Personal Identification by Superimposition of Three-dimensional Intraoral Models

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Abstract

Victim identification following disasters is an important task for the dentist. Use of records of previous dental treatment proved effective in victim identification after the crash of Japan Airlines Flight 123 in 1985. This dental identification procedure can be problematic, however. In exceptional cases, the victim may have had very little or no prior treatment, making identification by this means impossible. The purpose of this study was to establish a new method of dental identification based on morphological comparison of the oral cavity, rather than on evidence of prior dental treatment. This new method involves superimposing 3-dimensional (3-D) models created by digital impression-taking devices, use of which is becoming increasingly widespread in present-day dental treatment. A total of 75 dental models were used to obtain 3-D models. These were then used in a total of 77 superimposition tests. The results demonstrated that the degree of similarity was 98.03–41.30%, and the degree of difference 0.17–29.69%. This indicated that differences among the dental models could be identified with 100% precision. Personal identification by superimposition of such 3-D models offers a useful tool that could compensate for the shortcomings of standard dental identification.

Key words: Dental identification — Victim identification —
Digital impression device — 3-D model

Introduction

Victim identification following disasters is an important task for the dentist. Using findings obtained during earlier dental treatment was shown to be effective in victim identification following the Japan Airlines Flight 123 crash in 1985⁷⁾, since which, this method has

become established in the field of identity confirmation.

Dental identification usually involves the dentist having to actually travel to the scene to obtain intraoral photographs and dental X-rays of the victims. After that, the next task is to inspect the inside of the victim's mouth to check for evidence of previous dental treat-

ment and record any details thereof on an odontogram. These dental charts then serve as post-mortem dental records. Local dental clinics in the disaster area are then contacted to obtain dental records of individuals known to have undergone the same treatment as the victim, so that their treatment records may then potentially serve as ante-mortem dental records^{4,6)}. The victim can then be identified by comparing the post- and ante-mortem records to find a possible match. This method offers the advantage of allowing such work to be carried out with just a pen and paper. This is especially important in situations where damage to infrastructure local to the site of a disaster would make access difficult. International guidelines on the identification of disaster victims based on dental records have been issued by The International Criminal Police Organization³⁾.

This method of dental record-based personal identification is not without problems, however. In exceptional cases, the victim may have had very little prior treatment, or none at all, making identification by this method impossible. This suggests that a new method is required, one that does not rely on records of prior dental treatment.

At present, digital impression-taking devices/intraoral scanners such as the CEREC (Dentsply Sirona) or the TRIOS 3 (3shape) are becoming increasingly popular in dental treatment settings. These devices allow impressions to be obtained by optical scanning to create a 3-dimensional (3-D) model of the teeth. These models can then be used to fabricate dental prostheses with the aid of a dental CAD/CAM system, or as a model to aid explanation of a therapeutic strategy. There are numerous digital impression-taking devices/intraoral scanners available, and their functionality is constantly improving as new products are released and older models upgraded. Our group is currently attempting to develop a new method of personal identification based on the superimposition of 3-D intraoral models. This new method differs from the conventional one in that it does not require evidence of prior dental work for a

judgement to be made. The background to this research is the spread of digital impression-taking devices, which has meant an increase in the number of patients whose intraoral 3-D model data are stored at dental clinics. In addition, 3-D gypsum models created for purposes of dental treatment are also used. Such 3-D models created during dental treatment can replace ante-mortem records, while those obtained from disaster victims can be substituted for post-mortem records. The ability to identify an individual based on agreement between these two 3-D models (ante- and post-mortem) by means of superimposition would, undoubtedly, be of enormous value in disaster scenarios in the future.

The purpose of this study was to establish a new means of dental identification based on morphological comparison of the oral cavity, rather than evidence of prior dental treatment. Dental models were used first in preparation for its application to actual oral cavities.

Materials and Methods

Dental models representing various types of dental treatment were scanned with a digital impression-taking device. The digital 3-D models thus obtained were then superimposed using quality inspection software designed for industrial products, and the degree of coincidence determined. The mandibular models used for the experiment had all been fabricated to the same standard. The models were roughly uniform, showing differences in type of dental treatment, sites of tooth deficit, and individual differences in the finished product. It was believed that if these proved to be discriminative features, more precise judgments could be made when using 3-D models obtained from actual individual oral cavities. The design of this study meant that there were no ethical issues involved.

1. Dental models

Mandibular E50-models (NISSIN) obtained

Fig. 1 Specification of 3 points used to set 3-D model for superimposition

Fig. 4 Gradation maps for calibration test/Test results with reference value of 0.02 mm, at which measurement errors found

Fig. 2 Loose superimposition of 3-D models

Fig. 5 Gradation maps for calibration test (gradation maps for test number 01)/test results with reference value of 0.06 mm, at which no measurement errors detected

Fig. 3 Precise superimposition of 3-D models using spGauge fit function

from 75 cases of dental prosthetic or restoration treatment were evaluated.

2. Digital impression-taking device

The Trophy 3DI pro (Yoshida Dental) was selected as the digital impression-taking device as it has been reported to be comparable with that of other models^{1,2,5)}. It is handy

and portable, making it suitable for use at disaster sites, and the digitally scanned information can be output as a 3-D model offline.

3. Superimposition experiment

An industrial product inspection tool, spGauge (Armonicos)[®] was used for the 3-D model superimposition experiment.

4. Three-dimensional model superimposition method

Two 3-D models were set so that the measurement error between 3 points, the lingual groove of the second molar on either side and the mesial edge of the central incisors, was at the minimum value (Fig. 1). After the models were positioned (Fig. 2), superimposition was carried out using the best fit function of the software (Fig. 3). If a measurement error was

detected when superimposing the same 3-D model on itself, this would indicate that there was no measurement error in the spGauge fit function.

5. Calibration and test settings

A digital impression was taken twice from the same dental model and the 3-D models thus obtained superimposed on each other. The value at which no large measurement errors were read was set as the test value. Figure 4 shows the results of testing, with a reference value of 0.02 mm, at which measurement errors were found. Figure 5 shows the results of testing with a reference value of 0.06 mm, at which no measurement errors were detected. The calibration test was carried out 3 times using different dental models.

In the present experiment, with the test value set at 0.06 mm, the measurement error of the superimposed 3-D models was inspected in the increasing and decreasing directions at 6 levels each (level 1: 0.00–0.06 mm; level 2: 0.06–0.12 mm; level 3: 0.12–0.18 mm; level 4: 0.18–0.24 mm; level 5: 0.24–0.30 mm; and level 6: 0.30–5.00 mm), for a total of 12 levels. The proportion of sites falling within each of the measurement error ranges was calculated.

Table 1 shows the details of the 3 trials in the calibration experiment and 74 trials in the superimposition experiment, with a single model compared against the other 74 models. Because these 3-D models were created by manual operation, the external form was not uniform. In the gingival area of the 3-D model, there was a domain where the superimposition experiment was not performed. Table 1 includes this unnecessary domain (recorded outside of experiment). Therefore, only the ratio for ranges from level 6 to level 6 was calculated and used in the subsequent analysis (Table 2).

Results

Areas corresponding to levels ± 1 and ± 2 were defined as “degree of similarity”, and areas corresponding to levels ± 5 and ± 6 were

defined as “degree of difference”. Figure 6 shows a scatter plot of degree of similarity and degree of difference. Broadly speaking, 4 groups were observed. The same 3 cases that were used for the calibration trials were set as group A; 4 cases that could be differentiated, but had numerical values somewhat close to group A, were set as group B; 67 cases that could unquestionably be recognized as different were set as group C; and 3 cases judged to differ greatly were set as group D. In group A (test numbers 01–03), the degrees of similarity were 98.03%, 96.58%, and 91.06% and degrees of difference 0.44%, 0.22%, and 0.17%, respectively. Figure 7 shows the gradation maps for one case in group A. Figure 5, as described already, shows the calibration test result of test number 01. In group B (test numbers 9, 41, 49, and 57), the degrees of similarity were 87.00%, 83.08%, 81.97%, and 81.21% and degrees of difference 3.73%, 5.67%, 4.90%, and 4.60%, respectively. Figure 8 shows the gradation maps for one case in group B. In group C, the degrees of similarity of the 67 cases were in the range of 47.10%–79.64%, and the degrees of difference were in the range of 8.31%–26.67%. Figure 9 shows the gradation map for one case in group C. In group D (test numbers 15, 52, and 72), the degrees of similarity were 45.67%, 44.17%, and 41.30% and degrees of difference 28.79%, 29.69%, and 28.36%, respectively. Figure 10 shows the gradation maps for one case in group D.

Discussion

In the results of the superimposition experiment using 3-D models obtained from dental models made to a uniform standard, there was no confusion over which models could be judged to be different. In the present experimental environment, it appeared that identification could be reliably made under conditions of a $\geq 90\%$ degree of similarity and a $< 1\%$ degree of difference. Additionally, the gradation maps displaying degrees of difference as colors showed that even with the 4

Table 1 Details of 3 trials in calibration experiment and 74 trials in superimposition experiment (%) / raw data including outside of experiment domain shown.
 Level 1 represents range from 0.00 to 0.06 mm; level 2 from 0.06 to 0.12 mm; level 3 from 0.12 to 0.18 mm; level 4 from 0.18 to 0.24 mm; level 5 from 0.24 to 0.30 mm; level 6 from 0.30 to 5.00 mm. Table shows ratio of measurement error according to these ranges in percentage.

Test. No.	Out-side of experiment	level 6	level 5	level 4	level 3	level 2	level 1	level -1	level -2	level -3	level -4	level -5	level -6
01	4.23	0.00	0.00	0.02	1.20	10.20	32.46	38.21	11.62	1.67	0.18	0.08	0.13
02	0.00	0.01	0.01	0.02	0.23	5.47	41.39	42.73	8.44	0.98	0.30	0.24	0.18
03	19.43	0.00	0.01	0.21	4.27	14.56	27.40	22.18	9.23	2.01	0.56	0.06	0.07
2	14.95	2.90	1.43	4.22	8.17	16.53	14.41	10.07	7.83	4.86	2.99	1.78	9.85
3	14.09	2.48	1.16	2.22	4.65	14.61	18.55	14.99	10.85	5.85	3.56	1.42	5.57
4	11.45	7.08	3.13	5.40	10.50	14.07	13.06	11.24	6.32	3.90	2.93	1.97	8.94
5	11.84	3.94	1.47	2.99	7.00	13.01	16.77	17.12	12.65	4.31	2.19	1.47	5.24
6	15.25	2.31	2.03	2.90	5.94	10.25	14.67	16.74	11.52	6.05	4.74	2.98	4.62
7	8.18	6.71	3.72	5.76	11.00	13.07	14.39	11.24	7.89	3.73	1.94	1.55	10.82
8	12.16	2.33	1.19	3.28	8.33	15.15	16.43	14.40	9.23	5.05	2.60	1.69	8.17
9	8.92	0.85	0.70	1.14	2.44	8.69	31.34	29.22	9.99	3.20	1.64	0.97	0.88
10	16.21	1.36	1.08	2.97	6.76	16.73	19.64	12.50	8.47	5.37	2.42	1.07	5.42
11	14.43	0.84	0.90	1.97	3.65	11.74	27.07	21.26	5.06	2.49	1.68	1.06	7.84
12	10.83	1.44	1.11	2.08	6.02	14.99	23.27	14.66	7.32	3.54	2.23	1.25	11.26
13	7.54	2.23	1.12	2.25	5.59	13.60	20.72	16.74	11.94	6.15	3.97	3.12	5.03
14	7.11	2.24	0.87	1.87	4.40	13.24	24.10	22.30	10.89	5.57	2.07	1.21	4.16
15	9.14	6.48	3.93	6.20	10.06	12.32	12.44	9.76	6.98	4.61	2.32	1.60	14.15
16	13.24	2.16	2.36	5.89	10.29	15.85	15.54	10.76	6.23	3.54	2.43	2.02	9.69
17	13.11	2.95	0.99	1.99	4.83	11.18	15.41	19.45	14.60	7.75	4.34	1.29	2.12
18	11.18	6.27	2.05	3.62	7.09	12.59	20.39	14.75	7.87	4.37	1.83	1.35	6.63
19	12.68	2.10	1.36	2.47	6.35	10.67	23.03	19.51	10.40	4.06	1.91	0.76	4.68
20	13.58	3.92	1.86	3.26	7.33	14.92	15.85	13.78	8.05	4.59	2.71	2.03	8.11
21	5.16	1.96	1.14	2.15	6.13	18.25	24.04	18.44	7.66	3.44	2.46	1.75	7.43
22	6.48	1.82	2.37	4.91	8.74	12.14	14.47	14.50	10.90	6.20	4.32	3.58	9.58
23	13.22	3.30	3.20	5.15	9.33	12.72	14.02	12.57	9.66	4.28	2.68	1.79	8.09
24	11.63	1.46	2.33	5.46	10.72	15.48	15.96	13.17	7.13	4.06	2.11	1.49	8.99
25	13.89	1.49	1.94	4.24	5.85	9.57	14.39	15.00	12.86	7.26	4.66	3.74	5.12
26	10.14	4.86	2.01	5.51	9.04	13.24	14.53	14.65	8.74	4.75	2.67	2.12	7.75
27	9.43	4.90	1.56	3.35	7.39	13.67	21.20	16.06	8.70	3.65	1.93	1.11	7.05
28	21.00	5.72	2.14	3.99	7.03	10.65	14.58	11.30	7.59	4.11	3.23	1.90	6.75
29	9.23	1.74	1.54	2.33	5.53	13.08	20.10	20.37	11.14	4.91	2.56	1.57	5.90
30	12.05	0.86	1.04	2.38	7.33	13.00	17.85	19.37	12.36	4.91	2.77	1.65	4.42
31	14.75	5.92	3.25	5.18	9.48	10.63	10.93	13.04	9.77	4.60	1.96	1.10	9.39
32	10.33	2.60	2.62	5.69	10.51	13.64	13.92	10.43	6.92	4.82	3.82	3.97	10.74
33	19.54	0.17	0.32	1.80	6.08	11.90	18.03	18.45	9.60	5.09	2.82	2.07	4.13
34	14.56	2.49	2.51	4.55	7.22	11.64	15.98	13.30	7.88	4.50	3.53	2.58	9.27
35	14.07	2.65	1.64	1.79	3.45	13.03	23.85	17.05	10.42	3.86	1.68	0.82	5.70
36	12.89	8.84	3.44	5.20	9.75	12.29	13.82	11.73	6.45	3.81	2.36	1.16	8.28

Table 1 Details of 3 trials in calibration experiment and 74 trials in superimposition experiment (%) / raw data including outside of experiment domain shown (Continued).
 Level 1 represents range from 0.00 to 0.06 mm; level 2 from 0.06 to 0.12 mm; level 3 from 0.12 to 0.18 mm; level 4 from 0.18 to 0.24 mm; level 5 from 0.24 to 0.30 mm; level 6 from 0.30 to 5.00 mm. Table shows ratio of measurement error according to these ranges in percentage.

Test. No.	Out-side of experiment	level 6	level 5	level 4	level 3	level 2	level 1	level -1	level -2	level -3	level -4	level -5	level -6
37	12.52	1.53	1.06	1.80	4.18	12.59	23.69	19.67	8.66	4.43	2.59	1.65	5.64
38	7.17	4.64	1.70	3.58	7.01	10.74	18.57	19.08	12.20	6.88	3.00	1.71	3.71
39	10.61	4.33	3.42	6.09	8.87	9.20	10.54	11.03	11.33	6.17	2.60	1.92	13.91
40	12.10	3.31	1.75	3.46	8.10	14.14	18.19	14.22	7.98	5.10	3.25	1.17	7.23
41	4.13	1.07	0.66	0.99	3.17	12.04	29.36	28.05	10.20	4.43	2.21	1.21	2.50
42	9.98	2.59	2.05	5.28	9.55	17.41	13.47	11.08	8.33	5.29	3.52	2.30	9.14
43	10.11	5.68	1.43	1.83	5.35	9.13	22.10	19.83	7.49	3.63	2.55	1.44	9.40
44	11.87	6.02	3.16	5.67	9.62	10.92	11.37	11.17	8.78	4.51	2.61	2.11	12.21
45	11.93	1.55	1.22	2.29	6.53	14.24	19.43	19.35	10.73	4.16	2.43	1.17	4.97
46	13.95	4.18	1.64	3.65	6.35	9.43	14.00	15.22	10.01	5.96	5.23	4.18	6.20
47	13.56	0.95	2.30	5.45	9.49	11.77	13.11	14.41	10.52	5.50	2.14	1.20	9.63
48	14.88	4.22	2.03	4.42	9.36	13.00	15.28	11.56	9.26	4.07	2.17	1.56	8.17
49	12.17	2.02	0.66	1.67	3.75	7.62	20.90	30.19	13.28	4.51	1.62	0.82	0.80
50	7.72	3.38	1.74	3.94	10.13	14.94	15.48	12.14	8.18	6.25	3.97	2.40	9.73
51	13.00	0.79	1.22	1.57	4.57	15.01	24.00	18.18	7.81	3.40	1.61	1.17	7.68
52	16.50	8.68	3.53	5.53	8.83	10.48	9.26	9.64	7.50	4.72	2.76	2.16	10.42
53	12.37	1.57	0.80	2.10	6.54	16.91	22.44	16.56	7.88	3.34	2.50	1.54	5.44
54	11.35	1.25	1.45	2.71	6.08	11.56	22.15	20.39	10.22	4.33	1.76	1.16	5.58
55	6.32	5.36	3.47	6.81	10.34	14.90	15.14	11.82	7.92	4.24	2.22	1.10	10.37
56	7.12	3.05	2.32	5.21	13.28	21.17	14.88	8.94	5.72	5.63	2.79	1.47	8.41
57	12.91	1.39	0.50	1.43	4.47	12.01	25.42	24.00	9.30	4.58	1.87	0.92	1.20
58	8.24	4.58	2.19	3.53	7.04	13.27	21.08	18.68	7.53	3.82	2.39	1.05	6.60
59	8.90	1.94	1.38	2.71	5.69	14.10	20.47	19.33	11.99	6.14	1.75	0.92	4.66
60	12.12	3.45	2.48	5.20	9.60	12.31	17.44	11.80	7.34	5.65	3.49	1.76	7.35
61	10.40	2.09	1.74	3.00	6.39	12.81	20.70	15.99	9.01	5.55	3.62	2.59	6.10
62	14.91	0.89	1.22	2.14	7.47	13.43	19.31	15.45	10.77	4.73	2.08	1.65	5.94
63	7.87	5.33	3.41	5.66	11.85	16.32	14.55	9.70	6.17	3.00	1.90	1.35	12.89
64	15.66	1.56	3.00	4.43	7.29	12.43	14.89	10.85	7.99	4.94	3.79	2.65	10.51
65	9.54	2.91	1.26	1.87	3.78	8.94	23.02	25.50	13.55	3.68	1.77	1.16	3.03
66	15.59	2.40	2.07	3.48	7.13	13.62	18.81	14.29	7.87	4.54	1.93	1.25	7.03
67	9.79	3.02	1.65	3.40	6.08	13.57	23.60	21.72	8.04	2.53	0.83	0.37	5.39
68	21.79	2.70	1.27	4.31	8.13	12.03	18.71	12.36	6.75	4.08	1.96	0.85	5.03
69	9.97	3.61	1.87	4.52	8.05	13.67	19.23	17.81	9.28	4.20	2.17	1.15	4.47
70	11.65	1.80	1.59	2.24	5.70	13.90	19.31	19.61	11.98	3.88	2.11	1.68	4.55
71	9.77	8.27	3.02	4.53	9.63	11.70	12.18	12.52	8.65	4.03	3.49	2.14	10.06
72	8.53	4.60	5.56	9.27	11.54	12.63	12.67	7.91	4.57	3.37	3.56	3.62	12.16
73	8.31	3.70	1.36	1.69	2.90	6.96	28.41	26.57	11.08	4.61	1.55	1.12	1.74
74	7.85	4.03	3.33	5.24	7.75	11.25	16.25	13.62	8.03	5.13	3.92	2.73	10.87
75	9.61	2.92	2.80	3.51	6.37	12.62	19.04	13.98	8.41	5.60	4.00	2.71	8.44

Table 2 Ratio in range of level -6 from level 6 (%) / ratio only for ranges from level 6 to level -6 calculated. Outside of experiment domain shown in Table 1 excluded. Resemblance degree range includes level ± 1 and ± 2 . Difference in degree range includes level ± 5 and ± 6 .

Test No.	level 6	level 5	level 4	level 3	level 2	level 1	level -1	level -2	level -3	level -4	level -5	level -6	Resemblance degree	Difference degree
01	0.00	0.00	0.02	1.25	10.65	33.89	39.90	12.13	1.74	0.19	0.08	0.14	96.58	0.22
02	0.01	0.01	0.02	0.23	5.47	41.39	42.73	8.44	0.98	0.30	0.24	0.18	98.03	0.44
03	0.00	0.01	0.26	5.30	18.07	34.01	27.53	11.46	2.49	0.70	0.07	0.09	91.06	0.17
2	3.41	1.68	4.96	9.61	19.44	16.94	11.84	9.21	5.71	3.52	2.09	11.58	57.43	18.77
3	2.89	1.35	2.58	5.41	17.01	21.59	17.45	12.63	6.81	4.14	1.65	6.48	68.68	12.37
4	8.00	3.53	6.10	11.86	15.89	14.75	12.69	7.14	4.40	3.31	2.22	10.10	50.47	23.85
5	4.47	1.67	3.39	7.94	14.76	19.02	19.42	14.35	4.89	2.48	1.67	5.94	67.55	13.75
6	2.73	2.40	3.42	7.01	12.09	17.31	19.75	13.59	7.14	5.59	3.52	5.45	62.75	14.09
7	7.31	4.05	6.27	11.98	14.23	15.67	12.24	8.59	4.06	2.11	1.69	11.78	50.74	24.83
8	2.65	1.35	3.73	9.48	17.25	18.70	16.39	10.51	5.75	2.96	1.92	9.30	62.85	15.23
9	0.93	0.77	1.25	2.68	9.54	34.41	32.08	10.97	3.51	1.80	1.06	0.97	87.00	3.73
10	1.62	1.29	3.54	8.07	19.97	23.44	14.92	10.11	6.41	2.89	1.28	6.47	68.43	10.66
11	0.98	1.05	2.30	4.27	13.72	31.63	24.85	5.91	2.91	1.96	1.24	9.16	76.11	12.43
12	1.61	1.24	2.33	6.75	16.81	26.10	16.44	8.21	3.97	2.50	1.40	12.63	67.56	16.89
13	2.41	1.21	2.43	6.05	14.71	22.41	18.11	12.91	6.65	4.29	3.37	5.44	68.14	12.44
14	2.41	0.94	2.01	4.74	14.25	25.94	24.01	11.72	6.00	2.23	1.30	4.48	75.93	9.13
15	7.13	4.33	6.82	11.07	13.56	13.69	10.74	7.68	5.07	2.55	1.76	15.57	45.67	28.79
16	2.49	2.72	6.79	11.86	18.27	17.91	12.40	7.18	4.08	2.80	2.33	11.17	55.76	18.71
17	3.40	1.14	2.29	5.56	12.87	17.74	22.38	16.80	8.92	4.99	1.48	2.44	69.79	8.46
18	7.06	2.31	4.08	7.98	14.17	22.96	16.61	8.86	4.92	2.06	1.52	7.46	62.60	18.35
19	2.40	1.56	2.83	7.27	12.22	26.37	22.34	11.91	4.65	2.19	0.87	5.36	72.85	10.19
20	4.54	2.15	3.77	8.48	17.26	18.34	15.95	9.31	5.31	3.14	2.35	9.38	60.87	18.42
21	2.07	1.20	2.27	6.46	19.24	25.35	19.44	8.08	3.63	2.59	1.85	7.83	72.11	12.95
22	1.95	2.53	5.25	9.35	12.98	15.47	15.50	11.66	6.63	4.62	3.83	10.24	55.61	18.55
23	3.80	3.69	5.93	10.75	14.66	16.16	14.48	11.13	4.93	3.09	2.06	9.32	56.43	18.88
24	1.65	2.64	6.18	12.13	17.52	18.06	14.90	8.07	4.59	2.39	1.69	10.17	58.55	16.15
25	1.73	2.25	4.92	6.79	11.11	16.71	17.42	14.93	8.43	5.41	4.34	5.95	60.18	14.27
26	5.41	2.24	6.13	10.06	14.73	16.17	16.30	9.73	5.29	2.97	2.36	8.62	56.93	18.63
27	5.41	1.72	3.70	8.16	15.09	23.41	17.73	9.61	4.03	2.13	1.23	7.78	65.84	16.14
28	7.24	2.71	5.05	8.90	13.48	18.46	14.30	9.61	5.20	4.09	2.41	8.54	55.85	20.90
29	1.92	1.70	2.57	6.09	14.41	22.14	22.44	12.27	5.41	2.82	1.73	6.50	71.27	11.84
30	0.98	1.18	2.71	8.33	14.78	20.30	22.02	14.05	5.58	3.15	1.88	5.03	71.15	9.06
31	6.94	3.81	6.08	11.12	12.47	12.82	15.30	11.46	5.40	2.30	1.29	11.01	52.05	23.06
32	2.90	2.92	6.35	11.72	15.21	15.52	11.63	7.72	5.38	4.26	4.43	11.98	50.08	22.23
33	0.21	0.40	2.24	7.56	14.79	22.41	22.93	11.93	6.33	3.50	2.57	5.13	72.06	8.31
34	2.91	2.94	5.33	8.45	13.62	18.70	15.57	9.22	5.27	4.13	3.02	10.85	57.12	19.72
35	3.08	1.91	2.08	4.01	15.16	27.76	19.84	12.13	4.49	1.96	0.95	6.63	74.89	12.58
36	10.15	3.95	5.97	11.19	14.11	15.86	13.47	7.40	4.37	2.71	1.33	9.51	50.84	24.93
37	1.75	1.21	2.06	4.78	14.39	27.08	22.49	9.90	5.06	2.96	1.89	6.45	73.86	11.29
38	5.00	1.83	3.86	7.55	11.57	20.00	20.55	13.14	7.41	3.23	1.84	4.00	65.27	12.67

Table 2 Ratio in range of level -6 from level 6 (%) / ratio only for ranges from level 6 to level -6 calculated. Outside of experiment domain shown in Table 1 excluded. Resemblance degree range includes level ± 1 and ± 2 . Difference in degree range includes level ± 5 and ± 6 (Continued).

Test No.	level 6	level 5	level 4	level 3	level 2	level 1	level -1	level -2	level -3	level -4	level -5	level -6	Resemblance degree	Difference degree
39	4.84	3.83	6.81	9.92	10.29	11.79	12.34	12.67	6.90	2.91	2.15	15.56	47.10	26.38
40	3.77	1.99	3.94	9.22	16.09	20.69	16.18	9.08	5.80	3.70	1.33	8.23	62.04	15.31
41	1.12	0.69	1.03	3.31	12.56	30.62	29.26	10.64	4.62	2.31	1.26	2.61	83.08	5.67
42	2.88	2.28	5.87	10.61	19.34	14.96	12.31	9.25	5.88	3.91	2.55	10.15	55.87	17.86
43	6.32	1.59	2.04	5.95	10.16	24.59	22.06	8.33	4.04	2.84	1.60	10.46	65.14	19.97
44	6.83	3.59	6.43	10.92	12.39	12.90	12.67	9.96	5.12	2.96	2.39	13.85	47.93	26.67
45	1.76	1.39	2.60	7.41	16.17	22.06	21.97	12.18	4.72	2.76	1.33	5.64	72.39	10.12
46	4.86	1.91	4.24	7.38	10.96	16.27	17.69	11.63	6.93	6.08	4.86	7.21	56.55	18.83
47	1.10	2.66	6.30	10.98	13.62	15.17	16.67	12.17	6.36	2.48	1.39	11.14	57.62	16.29
48	4.96	2.38	5.19	11.00	15.27	17.95	13.58	10.88	4.78	2.55	1.83	9.60	57.68	18.77
49	2.30	0.75	1.90	4.27	8.68	23.80	34.37	15.12	5.13	1.84	0.93	0.91	81.97	4.90
50	3.66	1.89	4.27	10.98	16.19	16.78	13.16	8.86	6.77	4.30	2.60	10.54	54.98	18.69
51	0.91	1.40	1.80	5.25	17.25	27.59	20.90	8.98	3.91	1.85	1.34	8.83	74.71	12.48
52	10.40	4.23	6.62	10.57	12.55	11.09	11.54	8.98	5.65	3.31	2.59	12.48	44.17	29.69
53	1.79	0.91	2.40	7.46	19.30	25.61	18.90	8.99	3.81	2.85	1.76	6.21	72.79	10.67
54	1.41	1.64	3.06	6.86	13.04	24.99	23.00	11.53	4.88	1.99	1.31	6.29	72.55	10.65
55	5.72	3.70	7.27	11.04	15.91	16.16	12.62	8.45	4.53	2.37	1.17	11.07	53.14	21.67
56	3.28	2.50	5.61	14.30	22.79	16.02	9.63	6.16	6.06	3.00	1.58	9.05	54.60	16.42
57	1.60	0.57	1.64	5.13	13.79	29.19	27.56	10.68	5.26	2.15	1.06	1.38	81.21	4.60
58	4.99	2.39	3.85	7.67	14.46	22.97	20.36	8.21	4.16	2.60	1.14	7.19	66.00	15.71
59	2.13	1.51	2.97	6.25	15.48	22.47	21.22	13.16	6.74	1.92	1.01	5.12	72.33	9.77
60	3.93	2.82	5.92	10.92	14.01	19.85	13.43	8.35	6.43	3.97	2.00	8.36	55.63	17.11
61	2.33	1.94	3.35	7.13	14.30	23.10	17.85	10.06	6.19	4.04	2.89	6.81	65.30	13.97
62	1.05	1.43	2.51	8.78	15.78	22.69	18.16	12.66	5.56	2.44	1.94	6.98	69.29	11.40
63	5.79	3.70	6.14	12.86	17.71	15.79	10.53	6.70	3.26	2.06	1.47	13.99	50.73	24.94
64	1.85	3.56	5.25	8.64	14.74	17.65	12.86	9.47	5.86	4.49	3.14	12.46	54.73	21.01
65	3.22	1.39	2.07	4.18	9.88	25.45	28.19	14.98	4.07	1.96	1.28	3.35	78.50	9.24
66	2.84	2.45	4.12	8.45	16.14	22.28	16.93	9.32	5.38	2.29	1.48	8.33	64.67	15.10
67	3.35	1.83	3.77	6.74	15.04	26.16	24.08	8.91	2.80	0.92	0.41	5.97	74.19	11.56
68	3.45	1.62	5.51	10.40	15.38	23.92	15.80	8.63	5.22	2.51	1.09	6.43	63.74	12.59
69	4.01	2.08	5.02	8.94	15.18	21.36	19.78	10.31	4.67	2.41	1.28	4.97	66.63	12.33
70	2.04	1.80	2.54	6.45	15.73	21.86	22.20	13.56	4.39	2.39	1.90	5.15	73.34	10.89
71	9.17	3.35	5.02	10.67	12.97	13.50	13.88	9.59	4.47	3.87	2.37	11.15	49.93	26.03
72	5.03	6.08	10.13	12.62	13.81	13.85	8.65	5.00	3.68	3.89	3.96	13.29	41.30	28.36
73	4.04	1.48	1.84	3.16	7.59	30.98	28.98	12.08	5.03	1.69	1.22	1.90	79.64	8.64
74	4.37	3.61	5.69	8.41	12.21	17.63	14.78	8.71	5.57	4.25	2.96	11.80	53.34	22.75
75	3.23	3.10	3.88	7.05	13.96	21.06	15.47	9.30	6.20	4.43	3.00	9.34	59.80	18.66

Fig. 6 Scatter plot of degree of similarity and degree of difference

Fig. 9 Gradation maps for test number 17

Fig. 7 Gradation maps for test number 02

Fig. 10 Gradation maps for test number 52

Fig. 8 Gradation maps for test number 57

cases in group B, the group that most closely resembled group A, multiple sites could be found corresponding to level 5 or 6. These are the results of tests using dental models of fundamentally similar structure as samples, and the results showed that differences between models could be distinguished without any mistakes. Taking into account individual differences when actual oral measure-

ments are made, it is valid to suppose that identification at a greater level of accuracy than the present test is possible. Calibration is important when carrying out a 3-D model superimposition experiment. If 3-D models from 2 impressions of the same individual taken with no interval between them are superimposed and the measurement error is anything other than 0, this is likely to be due to a technical problem with the digital impression-taking device. It is necessary to compensate for fluctuations originating from the digital impression-taking device by superimposing two 3-D models that have undeniably come from the same individual and selecting test values for which no large measurement error is detected. Even in the same person, the shape of the incisal margin or cusps can change for reasons such as tooth attrition or fracture, and tooth morphology and tooth alignment thus change over time. The changes may be considerable if restoration or prosthetic treatment has been carried out. It

is therefore insufficient to simply superimpose ante- and post-mortem 3-D models and make an evaluation by looking at the extent to which they match. The person examining the models needs to make use of their expertise as a dentist, bearing in mind areas that are susceptible to change when considering contradictions. For this reason, the present method offers the significant advantage that it can display visually where and to what extent there are differences from the gradation map, rather than simply evaluating differences in intraoral structures on the basis of numerical values.

It is reasonable to suggest that this method of superimposing 3-D models could also be applied to the observation of treatment results in clinical practice, such as changes in the gums due to treatment of periodontal disease or changes in tooth alignment due to orthodontic treatment. If treatment results come to be evaluated in a clinical setting by such superimposition of 3-D models in the future, the details of chronological oral changes in the individual will be clarified. Furthermore, if this method becomes established, it will become possible to identify individuals based on tooth alignment or morphology, rather than by characteristic findings of previous dental treatment. The current drawback of this method is that it presupposes that 3-D models of many people are available. Therefore, much work must be done to encourage the creation of such 3-D models in large numbers of patients. For example, we would recommend the fabrication of 3-D models as a tool for explaining treatment options in a clinical setting; and would also suggest that they should be made as a standard part of dental examinations carried out at schools. More research needs to be done on the efficacy of such 3-D models for personal identification, however, as part of which, this group intends to compare the utility of such models with that of photographs as the next step. Agreement in the morphology of multiple

teeth provides strong evidence that it is the same individual, so it is likely that identification will be possible in the future from a superimposition test of just one tooth.

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