New method to evaluate sequelae of static facial asymmetry in patients with facial palsy using three-dimensional scanning analysis

Takahiro Azuma[a,1], Teruhiko Fuchigami[a,b,1], Katsuhiko Nakamura[a], Eiji Kondo[a], Go Sato[a], Yoshiaki Kitamura[a], Noriaki Takeda[a,*]

[a]Department of Otolaryngology, Tokushima University Graduate School of Biomedical Sciences, Tokushima, Japan

[b]Department of Otolaryngology, Tokyo Metropolitan Tama Medical Center, Tokyo, Japan

[1]These two authors contributed equally to this work.

Correspondence to: Noriaki Takeda, MD, PhD

Department of Otolaryngology, Tokushima University Graduate School of Biomedical Sciences

3-18-15 Kuramoto, Tokushima, 770-8503, Japan.

Phone: +81-88-633-7169, Fax: +81-88-633-7170.

E-mail: takeda@tokushima-u.ac.jp

Abstract

Objective: During the process of neural recovery after facial palsy, distressing sequelae of static and dynamic facial asymmetry develop in patients with facial palsy. A pronounced nasolabial fold is mainly responsible for static facial asymmetry, which leads to many psychological and social problems in patients. Objective and qualitative assessment of facial appearance is critical to determine the severity of sequelae of static facial asymmetry and whether an intervention is effective for treatment. In the present study, an attempt was made to develop three-dimensional analysis method to assess sequelae of static facial asymmetry after facial palsy.

Methods: Eight patients with sequelae of facial asymmetry after facial palsy and ten healthy volunteers were enrolled. We used three-dimensional scanning analysis with a portable non-contact optical scanner to obtain three-dimensional surface data from a patient's face and produced a three-dimensional digital model of the face. We then identified a reference plane fixed with the patient's face, and measured the depth of the nasolabial fold of the face.

Results: The nasolabial fold of the face on the affected side was significantly deeper than that on the unaffected side in patients with sequelae of static facial asymmetry after facial palsy. However, the depth of the facial nasolabial fold on the right side was not different from that on the left side in healthy volunteers. Affected-unaffected side differences in the depth of the nasolabial fold in patients with sequelae of static facial asymmetry after facial palsy were significantly larger than left-right differences in the depth of the nasolabial fold in healthy volunteers. Two weeks after treatment with botulinum toxin injection to the affected zygomaticus muscles, affected-unaffected side differences in the depth of the nasolabial fold were significantly decreased in the patients.

In the patients who received botulinum toxin, the absolute values of affected-unaffected side differences in the depth of the nasolabial fold measured using the three-dimensional scanning analysis showed a significant positive correlation with the visual analog scale scores of facial asymmetry marked by independent doctors.

Conclusion: The present findings suggest that affected-unaffected side differences in the depth of the nasolabial fold of the measured using three-dimensional scanning analysis can be used as an index of sequelae of static facial asymmetry. It is also suggested that the index can evaluate whether interventions are effective for the treatment of sequelae.

Keywords: facial asymmetry, sequelae after facial palsy, nasolabial fold of face, three-dimensional scanning analysis, botulinum toxin

1. Introduction

Patients with facial palsy suffer from distressing sequelae of static and dynamic facial asymmetry during the process of neural recovery after facial palsy [1,2]. The sequelae of static facial asymmetry after facial palsy are due to hypertonic contractures of the affected facial muscles. The sequelae of dynamic facial asymmetry are characterized by synchronous and involuntary facial movements, such as oral-ocular and ocular-oral synkinesis, which are caused by aberrant regeneration of facial nerve fibers to non-native facial muscles [3].

The sequelae of static facial asymmetry after facial palsy is characterized by a narrow eye, a deeper nasolabial fold with a built-up cheek, and a laterally pulled angle of the mouth on the affected side at rest in patients with facial palsy. Because facial muscles have few internal sensory receptors of muscle spindles without tendons attached to bones at both ends unlike other skeletal muscles [4], they are at high risk for prolonged muscle contractures. After facial palsy, uncontrolled hyperkinetic and repetitive ocular-oral synkinesis due to aberrant regeneration of the facial nerve induces hypertonic contractures of the affected zygomaticus and its related muscles, leading to static facial asymmetry [5].

Although the sequelae of static facial asymmetry are apparently manifested by both patients and doctors, objective and qualitative assessment of facial appearance is critical to determine the severity of sequelae of static facial asymmetry and whether an intervention is effective for treatment. Various facial nerve grading scales have been developed previously. The Sunnybrook facial grading scale is the current standard for assessment of facial function [6]. However, the Sunnybrook facial grading scale is based on the subjective evaluation of resting facial asymmetry, degree of voluntary facial movements, and degree of facial synkinesis associated with specific voluntary movements [7,8]. Technology-based objective methods to evaluate facial function are expected to be developed for clinical applications. Recently, we developed a computer-assisted analysis to evaluate oral-ocular synkinesis using percent asymmetry of eye opening width as an index, and used the index to show the therapeutic efficacy of botulinum toxin and biofeedback rehabilitation on oral-ocular synkinesis in patients with facial palsy [9,10].

In the present study, an attempt was made to develop a new objective method to evaluate the sequelae of static facial asymmetry after facial palsy. Because the pronounced nasolabial fold on the affected side is mainly responsible for facial asymmetry at rest, we first measured the depth of the nasolabial fold of the face. For this purpose, we used three-dimensional scanning analysis with a portable scanner and obtained three-dimensional surface data from the patient's face without touching it. We then produced a three-dimensional digital model of the face, identified a reference plane fixed with the patient's face, and measured the depth of the nasolabial fold. To prove that affected-unaffected side differences in the depth of the nasolabial fold can be used as an objective index of static facial asymmetry, we first examined whether the depth of the nasolabial fold in patients with sequelae of static facial asymmetry is increased compared with healthy volunteers. We then used the index and examined the effects of botulinum toxin injection to the affected zygomaticus muscles on the pronounced nasolabial fold of the patients. Finally, we examined the correlation between the index and the visual analog scale scores of facial asymmetry marked by independent doctors.

2. Materials and Methods

2.1. Participants

In the present study, eight patients with sequelae of facial asymmetry after facial palsy (Bell's palsy: five, Ramsay Hunt syndrome: one, and posttraumatic palsy: two patients; one male and seven females: mean age: 61.0 years old, ranges: 33-74 years old) were enrolled. They all showed a narrow eye, a deeper nasolabial fold with a built-up cheek, and a laterally pulled angle of the mouth on the affected side at rest (Fig. 1). A total of ten healthy volunteers (five males and five females; mean age: 42.7 years old, ranges: 28-67 years old) were also enrolled. This study was approved by the Committee for Medical Ethics of Tokushima University Hospital (#2694), and a written informed consent was obtained from each participant prior to the study.

2.2. Three-dimensional scanning analysis

Three-dimensional scanning analysis with a portable three-dimensional scanner (261 × 158 × 64 mm and 850 g) (Artec Eva, Artec, Luxembourg) was used (Fig. 2A). The structured light triangulation technique of the analysis obtained three-dimensional surface data from the subjects without touching them by illuminating them with a pattern of light projected by the scanner. According to the manufacturer's information, the three-dimensional accuracy of the analysis is 0.1 mm. The participants' heads were fixed on a head holder, and three small markers (a, b, c) were placed at the crossing of the vertical and horizontal bars of the head holder to make up a reference plane (Fig. 2B). Their superciliary arch and mental protuberance were held on the horizontal bars of the head holder. The perpendicular bisector of both inner canthi was aligned with the midway point between markers a and b, and their Reid's baseline and interorbital line were kept horizontal using a level tube. We scanned each participant's face with the head holder together using the handheld three-dimensional scanner that was manually moved around them in an arc at 180 degrees twice for about 10 sec (Fig. 2A). During scanning lightly, the participants were instructed to close their eyes and to avoid blinking.

After the geometry of the participant's face with three markers was captured, a three-dimensional digital model of the face with three markers was produced by a PC (W656SJ, Mouse Computer, Japan) equipped with Artec Studio 9 software (Artec, Luxembourg) according to the manufacturer's instructions (Fig. 3A).

2.3. Measurement of the depth of the nasolabial fold of the face

The three-dimensional digital model of the face with three markers was displayed on a PC and analyzed using 3D Reshaper software (HEXAGON, Stockholm, Sweden). We first made a plane passing through three makers as a reference plane (Fig. 3A). Next, we made a plane perpendicular to the reference plane passing the perpendicular bisector of the reference points of both inner canthi (plane A). Line A is the frontal view of the intersection between the surface of the face and plane A. We made planes parallel to plane A, passing the midway point between the reference points of the inner and outer canthi (planes B and B'). Lines B and B' are the frontal view of the intersections between the surface of the face and planes B and B', respectively. Accordingly, lines B and B' are parallel to line A.

To measure the depth of the nasolabial fold along line B on the left side, a lateral view image of the three-dimensional digital model of the face is shown in Fig. 3B. We identified curve B that is the lateral view of the intersection between the surface of the face and plane B. We then measured the distance between the highest point of the cheek on curve B and the reference plane (C in Fig. 3C), and the distance between the lowest point of the nasolabial fold on curve B and the reference plane (D in Fig. 3C). Finally, we measured the depth of the nasolabial fold along line B on the left side as the difference between C and D (* in Fig. 3C). In the same way, we measured the depth of the nasolabial fold along line B' on the right side

Affected-unaffected side differences in the depth of the nasolabial fold were calculated according to the following formula. Affected-unaffected side differences in the depth of the nasolabial fold = the depth of the nasolabial fold on the affected side - the depth of the nasolabial fold on the unaffected side.

2.4. Visual analog scale and Botulinum A toxin injection

Pre- and post-treatment images of the face in eight patients with facial palsy who received botulinum toxin were randomly presented and two doctors who were blinded to the patients' clinical data and independent from the examining doctors marked scores of each facial asymmetry using the visual analog scale from ten: the worst asymmetry to zero: perfect symmetry.

Without prior local anesthesia, botulinum A toxin (Botox, GlaxoSmithKline, UK; 5 units/0.1ml) was injected into the affected zygomaticus muscles using a tuberculin syringe with a 27-gauge needle. The mean dose of 3.4 units (ranges: 2.5-5.0 units) was administered to treat the sequelae of facial asymmetry in patients with facial palsy.

2.6. Statistical analysis

Mann-Whitney U and Wilcoxon signed-rank tests were performed for statistical difference analysis, and Spearman's correlation test was performed for correlation analysis using Statcel version 4 (OMS Publishing Inc., Saitama, Japan). $p<0.05$ was considered statistically significant.

3. Results

The median depth of the nasolabial fold of the face on the affected and unaffected side of patients with sequelae of static facial asymmetry after facial palsy was 7.35 mm (ranges: 5.58-12.2 mm) and 1.57 mm (ranges: 0.40-8.16 mm), respectively. Thus, the nasolabial fold on the affected side was significantly deeper than that on the unaffected side of the patients (Mann–Whitney U = 56.0, n1 =8, n2 = 8, Z = 2.52, $p<0.05$) (Fig. 4A). In contrast, the median depth of the nasolabial fold on the right and left side of healthy volunteers was 2.79 mm (ranges: 0.29-6.26 mm) and 1.61 mm (ranges: 0.15-7.97 mm), respectively. Thus, the depth of the nasolabial fold on the right side was not different from that on the left side of the controls (Fig. 4B).

The median affected-unaffected side differences in the depth of the nasolabial fold were 5.17 mm (ranges: 2.34-9.55 mm) in the patients with sequelae of static facial asymmetry after facial palsy. While the median left-right side differences in the depth in the nasolabial fold were 0.68 mm (ranges: 0.02-1.71 mm) in healthy volunteers. Thus, affected-unaffected side differences in the depth of the nasolabial fold in the patients were significantly larger than left-right differences in the depth of the nasolabial fold in the controls (Mann–Whitney U = 80.0, n1 =8, n2 = 10, Z = 3.55, $p<0.01$) (Fig. 5).

Two weeks after treatment with botulinum toxin injection to the affected zygomaticus muscles, affected-unaffected side differences in the depth of the nasolabial fold were significantly decreased to be 1.46 mm (ranges: -1.65-7.03 mm) in patients with sequelae of static facial asymmetry after facial palsy (Wilcoxon U=12.0, n=8, Z=2.10, $p<0.05$) (Fig. 6). In the patients who received botulinum toxin injection, the absolute values of affected-unaffected side differences in the depth of the nasolabial fold measured using the three-dimensional scanning analysis showed significant positive correlations with the visual analog scale scores of facial asymmetry marked by two independent doctors A and B who were blinded to the patients' clinical data in Fig. 7A and B, respectively ($p<0.05$ for each doctor).

4. Discussion

Progressive sequelae of static and dynamic facial asymmetry during the recovery process after facial palsy causes many psychological and social problems, including low self-esteem and poor quality of life [5,11,12]. The sequelae of static facial asymmetry after facial palsy includes a narrow eye, a deeper nasolabial fold with a built-up cheek, and a laterally pulled angle of the mouth at rest due to hypertonic contractures of the affected facial muscles. Generally, the responses of muscle spindles to changes in muscle length play an important role in regulating the contraction of muscles. However, because facial muscles have few muscle spindles unlike other skeletal muscles [4], they are at high risk for prolonged muscle contractures.

The pronounced nasolabial fold on the affected side is the most frequent and is mainly responsible for facial asymmetry at rest. The sequelae of facial asymmetry have primarily been evaluated by visual assessment. The depth of the nasolabial fold cannot be measured using lateral view picture of the face, because it is hidden by the cheek from a lateral view. In the present study, we used three-dimensional scanning analysis and could measure the depth of the nasolabial fold of the three-dimensional digital model of the face objectively and quantitatively to evaluate the degree of static facial asymmetry sequelae. Because the shape of the nasolabial fold is complex and may change during the recovery process after facial palsy, we determined bisector lines B or B' between the inner and outer canthi (Fig. 3) on the affected or unaffected (right or left) sides, and measured the depth of the nasolabial fold along lines B or B' on the affected or unaffected (right or left) sides.

In patients with sequelae of static facial asymmetry after facial palsy, the nasolabial fold on the affected side was deeper than that on the unaffected side. However, there were no left-right differences in the depth of the nasolabial fold in healthy volunteers. Moreover, affected-unaffected side differences in the depth of the nasolabial fold were increased in the patients compared with left-right difference in healthy volunteers. These findings suggest that affected-unaffected side differences in the depth of the nasolabial fold measured with three-dimensional scanning analysis can be used as an index of the sequelae of static facial asymmetry.

Botulinum toxin treatment improves facial hyperkinesis in patients with facial palsy [13]. Botulinum toxin blocks the presynaptic release of acetylcholine in the neuromuscular junction, resulting in temporary paralysis of hypertonic muscles, because it is preferentially taken up by hypertonic muscles [14]. In the present study, injection of botulinum toxin to the affected zygomaticus muscles reduced affected-unaffected side difference in the depth of the nasolabial fold, suggesting an improvement in sequelae of static facial asymmetry in patients with facial palsy. Botulinum toxin treatment has been reported to improve the sequelae of facial asymmetry at rest, which was evaluated using the Sunnybrook facial grading scale in patients with facial palsy [5,11,12]. Therefore, the present objective evaluation of the efficacy of botulinum toxin on static facial symmetry is consistent with previous subjective assessments. Moreover, in the present study, visual assessment of facial asymmetry using the visual analog scale was correlated with affected-unaffected side differences in the depth of the facial nasolabial fold measured using three-dimensional scanning analysis in patients with sequelae of static facial asymmetry who received botulinum toxin injection. All these findings suggest that affected-unaffected side differences in the depth of the facial nasolabial fold measured with three-dimensional scanning analysis are an objective index of static facial asymmetry sequelae in patients with facial palsy and that the index can assess the degree of static facial asymmetry and whether interventions are effective for treatment.

A systematic review and meta-analysis showed that three-dimensional face-scanning systems using portable face-scan devices are reliable for obtaining facial models [15]. However, it reported that involuntary facial movements, as well as landmark and facial region identification errors, are major factors that affect the accuracy of face-scanning systems. In the present study, participants' heads were fixed on a head holder to avoid involuntary facial movements, because motion artifacts were the main source of error in the measurement of portable face-scanning system [16]. To eliminate landmark identification errors, we first determined a reference plane passing through three makers of the head holder. We did not use anatomical facial regions or facial markers, such as small balls or ink spots, on the face to make a reference plane, because they may move relatively during the recovery process after facial palsy. We then used the inner and outer canthi as the reference points because of a minimum discrepancy on the paralytic face.

Three-dimensional face-scanning systems includes laser scanners, stereophotogrammetry, and structured light systems [17], which showed similar levels of accuracy in generating a three-dimensional digital model of the face in systematic review and meta-analysis [15]. Because recent advances in structured light technology provide a practical method with a structured lighting three-dimensional scanner, CCD camera, and computer software of a complex algorithm to reconstruct a three-dimensional digital model of the face, we used Artec Eva, a three-dimensional structured light scanning system (Artec, Luxembourg). It was reported that scanning with Artec Eva resulted in more accurate three-dimensional face models than FaceScan3D, which was used for various medical purposes [18,19]. Apart from a high cost, three-dimensional scanning analysis may be useful to evaluate static facial asymmetry after facial palsy and facial deformity caused by congenital abnormalities, neurological disorders and traumatic injuries.

The present study had several limitations. The number of participants was limited. Further studies are needed to build baseline data of enough number of healthy volunteers to determine the normal ranges of the depth of the nasolabial fold. Then, it will be determined which is better, the absolute values of the depth of the nasolabial fold or affected-unaffected side differences in the depth of the nasolabial fold as an objective index of the sequelae of static facial asymmetry in patients with facial palsy. These further studies will lead to evaluate the static sequelae of facial asymmetry using the depth of the nasolabial fold as an index and the dynamic sequelae of synkinesis using percent asymmetry of eye opening width as an index separately. Moreover, the point at the intersection of the nasolabial fold with lines B or B' may be slightly changed after Botulinum toxin injection, although the displacement of the intersection point is much smaller than identification errors of anatomical regions or markers on the nasolabial fold. Intra-examiner and inter-examiner variations and reproducibility, as well as the longitudinal application of the index measured using three-dimensional scanning analysis of the face have to be examined. Finally, the possibility that the height of the corner of the mouth is better than the depth of the nasolabial fold as an objective index of static facial asymmetry has to be examine in further studies.

5. Conclusion

In the present study, we used three-dimensional scanning analysis with a portable non-contact optical scanner to obtain three-dimensional surface data from the participant's face and produced a three-dimensional digital model of face. We identified a reference plane fixed with the face and measured the depth of the nasolabial fold in patients with sequelae of static facial asymmetry after facial palsy. The present findings suggest that affected-unaffected side differences in the depth of the nasolabial fold of the face measured using three-dimensional scanning analysis can be used as an index of the sequelae of static facial asymmetry. It is also suggested that the index can evaluate whether interventions are effective for the treatment of sequelae. Whether three-dimensional scanning analysis of the face can evaluate other facial deformities caused by congenital abnormalities, neurological disorders and traumatic injuries remains to be examined.

Disclosure statement

The authors declare that they have no conflict of interest.

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Figure Legends

Fig. 1

Sequelae of static facial asymmetry with a narrow eye, a pronounced nasolabial fold with a built-up cheek, and a laterally pulled angle of the mouth on the affected side at rest in a representative patient with left facial palsy.

Fig. 2

A: Three-dimensional scanning analysis with a portable three-dimensional scanner. An examiner held a portable three-dimensional scanner on both hands and scanned the participant's face with the head holder together using the handheld three-dimensional scanner that was manually moved around them in an arc at 180 degrees twice. B: The head of the participant was fixed on a head holder. Three small markers (a, b, c) were placed at the crossing of the vertical and horizontal bars of the head holder to make up a reference plane.

Fig. 3

A. Frontal view of a representative three-dimensional digital model of the face with three markers (a, b, c) on the head holder of a healthy volunteer. A reference plane passing through three makers was made. Line A: frontal view of intersection between the surface of the face and plane A that is perpendicular to the reference plane passing the perpendicular bisector of the reference points of both inner canthi. Lines B and B': the frontal lines of intersections between the surface of the face and planes B and B' that are parallel to plane A passing the midway point between the reference points of the inner and outer canthi.

B. Lateral view of the representative three-dimensional digital model of the face to measure the depth of the nasolabial fold on the left side. Curve B: lateral view of intersection between the surface of the face and plane B. Reference plane line: lateral view of the reference plane.

C. Lateral view of curve B and the reference plane to measure the depth of the nasolabial fold on the left side. C: distance between the highest point of the cheek on curve B and the reference plane. D: distance between the lowest point of the nasolabial fold on curve B and the reference plane. *: The depth of the nasolabial fold of the face (C-D) on the left side. Reference plane line: lateral view of the reference plane.

Fig. 4

A: The depth of the facial nasolabial fold (* in Fig. 3) in patients with sequelae of facial asymmetry after facial palsy (A). Black bar: affected side, white bar: unaffected side. n=8, *$p<0.05$. B: The depth of the facial nasolabial fold (* in Fig. 3) in healthy volunteers (B). Black bar: right side, white bar: left side. n=10.

Fig. 5

Comparison between affected-unaffected side differences in the depth of the facial nasolabial fold of patients with sequelae of static facial asymmetry after facial palsy (black bar, n=8) and left-right differences in the depth of the facial nasolabial fold of healthy volunteers (white bar, n=10). *$p<0.01$.

Fig. 6

Effects of botulinum toxin injection to the affected zygomaticus muscles on affected-unaffected side differences in the depth of the facial nasolabial fold in patients with sequelae of static facial asymmetry after facial palsy. n=8, *p<0.05.

Fig. 7

Correlation between the absolute values of affected-unaffected side differences in the depth of the nasolabial fold measured using three-dimensional scanning analysis and the visual analog scale scores of facial asymmetry of pre- (eight open circles) and post- (eight closed circles) treatment facial images marked by two independent doctors (A and B) separately in patients with sequelae of static facial asymmetry, who received botulinum toxin treatment. Doctor A: $r=0.61$, $p<0.05$ in Fig. 7A and doctor B: $r=0.58$, $p<0.05$ in Fig. 7B. Open circles: before treatment, closed circles: after treatment, n=8.

Fig. 1

Fig. 2

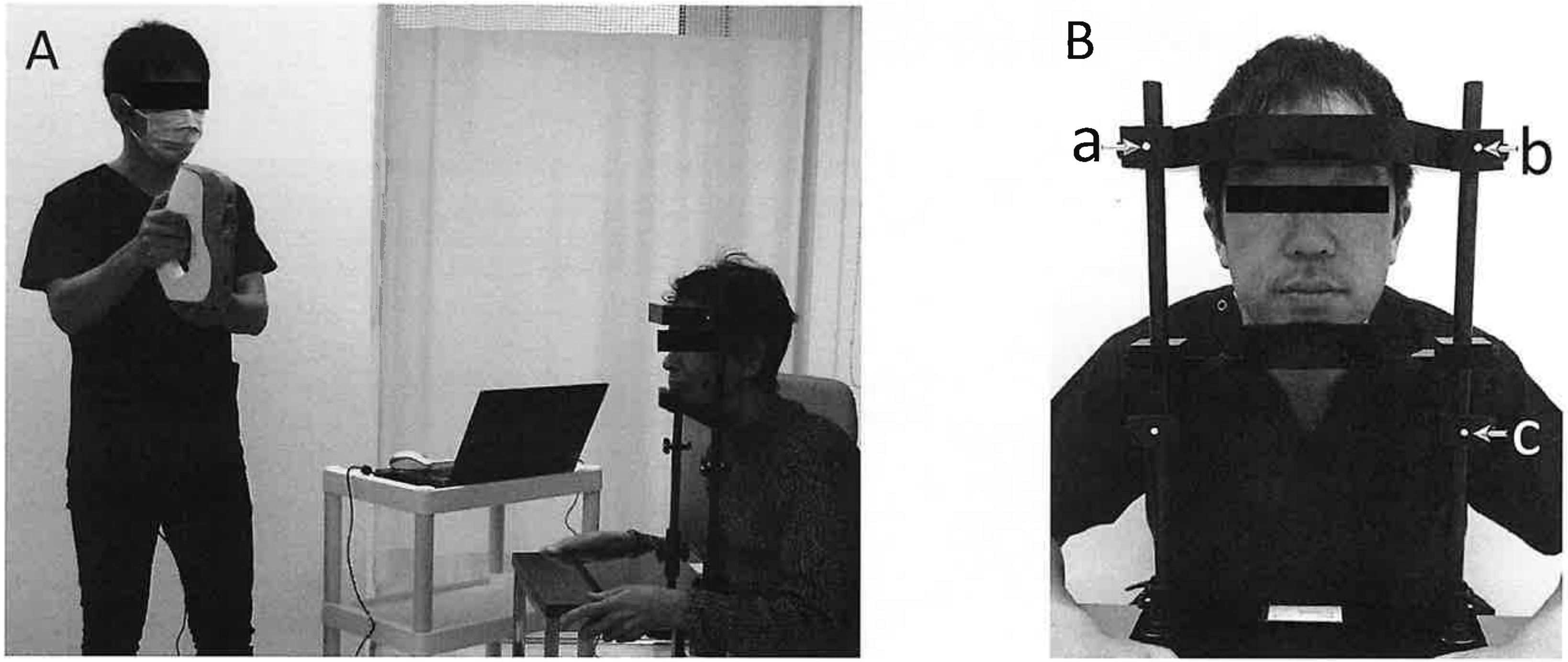


Fig. 3

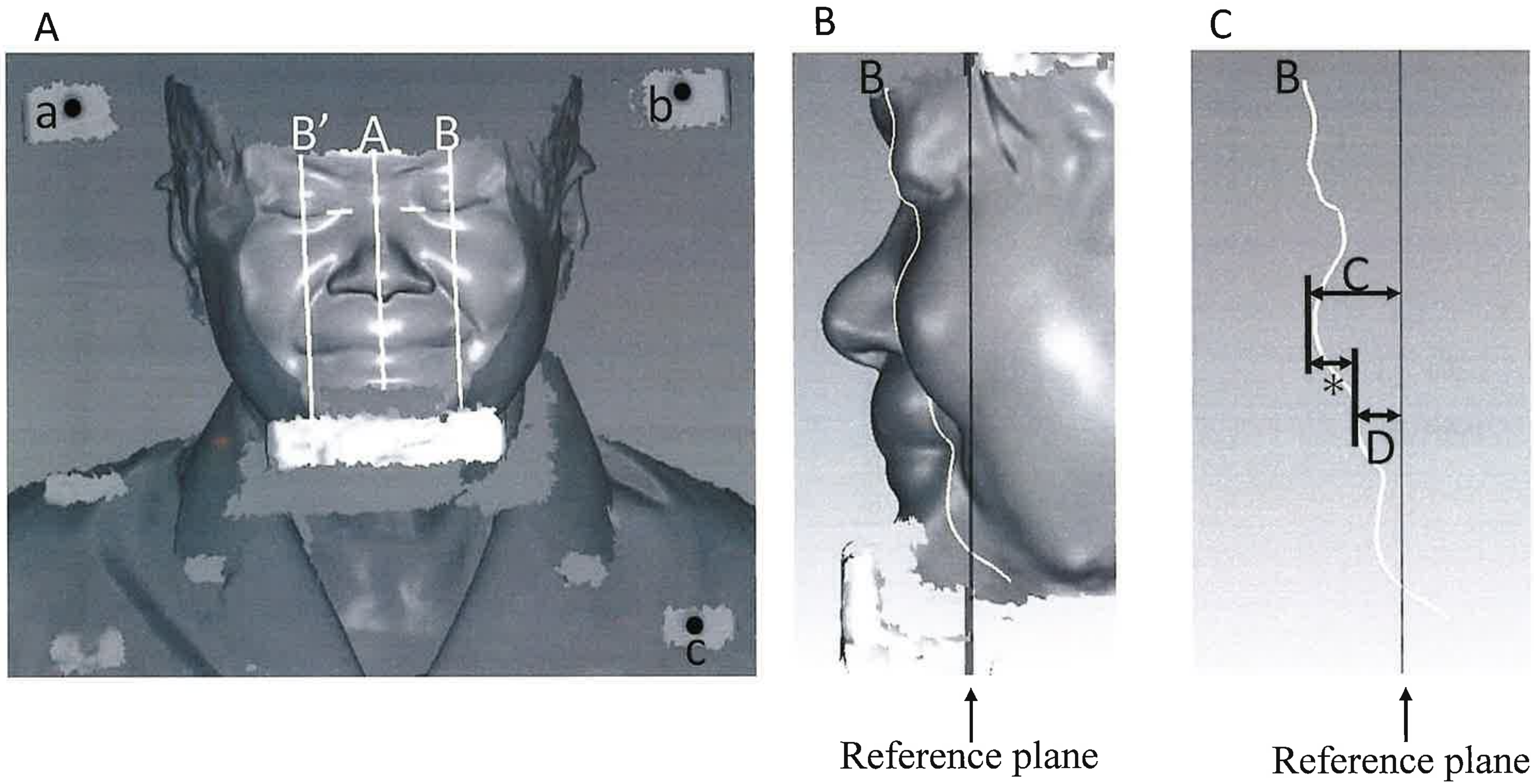
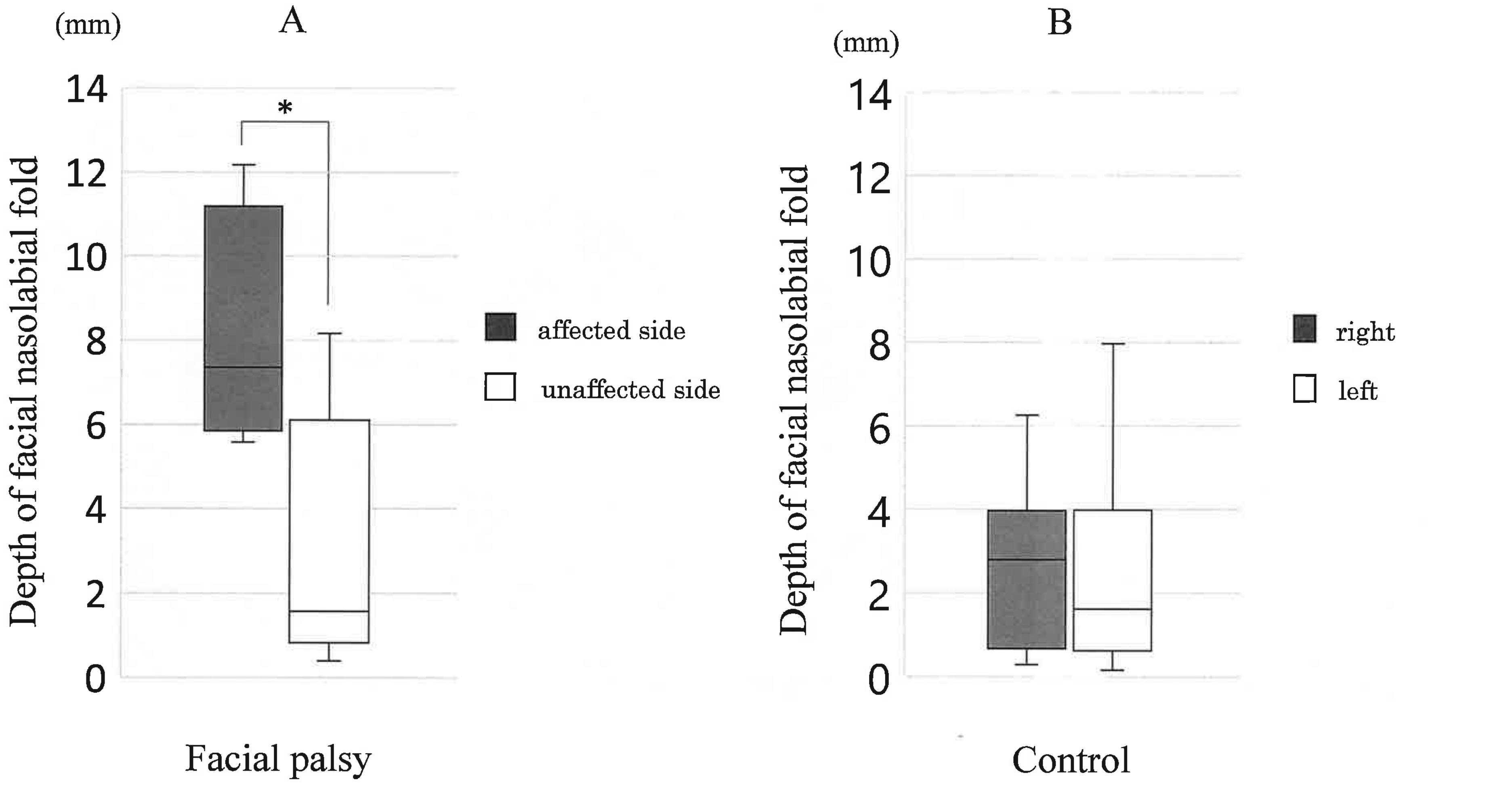


Fig. 4


A
(mm)
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10
8
6
4
2
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Depth of facial nasolabial fold
*
affected side
unaffected side
Facial palsy
B
(mm)
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12
10
8
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4
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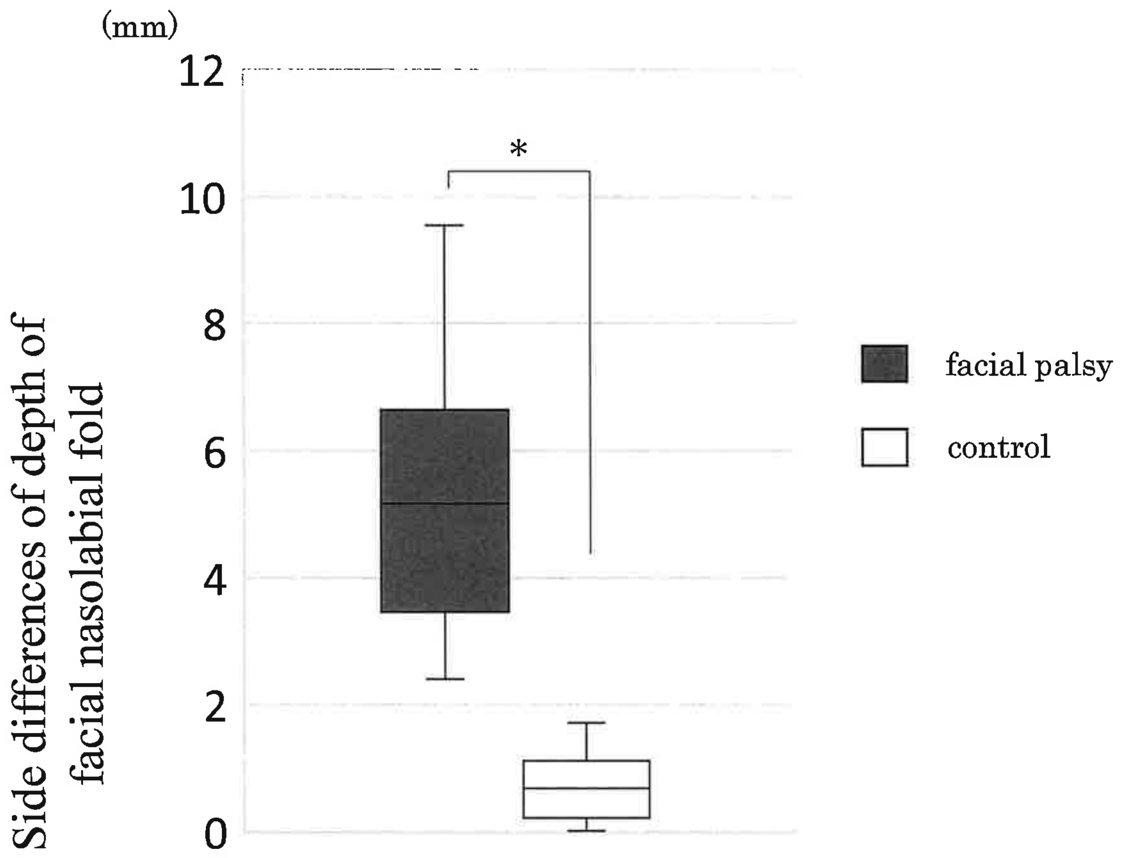
0
Depth of facial nasolabial fold
right
left
Control

Fig. 5



(mm)
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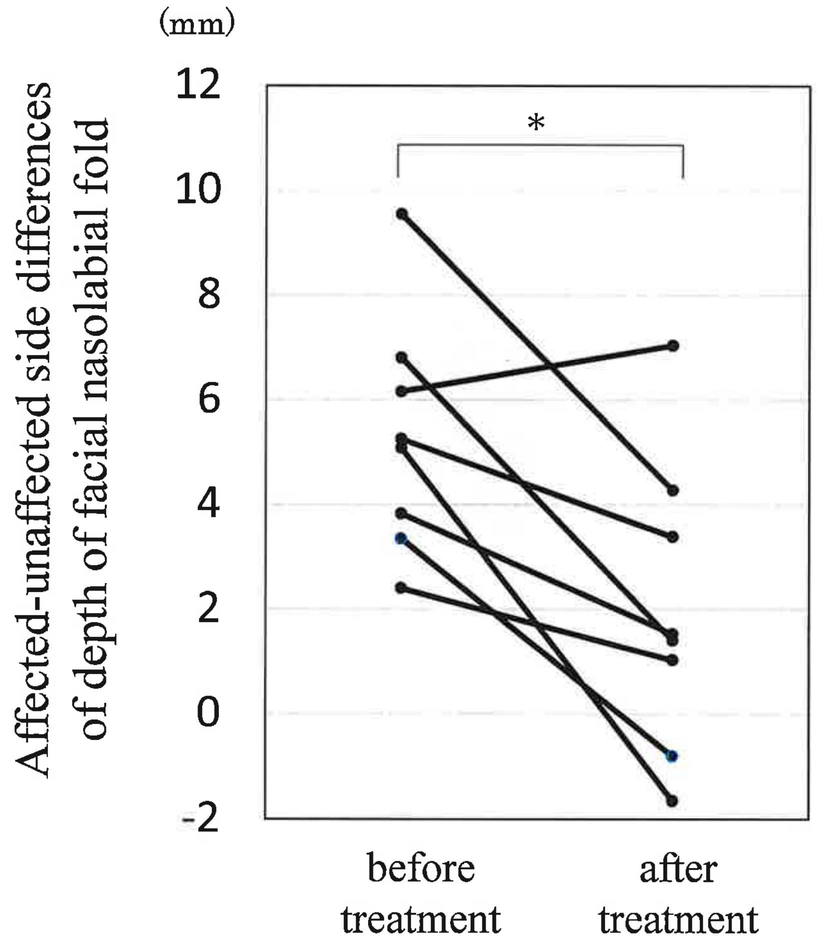
Side differences of depth of facial nasolabial fold
*
facial palsy
control

Fig. 6


Affected-unaffected side differences of depth of facial nasolabial fold
(mm)
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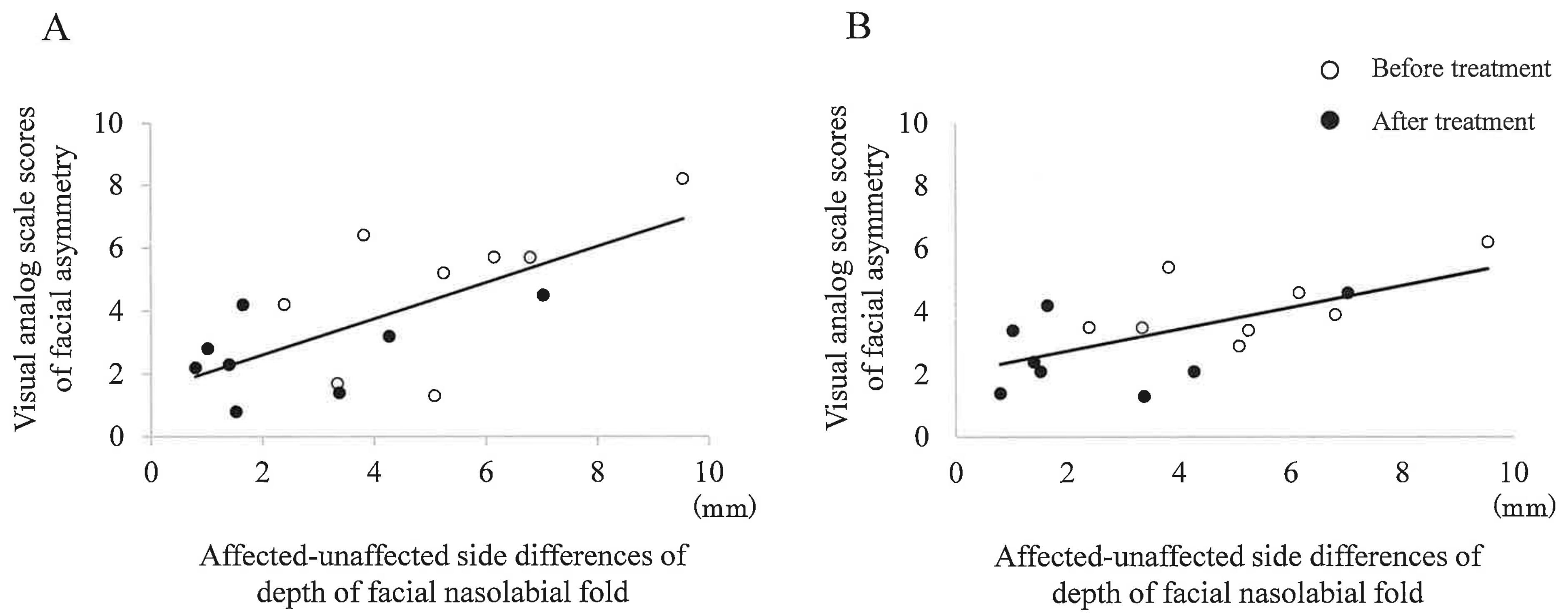
*
before treatment
after treatment

Fig. 7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Visual analog scale scores of facial asymmetry
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Affected-unaffected side differences of depth of facial nasolabial fold
B
Before treatment
After treatment
Visual analog scale scores of facial asymmetry
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8
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(mm)
Affected-unaffected side differences of depth of facial nasolabial fold