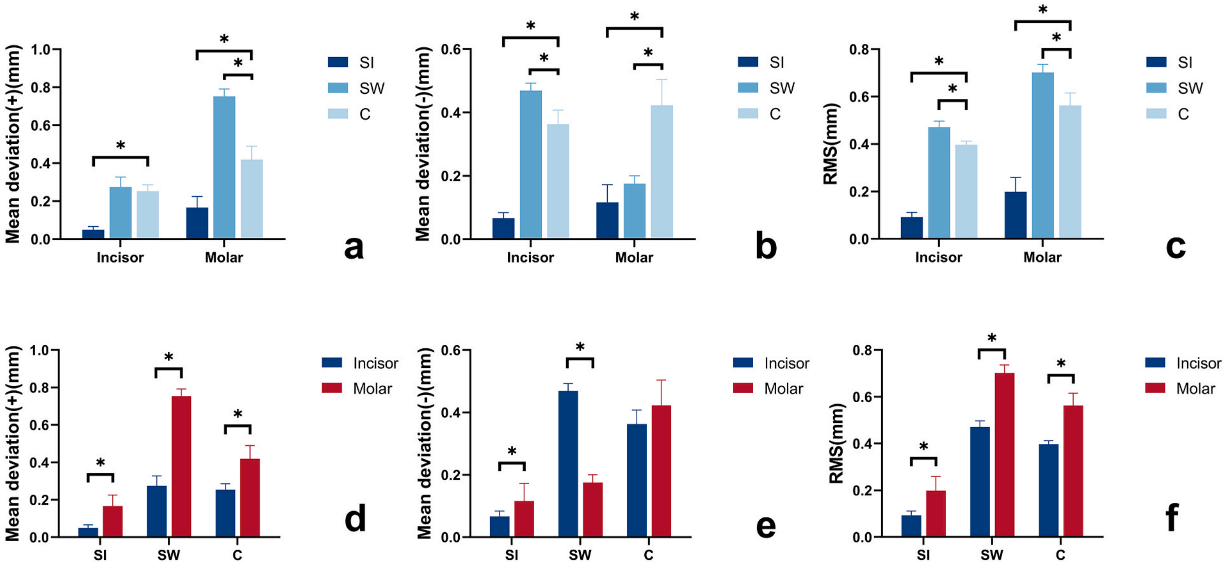

Fig. 4. Comparison of 3D deviations of models fabricated by three different processes: (a, d) Mean positive deviation; (b, e) Mean negative deviation; (c, f) Root mean square. SI: digital scanning impression technology; SW: digital scanning wax-pattern technology; C: traditional lost-wax casting method. *Statistically significant difference at $p < 0.05$.

had the smallest positive and negative deviations (Fig. 4a and b), with an average positive deviation of (0.05 ± 0.016) mm and an average negative deviation of (0.067 ± 0.016) mm. Of all 24 pairs of posterior models, the eight pairs, also made using the semi-digital scanning impression technique, showed the least deviation, with an average positive deviation of (0.166 ± 0.055) mm and an average negative deviation of (0.116 ± 0.052) mm (Fig. 4d and e). All 48 pairs of models exhibited some positive deviation, with the largest mean positive deviation of (0.752 ± 0.037 mm) for the posterior post and core models made by the semi-digital scanning wax-pattern technique (Fig. 4a and d). At the same time, the largest RMS was found in the semi-digital scanning wax-pattern technique for both anterior and posterior models (Fig. 4c and f). In addition, the positive deviations present in the corresponding anterior models were smaller than those in the posterior models, irrespective of the fabrication process used (Fig. 4d). Fig. 5 shows distributions of the deviations between the custom posts and cores model and the expected preparatory model using a predefined interval chromatogram.

According to the calculated results (Table 2), a total of 7001.3 mg of metals were recovered from the 54 groups of waste streams collected, with >90 % of which being precious metals and 40 % being gold.

The debris collected in the clinic was not a single component but a mixture of dental powder, bonding agent, diamond grit, and precious metal alloy particles. As these components are non-conductive except for the precious metal alloy particles, there is no need to gold plate the surface of the sample prior to the experiment and ultimately the remaining components are not visualized except for the precious metal alloy particles. Analysis of the precious metal elements by energy-dispersive X-ray spectroscopy (EDS) layered images (Fig. 6) shows that the alloy particles contained a significant number of precious metals—mainly gold, silver and platinum.

4. Discussion

The semi-digital scanning impression technique, the semi-digital scanning wax-pattern technique, and the traditional lost wax casting technique are the main custom pile core processing techniques currently available. Although the lost wax casting technique is the traditional process for custom posts and cores, the dimensional errors produced using this process are the largest, and factors affecting the fit of the post and core exist at every stage [30]. These includes, but are not limited to, the properties and quality of the impression and model materials, the technical sensitivity of the surrogate gap coating, differences in hand wax production, differences in properties of relevant materials in embedding and casting, and the technical sensitivity of post-casting grinding and polishing processes. These diverse differences in material properties, manual handling of wax engraving, and accuracy of equipment are inevitable. In addition, there are systematic errors in the control of solidification shrinkage and compensation of the alloy during the post and core casting process that are difficult to exclude [31]. In the other two digital design–dependent post and core fabrication processes, the semi-digital scanning wax-pattern technique adds a digital process to the traditional method, but the core morphology is still determined by the wax pattern. The reasonable size of the space for the core of the restoration still depends on the technician's mastery of the reserved space when making it by hand. The scattering of scanning light by the wax surface during the scanning process may adversely affect the accuracy of its results, making it difficult to achieve a high level of detail reproduction and stability [32]. Both factors together contribute to the poorer performance of the semi-digital scanning wax-pattern technique in shaping the morphology of the core. As one of the more sophisticated existing fabrication methods, the semi-digital scanning impression technique relies entirely on digital means to complete the design steps of the core section with a high degree of accuracy and repeatability, greatly reducing the influence of human factors. The electronic occlusal frame synergizes with computer aided design (CAD) of the digital model for checking the restoration space at the centric, protrusive, and lateral occlusions in virtual occlusion. The visual display of the excess or lack of space makes it easy to adjust to actual needs and ensures that all parts are generated and processed according to the set parameters. This process is certainly more objective and repeatable than hand-carving wax models, reducing technical sensitivity and

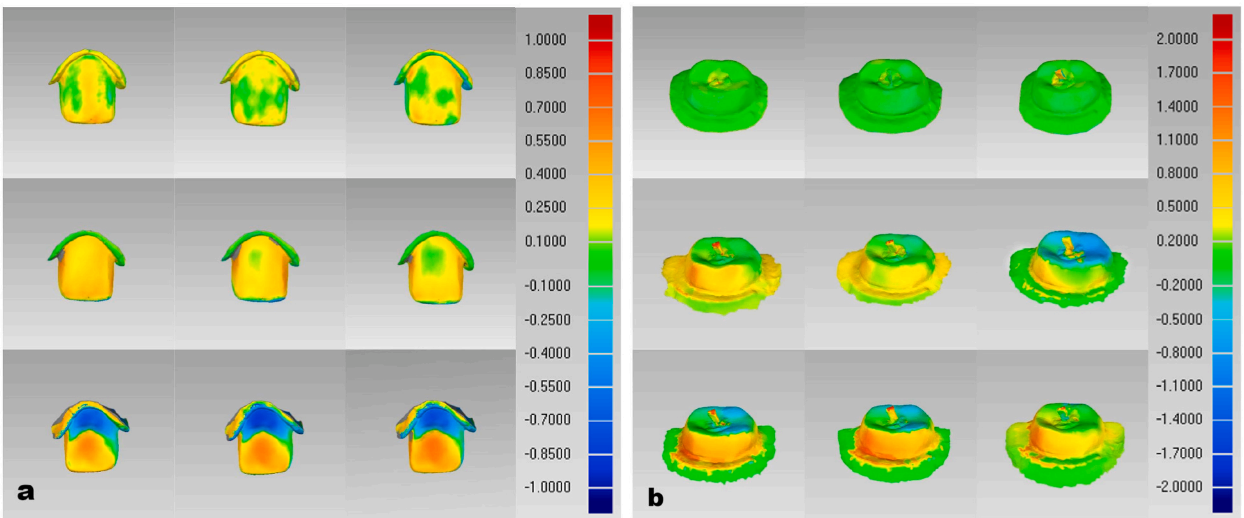

Fig. 5. 3D deviation chromatogram of the models fabricated by the three different processes (Deviation interval units: mm). (a) Incisor; (b) Molar.

Table 2
Statistical table for clinical collection of precious metals (mg).

Group	1	2	3	4	5	6	7	8	9
Weight	154.5	172.1	171.6	182.7	143.2	172.1	178.3	183.5	172.7
Group	10	11	12	13	14	15	16	17	18
Weight	195.2	167.6	171	167.8	169.7	178.2	172.3	175.5	161.5
Group	19	20	21	22	23	24	25	26	27
Weight	182	162.8	215.2	202.1	164.5	178.6	188.1	178.5	155.7
Group	28	29	30	31	32	33	34	35	36
Weight	164.2	174.1	161.6	163.5	164.4	172.8	165.2	186.1	231.5
Group	37	38	39	40	41	42	43	44	45
Weight	33.5	37.4	47.7	48.2	45.6	57.5	51.5	64.3	41.8
Group	46	47	48	49	50	51	52	53	54
Weight	27.2	31.1	32.5	22.1	21.7	25.7	37.2	32.4	43.5
Sum	7001.3								
Mean	129.7								

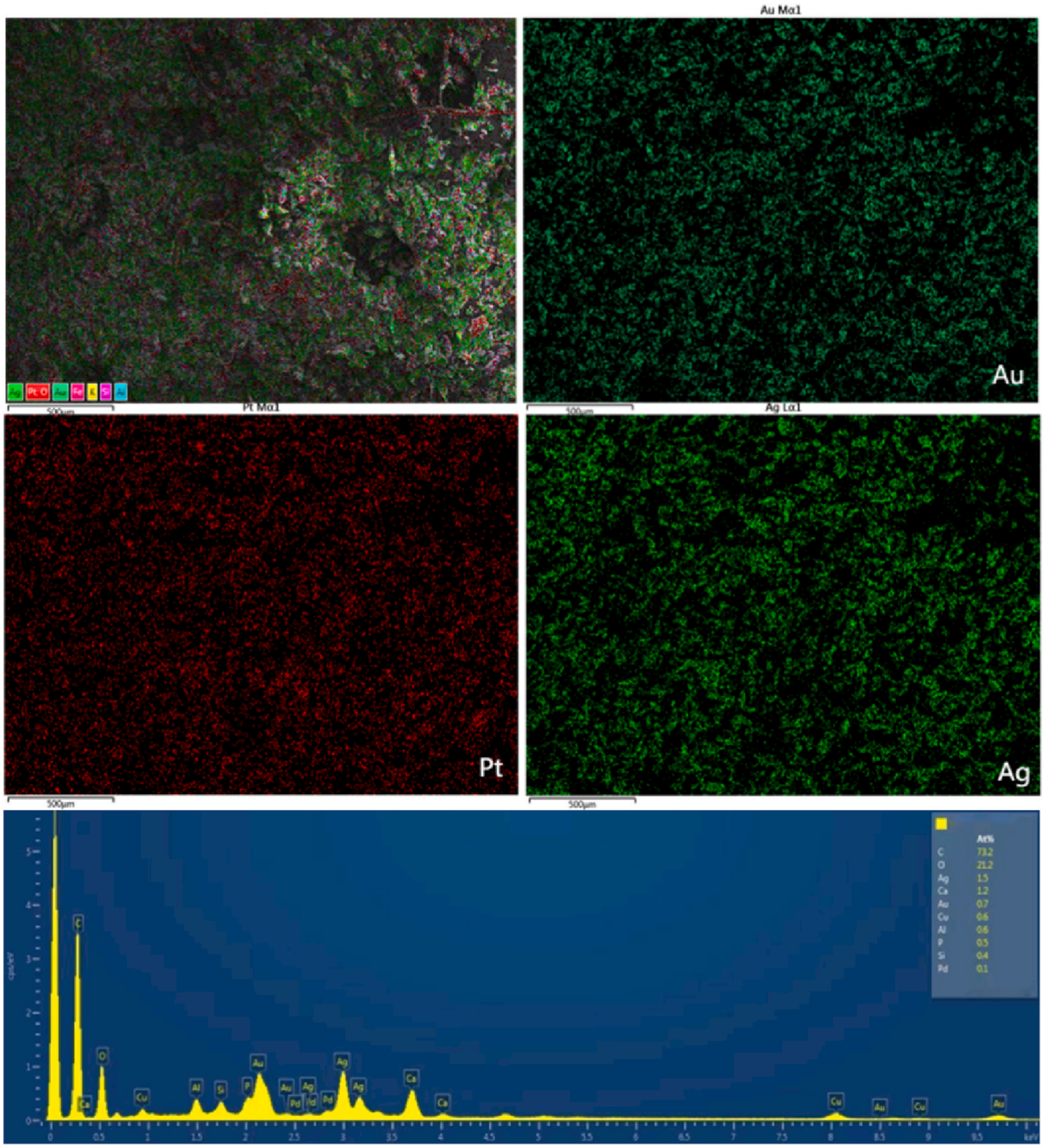

Fig. 6. EDS layered images of precious metal alloy particles.

dependence on skilled technician. However, even with the use of digital means, the same collaboration between the technician center and the clinician is required. The design is done by the technician in the machining center and still relies on the experience of the technician rather than directly generating the final form by setting fixed parameters. It is also possible that the physician may have individual requirements for the design of the core due to clinical realities and will need to adjust the form accordingly during the fitting process. Although the precision of existing 3D printing technology meets clinical standards, there are still mechanical deviations that cannot be eliminated during the printing process, all of which lead to the existence of discrepancies between the actual fabricated posts and cores, and the expected preparations [33–35]. All of the above descriptions suggest that, within the limited scope of the current state of fabrication techniques, the grinding of custom metal posts and cores is inevitable in fitting and/or tooth preparation after cementing, which is the reason for the generation of precious metal debris.

According to the current 3D deviation analysis, there is a discrepancy between the custom core and the expected preparation, regardless of the fabrication process used, which is relevant for both the single post form of the anterior post and core and the pinned split molar post and core. However, the dimensions of the crown cores of anterior teeth are more adaptable than those of posterior teeth, especially in the incisal edge area where they are relatively close to the expected restoration space (Fig. 5a). In contrast, the dimensions of the crown cores of the posterior teeth in the space of the occlusal surface deviate significantly from the expected restoration thickness (Fig. 5b). This deviation may be due to the fact that the technician can always check the adequacy of the restorative space under direct vision during the design and waxing of the anterior core, and the relatively simple shape of the anterior preparation, which is highly similar to the shape of the crown, allows the technician to perform the procedure more easily. In posterior teeth, on the other hand, the presence of numerous cusps of varying heights makes it difficult to control the wax fabrication, making it difficult to prescribe spaces of uniform thickness and narrow adjacent spaces, which is not conducive to direct comparison at any time to correct the suitability of restorative space dimensions. In post and core fabrication, because of the greater number of posterior root canals and the larger intercanal angles, pins are made to allow for the seating of non-parallel root canals [36]. The tip of the pin is often pre-fabricated with a clamping handle to facilitate clamping by the clinician, and this part of the metal is ground off after the post and core have been cemented in place. Also, a larger volume of the crown core of posterior teeth tends to be more abraded than that of anterior teeth when doing protrusive and lateral orientation to open up the restorative space.

Without considering the position of the teeth, even with metal restorations made with the more precise digital technique, errors reaching (0.108 ± 0.071) mm still exist between the actual clinical restoration requirements and the actual restoration. This error can be as high as (0.513 ± 0.243) mm, which corresponds to a loss of at least 0.135 mm^3 of metal per precious metal restoration due to grinding, if fabricated by the semi-digital scanning wax-pattern technique with a large deviation.

In fact, precious metal debris is not only generated and flowed during the fitting and tooth preparation after cementing of the cores, but also during the fitting of partial crowns, full crowns, inlays, cast brackets and telescopic crown removable dentures made of precious metal. Furthermore, when precious metal restorations are replaced, the removal process is often accompanied by the generation of large amounts of precious metal debris. This debris usually enters the patient's mouth first with the cooling water stream from the high-speed dental handpiece and is subsequently spat out into a mouthwash or sucked up by a saliva suction device, all eventually discharging into a centralized waterway system. There have been no targeted recovery measures for these precious metal particles, which are usually disposed of together with other waste in the pipeline. The precious metals used in the cases investigated in the current study were 40 % gold, 47 % silver and 4 % platinum. Based on the analysis of clinically collected debris, the average precious metal loss per post and core restoration during the shimming process was as high as 129.7 mg. It should be noted that the actual loss of precious metals during the sharpening process may be greater than this figure, as the water spray from the high-speed handpiece and some of the precious metal powder adhering to the patient's oral mucosa may not have been collected in the current study. In addition, if the precious metal product used has a higher precious metal content than the current brand, the calculated weight will be greater.

The above figures therefore serve as a warning that the amount of precious metal scrap lost from dental clinics is a staggering figure when calculated globally in aggregate. Precious metals still have irreplaceable value in restorative dentistry, and it is not realistic to abandon them at this time. Therefore, the design and development of measures for the collection of precious metals on integrated dental treatment tables is still something to look forward to in the future. In addition, although precious metal posts and cores are dominated by precious metal components, small amounts of added non-precious components (e.g., copper, tin, zinc, and indium) are still required to provide processability and good physical properties. These metal components cannot be ruled out as potentially harmful when discharged into water bodies and the ecological environment [37]. Besides the above metals, based on a similar principle, the emission of harmful metals also exists. In the past, due to the extensive use of amalgam for filling caries-induced tooth damage, large amounts of mercury were introduced into the environment during the removal and replacement of corresponding fillings. An environmental study reported that the waste mercury content from dental treatment accounted for 8%–14 % of the total mercury content of wastewater from sewage treatment plants [38]. In the 1960s, the Minamata disease incident in Japan, caused by chronic mercury poisoning, sparked international concern about metallic mercury pollution [39]. The growing recognition that mercury persists as a toxic component in the natural environment and also accumulates in animals and humans through bio-accumulation has indirectly contributed to the abandonment of amalgam in dental clinical practice [40].

5. Conclusion

It should be acknowledged that this study only initially calculated the amount of chair-side precious metal loss, and the influence of other factors (e.g., different tooth positions, different numbers of root canals, and defect size) on the amount of precious metal loss still needs to be investigated further. Moreover, these factors are also valuable in analysis of the reasonableness of the crown core size.

Based on the current results, and within the limitations of this study, the following conclusions can be drawn:

(1) The dimensions of the core of a custom single post and core of anterior teeth are closer to the expected restorative space dimensions than those of a pinned post and core of posterior teeth.
(2) The semi-digital scanning impression technique, the semi-digital scanning wax-pattern technique, and the traditional lost wax casting technique all inevitably result in discrepancies between the actual posts and cores produced and the expected preparations, wherein the semi-digital scanning impression technology shows better dimensional rationality of crown cores, whereas the semi-digital scanning wax-pattern technique shows the largest deviation.
(3) Custom precious metal posts and cores can have an average precious metal loss of 129.7 mg per case.

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Stomatological College of Nanjing Medical University (PJ2019-095-001). Informed consent was obtained from all subjects involved in the study.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Yumin Wu: Writing – original draft, Visualization, Investigation, Data curation. **Haowen Qi:** Writing – original draft, Validation, Investigation. **Yuhang Zhang:** Software, Resources. **Haifeng Xie:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Haifeng Xie reports financial support was provided by Jiangsu Commission of Health. Haifeng Xie reports financial support was provided by Jiangsu Provincial Key Research and Development Program. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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