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ORIGINAL ARTICLE

Three-dimensional evaluation of treatment results of the Alt-RAMEC and facemask protocol in growing patients

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Abstract

Purpose The aim of this retrospective study was to evaluate the skeletal, dental, and soft tissue effects of the alternating rapid maxillary expansions and constrictions (Alt-RAMEC) protocol combined with a facemask in prepubertal patients.

Methods The study group (mean age 9.74 ± 1.46 years) consisted of 20 patients with class III malocclusion characterized by maxillary retrognathism. They were treated with a facemask for 7 months following a 9-week Alt-RAMEC protocol. Cone-beam computed tomography (CBCT) records and three-dimensional (3D) photographs taken before (T0) and after the protraction and retention period (T1) were evaluated. The study group was compared with a well-matched control group of 16 untreated patients (mean age 9.44 ± 0.79 years) with the same malocclusion. The records for the control group included cephalometric radiographs and 3D photographs.

Results In the study group, significant forward movements of A point (3.49 mm), nasal (2.91 mm) and zygomatic bones were achieved. Intermolar, internasal, and interzygomatic widths increased. Soft tissue points followed the hard tissue movements, apart from b and pog. In the control group, A (0.97 mm), B (1.69 mm), Pog, and b points presented forward movement. Significant differences were found regarding the forward movement of the maxilla between the groups.

Conclusion The Alt-RAMEC/facemask protocol was effective not only in the maxillary region but also in the midface.

Keywords Retrognathia · Cone-beam computed tomography · Malocclusion, Angle class III · Maxillary protraction · 3dMDface system

Dreidimensionale Auswertung der Behandlungsergebnisse des Alt-RAMEC- und Gesichtsmaskenprotokolls bei wachsenden Patienten

Zusammenfassung

Zweck Ziel dieser retrospektiven Studie war es, die skelettalen, dentalen und weichgewebigen Auswirkungen der alternierenden schnellen Gaumennahterweiterung und -konstriktion (Alt-RAMEC-Protokoll) in Kombination mit einer Gesichtsmaske bei präpubertären Patienten zu untersuchen.

Authors Contribution N. Kucukkeles constructed the idea. N. Kucukkeles and H.N. Yilmaz planned the methodology to reach the conclusion, and organized and supervised the course of the project and the writing of the article. V. Sitaropoulou and B. Yilmaz collected, managed and reported the data. All the authors analyzed the data and took responsibility in logical interpretation. N. Kucukkeles, H.N. Yilmaz and V. Sitaropoulou performed the writing of the manuscript. All the authors read and approved the final manuscript.

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Methoden Die Studiengruppe (mittleres Alter 9,74 ± 1,46 Jahre) bestand aus 20 Patienten mit Klasse-III-Malokklusion mit retrognathem Oberkiefer. Sie wurden nach einem 9-wöchigen Alt-RAMEC-Protokoll 7 Monate lang mit einer Gesichtsmaske behandelt. Digitale Volumentomographien (CBCT) und dreidimensionale (3D) Fotografien, die vor (T0) und nach der Protraktions- und Retentionszeit (T1) aufgenommen worden waren, wurden ausgewertet. Die Studiengruppe wurde mit einer gut abgestimmten Kontrollgruppe von 16 unbehandelten Patienten (Durchschnittsalter 9,44 ± 0,79 Jahre) mit der gleichen Malokklusion verglichen. Die Aufzeichnungen für die Kontrollgruppe umfassten kephalometrische Röntgenaufnahmen und 3D-Fotografien.

Ergebnisse In der Studiengruppe wurden signifikante Vorwärtsbewegungen von A-Punkt (3,49 mm) sowie Nasen- (2,91 mm) und Jochbein erzielt. Die intermolaren, internasalen und interzygomatischen Abstände nahmen zu. Weichteilpunkte folgten den Hartgewebebewegungen, abgesehen von b und pog. In der Kontrollgruppe zeigten die Punkte A (0,97 mm), B (1,69 mm), Pog und b eine Vorwärtsbewegung. Bezüglich der Vorwärtsbewegung des Oberkiefers wurden signifikante Unterschiede zwischen den Gruppen festgestellt.

Schlussfolgerung Das Alt-RAMEC-Gesichtsmaske-Protokoll war nicht nur im Oberkieferbereich, sondern auch im Mittelgesicht wirksam.

Schlüsselwörter Retrognathie · Digitale Volumentomographie · Angle-Klasse-III-Malokklusion · Oberkieferprotraktion · 3dMDface System

Abbreviations

3D	Three-dimensional
Alt-RAMEC	Alternating rapid maxillary expansions and constrictions
CBCT	Cone-beam computed tomography
ICC	Intraclass correlation coefficient
RME	Rapid maxillary expansion
RP1	Frankfort horizontal plane
RP1ceph	Horizontal reference plane for the control group
RP2	Vertical reference plane
RP2ceph	Vertical reference plane for the control group
STRP	Soft tissue reference plane
T0	Initial
T1	After protraction and retention period

Introduction

Class III malocclusion is one of the most complicated malocclusions to treat, particularly in mixed and late deciduous dentitions. A facemask is frequently used for the early treatment of class III malocclusion characterized by maxillary retrognathism due to its efficiency in maxillary protraction. Rapid maxillary expansion (RME) combined with facemask therapy is a routine clinical procedure as it is assumed that RME disarticulates the circummaxillary sutures [1]. Liou [2, 3] presented a repetitive weekly protocol of alternating rapid maxillary expansions and constrictions (Alt-RAMEC) which was followed by intraoral maxillary protraction springs. He reported a 3 mm anterior movement of A point with only 9 weeks of Alt-RAMEC treatment in the patients with cleft lip and palate; compared to 1.6 mm anterior movement of A point in a RME group with 1-week expansion [4]. This difference was attributed to the Alt-RAMEC protocol which opens the circummaxillary sutures more extensively than 1 week of RME together with the effect of a double hinged expansion screw.

There are a few studies regarding the Alt-RAMEC and facemask protocol in which most used the Hyrax screw for expansion. However, Liou [5] stated that the anterior movement of the maxilla is not predictable with the Hyrax expansion screw considering the center of rotation of maxillary halves during expansion at the posterior nasal spine. He claimed that a double-hinged expander will allow the maxillary halves to freely move forward with the center of rotation at the contact points between the pterygoid plate and tuberosity. The results published by Liou [2–4] were very inspiring and therefore we decided to apply his protocol on class III growing patients (without cleft lip and palate) by comparing it with class III control patients to isolate the growth changes. Cone-beam computed tomography (CBCT) images and three-dimensional (3D) photographs were used in the study group not only to make precise measurements on A point but also to evaluate the changes on facial bones and soft tissues.

Materials and methods

The study was approved by the ethical committee of Marmara University, Institute of Health Sciences (no: 24.12.2014-11). MedCalc Statistical Software version 12.7.7 (MedCalc Software bvba, Ostend, Belgium) was used for the sample size calculation. Sample size estimation was based on a previous study [6] and a minimum of 10 patients for each group was required to obtain a difference of 1 mm for maxillary protraction (power of 0.80;

α level of 0.05). The study group comprised 20 patients (10 males, 10 females) with maxillary retrognathism and the mean initial age was 9.74 ± 1.46 years. This study group was compared with a control group of 16 untreated class III patients (10 males, 6 females) with a mean age of 9.44 ± 0.79 years and the same skeletal characteristics. None of the patients were able to bite edge to edge. Maxillary retrognathism was diagnosed by a decreased distance from N perpendicular to A point (<–1 mm), SNA (<80°) and maxillary depth (<90°). Inclusion criteria were as follows: patients with a class III skeletal relationship due to maxillary retrognathism; normal to low angle vertical growth pattern (SN-GoMe ≤32° ± 6); Wits appraisal less than –1 mm; age between 8–11 years; no previous orthodontic treatment; no systemic diseases, craniofacial anomalies or temporomandibular joint disorders. Exclusion criteria were patients with a large mandible (corpus length ≥ x + 7 mm), pseudo class III malocclusion (indicating presence of centric occlusion-centric relation discrepancy), high angle vertical growth pattern and patients who reported failure to follow the treatment protocol routine. The records of all patients were selected from the archive of the Department of Orthodontics, Faculty of Dentistry, Marmara University. According to the cervical vertebral maturation method, all patients were actively growing.

In the study group, the intraoral device was a double-hinged expansion screw (US patent number: 6334771B1) attached to posterior acrylic bite blocks with bilateral hooks for the attachment of elastics (Fig. 1). The screw was turned 1 mm/day (2 activations in the morning, 2 activations in the evening) during the first week and closed 1 mm per day during the following week. This alternating opening and closing was repeated for 9 consecutive weeks and then a Petit type facemask provided by ORMCO® (Adjustable Dynamic Protraction Facemask™, Ormco, Orange, CA, USA) was used for at least 16 h daily until a full class II molar and canine relationship was achieved. The direction of the protractive force was 30° forward and downward in relation to the occlusal plane and 500 g of protraction force was applied per side. Facemask protraction lasted 7 months and all patients had a class III Bionator for retention for 3 months on average. The treatment progress of one patient is shown in Fig. 2.

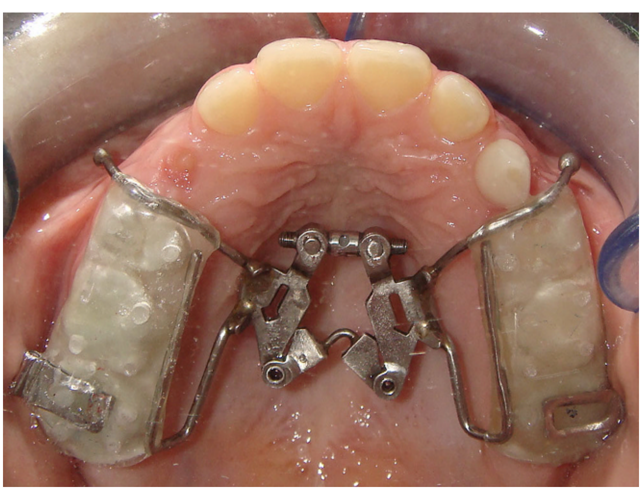

Fig. 1 Intraoral occlusal view of the expansion screw
Abb. 1 Intraorale okklusale Ansicht der Dehnschraube

CBCT images of the study group were taken with an Iluma Imtec Imaging machine (3M, Ardmore, OK, USA; x-ray tube current: 1–4 mA; field of view: 14.2 × 21.1 cm; voxel size: 0.0936 mm). CBCT images were taken just before the bonding of the expansion appliance (T0) and at the end of the retention period (T1). Furthermore, 3D photographs were taken using the 3dMDface system (3dMD LLC, Atlanta, GA, USA) at the same recording stages (T0, T1). The data were analyzed using MIMICs version 17.0 (Materialize Interactive Medical Image Control Systems, Leuven, Belgium).

For the control group, lateral cephalograms (Orthopantomograph OP300; Instrumentarium Dental, Tuusula, Finland) and 3D photographs were taken initially (T0) and at the end of the 9 month observation time (T1).

Skeletal and dental measurements

In the study group, the Frankfort horizontal plane (RP1) was formed between the right–left porion and right infraorbital point. The vertical reference plane (RP2) was passing through the porions, perpendicular to the RP1 (Fig. 3a). Bilateral measurements were also performed (Fig. 4a). For the control group, the horizontal reference plane (RP1ceph) was drawn with a 7° angle below the SN plane at Sella, and a perpendicular line was drawn to the first plane through Sella to establish a vertical reference plane (RP2ceph; Fig. 3c).

Soft tissue measurements

Three-dimensional photographs were superimposed by 3dMD patient software (3dMD Inc., Atlanta, GA, USA) and then transferred to MIMICs software. A vertical plane was formed by right–left endocantion and right alar curvature points. A second plane (soft tissue reference plane, STRP) was created parallel to the first plane, passing through the point which was the junction of the earlobe and the face skin (Fig. 3b, 4b). Color-coded superimpositions of the 3dMD photographs of one patient from each group are shown in Fig. 5.

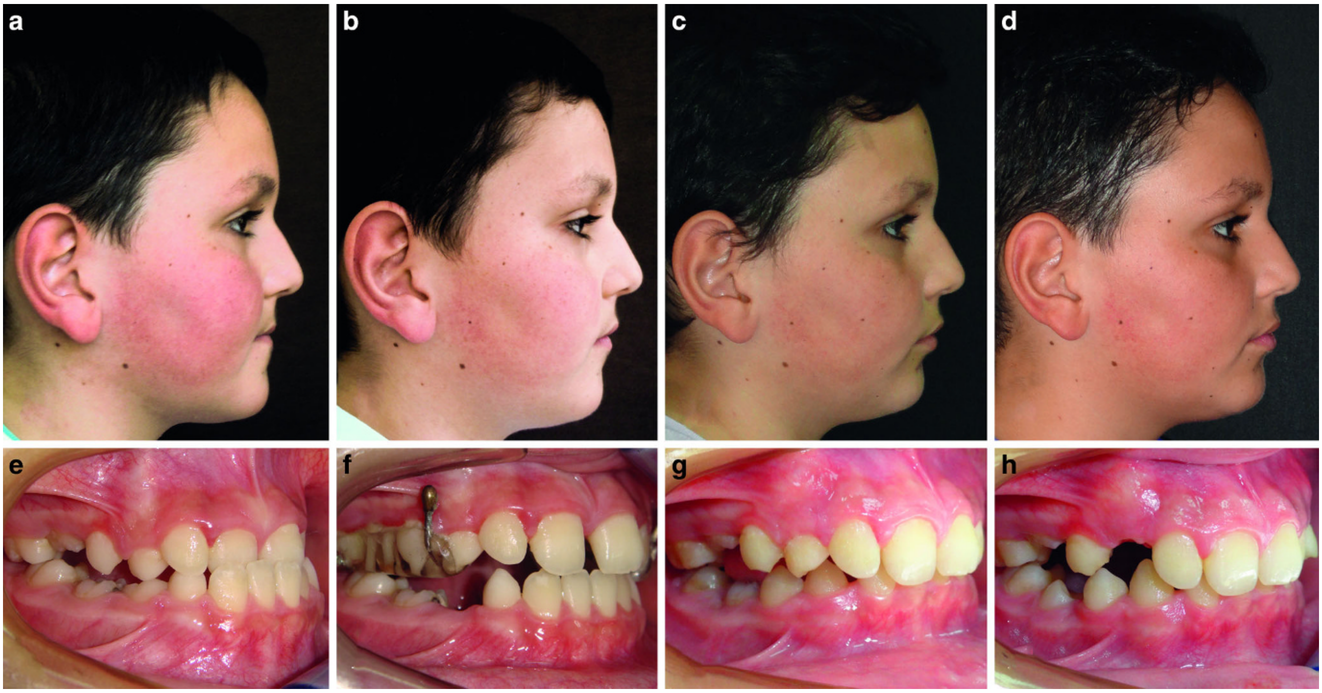

Fig. 2 **a**, **e** Initial pictures of a patient, **b**, **f** after the 9 week Alt-RAMEC (alternating rapid maxillary expansion and constriction) protocol, **c**, **g** after the facemask protocol, **d**, **h** after completion of the class III Bionator protocol

Abb. 2 **a**, **e** Ausgangsbilder eines Patienten, **b**, **f** nach dem 9-wöchigen Alt-RAMEC-Protokoll (abwechselnd schnelle Expansion und Konstriktion des Oberkiefers), **c**, **g** nach dem Gesichtsmaskenprotokoll, **d**, **h** nach Abschluss des Klasse-III-Bionatorprotokolls

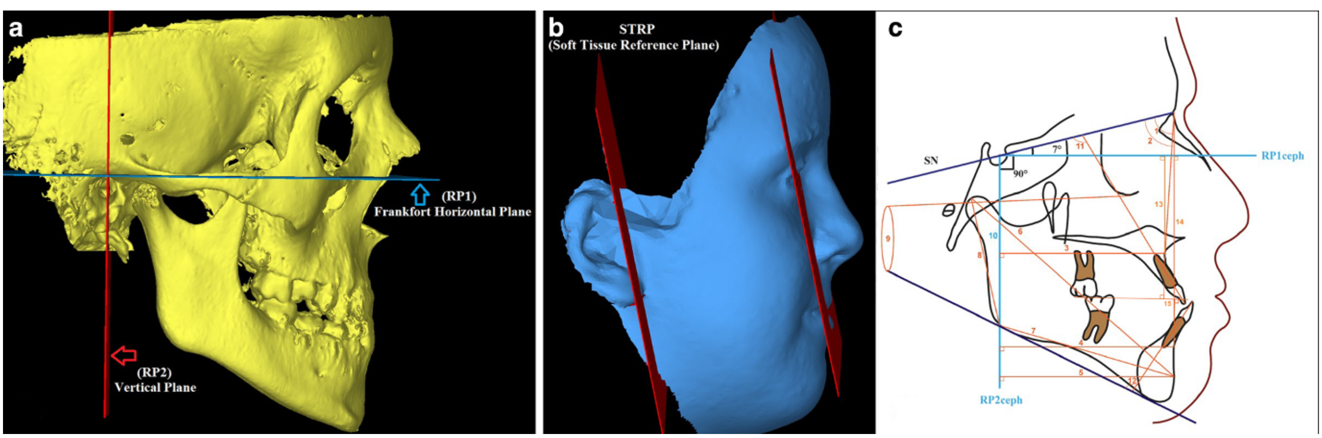

Fig. 3 **a** Reference planes used in the cone-beam computed tomographic images. **b** Soft tissue reference plane (STRP). **c** Reference planes and measurements used for cephalometric evaluation: 1, SNA (°); 2, SNB (°); 3, ARP2ceph (mm); 4, BRP2ceph (mm); 5, PogRP2ceph (mm); 6, TML (Total mandibular length) (mm); 7, CL (Corpus length) (mm); 8, RL (Ramus length) (mm); 9, FMA (°); 10, S-Go (mm); 11, U1-SN (°); 12, IMPA (°); 13, ARP1ceph (mm); 14, BRP1ceph (mm); 15, Wits appraisal (mm)

Abb. 3 **a** In den DVT(digitale Volumentomographie)-Bildern verwendete Referenzebenen. **b** Weichgewebe-Referenzebene (STRP). **c** Referenzebenen und Messungen für die kephalometrische Auswertung: 1, SNA (°); 2, SNB (°); 3, ARP2ceph (mm); 4, BRP2ceph [mm]; 5, PogRP2ceph [mm]; 6, TML (Gesamtlänge des Unterkiefers; [mm]); 7, CL (Korpuslänge; [mm]); 8, RL (Ramuslänge; [mm]); 9, FMA (°); 10, S-Go (mm); 11, U1-SN (°); 12, IMPA (°); 13, ARP1ceph (mm); 14, BRP1ceph (mm); 15, Wits-Beurteilung (mm)

Statistical analysis

IBM SPSS Statistics 22 (IBM, Armonk, NY, USA) program was used for statistical analysis. Conformity of the parameters to normal distribution was assessed using the Shapiro Wilks test and all parameters conformed to normal distribution. For intergroup comparisons, the Wilcoxon signed rank test was used, while the Mann–Whitney U test was used for intragroup comparisons. Significance was evaluated at a level of $P < 0.05$.

To assess the reliability of the measurements, 2 weeks after the first measurements, 20% of all the records were

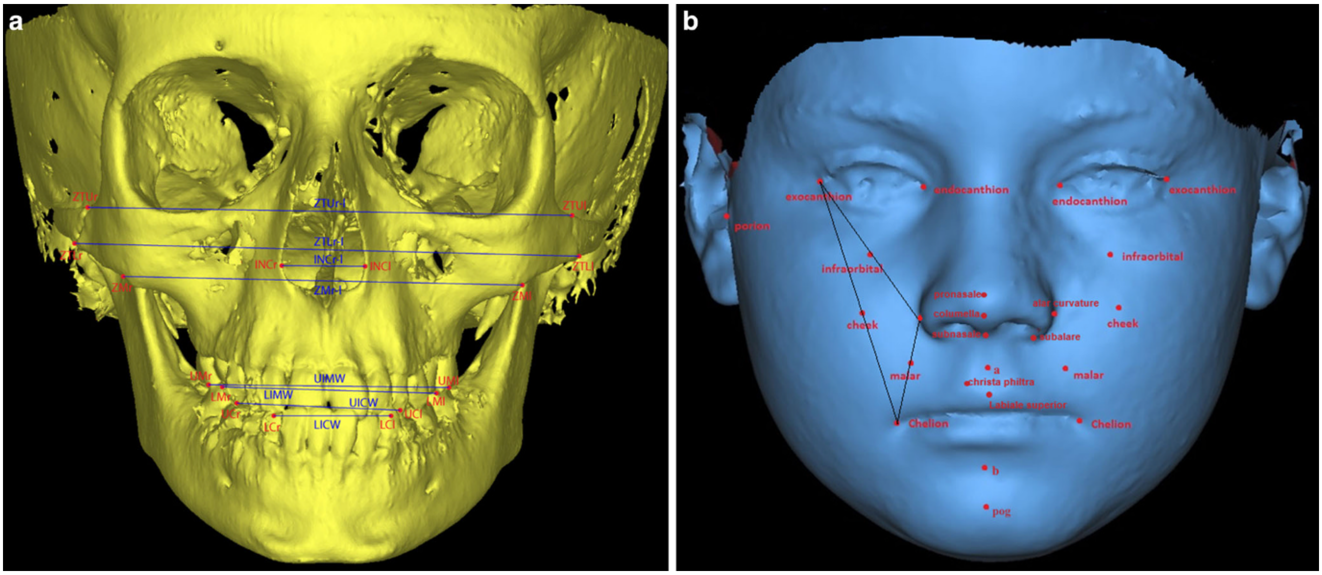

Fig. 4 **a** Bilateral measurements used in the cone-beam computed tomographic images: *INCr-l* the distance between right and left inner nasal contour point (INC); *ZMr-l* the distance between right and left lower borders of zigomaticomaxillary suture (ZM); *ZTUr-l* the distance between right and left upper borders of zygomaticotemporal suture (ZTU); *ZTLr-l* the distance between right and left lower borders of zygomaticotemporal suture (ZTL); *UICW* upper intercanine width; *LICW* lower intercanine width; *UIMW* upper intermolar width; *LIMW* lower intermolar width. **b** Soft tissue landmarks: infraorbital (*right, left*) the midpoint of the distance between exocanthion and the alar curvature; cheek (*right, left*) the midpoint of the distance between exocanthion and chelion; malar (*right, left*) the midpoint of the distance between chelion and the alar curvature
Abb. 4 **a** In den DVT(digitale Volumentomographie) Bildern verwendete bilaterale Messungen: *INCr-l* Abstand zwischen dem rechten und linken inneren Nasenkonturpunkt (INC); *ZMr-l* Abstand zwischen der rechten und linken unteren Grenze der Sutura zygomaticomaxillaris (ZM); *ZTUr-l* Abstand zwischen der rechten und linken oberen Grenze der Sutura zygomaticomaxillaris (ZTU); *ZTLr-l* Abstand zwischen der rechten und linken unteren Grenze der Sutura zygomaticomaxillaris (ZTL); *UICW* obere intercanine Breite; *LICW* untere intercanine Breite; *UIMW* obere intermolare Breite; *LIMW* untere intermolare Breite. **b** Weichgewebelandmarken: infraorbital (*rechts, links*) der Mittelpunkt des Abstands zwischen Exocanthion und Alarkrümmung; Wange (*rechts, links*) der Mittelpunkt des Abstands zwischen Exocanthion und Chelion; malar (*rechts, links*) der Mittelpunkt des Abstands zwischen Chelion und Alarkrümmung

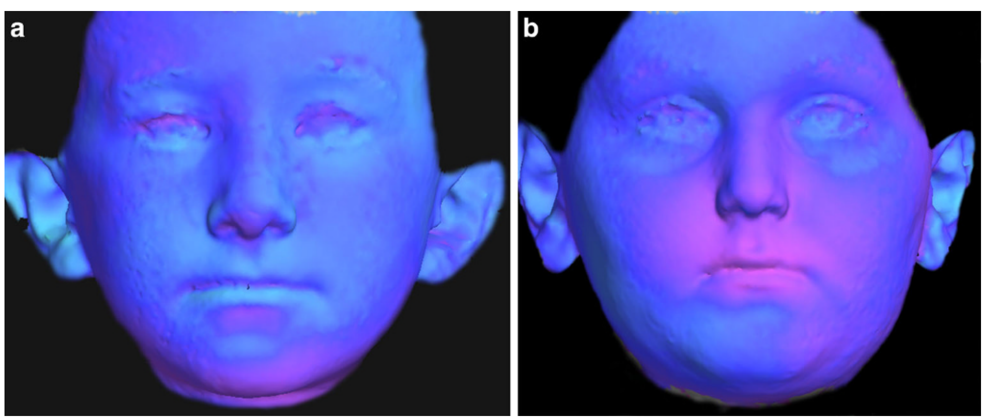

Fig. 5 Color-coded superimpositions of 3dMD photographs taken at T0 and T1: **a** a patient from the control group; **b** a patient from the study group
Abb. 5 Farbkodierte Überlagerungen von 3dMD-Fotografien zu den Zeitpunkten T0 und T1: **a** ein Patient der Kontrollgruppe; **b** ein Patient der Studiengruppe

randomly selected and analyzed by the same examiner. The intraclass correlation coefficient (ICC) of all parameters showed a high rate of agreement between the measurements and ranged from 0.803 to 1.000.

Results

No statistically significant difference was found when comparing of the mean initial (9.74 ± 1.46 years for the study group, 9.44 ± 0.79 years for the control group; $p = 0.438$) and final treatment ages (10.83 ± 1.50 years for the study group, 10.20 ± 0.79 years for the control group; $p = 0.139$) between two groups.

Table 1 Evaluation of the changes in the measurements and difference of the values of the skeletal, dental (CBCT) and soft tissue (the 3dMD system) parameters during the T0–T1 periods in the study group
Tab. 1 Auswertung der Veränderungen in den Messungen und der Differenz der Werte der skelettalen, dentalen (DVT) und Weichgewebeparameter (3dMD-System) während der T0-T1-Perioden in der Studiengruppe

Study group	T0 Mean ± SD	T1 Mean ± SD	T1–T0 (*p*)
SKELETAL			
SNA	78.35 ± 2.51	80.47 ± 2.67	2.12 ± 1.17**
SNB	78.27 ± 2.39	78.14 ± 2.37	–0.13 ± 0.92
Wits appraisal	–7.71 ± 2.15	–0.95 ± 2	6.76 ± 1.84**
ARP1	24.54 ± 3.56	25.69 ± 4.14	1.15 ± 1.09**
ARP2	81.19 ± 3.97	84.68 ± 4.49	3.49 ± 1.31**
ANSRP2	85.79 ± 4.83	88.79 ± 5.39	3 ± 1.81**
BRP1	59.15 ± 4.2	60.54 ± 4.67	1.4 ± 1.8**
BRP2	80.95 ± 4.52	82.24 ± 5.56	1.29 ± 1.9**
Pog RP2	81.13 ± 4.74	83.11 ± 6.19	1.98 ± 2.6**
INClRP2	77.84 ± 4.04	80.8 ± 4.63	2.96 ± 2.08**
INCrRP2	77.9 ± 4.79	80.76 ± 5.01	2.86 ± 1.14**
ZMlRP2	56.79 ± 2.77	58.82 ± 3.64	2.03 ± 1.62**
ZMrRP2	56.55 ± 3.23	58.35 ± 3.85	1.80 ± 1.24**
ZTLlRP2	36.34 ± 2.58	38.05 ± 2.92	1.71 ± 1.38**
ZTLrRP2	36.6 ± 2.68	37.59 ± 3.25	0.99 ± 1.29**
ZTUlRP2	45.42 ± 3.24	46.63 ± 3.62	1.21 ± 1.61**
ZTUrRP2	45.97 ± 3.27	47.07 ± 3.79	1.10 ± 1.57*
INCr-L	20.52 ± 1.76	22.31 ± 1.59	1.79 ± 1.23**
ZMr-l	82.48 ± 3.18	84.48 ± 3.16	2.01 ± 2.31**
ZTLr-l	109.59 ± 4.27	111.06 ± 4.3	1.47 ± 1.16**
ZTUr-l	104.82 ± 4.19	106.33 ± 4.3	1.51 ± 1.41**
TML	108.99 ± 4.91	111.62 ± 4.8	2.62 ± 1.81**
CL	77.86 ± 2.96	79.54 ± 3.3	1.68 ± 0.98**
RL	47.93 ± 3.17	49.38 ± 2.85	1.45 ± 1.71**
FMA	26.11 ± 3.94	26.64 ± 3.57	0.52 ± 1.51
S-Go	75.41 ± 4.14	77.02 ± 3.94	1.61 ± 1.47**
DENTAL			
U1-SN	99.59 ± 6.45	101.88 ± 6.1	2.34 ± 5.2*
IMPA	85.28 ± 3.83	83.44 ± 5.15	–1.84 ± 3.65*
U6RP2	54.5 ± 3.64	59.25 ± 4.5	4.75 ± 1.92**
UICW	30.64 ± 4.02	33.36 ± 3.93	2.72 ± 2.83**
UIMW	50.65 ± 2.87	52.05 ± 2.93	1.40 ± 0.99**
LICW	26.07 ± 1.78	26.64 ± 1.86	0.57 ± 1.57
LIMW	46.36 ± 1.92	47.31 ± 1.55	0.95 ± 1.25**

Skeletal changes

The A point presented a statistically significant forward and downward movement of 3.49 ± 1.31 and 1.15 ± 1.09 mm during T0–T1, respectively (Table 1). In the control group, the A point moved 0.97 ± 1.27 mm forward and 1.11 ± 1.9 mm downward. These changes were also statistically significant (Table 2). The forward movement of the A point was significantly higher in the study group when compared with the control group (Table 3). The changes in the SNA angle were in accordance with the A point movement.

Regarding the mandibular changes, the B point (1.29 ± 1.9 mm) and Pogonion (1.98 ± 2.6 mm) moved significantly forward in the study group (Table 1). In the control group, all mandibular skeletal measurements except ramus length showed statistically significant increases (Table 2). When the groups were compared regarding the mandibular skeletal changes during T0–T1, no significant difference was observed except for SNB (1.06 ± 1.12°) in the control group (Table 3).

Table 1 (Continued)
Tab. 1 (Fortsetzung)

Study group	T0 Mean ± SD	T1 Mean ± SD	T1–T0 (*p*)
SOFT TISSUE			
a-STRP	78.89 ± 3.74	80.99 ± 3.87	2.1 ± 1.59**
b-STRP	66.2 ± 4.28	66.36 ± 4.56	0.16 ± 1.97
Pog-STRP	64.6 ± 4.76	64.96 ± 4.99	0.36 ± 2.04
Subalare l-STRP	76.91 ± 3.65	78.37 ± 3.81	1.46 ± 1.37**
Subalare r-STRP	76.62 ± 3.56	78.18 ± 3.6	1.56 ± 1.08**
Alar curvature l-STRP	74.98 ± 3.5	76.12 ± 3.58	1.14 ± 1.4**
Alar curvature r-STRP	74.12 ± 3.43	75.52 ± 3.37	1.4 ± 1.17**
Subalare r-l	19.44 ± 1.78	21.16 ± 2.78	1.71 ± 2.34**
Alar curvature r-l	31.25 ± 2.33	33.21 ± 2.75	1.96 ± 1.4**
Cheek l-STRP	71.15 ± 4.36	72.19 ± 4.31	1.04 ± 1.18**
Cheek r-STRP	70.15 ± 3.85	71.15 ± 3.86	1.0 ± 1.29**
Columella-STRP	90.48 ± 3.83	92.25 ± 3.68	1.78 ± 1.36**
Labiale superior-STRP	78.76 ± 3.99	81.43 ± 4.0	2.66 ± 1.82**
Infraorbital l-STRP	70.64 ± 3.8	71.13 ± 3.63	0.49 ± 1.2
Infraorbital r-STRP	69.98 ± 3.62	70.44 ± 3.49	0.46 ± 1.12
Christa philtra l-STRP	78.52 ± 4.0	81.16 ± 4.06	2.64 ± 1.88**
Christa philtra r-STRP	78.46 ± 3.95	81.21 ± 3.96	2.74 ± 1.85**
Malar l-STRP	72.86 ± 3.61	75.06 ± 3.91	2.21 ± 1.65**
Malar r-STRP	71.83 ± 3.47	74.58 ± 3.5	2.75 ± 1.45**
Pronasale-STRP	95.67 ± 3.9	97.64 ± 3.99	1.97 ± 1.4**
Subnasale-STRP	81.58 ± 3.75	83.27 ± 3.79	1.69 ± 1.47**

Wilcoxon signed rank test * $p < 0.05$ ** $p < 0.01$
SD standard deviation, *STRP* soft tissue reference plane, *r* right, *l* left

The changes in Wits appraisal were statistically significant in the study group (6.76 ± 1.84 mm) and these changes were statistically higher than in the control group (0.42 ± 1.55 mm).

The evaluation of changes in the nasomaxillary and zygomatic bones could be carried out solely in the study group since the control group only had cephalometric radiographs. Both the nasal and zygomatic bones moved significantly forward during treatment (Table 1). The amount of skeletal expansion at the nasal level was 1.79 ± 1.23 mm which was statistically significant. The amount of skeletal expansion, which was lesser in the upper part of the face, was also statistically significant at the zygomatic bone level after the treatment.

Dental changes

Regarding the incisor inclinations, proclination of the upper incisors (U1-SN) and retroclination of the lower incisors were seen in both groups; however, these changes were statistically significant only in the study group (Tables 1 and 2). On the other hand, upper incisor proclination in the study group was significantly higher when compared to the control group (Table 3).

Since the control group was evaluated with cephalometric radiographs, upper and lower intercanine and intermolar distances could only be measured in the study group. Intermolar and intercanine distances except lower intercanine width presented significant increases in both arches during treatment (Table 1).

Soft tissue changes

In the study group, all the measured points moved significantly forward during treatment, apart from b point, pog and infraorbital l and r (Table 1). Additionally, nasal width presented significant increases in the distances for subalare r–l (1.71 ± 2.34 mm) and alar curvature r–l (1.96 ± 1.4 mm). In the control group, only b point (1.03 ± 1.84 mm) moved significantly forward due to growth (Table 2). When the groups were compared, all the parameters presented statistically significant differences except b, pog, cheek, and infraorbital points (Table 3).

Table 2 Evaluation of the changes and differences of skeletal, dental, and soft tissue parameters in the control group during the T0–T1 period
Tab. 2 Auswertung der Veränderungen in den Messungen und der Differenz der Werte der skelettalen, dentalen und Weichgewebeparameter während der T0-T1-Periode in der Kontrollgruppe

Control group	T0 Mean ± SD	T1 Mean ± SD	T1–T0 (*p*)
SKELETAL			
SNA	78.19 ± 3.08	78.88 ± 2.73	0.69 ± 1.14*
SNB	79.06 ± 3.34	80.13 ± 3.67	1.06 ± 1.12**
Wits appraisal	–7.53 ± 1.83	–7.11 ± 1.56	0.42 ± 1.55
ARP1	49.18 ± 2.92	50.29 ± 3.98	1.11 ± 1.9*
ARP2	64.35 ± 4.79	65.32 ± 5.02	0.97 ± 1.27*
ANSRP2	70.79 ± 3.69	72.12 ± 4.85	1.33 ± 2.15
BRP1	84.49 ± 6.3	86.22 ± 5.41	1.73 ± 2.6*
BRP2	62.47 ± 7.51	64.16 ± 8.32	1.69 ± 2.14**
PogRP2	61.81 ± 8.27	63.96 ± 9.15	2.15 ± 2.31**
TML	106.43 ± 4.46	108.53 ± 5.11	2.1 ± 2.9*
CL	70 ± 3.88	71.25 ± 3.93	1.25 ± 0.75**
RL	50.71 ± 3.55	52.23 ± 4.43	1.52 ± 3.04
FMA	29.25 ± 4.95	29.56 ± 5.49	0.31 ± 2.41
S-Go	69.31 ± 3.94	70.71 ± 4.54	1.4 ± 1.73**
DENTAL			
U1-SN	102.81 ± 9.25	104.63 ± 7.63	1.81 ± 3.51
IMPA	89.31 ± 5.53	88.69 ± 5.11	–0.63 ± 3.61
SOFT TISSUE			
aSTRP	77.76 ± 4.45	77.94 ± 4.64	0.59 ± 0.93
bSTRP	66.98 ± 5.0	68.01 ± 5.26	1.03 ± 1.84*
PogSTRP	64.84 ± 6.08	65.76 ± 6.53	0.91 ± 2.23
Subalare lSTRP	75.23 ± 3.96	75.66 ± 4.47	0.44 ± 1.14
Subalare rSTRP	75.46 ± 3.99	75.79 ± 4.19	0.33 ± 1.27
Alar curvature lSTRP	73.56 ± 3.81	74.06 ± 4.25	0.5 ± 1.08
Alar curvature rSTRP	73.28 ± 4.07	73.37 ± 4.29	0.09 ± 1.05
Subalare r-l	21.4 ± 1.97	21.54 ± 1.97	0.14 ± 1.44
Alar curvature r-l	31.49 ± 1.94	31.8 ± 2.07	0.31 ± 0.6
Cheek lSTRP	70.4 ± 5.17	70.76 ± 5.05	0.36 ± 0.73
Cheek rSTRP	69.56 ± 4.98	69.88 ± 5.15	0.32 ± 0.93
ColumellaSTRP	88.85 ± 4.43	88.77 ± 4.48	–0.08 ± 1.53
Labiale superiusSTRP	77.92 ± 4.93	78.11 ± 5.21	0.2 ± 1.11
Infraorbital lSTRP	70.03 ± 4.59	70.15 ± 4.58	0.12 ± 0.71
Infraorbital rSTRP	69.49 ± 4.5	69.75 ± 4.5	0.26 ± 0.76
Christa philtra lSTRP	77.78 ± 4.72	77.76 ± 5.16	–0.03 ± 1.07
Christa philtra rSTRP	77.52 ± 4.72	77.81 ± 5.02	0.29 ± 1.03
Malar lSTRP	72.26 ± 4.54	72.16 ± 4.73	–0.1 ± 1.18
Malar rSTRP	71.52 ± 4.35	71.79 ± 4.51	0.27 ± 0.94
PronasaleSTRP	94.29 ± 4.52	94.81 ± 4.71	0.53 ± 0.98
SubnasaleSTRP	80.78 ± 3.98	81.25 ± 4.49	0.47 ± 0.9

Wilcoxon signed rank test * $p < 0.05$ ** $p < 0.01$
SD standard deviation, *STRP* soft tissue reference plane, *r* right, *l* left

Table 3 Evaluation of the differences of skeletal, dental, and soft tissue parameters between study and control group during the T0–T1 period
Tab. 3 Auswertung der Unterschiede von skelettalen, dentalen und Weichgewebeparametern zwischen Studien- und Kontrollgruppe während der T0-T1-Periode

	Study group T1–T0 Mean ± SD	Control group T1–T0 Mean ± SD	Study vs control *p*
SKELETAL			
SNA	2.12 ± 1.17	0.69 ± 1.14	**
SNB	–0.13 ± 0.92	1.06 ± 1.12	**
Wits appraisal	6.76 ± 1.84	0.42 ± 1.55	**
ARP1	1.15 ± 1.09	1.11 ± 1.9	**NS**
ARP2	3.49 ± 1.31	0.97 ± 1.27	**
ANSRP2	3 ± 1.81	1.33 ± 2.15	*
BRP1	1.4 ± 1.8	1.73 ± 2.6	**NS**
BRP2	1.29 ± 1.9	1.69 ± 2.14	**NS**
PogRP2	1.98 ± 2.6	2.15 ± 2.31	**NS**
TML	2.62 ± 1.81	2.1 ± 2.9	**NS**
CL	1.68 ± 0.98	1.25 ± 0.75	**NS**
RL	1.45 ± 1.71	1.52 ± 3.04	**NS**
FMA	0.52 ± 1.51	0.31 ± 2.41	**NS**
S-Go	1.61 ± 1.47	1.4 ± 1.73	**NS**
DENTAL			
U1-SN	2.34 ± 5.2	1.81 ± 3.51	**
IMPA	–1.84 ± 3.65	–0.63 ± 3.61	**NS**
SOFT TISSUE			
aSTRP	2.1 ± 1.59	0.59 ± 0.93	**
bSTRP	0.16 ± 1.97	1.03 ± 1.84	**NS**
PogSTRP	0.36 ± 2.04	0.91 ± 2.23	**NS**
Subalare lSTRP	1.46 ± 1.37	0.44 ± 1.14	*
Subalare rSTRP	1.56 ± 1.08	0.33 ± 1.27	**
Alar curvature lSTRP	1.14 ± 1.4	0.5 ± 1.08	**NS**
Alar curvature rSTRP	1.4 ± 1.17	0.09 ± 1.05	**
Subalare r-l	1.71 ± 2.34	0.14 ± 1.44	*
Alar curvature r-l	1.96 ± 1.4	0.31 ± 0.6	**
Cheek lSTRP	1.04 ± 1.18	0.36 ± 0.73	**NS**
Cheek rSTRP	1 ± 1.29	0.32 ± 0.93	**NS**
ColumellaSTRP	1.78 ± 1.36	–0.08 ± 1.53	**
Labiale superiusSTRP	2.66 ± 1.82	0.2 ± 1.11	**
Infraorbital lSTRP	0.49 ± 1.2	0.12 ± 0.71	**NS**
Infraorbital rSTRP	0.46 ± 1.12	0.26 ± 0.76	**NS**
Christa philtra lSTRP	2.64 ± 1.88	–0.03 ± 1.07	**
Christa philtra rSTRP	2.74 ± 1.85	0.29 ± 1.03	**
Malar lSTRP	2.21 ± 1.65	–0.1 ± 1.18	**
Malar rSTRP	2.75 ± 1.45	0.27 ± 0.94	**
PronasaleSTRP	1.97 ± 1.4	0.53 ± 0.98	**
SubnasaleSTRP	1.69 ± 1.47	0.47 ± 0.9	**

Mann–Whitney U test * $p < 0.05$ ** $p < 0.01$
SD standard deviation, *NS* not significant, *STRP* soft tissue reference plane, *r* right, *l* left

Discussion

The aim of this study was to evaluate the treatment effects of the facemask followed by the Alt-RAMEC protocol in growing class III children. There were few studies reporting successful results and they mostly used a Hyrax screw and some of them used shorter Alt-RAMEC protocols [4, 7–10]. However, the Hyrax screw was not reported favorable for the efficient advancement of the maxilla [5], which was the reason we decided to use a double-hinged expander in the study group. The duration of the Alt-RAMEC protocol in our study lasted 9 weeks since 7–9 weeks of the Alt-RAMEC protocol would be necessary in order to adequately open the coronal running sutures for maxillary protraction [7]. Looking at the literature, there are differences between the Alt-RAMEC protocols used in the various studies. Masucci et al. [10] applied 5 weeks of Alt-RAMEC treatment and reported more favorable results when compared to a RME only protocol (SNA angle increased 2.7° and 1.5°, respectively). On the other hand, Celikoglu and Buyukcavus [11] did not find any difference between 5- and 9-week expansion protocols.

All of the previous studies evaluating the effects of the Alt-RAMEC protocol followed by facemask treatment have been conducted using lateral cephalometric films [4, 8–11]. However, the maxilla is a complex anatomical structure and requires to be evaluated in all dimensions. Thus in this study, cone-beam images obtained from the archive of the orthodontic department were used.

Discussion of treatment results

Liou and Tsai [4] reported 5.8 ± 2.3 mm forward movement of A point after a 9-week Alt-RAMEC protocol followed by intraoral protraction springs, which was higher than the 3.49 ± 1.31 mm in our study group. This difference might be explained by skeletal differences in patients with a cleft lip and palate and the use of cephalometric films which we believe are not favorable in determining the A point in cleft lip and palate patients [12]. On the other hand, they were able to achieve this amount of protraction faster than in our group. This may be due to the tooth-borne, noncompliance protraction springs which were in the mouth for 24 h, whereas the facemask was used for 16 h a day in our study group. Moreover, they took the records immediately after protraction while our records were taken after retention with the Bionator appliance.

The maxillary advancement in our study group was significantly higher than that in the control group. The results were in accordance with the study of Canturk and Celikoglu [6] who compared treatment results of the facemask started simultaneously and after the Alt-RAMEC procedure. He reported 3.02 and 3.84 mm of forward movement of the A point, respectively. Liou [4] found 5.47 mm and Isci et al. [8] reported 4.13 mm, while Kaya et al. [9] achieved only 2 mm of maxillary protraction. These differences might be due to several factors such as the severity of class III malocclusion, different expansion device, age, treatment duration, and patient cooperation.

Our treatment results regarding the mandible were not in agreement with other studies where the B point and Pogonion moved backward, SNB angle decreased and FMA angle increased [4, 6, 8–10]. In our study, there was no significant difference between the two groups in terms of sagittal mandibular growth so the protocol was not efficient on the mandibular growth. It might be explained by the last records being taken after the retention stage (Bionator) in our study. FMA did not present any significant changes either. This might be due to a significant increase in S-Go distance, and possibly to control of the vertical dimension bought about by the posterior acrylic of the intraoral device.

Proclination of the upper incisors and retroclination of the lower incisors were observed in the study group, as was found in previous facemask studies [8, 9]. Mesial migration of the dentition, proclination of upper incisors, periodontal damage or root resorption in anchored teeth are the possible risks of tooth-borne devices since the force is applied to the teeth. In our study, forward movement of the upper first molars was 4.75 mm; however, this amount included not only mesial migration of molars but also the forward movement of the maxilla which was 3.49 mm. Therefore, the actual amount of dental mesial movement for the molars was 0.96 mm. In order to avoid these side effects mentioned above and increase the skeletal effect on the maxilla, researchers applied the combination of a hybrid hyrax, facemask and Alt-RAMEC protocol [13]. Mini-implants were placed on the anterior palate and a hybrid hyrax with additional buccal wires were added to the mini-implants for the expansion and facemask use. They concluded that the sagittal forces were transferred to the maxillary bone and dental side effects were avoided. Besides, the risk of periodontal damage to the posterior teeth was eliminated since the transverse forces were also applied to the mini-implants.

Nasal and zygomatic bones were also affected by the treatment in the study group. Nasal and zygomatic bones followed the forward movement of the maxilla. However, the values were decreasing towards higher structures (nasal area: 2.91 mm, zygomaticomaxillary area: 1.91 mm, lower zygomaticotemporal area: 1.35 mm, upper zygomaticotemporal area: 1.15 mm). Consequently, the technique was effective not only in the maxillary area but in the midface as well.

Evaluating the transverse changes, the protocol affected not only the maxilla but also the nasal bones and zygomatic sutures. The expansion achieved at the nasal level was 1.79 mm during T0–T1. The amount of expansion in other studies varies between 1.16 and 1.66 mm [14]. The distances between the zygomatic sutures were also significantly increased during treatment and the values again decreased towards higher structures due to a triangular opening pattern of the expansion as it was reported previously [7].

Upper–lower intermolar and upper intercanine distances were also increased during treatment and the changes were in agreement with other studies [14].

Evaluating the effects of treatment on the soft tissues compared to the control group, subalare, alar curvature (right only), columella, upper lip points, malar area, and pronasale all presented slight but significant forward movements showing that the soft tissue changes followed the changes of the underlying skeletal structures. Subalare and alar curvature distances might have been increased as a result of the expansion protocol. These results were in agreement with many other studies [6, 8, 9].

Conclusions

- Significant skeletal, dental, and soft tissue changes were encountered with the Alt-RAMEC (alternating rapid maxillary expansions and constrictions) + facemask protocol when compared with the control group.
- The maxilla moved forward (3.49 mm) and downward (1.15 mm) with treatment.
- The treatment did not affect normal growth of the mandible.
- Nasal and zygomatic bones moved significantly forward, while internasal and interzygomatic distances increased significantly.
- Soft tissue changes followed the skeletal changes in the study group, with all the measured points moving forward, apart from b, pog and infraorbital points.
- The treatment did not affect only the maxilla, but neighboring facial bones as well.

Compliance with ethical guidelines

Conflict of interest V. Sitaropoulou, H.N. Yilmaz, B. Yilmaz and N. Kucukkeles declare that they have no competing interests.

Ethical standards For this article no studies with human participants or animals were performed by any of the authors. All studies performed were in accordance with the ethical standards indicated in each case. This retrospective study was performed after consultation with the institutional ethics committee and in accordance with national legal requirements. For images or other information within the manuscript which identify patients, consent was obtained from them and/or their legal guardians. The study was approved by the ethical committee of Marmara University, Institute of Health Sciences (no: 24.12.2014-11).

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