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Adult maxillary expansion: CBCT evaluation of skeletal changes and determining an efficiency factor between force-controlled polycyclic slow activation and continuous rapid activation for mini-screw-assisted palatal expansion - MASPE vs. MARPE

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Abstract

Aim This consecutive retrospective study compared Mini-implant Assisted Slow Palatal Expansion (MASPE) with rapid palatal expansion (MARPE) using a bone-borne skeletal expander in adults with a narrow maxilla. CBCT scans analyzed transverse changes and potential pterygoid process deformation before (T1) and after expansion (T2).

Materials and methods The Force Controlled PolyCyclic (FCPC) SLOW palatal expansion group (FCPC-MASPE-G) comprised 35 adults aged 18–54 years and received a skeletal expander limiting expansive force only allowing 500 cN at the activation wrench (force control). Discontinuous, polycyclic activations according to the FCPC-protocol were applied. The MARPE-group ($n=6$) underwent continuous RAPID activation without FCPC until the desired width was reached. CBCT scans were taken pre and post-expansion. Inclusion criteria for both groups were successful outcomes without surgical assistance.

Results The maxilla opened transversally in both groups mildly V-shaped, with a pyramidal shape in the coronal plane, impacting the zygomatic bone. Width measurements at T2 indicated superior mechanical response in FCPC-MASPE-G. Response of zygomaticomaxillary sutures was similar in both groups ($p<0.001$ to 0.025). Pterygoid process deformations were notably less in FCPC-MASPE-G (0.87–1.35 mm, $p<0.001$) compared to MARPE-G (2.70–3.04 mm, $p<0.001$ to 0.009). Dental measurements were similar ($p<0.001$ to 0.023), but the ratio "Mid-palatal suture Opening Related to Expander opening" (M.O.R.E.-factor) was better with 84% in FCPC-MASPE-G than with 50% in MARPE-G.

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Conclusion Slow expansion with FCPC protocol effectively widens the maxilla in adults, with significant impact on bones and sutures and less pterygoid process deformation compared to rapid expansion. Cranial complications were absent in both groups.

Keywords MARPE, Skeletal palatal expander, Slow expansion, Orthodontic mini-implants, Mini screws in palate, Cranial complications, Mid-palatal suture, Cranial sutures

Introduction

Tooth borne maxillary expansion is a common orthodontic treatment used predominantly in childhood and adolescence to address narrow dental arches before the fusion of mid-palatal and circummaxillary sutures [1, 2]. However, in adults, conventional tooth-borne expanders often face limitations due to increased resistance from fused sutures, necessitating alternative approaches [1, 3]. Surgically assisted rapid palatal expansion (SARPE) is typically recommended for adults, despite associated surgical risks and the need for sedation or general anesthesia [4].

The implementation of two to four palatal orthodontic mini-implants (OMIs) as skeletal anchorage in combination with teeth as dental anchorage (hybrid expander) allows for higher expansion forces to overcome the increased resistance of the circummaxillary sutures in more adult patients [5].This hybrid expander technique is referred to as the MARPE technique (Mini-implant Assisted Rapid Palatal Expansion) and is considered "rapid" with 2–3 activations per day (0.4–0.6 mm/day). This technique has become increasingly popular, although due to the rapid opening protocol and due to weaknesses in the expander design dental side effects and plastic deformation, breakage or loosening [6, 7] of connecting wires and OMIs may occur. Additionally, potential cranial complications such as infraorbital numbness was observed clinically [6] and pterygoid deformations, with a risk of cranial fractures [8, 9] might arise, as found in finite element analysis studies. Fear of these complications could necessitate surgical assistance [10]. Therefore, it is advisable to apply a slow expansion protocol [11, 12] in order to reduce the occurrence of these side effects.

To address the challenges in adult patients, the Mini-screw Assisted Rapid Palatal Expansion (MARPE) technique has emerged as a promising alternative. This approach utilizes two to four palatal orthodontic Mini-screws as skeletal anchorage in combination with dental anchorage, allowing for higher expansion forces to overcome the increased resistance of the circummaxillary sutures [5]. Despite its popularity, rapid expansion protocols in MARPE may lead to dental side effects and potential cranial complications, prompting caution in its application [6].

In contrast, the introduction of pure bone-borne maxillary expanders offers a potential solution to mitigate adverse effects associated with MARPE. These expanders, such as the Micro4-expander and PowerScrew, can be activated either rapidly or slowly [11, 13]. Slow expansion over an extended period has been shown to generate low forces, effectively opening the mid-palatal suture while minimizing risks. Recent innovations in force-controlled activation protocols, such as the Force Control PolyCyclic protocol (FCPC), have further enhanced the safety and efficacy of slow expansion techniques. By limiting expansion forces to 100–120 N with a torque wrench of 400–500 cN and incorporating periodic contraction phases, these protocols aim to stimulate sutural growth while reducing the likelihood of complications [11, 12]. In this publication this innovative force-controlled activation protocol for adult patients was described in combination with a twice-daily polycyclic "expansion-contraction" procedure (Force Control PolyCyclic protocol=FCPC protocol. During expansion force is limited as described above, contraction means turning back the jack screw until zero expansion force (normally 6 turns back) thus possibly stimulating sutural growth [11].

Advanced imaging techniques, such as Cone Beam Computed Tomography (CBCT) coupled with computer software analysis, enable precise evaluation of craniofacial structures during orthodontic treatment [14, 15],. This allows for real-time assessment of bone movements and cranial adaptations, facilitating the comparison of different expansion protocols [16].

The primary objective of this study was to compare the cranial effects and transversal changes between two groups: the FCPC-Mini-screw Assisted Slow Palatal Expansion Group (FCPC-MASPE-G) [11] and the Mini-screw Assisted Rapid Palatal Expansion Group (MARPE-G). Both groups underwent treatment using pure bone-borne skeletal expanders (Micro4-expander), with the FCPC protocol implemented in the former group. In a secondary objective the study aimed to evaluate the efficiency of the expansion process in terms of reliability of expander and anchorage, and midpalatal suture opening in relation to the activation protocol used.

Materials and methods

Study design

This consecutive retrospective study adhered to the principles outlined in the Declaration of Helsinki and has received approval from the local Review Board (declaration section of manuscript), which had been obtained during a previous MASPE study [11]. The force controlled polycyclic slow expansion group (FCPC-MASPE-G) comprised 35 consecutive adult patients (28 females, 7 males – 80%/20%) aged between 18 and 54 years (29.2 ± 9.41 years) who did not require surgical intervention. The rapid expansion group (MARPE-G) consisted of 6 consecutive patients (5 females, 1 male – 83%/ 17%) aged between 18 and 34 years (26.3 ± 6.4 years), also successfully treated without surgical assistance. A cone beam computed tomography (CBCT) scan of the head (16.5×12.0 to 23.0×17.0 cm), 0.4 mm voxel size, 120 kV) was conducted before and after the midpalatal suture opening [11], with the orientation set to the Frankfort horizontal plane, skeletal midline, and aligned through the deepest part of the lateral aspects of the zygomatic bone [14, 17].

Both groups received treatment with pure bone-borne palatal expanders (Fig. 1) [13]. In the FCPC-MASPE-G (Fig. 1a), the expansion force at the activation key was limited to 500 cN (force control measured with a spring scale, 10 N, Arbor Scientific, Ann Arbor, USA) (Fig. 1b) while employing discontinuous, polycyclic activations (FCPC protocol, see introduction).The MARPE-G (Fig. 1c)utilized continuous activation with 2 opening turns per day (2×0.17 mm) without the FCPC protocol until the desired width was achieved [5]. The mean time of the midpalatal suture opening in FCPC-MASPE-G was around 3–4 months [11].

Patient consent was obtained for a cranial CBCT scan (KaVo 3D eXam, KaVo Dental GmbH, Biberach, Germany) prior to treatment (T1). A subsequent CBCT (T2) was conducted one month after the completion of maxillary expansion in the MARPE-G group, while in the FCPC-MASPE-G group, it was performed three months later.

The inclusion criteriawere: (1) patients older than 18 years, (2) Micro4-expander with Powerscrew™ [11], (3) maxillary transverse deficiency greater than 2 mm measured by WALA ridge points at the lower first molars [18], (4) a CBCT within 5 months after completion of the active expansion, (5) lack of previous orthodontic treatment or maxillary osteotomy, (6) absence of active periodontal disease with lack of dental hygiene and (7) absence of any craniofacial syndromes.

Mini screws and expander design

Previously, four orthodontic mini-implants measuring 16 mm in length and 2.5 mm in diameter, manufactured by Jeil company, (Seoul, South Korea), were positioned in the anterior palate at the M4-M5 locations. These locations are halfway between the palatal cusp of the first and second premolars to the mid-palatal line. The placement was conducted under local anesthesia [6, 13]. After a period of 3 months without loading, secondary stability of the OMIs was achieved [11]. Subsequently, the H-shaped skeletal expander (Micro4-expander Powerscrew) was positioned and cemented onto the heads of the implants.

3D analysis

At T1 and T2, the OsiriX DICOM viewer was employed to quantify the jackscrew opening, identify dental, sutural, and skeletal landmarks, and measure them as distances and angles in axial, sagittal, and coronal cross-section directions. This facilitated the comparison of widths and angles, providing a deeper understanding of maxillary widening in comparison to changes in cranial bone structures, primarily focusing on the sphenoid bone area. Measurements were conducted by two observers (D.W. and E.C.) following a previously established consensus methodology for simple landmark identification processes.

Cranial landmark identification and measurements

At T1 and T2, distance measurements between the following cranial landmarks were conducted: Measurements were taken between the frontal processes of the

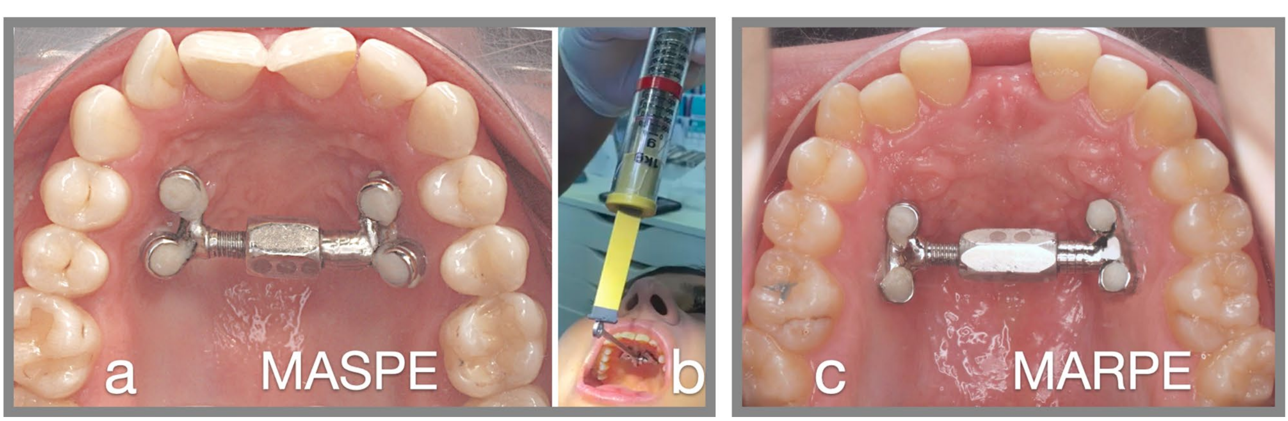

Fig. 1 Micro4-expander in use clinical use. **a**) in the **FCPC-MASPE-G** after expansion, **b**) Torque wrench key in clinical use for the application of the activation FCPC-protocol iC) MARPE-G after expansion and **c**)

maxilla bones (Fig. 2a), between the frontal processes of the zygoma bones [16, 17, 19] at the level of the fronto-zygomatic suture(Fig. 2b), between the tubercles of the lowest part of the zygomatic bone (Fig. 2c), and between the infraorbital foramen at the coronal cross-sections with the first premolars (Fig. 2d). Additionally, the angle (axial cross-section) between the sphenoid crest and the bilateral most distant points on the facies lateralis of the zygomatic bones was measured to detect the lateral displacements of the maxillary and zygomatic bones [15] (Fig. 2e).

Further measurements included determining the distance between the foramina of the pterygoid canal in the sphenoid bones [9, 20](Fig. 2f) and the distance at the most caudal and external part of the lateral pterygoid processes to identify any deformations of the pterygoid process (Fig. 2g) [21].

The distance between the posterior tuberosities of the maxilla articulating with the pterygoid processes (pterygomaxillary sutures in axial cross section) was also measured to monitor skeletal changes caused by maxillary widening related to the pterygoid process (Fig. 2h).

Finally, the distance between the inner edges of the two optic foramens in the sphenoid bone (axial cross-section) was also measured, as these structures represent very precise and easily identifiable landmarks. Since this bilateral measurement points are very close to the superior orbital fissure, which contains vascular structures as well as the abducens nerve and oculomotor nerve, positional changes can have critical clinical implications (Fig. 2.i). The two following reference points for distance measuring were defined as the points where the plane originating from the horizontal plate of the palatine bone intersects with the furthest posterior part of the mesial plate of the pterygoid processes(*) (Fig. 2l).

Suture width measurements

The widths of the sutures mentioned below were measured on both sides at T1 and T2 to investigate whether maxillary widening would also affect the zygomatic and temporal bones. These sutures were measured at their lowest and outermost sections. Firstly, the zygomaticomaxillary sutures (Fig. 2j) were measured in coronal cross-section. Secondly, in axial cross-sections, the widths of the zygomaticotemporal sutures [15, 17, 22, 23] (Fig. 2k) were measured; thirdly, the widths of the pterygopalatine sutures (→) were measured at the level of the pyramidal process of the horizontal plate of the palatine bone and the medial plate of the pterygoid process. The location for measuring the pterygopalatine suture on the medial plate of the pterygoid process was chosen based on its relationship to the horizontal plate of the palatine bone at this level, as this anatomical structure is easily identifiable as a reference point. This horizontal reference point is radiographically visible and highly precise, allowing for consistent measurements at the same location. Finally, mid-palatal suture widths were measured at three locations (anterior nasal spine, central at the level of the hex nut placement, and posterior nasal spine) in a transverse direction [21, 24] (Fig. 2l).

Dental measurements

The intercanine measurements were taken at the apices and cusps at both T1 and T2 (Fig. 3a). For intermolar measurements, the apex of the palatal root and the palatal cusp were selected (Fig. 3b).

Prerequisites required for an efficiency analysis to quantify different palatal expansion methods: the M.O.R.E.-factor

To compare FCPC-MASPE-G and MARPE-G outcomes, we calculated the relationship between mid-palatal suture opening and expander opening. This assesses expander and activation protocol performance. Jackscrew opening and mid-palatal suture opening at M-point (halfway distance between anterior and posterior nasal spine) (Fig. 4a) were measured at T1 and T2. Jackscrew opening was calculated by subtracting pre-activation width from total opening, enabling standardized comparison across expander types, mini screw systems, and activation protocols—termed M.O.R.E.-factor (Mid-palatal Opening Related to Expander opening-factor).

Statistical analysis

The data consist of four sets of variables (distances, angles, sutures, and dental results) measured at two time points (T1, T2) for 35 patients in the FCPC-MASPE-G and 6 patients in the MARPE-G. For this analysis, the Paired Student's t-test was used to assess the change at T1 and T2 within each group. To assess the differences between the two groups, Student's t-test for independent samples was conducted at T1/T2, as well as for the differences between the two time points (equivalent to the interaction effect in one-way ANOVA analysis). The Intraclass correlation coefficient was employed to evaluate the reliability of the measurements in the lateral and medial plates of the pterygoid process for two observers. Differences between T1 and T2 are presented in tables to illustrate the changes in the analyzed variables. P-values < 0.05 were considered statistically significant.

Results

With a sample size of 35 patients in the FCPC-MASPE-G and 6 patients in the MARPE-G, we are able to detect, with a statistical power of 80%, a difference of at least 1.2 mm SD in any continuous variable between the two groups, using a Student's T-test for independent data. In the pretreatment comparison (T1), the statistical analysis demonstrated no statistically significant difference

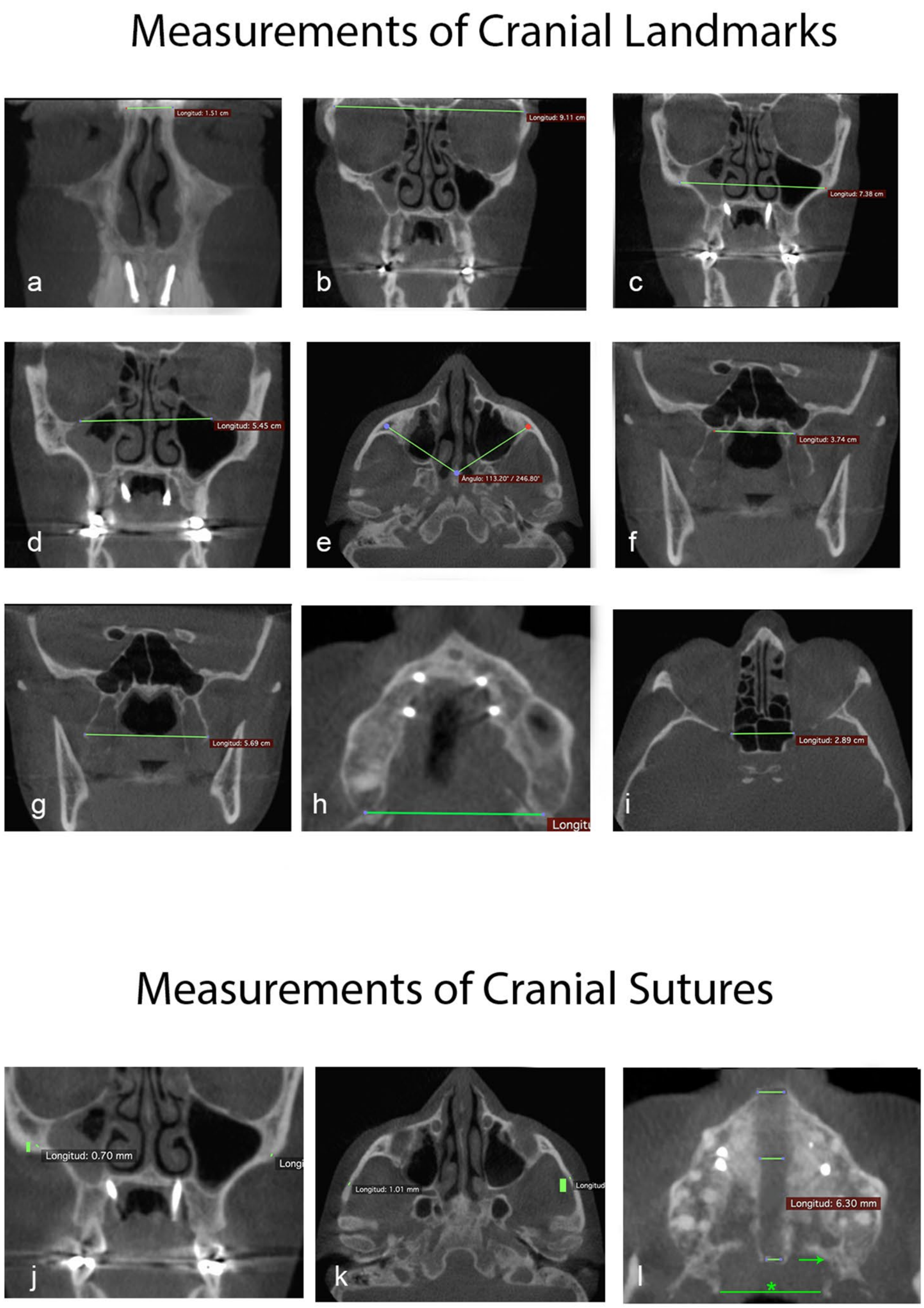

Fig. 2 Measurements of cranial landmarks and sutures. **a**) distance between frontal processes of the maxilla bones, **b**) distance between frontal processes of zygoma bones, **c**) distance between zygoma tubercle, **d**) distance between infraorbital foramen **e**) angle between the sphenoid crest and the bilateral most distant points (outer part) on the facies lateralis of the zygomatic bones, **f**) distance between the foramina of the pterygoid canal of the pterygoid processes, **g**) distance at the most caudal and external part of the lateral pterygoid processes, **h**) distance between maxillary tuberosities and at the level of the pterygoid processes with the pterygomaxillary sutures in axial cross-section, **i**) distance between the two optic foramen **j**) zygomaticomaxillary suture measurement (lowest part), **k**) zygomaticotemporal suture measurement and **l**) Three width measurements of the mid-palatal suture (anterior nasal spine, central at the level of the hex nut placement and posterior nasal spine). Width measurement of the pterygopalatine suture. The * symbol indicates the measuring line between the two reference points where the plane originating from the horizontal plate of the palatine bone intersects with the furthest posterior part of the mesial plate of the pterygoid processes

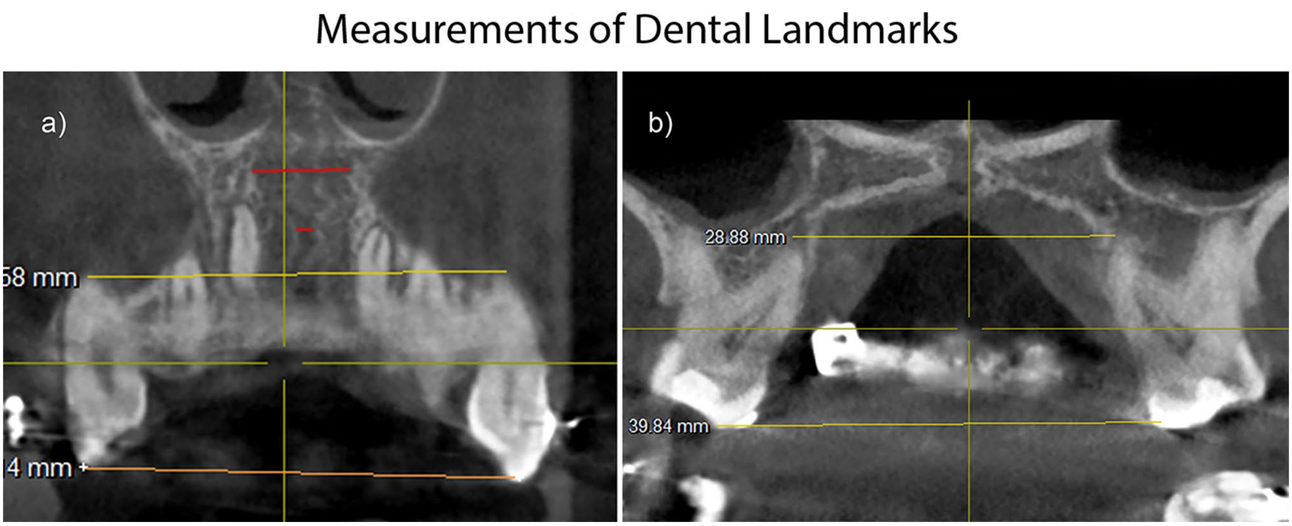

Fig. 3 **a**) Intercanine distance measured between apices and cusps. After 3 months midpalatal suture starts to close with gradual bone margin appositions (red lines). **b**) Intermolar distance between palatal apex and palatal cusp of the first permanent upper molars

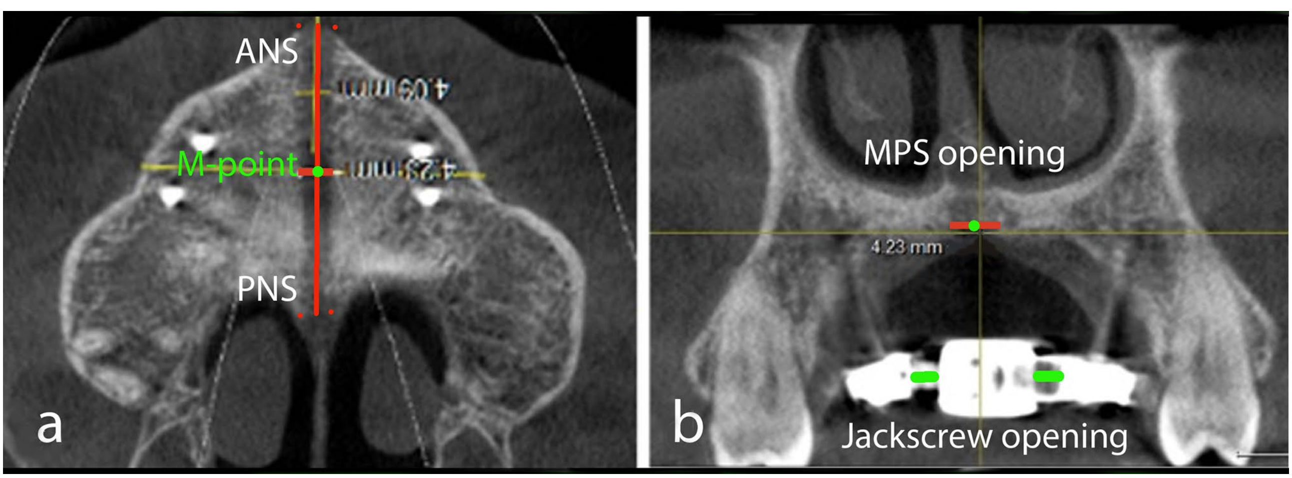

Fig. 4 Standardization of M.O.R.E.-factor calculation involves **a**) halfway distance between anterior and posterior nasal spine the M-point is located to measure the width of midpalatal suture opening, and **b**) measuring of the midpalatal suture opening

between the two groups, indicating intragroup homogeneity. This justifies comparing the two groups, even though the rapid group comprised only six patients (Table 1).

In both groups, skeletal expanders induced cranial, sutural, and dental changes, primarily characterized by an increase in the width of the maxillary, palatine, and zygomatic bones (Table 2). In the MARPE-G, the mean jackscrew opening was 7.1 mm with a mean treatment duration of 23±5 days, while in the FCPC-MASPE-G, these values were 5.2 mm and 81.2±31 days, respectively [11].

Following maxillary disjunction in both the FCPC-MASPE-G and MARPE-G, statistical analysis revealed significant widening across all analyzed parameters (cranial, sutural, and dental). Notably, a stable MARPE-G with minimal changes was observed in the posterior part of the sphenoid bone, specifically at the foramen of the pterygoid canal ($p=0.068$) and the optic foramen ($p=0.990$). The primary distinction between the two groups was the twofold greater deformation of the pterygoid processes observed in MARPE-G (Table 2).

In the FCPC-MASPE-G zygomaticomaxillary and zygomaticotemporal sutures appear to significantly respond to mechanical stimulation with increased sutural widening, whereas in MARPE-G the zygomaticotemporal sutures show no statistical changes in width. In both groups the pterygopalatine suture does not respond significantly to the significant widening of the mid-palatal suture (Table 2).

Table 1 Statistical comparison to assess similarities between slow and rapid expansion groups at T1 and T2

Intercranial bones distances	FCPC-Slow Expansion Group (MASPE)				Rapid Expansion Group (MARPE)			
	T1 (n=35)	T2 (n=35)	T2-T1 (N=35)	**P-value (*) T1 vs T2**	T1 (n=6)	T2 (n=6)	T2-T1 (n=6)	**P-value (*) T1 vs T2**
Distance (mm) - Frontal Process of Maxilla								
Mean (SD)	13.47 (1.03)	14.11 (1.44)	0.64 (0.78)	**< 0.001**	14.20 (0.88)	14.52 (1.56)	0.32 (1.03)	0.473
Range	12.00 - 16.24	11.80 - 18.40	-0.90 - 2.70		13.20 -15.60	12.40 16.90	-0.98 - 1.49	
Distance (mm) - Infraorbital Foramen								
Mean (SD)	55.27 (3.83)	58.19 (3.97)	2.92 (1.77)	**< 0.001**	52.07 (1.85)	55.50 (1.62)	3.43 (0.69)	**< 0.001**
Range	46.65 - 64.90	46.88 - 66.90	0.23 - 7.71		49.67 - 55.08	53.77 - 58.00	2.71 - 4.53	
Distance (mm) - Frontal Process of Zygoma								
Mean (SD)	90.86 (4.65)	91.67 (4.16)	0.81 (1.55)	**< 0.001**	87.17 (4.49)	87.65 (4.24)	0.47 (0.67)	0.145
Range	77.89 - 98.60	83.02 - 99.30	-1.50 - 5.13		80.23 - 94.20	81.21 - 94.34	-0.30 - 1.22	
Distance (mm) - Zygoma Tubercle								
Mean (SD)	82.56 (6.21)	84.57(5.95)	2.01 (1.47)	**< 0.001**	84.01 (4.52)	85.26 (4.97)	1.24 (1.40)	0.083
Range	64.80 - 94.50	65.90 - 94.80	0.20 - 5.20		79.45 - 92.43	78.31 - 90.89	1.00 - 2.96	
Distance (mm) - Pterygoid. lateral plate (Ob.1)								
Mean (SD)	52.23 (4.56)	53.10 (4.57)	0.87 (0.91)	**< 0.001**	53.64 (2.87)	56.57 (2.10)	2.80 (1.65)	**0.008**
Range	45.26 - 68.00	44.59 - 68.90	- 0.95 - 3.45		48.34 -56.60	54.13- 59.27	0.23 - 3.32	
Distance (mm) - Pterygoid. lateral plate (Ob.2)								
Mean (SD)	52.80(4.54)	54.03 (4.30)	1.22 (0.87)	**< 0.001**	53.53 (3.58)	56.44 (2.02)	3.04 (1.76)	**0.009**
Range	45.28 - 68.30	47.03 - 69.12	- 0.39 - 3.64		48.02 - 57.48	54.13 - 59.27	1.79 - 3.26	
Distance (mm) - Pterygoid. medial plate (Ob.1)								
Mean (SD)	29.51 (2.18)	30.87 (2.57)	1.35 (1.10)	**< 0.001**	29.80 (1.75)	31.97 (1.51)	2.17 (1.19)	**0.007**
Range	25.57 - 33.00	26.90 - 35.60	-0.2 - 4.14		28.02 - 32.23	30.14 - 33.71	1.56 - 3.24	
Distance (mm) - Pterygoid. medial plate (Ob.2)								
Mean (SD)	29.51 (2.40)	30.57 (2.37)	1.06 (0.85)	**< 0.001**	29.64 (2.00)	31.69 (2.30)	2.04 (0.60)	**< 0.001**
Range	25.30 - 33.10	26.05 - 34.56	- 0.9 - 3.12		27.33 - 31.89	29.10 - 34.05	0.88 - 4.36	
Distance (mm) - Optic Foramen								
Mean (SD)	26.50 (2.18)	26.50 (2.37)	- 0.017 (0.78)	0.99	27.85 (1.59)	27.58 (1.27)	-0.27 (0.48)	0.526
Range	23.04 - 30.07	22.70 - 31.00	1.50-2.54		27.60 - 32.02	27.64 - 32.22	-0.90 - 0.24	
Distance (mm) - Maxillary Tuberosity								
Mean (SD)	43.50 (4.29)	47.21 (4.11)	3.70 (2.14)	**< 0.001**	44.46 (2.68)	48.06 (3.28)	3.60 (0.80)	**< 0.001**
Range	37.00 - 52.93	39.70- 55.74	0.7 - 7.78		41.64 - 48.80	44.45 - 53.57	2.62 - 4. 77	
Distance (mm) - Foramen Pterygoid Canal								
Mean (SD)	33.37 (2.86)	33.55 (2.79)	0.18 (0.57)	0.068	35.29 (2.50)	35.37 (1.68)	0.08 (0.91)	0.836
Range	28.00 - 42.51	28.10 - 41.64	0.90 - 1.50		31.52 - 37.98	32.64 - 36.95	-1.95 - 0.43	
Angle (degree) - Zygoma Body to Sphenoid Crest								
Mean (SD)	111.78 (9.27)	112.92 (8.90)	1.14(1.55)	**< 0.001**	112.5 (3.04)	114.11 (2.87)	1.58 (0.41)	**< 0.001**
Range	86.34 - 133.95	90.97 - 133.96	2.47 - 4.63		108.4 - 115.50	110.1 - 116.7	1.18 - 2.10	

(*) Paired Student's T test

(**) Independent data Student's T test

Widths of Cranial Sutures	FCPC-Slow Expansion Group (MASPE)				Rapid Expansion Group (MARPE)			
	T1 (n=35)	T2 (n=35)	T2-T1 (N=35)	**P-value (*) T1 vs T2**	T1 (n=6)	T2 (n=6)	T2-T1 (n=6)	**P-value (*) T1 vs T2**
Suture (mm) - Zygomaticotemporal (left)								
Mean (SD)	0.49 (0.21)	0.63 (0.24)	0.13(0.25)	**0.003**	0.48 (0.83)	0.57 (0.04)	0.09 (0.94)	0.063
Range	0.20 - 1.14	0.30 - 1.06	-0.26 - 0.80		0.40 - 0.62	0.53- 0.64	-0.11 - 0.24	
Suture (mm) - Zygomaticotemporal (right)								
Mean (SD)	0.55 (0.23)	0.65 (0.32)	0.10 (0.28)	**0.035**	0.47 (0.72)	0.53 (0.12)	0.05 (0.14)	0.395
Range	0.31 - 1.25	0.20 - 1.60	-0.56 - 1.15		0.42 - 0.62	0.35 - 0.68	-0.9 -0.24	
Suture (mm) - Zygomaticomaxillary (left)								
Mean (SD)	0.52 (0.12)	0.66 (0.19)	0.14 (0.22)	**< 0.001**	0.58 (0.10)	0.66 (0.10)	0.85 (0.65)	**0.025**
Range	0.37 - 0.80	0.27 - 1.20	-0.39 - 0.71		0.40 - 0.68	0.52 - 0.82	0.03 - 0.18	
Suture (mm) - Zygomaticomaxillary (right)								
Mean (SD)	0.52 (0.21)	0.68 (0.18)	0.15 (0.24)	**< 0.001**	0.52 (0.78)	0.63 (0.42)	0.10 (0.07)	**0.02**
Range	0.13 - 1.15	0.27 - 1.02	-0.49 - 0.58		0.00 - 0.22	0.56 - 0.68	-0.04 - 0.26	
Suture (mm) - pterygopalatine (left)								
Mean (SD)	0.37 (0.11)	0.38 (0.17)	0.01 (0.17)	0.652	0.35 (0.15)	0.29 (0.13)	- 0.06 (0.22)	0.551
Range	0.16 - 0.56	0.00 - 0.83	-0.40 - 0.41		0.10 - 0.53	0.19 - 0.55	-0.30 - 0.22	
Suture (mm) - pterygopalatine (right)								
Mean (SD)	0.35 (0.10)	0.38 (0.20)	0.03 (0.20)	0.341	0.34 (0.19)	0.30 (0.04)	- 0.04 (0.21)	0.642
Range	0.20 - 0.50	0.00 - 0.90	-0.40 - 0.53		0.12 - 0.59	0.26 - 0.35	-0.32 - 0.23	
Suture (mm) - Anterior Midpalatal (ANS)								
Mean (SD)	0.58 (0.21)	6.32 (2.30)	5.73 (2.29)	**< 0.001**	0.13 (0.10)	5.93 (1.16)	5.79 (1.19)	**< 0.001**
Range	0.20 - 1.02	2.39 - 12.10	1.92 - 11.04		0.00 - 0.22	4.56 - 7.59	4.34 - 7.39	
Suture (mm) - Central Midpalatal / Hexnat								
Mean (SD)	0.45 (0.36)	5.08 (2.07)	4.63 (2.06)	**< 0.001**	0.50 (0.34)	4.08 (0.59)	3.57 (0.60)	**< 0.001**
Range	0.10 - 1.60	2.01 - 11.03	1.73 - 10.68		0.20 - 1.00	3.14 - 4.78	2.84 - 4.36	
Suture (mm) - Posterior Midpalatal (PNS) (Ob.1)								
Mean (SD)	0.36 (0.30)	3.41 (1.16)	3.04 (1.12)	**< 0.001**	0.15 (0.15)	2.66 (0.45)	2.51 (0.43)	**< 0.001**
Range	0.00 - 1.26	1.74 - 5.96	1.34 - 5.81		0.00 - 0.40	2.03 - 3.26	1.83 - 2.94	
Suture (mm) - Posterior Midpalatal (PNS) (Ob.2)								
Mean (SD)	0.40 (0.36)	3.13 (1.05)	2.72 (0.95)	**< 0.001**	0.12 (0.14)	2.91 (0.25)	2.79 (0.31)	**< 0.001**
Range	0.10 - 1.65	1.30 - 5.07	1.10 - 4.87		0.00 - 0.34	2.52 - 3.20	2.32 - 3.20	

(*) Paired Student's T test

(**) Independent data Student's T test

Interdental Distances	FCPC-Slow Expansion Group (MASPE)				Rapid Expansion Group (MARPE)			
	T1 (n=35)	T2 (n=35)	T2-T1 (N=35)	**P-value (*) T1 vs T2**	T1 (n=6)	T2 (n=6)	T2-T1 (n=6)	**P-value (*) T1 vs T2**
Dental (mm) - Apices of upper canines								
Mean (SD)	26.16 (3.76)	32.00 (3.63)	5.83 (2.63)	**< 0.001**	25.69 (2.76)	30.82 (3.29)	4.80 (1.11)	**< 0.001**
Range	20.85 - 34.01	25.82 - 39.70	0.30 - 12.06		21.00 - 28.44	24.42 - 34.07	3.47 - 6.01	
Dental(mm) - Cusps of upper canines								
Mean (SD)	30.93 (3.89)	36.67 (3.35)	5.74 (2.27)	**< 0.001**	29.73 (3.48)	33.99 (3.20)	3.75 (2.85)	**0.023**
Range	23.40 - 37.60	29.40 - 43.00	2.02 - 11.17		23.38 - 32.56	27.78 - 36.56	0.67 - 8.29	
Dental (mm) -Palatal apices of first upper molars								
Mean (SD)	31.29 (2.64)	36.06 (3.66)	4.77 (2.30)	**< 0.001**	32.74(2.82)	37.74 (2.52)	5.00 (0.99)	**< 0.001**
Range	24.81 - 36.00	29.33 - 43.10	1.40 - 10.35		29.28 - 37.46	31.05 - 38.85	3.24 - 5.94	
Dental (mm) - Palatal cusps of first upper molars								
Mean (SD)	38.81 (3.43)	43.61 (4.27)	4.79 (1.89)	**< 0.001**	35.37 (3.82)	40.61 (3.05)	5.40 (1.59)	**< 0.001**
Range	30.80 - 44.50	34.89 - 52.70	2.01 - 8.80		30.34 - 40.12	34.78 - 42.34	3.48 - 7.35	

(*) Paired Student's T test

(**) Independent data Student's T test

Jackscrew Opening	FCPC-Slow Expansion Group (MASPE)				Rapid Expansion Group (MARPE)			
	T1 (n=35)	T2 (n=35)	T2-T1 (N=35)	**P-value (*) T1 vs T2**	T1 (n=6)	T2 (n=6)	T2-T1 (n=6)	**P-value (*) T1 vs T2**
Distance (mm)								
Mean (SD)	0.56 (0.23)	5.77 (1.49)	5.21 (1.51)	**< 0.001**	0.45 (0.15)	7.55 (0.46)	7.10 (0.51)	**< 0.001**
Range	0.20 - 1.00	3.80 - 10.40	1.41 - 13.30		0.20 -0.60	7.00 - 8.20	4.20- 6.80	
MORE- Factor			88.9%				50.2%	

(*) Paired Student's T test

Table 2 Distances between cranial and dental landmarks, sutural widths, and angle changes were measured prior to treatment start (T1) and after mid-palatal suture opening (T2) and compared between slow and rapid expansion groups

Intercranial bones distances	T1 Mean difference		T2 Mean difference		T2-T1 Mean diff.	
	Slow-Rapid at T1	**P-value (**) Slow vs Rapid at T1**	Slow-Rapid at T2	**P-value (**) Slow vs Rapid at T2**	Slow-Rapid at T2-T1	**P-value (**) Slow vs Rapid at T2-T1**
Distance (mm) - Frontal Process of Maxilla Mean (SD) Range	-0.72 (0.44)	0.114	-0.41 (0.64)	0.524	0.31 (0.36)	0.395
Distance (mm) - Infraorbital Foramen Mean (SD) Range	3.20 (1.60)	0.054	2.69 (1.66)	0.113	-0.50 (0.73)	0.502
Distance (mm) - Frontal Process of Zygoma Mean (SD) Range	3.68 (204)	0.079	4.02 (1.84)	**0.035**	0.33 (0.65)	0.605
Distance (mm) - Zygoma Tubercle Mean (SD) Range	-1.45 (2.66)	0.588	- 0.68 (2.57)	0.792	0.77 (0.64)	0.24
Distance (mm) - Pterygoid. lateral plate (Ob.1) Mean (SD) Range	-1.40 (193)	0.472	- 2.54 (1.80)	0.167	-1.82 (0.73)	0.051
Distance (mm) - Pterygoid. lateral plate (Ob.2) Mean (SD) Range	-0.72 (1.96)	0.715	-3.33 (1.91)	0.089	-1.93 (0.46)	**< 0.001**
Distance (mm) - Pterygoid. medial plate (Ob.1) Mean (SD) Range	-0.28 (1.03)	0.784	-1.10 (1.08)	0.318	-0.81 (0.49)	0.105
Distance (mm) - Pterygoid. medial plate (Ob.2) Mean (SD) Range	-0.13 (0.95)	0.888	-1.11 (1.04)	0.294	-0.97 (0.36)	**0.011**
Distance (mm) - Optic Foramen Mean (SD) Range	-1.35 (0.93)	0.154	-1.08 (0.65)	0.124	0.26 (0.35)	0.457
Distance (mm) - Maxillary Tuberosity Mean (SD) Range	-0.95 (1.82)	0.604	-0.85 (1.77)	0.634	0.10 (0.89)	0.91
Distance (mm) - Foramen Pterygoid Canal Mean (SD) Range	-1.92 (1.24)	0.131	-1.81 (1.18)	0.132	0.10 (0.27)	0.715
Angle (degree) - Zygoma Body to Sphenoid Crest Mean (SD) Range	-0-74 (3.85)	0.847	-1.18 (3.70)	0.751	-0.43 (0.64)	0.504

Widths of Cranial Sutures	T1 Mean difference		T2 Mean difference		T2-T1 Mean diff.	
	Slow-Rapid at T1	**P-value (**) Slow vs Rapid at T1**	Slow-Rapid at T2	**P-value (**) Slow vs Rapid at T2**	Slow-Rapid at T2-T1	**P-value (**) Slow vs Rapid at T2-T1**
Suture (mm) - Zygomaticotemporal (left) Mean (SD) Range	0.01 (0.09)	0.846	0.06 (0.04)	0.171	0.04 (0.10)	0.674
Suture (mm) - Zygomaticotemporal (right) Mean (SD) Range	0.07 (0.09)	**0.043**	0.12 (0.13)	0.372	0.04 (0.12)	0.714
Suture (mm) - Zygomaticomaxillary (left) Mean (SD) Range	- 0.05 (0.05)	0.284	0.00 (0.08)	0.992	0.05 (0.04)	0.205
Suture (mm) - Zygomaticomaxillary (right) Mean (SD) Range	0.00 (0.04)	0.928	0.05 (0.03)	0.127	0.05 (0.52)	0.33
Suture (mm) - pterygopalatine (left) Mean (SD) Range	0.01 (0.05)	0.795	0.08 (0.07)	0.264	0.07 (0.07)	0.37
Suture (mm) - pterygopalatine (right) Mean (SD) Range	0.01 (0.08)	0.906	0.08 (0.04)	**0.027**	0.07 (0.91)	0.406
Suture (mm) - Anterior Midpalatal (ANS) Mean (SD) Range	0.45 (0.09)	**< 0.001**	0.39 (0.97)	0.689	-0.06 (0.96)	0.953
Suture (mm) - Central Midpalatal / Hexnat Mean (SD) Range	-0.05 (0.16)	0.766	1.00 (0.42)	**0.026**	1.05 (0.42)	**0.02**
Suture (mm) - Posterior Midpalatal (PNS) (Ob.1) Mean (SD) Range	0.21 (0.12)	0.096	0.74 (0.48)	0.133	0.52 (0.25)	0.056
Suture (mm) - Posterior Midpalatal (PNS) (Ob.2) Mean (SD) Range	0.27 (0.15)	0.075	0.21 (0.20)	0.302	-0.06 (0.20)	0.767

Interdental Distances	T1 Mean difference		T2 Mean difference		T2-T1 Mean diff.	
	Slow-Rapid at T1	**P-value (**) Slow vs Rapid at T1**	Slow-Rapid at T2	P-value (**) Slow vs Rapid at T2	Slow-Rapid at T2-T1	**P-value (**) Slow vs Rapid at T2-T1**
Dental (mm) - Apices of upper canines Mean (SD) Range	0.47 (1.6)	0.77	1.17 (0.62)	0.463	0.70 (0.61)	0.264
Dental(mm) - Cusps of upper canines Mean (SD) Range	1.19 (1.69)	0.048	2.68 (1.47)	0.076	1.48 (1.05)	0.165
Dental (mm) -Palatal apices of first upper molars Mean (SD) Range	-1.45 (1.17)	0.226	-1.67 (1.56)	0.29	-0.22 (0.96)	0.814
Dental (mm) - Palatal cusps of first upper molars Mean (SD) Range	3.43 (1.53)	**0.031**	2.9 (1.82)	0.11	-0.44 (0.81)	0.593

Jackscrew Opening	T1 Mean difference		T2 Mean difference		T2-T1 Mean diff.	
	Slow-Rapid at T1	**P-value (**) Slow vs Rapid at T1**	Slow-Rapid at T2	**P-value (**) Slow vs Rapid at T2**	Slow-Rapid at T2-T1	**P-value (**) Slow vs Rapid at T2-T1**
Distance (mm) Mean (SD) Range	0.11 (0.09)	0.273	-1.77 (0.62)	**0.007**	-1.88 (0.62)	**0.005**

(**) Independent data Student's T test

Similarities and differences between both groups

Analyzing cranial, sutural and dental measurements between both groups at T1 revealed no statistical significance, suggesting a similarity between both groups prior to treatment start. At T2 differences appeared in the intergroup comparison in the amount of central midpalatal suture and jackscrew widening, indicating a different mechanical behavior between MARPE-G and FCPC-MASPE-G (Table 1).

Most landmarks were similar between both groups during T1 and T2. The mean difference amidst FCPC-MASPE-G and MARPE-G revealed that three out of four analyzed distances between the pterygoid processes experienced notable increases (p=0.00-0.051) (Table 1), indicating statistically relevant deformations (observer 1 and 2). The interclass correlation coefficient between observer 1 and 2 for the lateral and internal plates of the pterygoid process was 0.894 (95% CI) and 0.965 (95% CI), respectively.

In this study, the midpalatal suture also shows comparable sutural response in both groups, with greater opening observed at the anterior nasal spine and approximately 50% less opening at the posterior nasal spine indicating a V-shaped opening.

Central Midpalatal Opening Related to the Expander opening is called the M.O.R.E.-factor. This stands for the percentage representing the efficiency of any maxillary expansion device. In the FCPC-MASPE-G (4.63 mm divided by 5.21 mm*100), this factor was approximately 88.9%, while in the MARPE-G with rapid palatal expansion (3.57 mm divided by 7.1 mm*100) it was only 50.2% (Table 2).

A low percentage reveals an inefficient device with anchorage loss and/or expander deformation. Conversely, a high M.O.R.E.-factor confirms a highly efficient expansion procedure.

Discussion

This study was conducted on two groups of adult patients, in all of which successful maxillary expansion had been performed using the same expander but with different activation protocols. The Slow Expansion Group utilized the FCPC-activation protocol [11] while the Rapid Expansion Group continuously opened the expander two turns per day similar to the MARPE activations protocol [6]. The objective was to assess the outcomes of the two groups in terms of skeletal, sutural and dental changes, as well as to establish an efficiency relation to evaluate the effectiveness of the expansion procedures in both groups.

Recently, the assessment of low-dose CBCT technology (lower kV settings with larger voxel sizes) has proven to be an effective tool for measuring bone and dental landmarks clinically, as well as for evaluating mid-palatal and circummaxillary sutures and their changes in width [3, 16]. However, this recent low-radiation technology could not be applied because this retrospective study, spanning several years, did not allow for its use at that time. The high-resolution CBCT imaging used in the present study is essential for detecting sutural changes, bone remodeling, and potential asymmetries that could influence treatment planning and follow-up. This necessity justifies performing an additional CBCT after 3 months to assess treatment efficacy and analyze cranial changes, providing critical clinical information that other methods could not offer.

In concordance with other MARPE studies [5, 25, 26] the mechanical opening of the maxillary bone with bone borne expanders, had a greater impact on the lower midfacial bone structures (maxilla, palatal bone and sphenoid bone), and also affected distant structures such as the zygomatic bones (Table 2) [25, 27]. This opening in coronal cross-sectional direction has a pyramidal configuration with the base in the palatine bones and the apex in the frontal process of the maxillary bone [12]. This is also observed in a MARPE study where the increase in nasal cavity width and nasal floor width, by 1.61±0.94 mm and 2.20±1.01 mm respectively, significantly improves the upper airway and can be beneficial for OSAS (Obstructive Sleep Apneas Syndrome) patients by enhancing airway passage through the nose [19].

At T2 we observed in our adult patients in MARPE-G an increase in distance in the frontal process of the maxilla with mean 0.32 mm and in the (*slow*) FCPC-MASPE-G a statistically significant with mean increase inter distance of 0.64 mm (p=0.000, Table 2). This leads to the conclusion that during rapid expansion skeletal structures have less time to adapt to deformation. During *rapid* activation (2×0.2 mm /d) Ahmida et al. [17] observed in children (12.7±1.74 years) frontonasal process widening values of 1.00±0.54 mm. This observation suggests that the greater sutural widening in this young age group is due to more adaptable sutures. Therefore, the present study demonstrates that the increase in nasal width, which is less than 1 mm, has little clinical significance from an aesthetic perspective. However, this should be considered in patients who do not have OSAS with broad nasal widths, where SARPE with disjunction of the pterygomaxillary suture is more indicated [10].

Between the initial measurement (T1) and the follow-up measurement (T2), there was a significant increase in the distances between the median plates and the lateral plates of the pterygoid processes in both groups. The increase amounted to 0.87–1.35 mm for FCPC-MASPE-G and 2.04–3.04 mm for MARPE-G (Table 2). This indicates that even with a slower activation rate and limited force (FCPC-MASPE-G), deformations in the pterygoid processes still occur, albeit approximately 50–60% less than in the MARPE-G. These pterygoid processes deformation (3 out of 4 measurements) are statistically more effectively detected in the lateral pterygoid plate due to the measurements being taken over a greater caudal distance, as it involves angular deformation (Table 1) [8]. Clinically, this suggests that, with less deformation of the pterygoid processes during the process of maxillary disjunctions, cranial stress and tension are also reduced or better controlled, thereby decreasing the risk of unpredictable cranial complications [8, 9], although not eliminating them [20]. Performing slow disjunctions over months of activation allows for better cranial adaptation to mechanical expansion [11], leading to less deformation of the pterygoid processes. This is because the extended time frame gives cranial sutures a greater capacity to absorb tensile forces and compressions, functioning as areas of increased mechanical resilience [11]. From a clinical perspective, despite the differences observed in the deformations of the pterygoid processes between the two groups, it should be noted that SARPE is the treatment of choice, particularly in cases with high mechanical resistance and in mature adult age groups [10].

Hybrid skeletal expanders resulted in even greater levels of pterygoid process deformation due to the higher cantilever arm of the wire arms placed on the molar bands [28]. This finding is supported by another MARPE study conducted by Cantarella et al., which reported mean pterygoid process deformations of 1.35 mm on the right side and 2.17 mm on the left side of the pterygoid process with 80% statistical power [21].

All of these observations align with other finite element studies that have demonstrated deformations of approximately 2 mm per side in the pterygoid processes following rapid palatal expansion [8, 20, 21]. Given that the pterygoid processes are integral components of the unpaired sphenoid bone, this increase in distance leads to notable deformations and risk of cranial fractures. Formularende.

In this study, the analysis of suture widening within the FCPC-MASPE-G revealed a consistent and significant increase across all examined sutures, except for the pterygopalatine sutures (Table 2, paired t-test). At T2, even in both groups during slow and rapid activation, there was almost no widening of the pterygopalatine sutures, with minimal variability but lacking statistical significance (0.01 mm to 0.30 mm). This could be explained by the pyramidal part of the palatine bone, due to maxillary expansion, acting mechanically like a wedge-shaped structure that slides between the pterygoid process and maxillary tuberosity [9, 21], leading to a compression of the pterygopalatine sutures. This would elucidate why some pterygopalatine suture measurements were even zero millimeters [21]. Variations of the spatial orientation of the pterygoid process against the pyramidal process could explain the statistically significance in the comparison post-treatment groups (T2 FCPC-MASPE-G vs. T2 CG, independent samples Test) of the right pterygopalatine suture ($p=0.027$) (Table 1), where significant widths increasing was observed.

It is well known that maxillary disjunction generates strains and stresses in the cranial structures, especially in the zygomatic arch [29], as it represents a buttress of great resistance against maxillary expansion with high tension exerted in the orbit of the unpaired sphenoid bone, orbital fissure, and the pterygoid processes [30]. Headache and diplopia due to increasing intracranial pressure (pseudotumor cerebri syndrome) have been reported [31]. Moreover, in both groups, even with rapid activation, the distance between both optic foramina and both pterygoid canals did not change between T1 and T2 (Table 2).

This is consistent with the unchanging diameter of the optic nerve sheath further supporting the safety of the MARPE technique [32].

But, according to Boryor's study [33], the upper rim of the zygomatic bone is also subjected to higher compressive stress, where the zygomaticomaxillary and zygomaticotemporal sutures act as mechanically elastic cranial components. Exceeding their elastic limits, especially in mature adult skulls that are less resilient, leads to a decrease in mechanical absorption, and therefore the occurrence of negative consequences [33, 34].

Our findings indicate that at T1, the mean width of the zygomaticomaxillary and zygomaticotemporal sutures in the FCPC-MASPE-G ranged between 0.52 and 0.55 mm. At T2, this group exhibited a significant increase in width in both sutures, approximately one-tenth of a millimeter ($p<0.001$ to 0.035, Table 2). In the MARPE-G group at T2, the widening of only the anterior zygomaticomaxillary sutures was significant ($p=0.02$), contrary to the insignificant widening of the posterior sutures (Table 2). These results in the MARPE-G sutural behavior are consistent and similar to those found in the study by Ghoneima et al. [22]. Here a rapid maxillary expansion protocol applied to younger patients (mean age, 12.3±1.9 years) showed a statistical absence of zygomaticotemporal suture widening. As no widening of the more posterior sutures (zygomaticotemporal) was observed during rapid activation, slow (and polycyclic) maxillary expansion, allowing for the development of metabolic activity, should be preferred, as observed in the FCPC-MASPE-G at T2. However, it should be noted that the statistical differences observed in the zygomaticotemporal sutures between T1 and T2 in both groups are very small, ranging positively from 0.05 to 0.13 mm (mean values), indicating an adaptive sutural response with minimal clinical relevance. But, due to the larger number of individuals in the FCPC-MASPE-G group, it is easier to detect statistically significant intragroup differences and may explain the absence of significance in the MARPE-G group. Additionally, this small difference between groups is not observed in the anterior zygomaticomaxillary sutures, which demonstrates statistical consistency following the "V" shape maxillary disjunction, despite the difference in the number of individuals between the groups.

However, in the post-treatment comparison of FCPC-MASPE-G and MARPE-G using the independent sample Test, both analyzed zygomatic sutures showed an absence of statistical significance (Table 1). This indicates that the small differences in widening could not be detected statistically or can be explained due to the metabolic activity of the sutures with additional bone apposition at their margins [35], particularly after the 3 months of treatment in the FCPC-MASPE-G. This lack of statistical significance can clearly be observed in Fig. 3a.

Considering that FCPC-MASPE-G enhances sutural response, the success rate of mid-palatal suture opening has been demonstrated to be 100% in adult patients under 30 years of age (n=21) [11] and has been further supported by a study conducted by Ponna [12], with an average age of 24.1 years, achieving a 100% success rate (n=17).

In February 2014, while still using the "2 activations/day" MARPE protocol [5, 6], we encountered a cranial complication in a 43-year-old female patient. The rapid widening resulted in an unexpected excessive unilateral opening of the frontomaxillary suture, approximately 6 mm, causing asymmetric widening of the nose and leading to an unaesthetic facial appearance (Fig. 5).

This experience has prompted us to limit the uncontrolled expansion force to 500 cN for activating the torque wrench and to change the rapid activation rate in adult skeletal expansions to a slow activation rate [11, 12]. The resulting expansive force level is consistent with other clinical studies in late adolescents, where 100 to 120 N have been clinically recorded as effective [36, 37]. Slow expansion and sutural response after midpalatal suture opening were investigated in an experimental animal study. Mature New Zealand rabbits underwent miniscrew-assisted slow maxillary widening with a light expansive force of only 100 g over 3 months, demonstrating that this was sufficient for the midpalatal sutures to

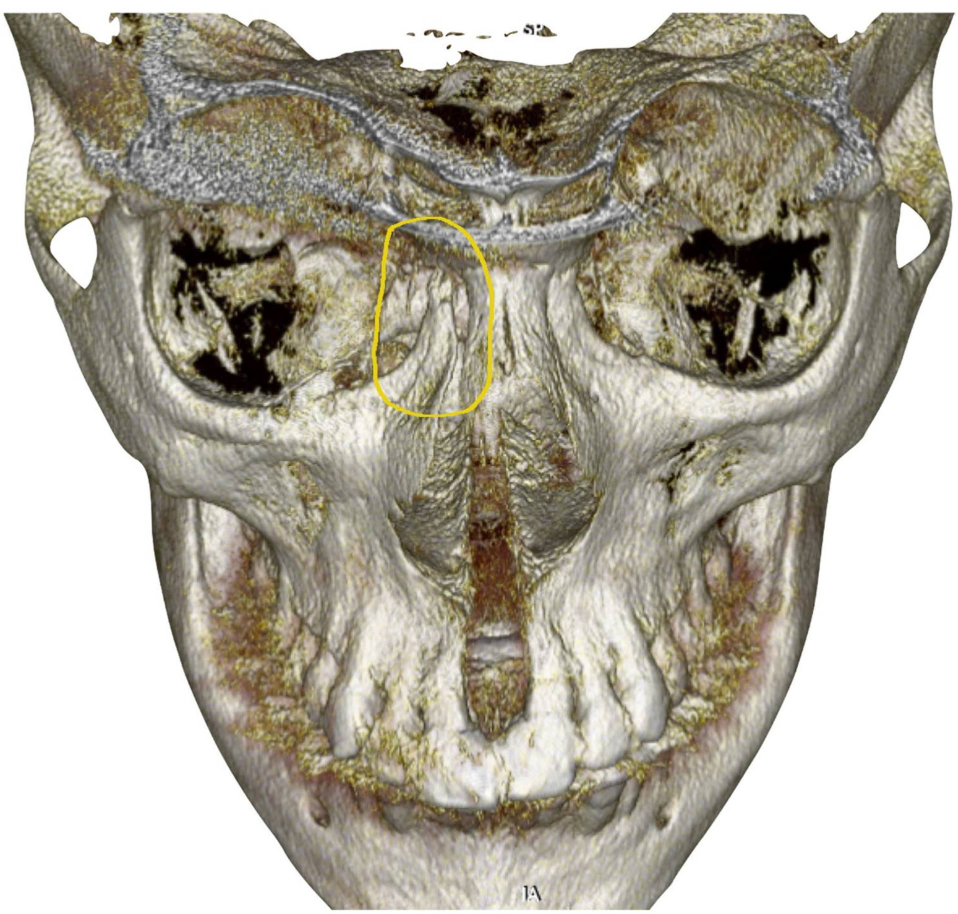

Fig. 5 Detachment of the right frontal process of the maxilla during palatal expansion in an adult patient who did not adhere to the prescribed force limitation (1200cN at the activation key)

open continuously. Consequently, the response in the sutures led to histologically proven formation of new bone after 2 weeks [35](Fig. 3a).

Moreover, the alternate opening- closing of sutures has also been tested in animal studies and proved to be more effective in generating anabolic stimuli with cell proliferation as a sutural response than continuous forces and therefore more suitable to weakening circummaxillary sutures [38].

In the context of circummaxillary sutural strategy, the incorporation of maxillary contraction/expansion activations on a weekly basis along with maxillary protraction strategies in class III treatments, even among late adolescents, has been demonstrated by Liou as Alt-RAMEC [39]. This approach allows for the advancement of the maxilla by 2.5 to 5 mm, indicating improved disarticulation of the pterygopalatine suture of the pterygoid process [39, 40].

In addition to the already implemented Force Control for adult maxillary expansion, the above findings led to a further improvement of the protocol by adding polycyclic closing-opening activations twice a day, resulting in the FCPC protocol.

Analyzing the sutural response between the FCPC-MASPE-G and the MARPE-G, it can be concluded that the FCPC protocol generates a superior bone and sutural response, and this difference is statistically significant in the paired T-test comparison (Table 2). The primary distinction between the two groups was the FCPC protocol characterized by its "slow," "force-controlled," and "discontinuous polycyclic" nature, as opposed to the "rapid," "unlimited in force," and "continuous" approach during maxillary opening.

This demonstrates that mini-screw-anchored slow palatal expansion (MASPE) in adult patients conducted over a period of 3–4 months is feasible, possible, and more recommendable [11, 12]. Therefore, weakening circummaxillary sutures over this period may reduce the risk of potential cranial base fractures or micro-fractures of the interdigitated osseous bone surfaces [8, 41, 42], particularly in adult patients with stiffer elastic properties [9, 33].

This study comprised two highly similar groups, both utilizing identical expansion devices with the same mini-screw configuration, very similar average ages, and solely successful outcomes. The only distinction lied in the activation protocol. By comparing expander opening to midpalatal suture opening (M.O.R.E.-factor), an efficiency ratio between the two groups was established to determine the expansion procedure with the fewest side effects.

The following formula has been used:

Mean Mid-palatal Opening: Mean Expander opening x 100 = performance %.

Example Ideally, if the jack screw of the expander were opened by 4 mm, the midpalatal suture should also open by exactly 4 mm. In such a scenario, the M.O.R.E.-factor would be 100%.

Three principal variables strongly influence the M.O.R.E.-factor: Firstly, the prevailing availability and quality of bone and the maturation of sutures, which correlate with age. Secondly the activation protocol, particularly whether it is rapid or slow (in addition eventually being polycyclic). And thirdly the variables of the expansion device, particularly in terms of rigidity and design of the expander [43], including its wire arms, length and diameter of the mini screws used and their stability in the bone [7, 44, 45].

While the FCPC-MASPE-G exhibited a M.O.R.E.-factor of 88.9%, the MARPE-G reached values of 50.2%. This difference suggests that limiting the expansion force and applying a slow and polycyclic protocol reduces the risk of expander complications and deformations during mid-palatal suture opening, with fewer implant displacements [46] and OMI bending [43, 47].Hybrid skeletal expanders (OMI:1.8 mm x 7 mm) achieved 43,2%, which is half of the aforementioned value [19]. In contrast, tooth-anchored expanders exhibit a M.O.R.E.-factor of approximately 30%, which is only one third (!) of the value mentioned above [48].

This study demonstrates that using the novel, slow contraction-expansion FCPC-protocol for non-surgical skeletal expansion in mature patients is advisable and advantageous.

In summary, while conventional tooth-borne expanders may be inadequate for adult patients, innovative techniques such as MARPE and slow expansion protocols offer promising alternatives. With careful consideration of expansion protocols and advancements in imaging technology, orthodontic treatment can be tailored to optimize outcomes while minimizing risks for adult patients requiring maxillary expansion.

Limitations of the study

One limitation was the relatively small size of the MARPE group (n=6) compared to the FCPC-MASPE group (n=35). Since this was a consecutive retrospective study, the assignment of treatment between the two groups was not random, which may pose a potential risk of selection bias. However, the pretreatment comparison demonstrated no statistically significant or relevant differences between the two groups, indicating intergroup homogeneity. This justifies comparing the two groups, although the rapid group comprised fewer patients.

After the introduction of the polycyclic slow activation protocol more than 10 years ago, which led to improved outcomes and fewer side effects, it was deemed unethical to continue enlarging the rapid group. Additionally, the limited number of CBCT radiographs in the MARPE-G group is less accessible in a retrospective study spanning several years, where this type of pre- and post-radiographs was particularly infrequent. Another limitation was that for the MARPE group, T2 measurements was one month after the end of maxillary expansion, while for the FCPC-MASPE group, it was three months.

Conclusion

1. SLOW expansion with FCPC protocol (FCPC-MASPE-G) can effectively widen the maxilla in adults, significantly impacting bones and sutures. However, there is 50–60% less pterygoid process deformation compared to RAPID expansion.
2. Mini-implant assisted SLOW maxillary expansion (MASPE) combined with the FCPC-protocol appears to be the more effective method for widening the mid-palatal and circummaxillary sutures.
3. In both groups, the maxillary and zygomatic bones, as well as the entire zygomatic arches were significantly displaced in a lateral direction resulting in a V-shape maxillary disjunction opening.
4. An efficiency or performance factor (M.O.R.E.-factor) can be established by comparing expander widening with the resulting midpalatal suture widening: For the SLOW-Group with FCPC protocol, this ratio was 88.6%, while for the RAPID group, it was only 50.2%.

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Author contributions
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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This manuscript is a retrospective study involving human participants and includes a statement on ethics approval and consent of the local review Board with number RB No. EK-2-2014/0016. Of the above sample of patients, a previous CBTC study has been performed (reference*). This previous article did not investigate the cranial changes that the authors have analyzed in the present study. **Reference: Success and complication rate of mini-screw assisted non-surgical palatal expansion in adults - a consecutive study using a novel force-controlled polycyclic activation protocol. Head Face Med [Internet]. 2021 Dec 1 [cited 2023 May 13];17* [1].

Consent for publication
This manuscript does not contain any individual person's data in any form that compromises their publication and therefore is not applicable.

Competing interests
The authors declare no competing interests.

Supplementary information
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Conflict of interest
None declared.

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