Three-dimensional evaluation of the dental arch in cleft lip and palate after prosthetic treatment

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Abstract

Purpose: This study aimed to evaluate the stability of the surface of the maxillary teeth and mucosa in cleft lip and palate (CLP) patients with a maxilla defect or tissue deficiency according to the duration of observation and cleft type.

Methods: Pairs of maxillary casts taken from 18 patients at different time points after prosthodontic treatment were investigated in this study. All 36 casts were scanned with an intraoral scanner, and the acquired images were saved in standard tessellation language (STL) files. The two STL files for each patient were then superimposed using three-dimensional (3D) evaluation software, with 3D deviations shown as a color map. Areas with a 3D deviation within ±0.100 mm were defined as stable. The influence of cleft type and duration of observation on the ratio of stable areas to the entire maxillary surface comprising the teeth and mucosa was investigated using multiple regression analysis. Statistical significance was set at p <0.05.

Results: Multiple regression analysis showed that the duration of observation was significantly associated with the stable area ratio (B = -23.463, P<.001), whereas cleft type was not (β = 0.13, P = 0.301).

Conclusion: The maxillary teeth and mucosa of CLP patients changed over time, with stable areas showing a negative correlation with the observation period. However, the stability of the dental arch was not significantly affected by the cleft type. 3D analysis of the casts of CLP patients allowed for measurements and to accurately assess relapse of the maxillary arch after prosthetic treatment.

Keywords: Three-dimensional; cleft lip and palate; relapse; long time observation; prosthetic treatment.

1. Introduction

Cleft lip and palate (CLP) is the most prevalent congenital malformations. The incidence of CLP in Japan at 1 in 495-695 live births is higher than the global incidence of 1 in 1008 live births[1–3]. Habitabilitve surgeries begin after birth and are generally performed up to the age of 12 months. Multidisciplinary interventions include appropriately timed orthodontic and prosthodontic treatments[4]. Palatal expansion and bone grafting are often followed by orthodontic treatment[5,6], but in some cases relapse occurs after prosthodontic treatment involving the maxillary arch[7].

Nicholson and Plint reported a long-term study on the stability of the maxillary arch after palatal expansion[8]. They measured study casts using Vernier calipers and found that transverse measurements of the maxillary arch showed a high degree of relapse of the maxillary dentition. Moreover, the presence of bone grafting after expansion did not reduce the degree of relapse. Al-Gunaid et al.[9] analyzed relapse of the maxillary teeth in patients with unilateral CLP and found significant relapse in the interval between removal of a fixed edgewise appliance and post-orthodontic treatment. In both studies, arch width was measured as the distance between each maxillary canine and the first molar. No changes were detected in the angle of the tooth axis or mucosal surface of the maxilla. With advances in technology, the three-dimensional (3D) surface data of casts can now show not only the width between two points but also differences in the entire maxillary surface (i.e., of the maxillary teeth and mucosa) between the two datasets.

Study casts are typically used in prosthodontic treatment for diagnosis and treatment planning. They also provide invaluable information for evaluating treatment outcomes[10]. Diagnostic measurements are traditionally obtained from dental plaster casts[11,12], but considerable developments have been made recently in digital impression systems. In previous studies[13,14], digital technology has been used to obtain highly accurate impressions of the com-
plete dental arch. 3D analysis of the dental arch is now available for measurements performed on casts[15,16] and offers some advantages over traditional dental plaster casts. Elbashit et al. reported the feasibility and accuracy of using an intraoral scanner to digitize the plaster casts of patients with maxillofacial defects[17]. A more convenient approach would be to analyze casts using 3D data.

Prosthodontic treatment in CLP patients with a maxilla defect or tissue deficiency is usually performed after orthodontic treatment for recovery of function, such as mastication and speech. The treatment also aims to achieve good esthetic outcomes and to prevent teeth and alveolar arch relapse. Therefore, prosthodontists must consider maxilla–mandible relations after orthodontic treatment. One way to prevent relapse of the maxillary arch, even after palatal expansion, and to ensure recovery after anterior maxillary defect repair is using either fixed or removable partial dentures. Therefore, it is important to observe the changes that occur after prosthetic treatment in patients with CLP.

The aim of this study was to compare the stability of the dental arch between bilateral and unilateral cleft types in CLP patients with a fixed partial denture or removable partial denture. A secondary aim was to clarify the correlation between the stable areas observed in the casts and the duration of observation. These are important questions in the clinic as the details about tooth movement in CLP patients are not known, although it should be explained to patients when a treatment plan is made.

2. Materials and Methods

2.1. Participants

Pairs of dental maxillary casts taken from 18 patients with CLP (9 males and 9 females) at different time periods after prosthodontic treatment were investigated in this study: one taken just after prosthesis delivery and the other taken several years later. All patients underwent prothetic treatment during the retaining period. Sex, classification of cleft type, type of prosthesis, prosthetic teeth, duration of observation, expansion, second bone grafting, and palatoplasty methods are shown in Figure 1. Among the 18 patients, 8 had bilateral CLP and 10 had unilateral CLP.

2.2. Data acquisition

The pair of casts were prepared with a dental stone (New Plas-tone II white; GC Corp, Tokyo, Japan) by taking impressions with irreversible hydrocolloid (Fig. 2) (Algiate Z, normal set white; Dentsply Sirona, Tokyo, Japan). They were then scanned with an intraoral scanner (Trophy 3DI; Yoshida Dental Mfg. Co., Ltd., Tokyo, Japan). Scanning was initiated from the occlusal surface of the second molar, followed by the buccal and palatal surfaces of the teeth, and then the probe was moved to the other side of the maxilla. When all the teeth had been scanned, the probe was moved to the palatal part in a circular motion. Standard tesselation language (STL) files were saved for 3D deviation analysis.

2.3. Three-dimensional evaluation

The two STL files from the same patient, one taken from each cast, were geometrically superimposed on each other using a best-fit algorithm, and 3D deviations were calculated using 3D evaluation software (SpGauge 2019, Armonicos, Shizuoka, Japan). The previous 3D cast data were defined as the reference, and the latest was defined as the target. To avoid the effect of impression errors, such as air bubbles, the search range of the best-fit algorithm was set at five out of ten. The sampling and offset were turned off. The 3D deviations were plotted as a color map with an error scale of 1.0 mm. The specific values of each color were calculated, and areas with 3D deviation within ±0.100 mm have been displayed in green and defined as stable (Fig. 3). The red color of the color bar indicates that the target data were above the reference data. The blue color indicates that the target data were below the reference data. The ratio of stable areas to the entire maxillary surface comprising the teeth and mucosa was calculated for each pair of scans. The width of each cast was measured between the left and right side molars using 3D measurements thrice, and the mean was obtained. The differential value of the width of the latest casts minus the width of the previous casts was used for further analysis.

2.4. Ethical considerations

This study was conducted in accordance with the principles of the Declaration of Helsinki. This study was approved by the Ethics Committee of Tokyo Medical and Dental University (approval number: D2016-085). Information about the study was made available to the public, including patients at our clinic, on our institution’s homepage (http://www.tmd.ac.jp/med/be-c/medrepos/pdfd/D2016-085.pdf), and the requirement for written informed consent was waived by the ethics committee of our institution.

2.5. Statistical analyses

The Shapiro–Wilk test was used to confirm the normality of the continuous data. Base 10 logarithmic transformation was applied to the data for the duration of observation. Student’s t-test was used to assess the difference in the stable area ratio between the cleft types. The differential values of molar width between different cleft types were tested by Student’s t-test. The relationship between the stable area ratio and the duration of observation was confirmed using the graph and linear regression analysis. The influence of the two cleft types (bilateral and unilateral) and duration of observation on the stable area ratio were investigated using multiple regression analysis. The variance inflation factor (VIF) was used to check for multicollinearity. A VIF value less than 5 indicated no collinearity in the model. All computations were performed using SPSS statistical software (ver. 21.0; IBM Corp., Japan, Inc., Japan). Statistical significance was set at P<0.05.

3. Results

All superimposed casts were successfully color-coded for 3D deviation, and all records of the point cloud ratio were obtained without error. The superimposed mapping in each case showed that no differences between the two casts exceeded ±1.0 mm over the entire maxillary surface. In the superimposed images, the mucosal surfaces of the cleft defect appear mostly in light blue or blue, indicating a change in the negative direction compared with the reference data. Molars appear light yellow, indicating a change in the positive direction on the lingual surfaces of the teeth and buccal cusps. The normality of the stable area ratio was not statistically significant (P=0.307). The normality of the duration of observation was rejected (P = 0.022), but the log-transformed data were close to a normal distribution (P = 0.068). The difference in the stable area ratio between the unilateral and bilateral cleft types was 10.3%, but the difference...
was not significant (Fig. 4, $P = 0.143$, Student's t-test). The mean of the changed width of eight bilateral CLP patients was 0.276 mm, while the mean of the changed width of 10 unilateral CLP patients was 0.464 mm. The mean absolute value of the width changes in 18 patients was 0.825 mm. There was no significant difference between cleft types in width changes of the molars ($P = 0.162$, Student's t-test).

The stable area ratio decreased as the duration of the observation increased (Fig. 5A). The model shows nonlinearity, with a rapid decline in the early stages before leveling off to become almost constant. When the duration of observation was logarithmically transformed, the data could be fitted with a linear regression model (Fig. 5B, $R^2 = 0.763$, $P < 0.01$).

Table 1 shows the results of multiple regression analysis for the stable area ratio. The adjusted $R^2$ of the model was 0.765, indicating that the duration of observation and cleft type could explain 76.5% of the stable area ratio in this model. Multiple regression analyses revealed that the duration of observation was significantly associated with the stable area ratio ($B = -23.463$, $\beta = -0.846$, $P < 0.001$). The Cleft type had no significant effect on the stable area ratio ($B = 3.778$, $\beta = 0.131$, $P = 0.301$). The VIF for the two independent variables is 1.079.

### Table 1: Characteristics of 18 patients with cleft lip and palate.

| Patient No. | Sex | Cleft type       | Prosthesis | Duration of observation (years) | Prosthetic teeth | Second bone grafting | Palatoplasty |
|-------------|-----|-----------------|------------|---------------------------------|-----------------|---------------------|-------------|
| 1           | Male| Unilateral (left) | FPD        | 1                               | 1, 2, 3        | +                   | /           |
| 2           | Male| Bilateral       | FPD        | 1                               | 2, 1, 2, 3      | +                   | /           |
| 3           | Female| Unilateral (left) | FPD        | 1                               | 1, 2, 3        | +                   | push back  |
| 4           | Male| Bilateral       | FPD        | 2                               | 2, 1, 2, 3, 4   | -                   | /           |
| 5           | Male| Unilateral (left) | FPD        | 2                               | 1, 2, 3        | -                   | /           |
| 6           | Male| Unilateral (right) | FPD        | 2                               | 1, 2, 4        | +                   | /           |
| 7           | Female| Unilateral (left) | FPD        | 3                               | 1, 2, 3, 4, 6   | -                   | /           |
| 8           | Female| Unilateral (right) | FPD        | 6                               | 3, 2, 1        | +                   | push back  |
| 9           | Female| Bilateral       | FPD        | 7                               | 1, 2, 3, 4     | +                   | push back  |
| 10          | Female| Unilateral (left) | FPD        | 10                              | 1, 2, 3, 4     | +                   | /           |
| 11          | Male| Unilateral (left) | FPD        | 12                              | 4, 2, 1, 2, 3, 4| +                   | /           |
| 12          | Female| Unilateral (right) | FPD        | 15                              | 4, 2, 1, 1     | +                   | /           |
| 13          | Male| Bilateral       | FPD        | 15                              | 4, 2, 1, 2, 3, 4| +                   | push back  |
| 14          | Female| Unilateral (left) | FPD        | 16                              | 3, 1, 2, 4     | /                   | /           |
| 15          | Female| Bilateral       | RPD        | 17                              | 652, 12        | +                   | /           |
| 16          | Female| Bilateral       | RPD        | 24                              | 4                | +                   | /           |
| 17          | Male| Unilateral (left) | RPD        | 26                              | 4                | -                   | /           |
| 18          | Male| Bilateral       | RPD        | 36                              | 5                | +                   | /           |

**Fig. 1.** Characteristics of 18 patients with cleft lip and palate.

This study demonstrates the utility of 3D scanning and 3D analysis for comparing two casts taken from CLP patients at different times during prosthodontic treatment in order to observe changes in their intraoral condition following treatment. This method has several advantages. First, when comparing two superimposed casts, the degree and direction of changes in each color-coded area are clearly evident. Second, 3D analysis makes it possible to present the changes in numerical form and thus obtain more information from the casts in addition to the physical distance measured between two points using Vernier calipers. The feasibility and accuracy of this method have been reported previously[17]. In addition, the scanning time for each cast was approximately 6 minutes to obtain the 3D data in this study. The 3D analysis results are also clear and allow dentists to easily understand the changes occurring in the dentition and oral structures.

**Discussion**

The 3D scanning and 3D analysis method described in this study provides a useful tool for dental professionals to observe changes in the maxillofacial region of patients with cleft lip and palate. The method allows for the accurate measurement of changes in the maxillary and mandibular regions, which is essential for planning and monitoring treatment outcomes. The results from this study can aid in the development of personalized treatment plans for patients with cleft lip and palate, ensuring that the required changes are addressed effectively. Additionally, the 3D imaging data can be used to provide patients with a better understanding of their treatment progress and expected outcomes, which can positively impact their psychological well-being and compliance with treatment plans.
tissue surfaces over long-term observation. Knowing these morphological changes can help dentists to plan future treatment and/or adjust the prosthesis as needed.

In this study, the color-coded images for each pair of casts showed some tooth mobility and soft tissue changes during the observation period. The cleft defect showed a tendency to move inward. This can be attributed to bone changes in the maxillary defect due to instability of the bone around the defect due to surgery or missing teeth. Changes in the distance between the bilateral molars represent changes in the palate resulting from relapse, because it is known that maxillary bone tends to move in a palatal direction after orthodontic treatment, including palatal expansion, in CLP patients[18]. This finding is in good agreement with other reports of maxillary changes in CLP patients after prosthetic treatment[4,19].

The occlusal surfaces of some teeth exhibited some changes. Dental fillings for treatment are considered as one of the factors that affect the shape of the teeth as well as their wear. A previous study reported mean changes in upper canine width and molar width of -0.21 mm and -0.18 mm, respectively, during 7 years of observation in young adults[20]. More width changes were observed in this study compared with the data of normal adults. In the present study, changes in the entire maxillary surface between the two casts did not exceed 1.0 mm whereas palatal expansion is usually performed on a larger scale. Comparing the dynamics of orthodontic treatment, only slight changes occurred in the patients in this study even after more than 10 years. Despite this small scale change, it is important for prosthodontists to detect such changes for future rehabilitation planning for patients with CLP.

A negative correlation was found between the stable area ratio in the superimposed casts, and the log-transformed duration of observation suggests that patients tended to show more relapse over time. There are few studies on the stability of the dental arch in patients with complete unilateral CLP at the end of orthodontic rehabilitative treatment with prostheses[19]. Meanwhile, in the literature, different durations of follow-up showed relapse of the maxillary arch after prosthetic treatment in patients with CLP. In the present study, stable areas gradually decreased after delivery of the prosthesis. Even after 1 year, the teeth and palatal tissue also showed some changes. This suggests that CLP patients require more attention from dentists for possible occlusal problems due to a lack of dental arch stability.

In this study, the duration of observation was an important factor affecting stable areas. Interestingly, the unilateral and bilateral cleft types did not show statistical significance in the multiple regression analysis. However, this could not be investigated in detail because of the small number of patients. The bilateral cleft type may involve more tissue change because of the instability of the premaxilla, but further research is needed in this regard.

This study used a digital approach to evaluate changes in the cast surface of patients with CLP undergoing different types of prosthetic treatment. All changes in their oral condition could be observed on color-coded images generated using 3D software, which revealed more changes in the maxillary arch during long-term follow-up than during short-term follow-up. As different types of prosthetic treatments may influence maxillary arch stability in CLP patients, further...
5. Studies are needed to evaluate this stability in relation to the different types of rehabilitative treatment that can be provided.

This study has some limitations. A relatively small number of patients were studied, and there was no control group without a cleft for comparison. Because some clinical information was not available, such as secondary bone grafts and maxillary expansion, only cleft type and duration of observation were selected as independent variables. In addition, some patients in this study visited the clinic for regular examinations, but other patients stopped attending regular follow-up visits after delivery of the prosthesis. If the latter patients received regular oral examinations, this may have influenced the outcomes of the dental arch changes. Another limitation is that, for the 3D data, the number of changes in each group of casts was not calculated by the software. Further studies with larger numbers of patients, including those with and without maxillary malformation and wearing various types of prostheses, are warranted. Calculating the changes in dental arch measurements using 3D software should also be investigated in future studies.

5. Conclusion

3D Analysis of the casts of CLP patients revealed changes in dentition and enabled the measurements of the mucosal surface and assessment of relapse of the maxillary arch after prosthetic treatment. The maxilla of patients with CLP showed changes over time. However, the stability of the dental arch was not significantly affected by the cleft type. Casts taken during long-term observation showed fewer stable areas compared with casts taken during the short-term observation, indicating a strong negative correlation between the stable areas and the duration of observation. Further studies are required to explain these changes in detail.

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Conflicts of interest

The scanner used in this study was provided free of charge by Yoshida Dental Japan.

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