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The Use of a 3D Image Comparison Program for Dental Identification

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Abstract: Dental identification involves compiling a prescribed dental chart of a deceased person's oral findings which is then compared with antemortem dental information. However, this process is complicated, and a comparison can be difficult. In this study, the authors evaluated whether it is possible to identify images from antemortem dental information images using an image comparison program (AKAZE) with one-sided cross-sectional images generated from the STL (Standard Triangle Language) data of upper and lower jaw models acquired with an intraoral scanner. From the STL data of 20 patients, 120 cross-sectional images were generated by three practitioners and compared with the cross-sectional images of 20 patients generated later, and the degree of agreement calculated by AKAZE was analyzed. Statistically significant differences were found between images of the same and different models, and statistically significant differences were obtained when comparing one-sided images with limited information, suggesting that partial dentition information can be used to identify the same dentition.

Keywords: dental identification; intraoral scanner; STL data; image comparison program

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1. Introduction

The usefulness of dental identification is currently being demonstrated [1]. Dental identification using dental findings involves matching the information of a body obtained by a dentist in a post-mortem examination room with information on the missing person from a dental clinic, which is finally authenticated by the police [2]. Specifically, police confirm the identity of the missing person by comparing the dental chart prepared from the information obtained from a visual examination of the body's mouth, which includes intraoral photography and dental X-rays obtained at a morgue, with the antemortem dental information record provided by a dental clinic. DNA identification is an effective means of identification, but it is difficult to obtain antemortem samples when a person's home is destroyed in a major disaster [2,3]. On the other hand, dental information is considered useful because it is likely to be preserved if a family dentist's office is not lost in a disaster, which can then be used to confirm a patient's identity [2,3]. In fact, following the 11 March 2011 earthquake and tsunami in Japan, dental information has been used to identify individuals in more than 1000 cases, about seven times more than DNA analysis and three times more than fingerprint identification [1,4].

However, the dental charts used in conventional methods are complicated, and the antemortem dental information records being compared, which are submitted by dental institutions and dental associations in the area, differ in the level of detail provided by the medical professionals who prepared the records. The process of making a dental chart from the information on a cadaver takes a long time, as it requires review by several people after the oral conditions are accurately reproduced on the chart [5]. In addition, rigor mortis and foreign bodies in a mouth may make it difficult to open the mouth and, thus, to directly view the oral cavity [5,6]. Moreover, if the dental clinic itself has disappeared, it may be difficult to prepare documentation before death [5–8]. If the information on a large number of bodies needs to be collected in the event of a major disaster, current methods must rely on human tactics, as it is impossible to collect sufficient information due to the decomposition of bodies. In fact, during the Great East Japan Earthquake, 2000 dentists and more than 30,000 police officers were involved in identification work alone [1,2,4].

Another problem is that a dental chart is not always a decisive factor in identification, for example, in cases where there are many healthy teeth and few characteristic treatment marks [5–8].

One solution to these problems is the use of digital technology with image comparison programs. The authors believe that it is a good idea to use digital technology to streamline the identification of unidentified persons.

Since the dentition may be partially lost in a high-energy disaster, such as an airplane crash or large-scale natural disaster, the ability to identify the same model even from partial dentition information is very useful for identification. In addition, the recent popularity of portable intraoral scanners has made the acquisition of 3D data practical, even in disaster areas [9]. Furthermore, in disaster areas, if intraoral 3D data of a person can be obtained, identification can be performed anywhere and anytime, which would greatly improve work efficiency.

In the advancement of dental care, digital technology not only improves dental technology but also changes the workflow of dental care and digitizes various pieces of patient information obtained in clinical practice. This digitized patient information can be processed by software, and various types of data can be integrated and used [10–14]. Among them, an optical impression taken with an intraoral scanner enables the output of maxillofacial morphology, including the dentition, into STL data, a standard format, and the creation of accurate three-dimensional reconstructive scan data [9]. An intraoral scanner is small, easy to maneuver, and can be easily used on patients with small mouths, making it easy for dentists to operate. Therefore, its use in the examination room is also feasible. If STL data prepared by a dental clinic are available in advance, an intraoral scanner can be used at the time of identification to collect more accurate intraoral information than when information is collected by visual examination and then transcribed onto a dental chart for matching. As a result, the data obtained from a cadaver and the data stored in the dental clinic can be matched on a computer, which can improve the efficiency of the work. In addition, if the data are stored as digital data, it will be possible, in the future, to prevent the loss of data before death by storing the intraoral conditions in a place where there is little risk of loss, even in the event of a disaster.

Currently, comparative studies of identification using 3D image data include evaluating bone anatomical features, such as the frontal sinus, sphenoid sinus, and cleft palate [15–18]; superimposing 3D data on dental models of maxillary first and second molars [19]; evaluating from the morphology of anterior teeth [20,21]; and implementing 3D data identification software studies [22,23]. However, the comparison of 3D data is time-consuming due to the large number of feature points [23]; thus, the authors believe that its current use is not realistic considering its role as a screening tool for dental identity verification.

Although comparing two-dimensional images can be thought of as comparing photographs, it is extremely difficult to compare two photographs. The position of the light source and the angle at which the camera was used can result in completely different photographs of the same subject [24]. The use of STL data makes it possible to store intraoral information under the same conditions, thus solving the problem of comparing photographs. If it becomes possible to compare anatomical features, such as the arrangement of the dentition and tooth contours, this may be useful in cases where there are no treatment scars and features that were difficult to identify using conventional identification methods that cannot be extracted from medical records. When comparing STL data, which are three-dimensional, the number of feature points to be compared is enormous, and the computational load required for feature extraction and matching processes is extremely high, requiring long comparison times [25]. Therefore, in this study, the STL data were sectioned at a specific reference plane, and a cross-sectional image was created as the comparison image. By creating the comparison image at the reference plane, the same image can always be created from the STL data, and the authors believe that this is optimal for identification.

In this paper, the authors report a new identification method using an image comparison program (AKAZE) [26–29] and binarized images created from cross-sectional images of left unilateral STL data of the upper and lower jaws, obtained by using an intraoral scanner.

2. Materials and Methods

Volunteers were recruited at Kanagawa Dental University Hospital, and 20 subjects with more than 20 teeth were recruited. Plaster casts of the maxilla and mandible were obtained from the subjects after informed consent. STL data were acquired by the three dentists using the TRIOS® intraoral scanner (3Shape, Copenhagen, Denmark) from the maxillary and mandibular models of 20 subjects (model numbers 1–20) with more than 20 teeth. The acquired STL data were trimmed using Autodesk Meshmixer® (Autodesk, Tokyo, Japan) for the left lateral dentition only, and the plane formed by two points at the proximal and distal corners of the central incisors, and the midpoint of the central limb ridge of the most posterior tooth was defined as the reference plane. For the maxilla, the plane with the reference point 2.5 mm vertically down from the reference plane toward the root was used as the cross-section. For the mandible, a plane with a reference point 2.5 mm vertically down from the reference plane toward the root for anterior teeth and 1.5 mm for posterior teeth was used as the cross-sectional plane. The sliced cross-sectional images were binarized in Adobe Photoshop® (Adobe, San Jose, CA, USA) to produce a total of 120 binarized cross-sectional images, 60 each for the maxillary and mandibular models. Figure 1 shows the procedure used to generate the binarized images. On a separate day, one of the three dentists read all 20 models and generated images in the same manner as above, generating 20 images each for the maxillary and mandibular model sections, for a total of 40 images. The images generated by these two methods were used to analyze the discrimination ability.

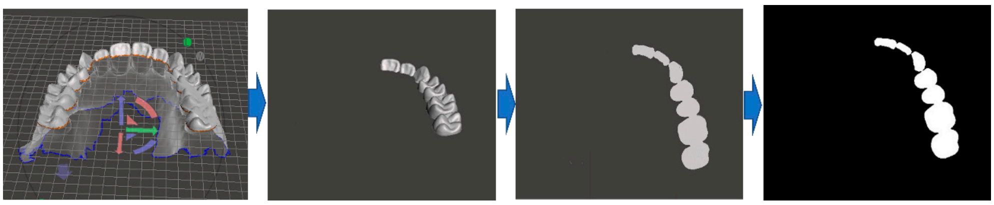

Figure 1. Binarized image creation procedure. In order, from the left image: 1—Captured STL data displayed in Autodesk Meshmixer. 2—STL data sliced by the length set from the reference point in Autodesk Meshmixer. 3—Sectional image of the sliced data. 4—Binarized sliced image with intermediate values using Adobe Photoshop. 5—Binarized sliced image using Adobe Photoshop. 6—Sectional image of the sectioned data.

The same maxillary model was read and imaged by the three dentists once a day for seven days, and 21 images were generated from the same model using the same method. To compare these 21 images, one image was taken on a different day from the same model using the same criteria. These two images were used to evaluate the differences between the practitioners.

Although there are various methods for image comparison, the AKAZE method was used in this study. In this study, we implemented and used an image comparison program based on the AKAZE method using OPEN CV and Python. The AKAZE method is an algorithm that can detect total features in a short time while maintaining high recognition accuracy. It is superior to other methods, such as SIFT (Scale-Invariant Feature Transformer) [25] and SURF (Speeded-Up Robust Features) [30], in terms of processing speed and has properties that are resistant to rotation and expansion. The AKAZE method can determine whether objects photographed from different angles are identical, can compare and determine whether the same object appears in two images by calculating their feature values, and can quantify the degree of similarity between images by comparing their calculated values. Figure 2 shows an image comparison using AKAZE. AKAZE can be used free of charge because there is no patent approval, and the software implementation is relatively simple [26]. In this study, the AKAZE value was defined as the average value of the Hamming distance of the feature values between binary images, where the lower the value calculated by brute-force matching of the feature points detected by AKAZE is, the more similar the images are.

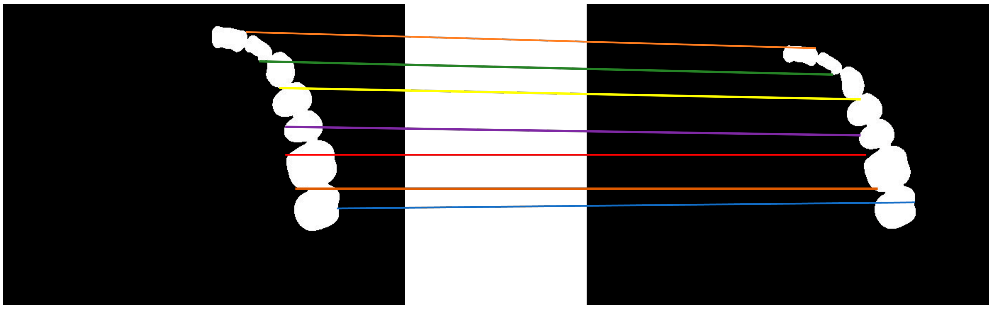

Figure 2. Image comparison using AKAZE.

In this study, the AKAZE values of the 120 generated images were compared with those of the 20 left maxillary and mandibular images generated on different days using the same criteria for the same 20 patients, and the AKAZE values of the images generated by the same model and those generated by different models were analyzed. To evaluate the discrimination ability of this method between the same and different models, the authors analyzed the difference between the average AKAZE values of the same and different models in 2400 comparisons of the maxilla and mandible, respectively. To evaluate the difference between the most similar and different models and the same model, the AKAZE values of the same model were obtained from 120 comparisons of each of the 20 different models and the top three species (1st model, 2nd model, and 3rd model), and the lowest AKAZE values among the different models were compared and analyzed. In addition, to evaluate inter-surgeon differences, the authors compared 21 images from a total of 21 STL data generated once a day for 7 days by 3 dentists from the same model with images generated by the same model later and evaluated the results. The Mann–Whitney U test was used to analyze the differences in AKAZE values for each analysis. All statistical analyses were performed with EZR [31], which is a package for R. More precisely, it is a modified version of R commander designed to add statistical functions frequently used in biostatistics. This study was approved by the Kanagawa Dental College Ethics Committee (No. 777).

3. Results

The results of the AKAZE values for each of the upper and lower jaws are shown as scatter plots in Figures 3 and 4, with the image of the same model showing the lowest values in all comparisons. The minimum and maximum values for the same model ranged from 3.1 to 41.2, and the values for the different models were all above 43.

When comparing the mean AKAZE values of the same model with those of different models for the maxilla and mandible, the mean values are 31.73 ± 9.06 and 68.19 ± 13.42 for the maxilla and 30.36 ± 9.90 and 71.37 ± 11.08 for the mandible, respectively, which shows statistically significant differences in the AKAZE values (p-value < 0.01; Figures 5 and 6).

As an analysis for each of the 20 model comparisons, the same model similarity average and the 1st, 2nd, and 3rd models of the maxilla and mandible, respectively, were compared. The top three models with the lowest AKAZE values in the heterogeneous model comparison out of 120 comparisons for each model were ranked, and the same rank was connected by a line. The means of each model are shown in the table, and statistically significant differences were found between the means of the same model and the 1st model (p-value < 0.01), while the 1st and 2nd and the 2nd and 3rd models did not show statistically significant differences (p-value < 0.01; Figures 7 and 8 and Tables 1 and 2).

In the interoperate analysis, the means for each surgeon were as shown in the table and showed no statistically significant differences between practitioners (Table 3).

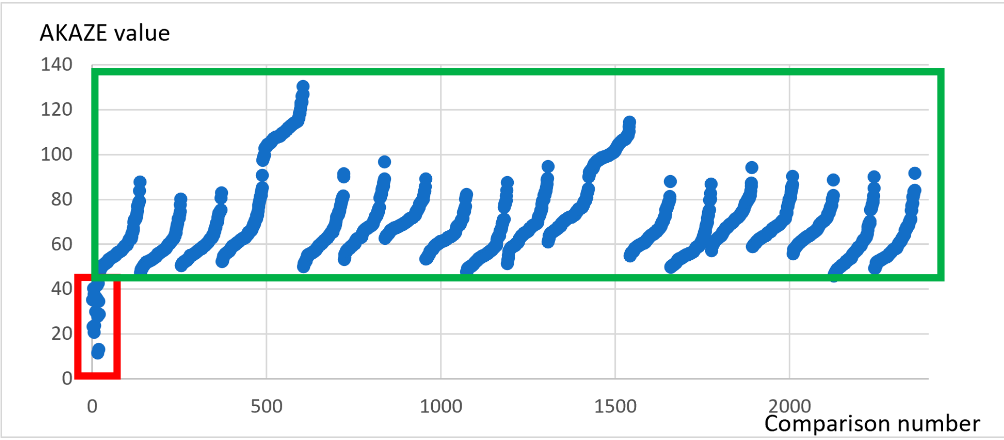

Figure 3. Scatter plot of the AKAZE values for the comparison of 2400 maxillary images.

The scatter plots are numbered for each comparison, with the results for the same model bordered in red, from number 1 to 60, and the results for the different models bordered in green, from number 61 to 2400.

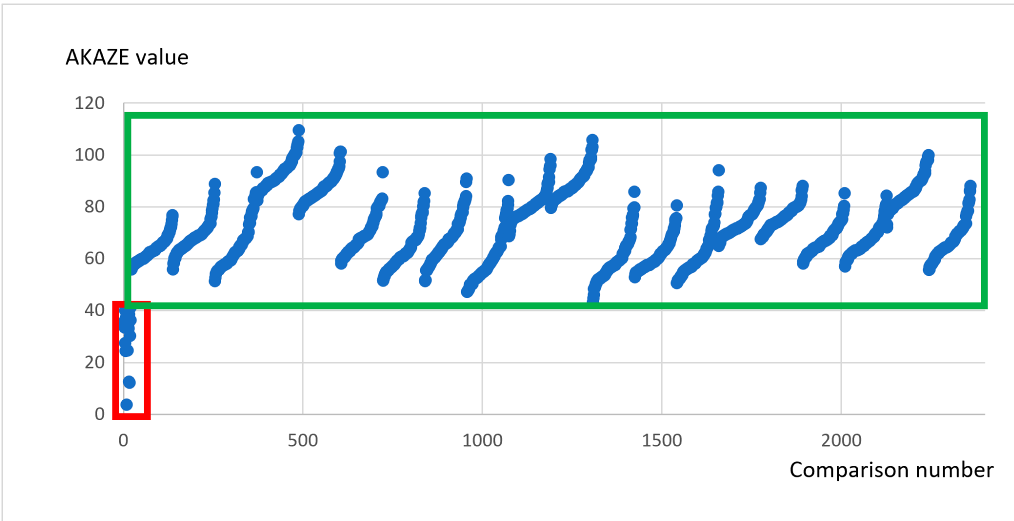

Figure 4. Scatter plot of the AKAZE values for the comparison of 2400 mandibular images.

The scatter plots are numbered for each comparison, with the results for the same model framed in red, from number 1 to 60, and the results for the different models framed in green, from number 61 to 2400.

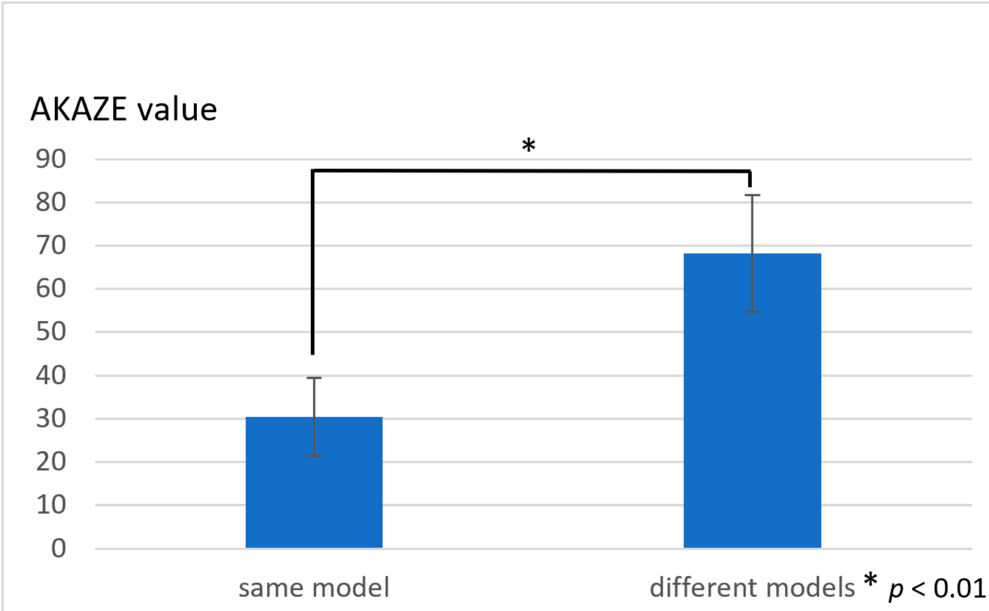

Figure 5. Comparison of the average AKAZE values of the same model with different models for the maxilla.

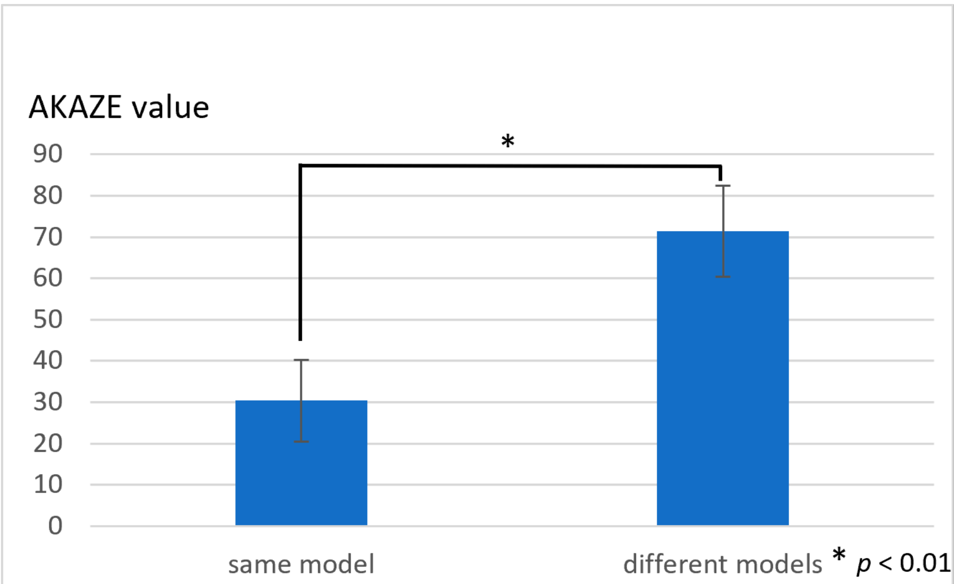

Figure 6. Comparison of the average AKAZE values of the same model with different models for the mandible.

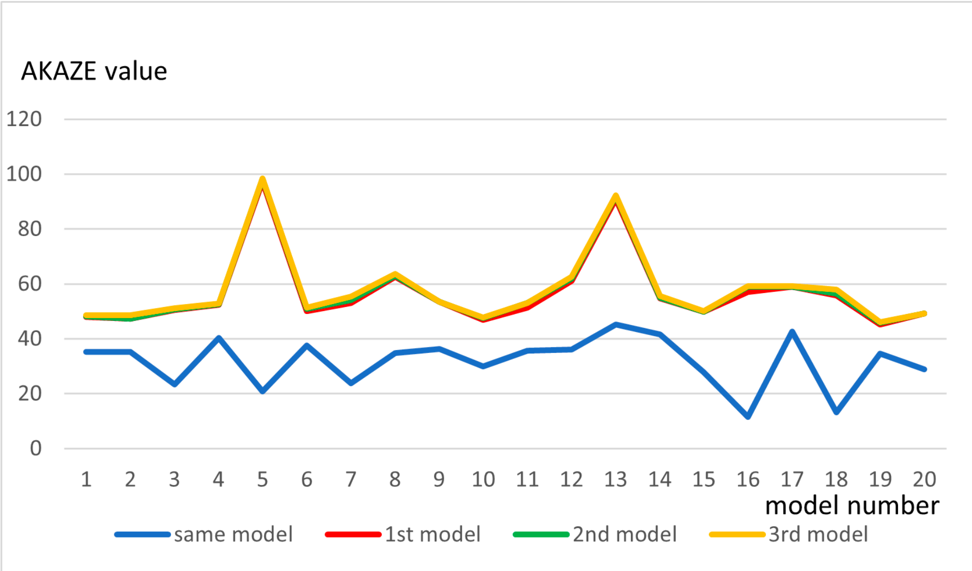

Figure 7. Comparison of the average AKAZE values of the same model with the 1st, 2nd, and 3rd models for the maxilla.

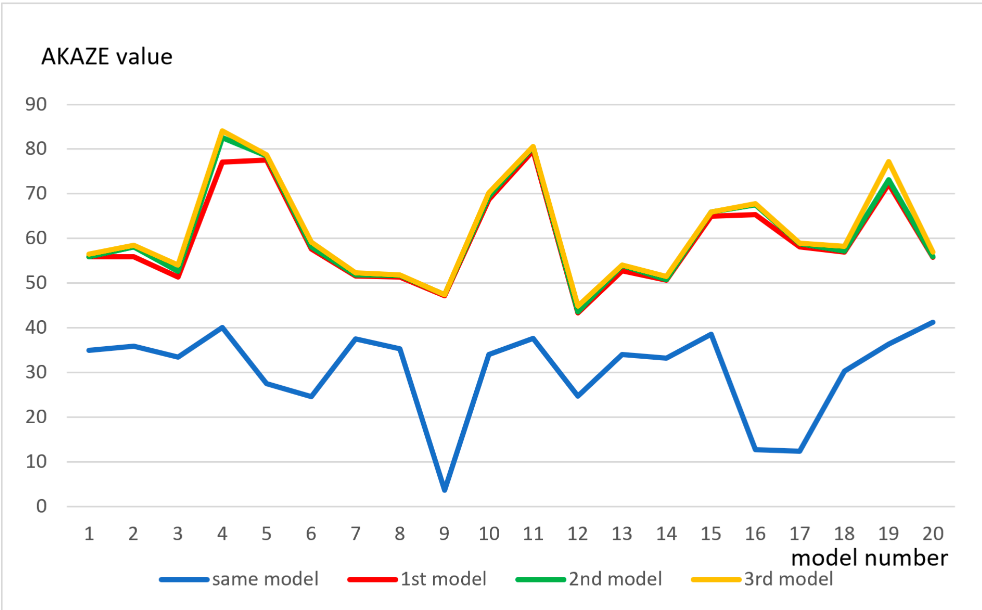

Figure 8. Comparison of the average AKAZE values of the same model with the 1st, 2nd, and 3rd models for the lower jaw.

Table 1. The mean of the same and 1st model shows a statistically significant difference for the maxilla, while the means of the 1st, 2nd, and 3rd models do not show a statistically significant difference.

	Mean	SD	p-Value
Same model	31.7	9.06	-
1st model	56.8	*13.3*	<0.01 * (difference from same model)
2nd model	57.4	*13.5*	>0.1 (difference from 1st model)
3rd model	57.8	*13.4*	>0.1 (difference from 2nd model)

* $p < 0.01$.

Table 2. The mean of the same and 1st model shows a statistically significant difference for the mandible, while the means of the 1st, 2nd, and 3rd models do not show a statistically significant difference.

	Mean	SD	*p*-Value
Same model	30.8	10.3	-
1st model	59.7	10.3	<0.01 * (difference from same model)
2nd model	60.7	11.0	>0.1 (difference from 1st model)
3rd model	61.4	11.2	>0.1 (difference from 2nd model)

* $p < 0.01$.

Table 3. Comparison of AKAZE values when creating images of 7 identical models from each surgeon (A, B, and C) which does not show statistically significant differences.

Practitioner	Mean	SD	*p*-Value
A	34.2	3.23	>0.1 (difference from B to C)
B	35.0	2.49	>0.1 (difference from A to C)
C	35.0	3.77	>0.1 (difference from B to C)

4. Discussion

In previous studies, dentition-based features have been proposed as candidates for use in personal identification [24]. In this study, statistically significant differences were obtained when comparing the same and different models in one-sided images. This suggests that an image comparison program could be used to identify the same model when comparing the dentition information of a jaw where information is limited.

In this study, cross-sectional images were created as materials for identification based on specific criteria. The time required to create a cross-sectional image (from photography to a binarized image) is about 3 to 5 min, and the time required to compare images is about 1 min when the program is already implemented because it only involves specifying the images. Therefore, it seems possible to produce documents in a short period, which suggests that this method does not require a large number of personnel in large-scale disasters, as is the case with conventional methods. It has been reported that the accuracy of identification using dental findings varies with the level of skill [32]. However, identification using materials prepared based on specific criteria and digital technology does not require personnel with specialized knowledge to perform the work and intuition or application based on empirical rules; thus, the work can be performed by persons other than those involved in the dental profession. In the future, it may be possible to perform identification mechanically using AI or other means. The possibility of the mechanization of this work is considered to be very beneficial because, in normal times, it is necessary to continuously generate a large number of comparative data in order to confirm the identity of a person.

The AKAZE method used in this study to compare binary images detects unique points that can be distinguished from others as feature points and have often been used [27–29] in photo matching as a means of image comparison. The objectivity of the AKAZE method is considered to be ensured, because the similarity is quantified in image comparisons.

Gingival mucosa is not suitable for comparison with previously recorded data, because gingivitis is said to cause inflammatory and non-inflammatory shrinkage due to age and excessive daily brushing pressure [33,34]. On the other hand, teeth are unlikely to change position or morphology in the short term without dental intervention [35]. The reference plane was chosen because it does not include the periodontal mucosa, which is more likely to change shape, and because it allows the creation of cross-sectional images that contain characteristic information, such as the positional relationship of the remaining teeth and the abundance of each tooth. By gradually lowering the cutting points perpendicular to the reference plane from the incisal edge of the anterior tooth to the occlusal ridge of the most posterior tooth, the authors determined a cross-section that met the above conditions and could produce a difference in results using the AKAZE technique.

5. Conclusions

In this paper, a new identification method using an image comparison program (AKAZE) was developed for an easier and faster comparison of dentition shapes for identification. The accuracy was verified, and good results were obtained. The results of this study suggest that it is possible to identify the same model even with partial dentition information. The comparison of binary images is reproducible because it uses the AKAZE method, which is very versatile and relatively easy to implement in software. Since identification is based on a synthesis of various information such as gender, clothing, and adornment, it is not necessary to completely identify an individual based on dental findings alone; what is required in dentistry is screening. It is suggested that this method may be useful for identity verification screening. The central incisor and the most posterior tooth were selected as the reference plane to create the 2D images. However, since partial dentition information can be identified from the results of this study, it is possible to create images using a different reference plane and compare the images, if STL data are available. There will be almost no influence on the accuracy of the comparisons if the criteria are clearly determined for creating a plane that contains a large amount of tooth information, according to the remaining condition of the teeth. When performing image analysis, such as comparisons, it is necessary to extract the measurement target by determining the threshold value based on the luminance of the image. In this study, Adobe Photoshop was used to set the threshold so that the color was divided between the teeth and other areas, and black-and-white binarization was performed.

This study only compared the results using the plaster model, and the plaster cast model contains many bubbles, which may cause noise and outliers, as well as affect accuracy. In the future, the authors plan to verify whether identification is possible by creating images using the same method from STL data obtained directly from the patient's mouth.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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