Success rate and suture separation ratio of non-surgical maxillary expansion depending on age and gender

Ji Yoon Jeon

The Graduate School
Yonsei University
Department of Dentistry

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Ji Yoon Jeon

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of Ji Yoon Jeon is approved.

Thesis Supervisor: Kee-Joon Lee

Han-Sung Jung

Chooryung Judi Chung

Sung-Hwan Choi

Hwi-Dong Jung

The Graduate School
Yonsei University

December 2021

감사의 글

대학원 박사 과정을 마무리하고 논문이 완성되기까지 긴 시간 동안 많은 관심과 아낌없는 가르침으로 부족한 제자를 이끌어 주시고 따뜻하게 격려해 주신 이기준 지도 교수님께 진심으로 감사드립니다. 바쁘신 와중에도 귀중한 시간을 내주시어 논문을 완성하기 위해 많은 조언과 가르침을 주신 정한성 교수님, 정주령 교수님, 최성환 교수님, 정휘동 교수님께 깊이 감사드립니다.

또한 많이 부족한 저를 연세대학교 치과교정학교실에서 교정학을 배울 수 있도록 기회를 주시고 교정과 전문의로서 올바른 의술을 펼칠 수 있도록 많은 가르침을 주신 황충주 교수님, 김경호 교수님, 유형석 교수님, 차정열 교수님, 최윤정 교수님, 박선형 교수님께 다시 한번 감사의 말씀을 드리고 싶습니다.

3년의 수련 기간 동안 가족보다 더 많은 시간을 보내며 서로에게 큰 힘이 되어주고 동고동락한 교정과 의국 동기 강주영, 이채경, 최은학, 한우진 선생과 의국 선배로서 많은 조언과 도움을 주신 천주희 선생님과 홍현기 선생님, 든든한 의국 후배님들께도 이 지면을 빌어 감사의 마음을 전합니다.

마지막으로 지금의 저를 있게 해 주시고 아낌없는 지원과 응원을 보내주시는 사랑하고 존경하는 할머니, 할아버지, 부모님과 동생에게도 고마운 마음을 전합니다.

2021년 12월 저자 씀

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ABSTRACT

Success rate and suture separation ratio of non-surgical maxillary expansion depending on age and gender

Ji Yoon Jeon

Department of Dentistry, The Graduate school, Yonsei University

(Directed by Professor Kee-Joon Lee, D.D.S., M.S., Ph.D.)

Introduction

This study aimed to assess the success rate and the amount of suture separation after the miniscrew-assisted rapid palatal expansion (MARPE) procedure in relation to the chronological age and gender of the patients.

Methods

The periapical radiographs of 215 subjects (95 male; 120 female; range, 6-60 years) who had undergone MARPE treatment were retrospectively analyzed. The success of suture separation was determined and, in suture-separated subjects, the amount of suture separation was evaluated by suture separation ratio calculated from the periapical radiograph obtained after active expansion. Association tests were performed using linear-by-linear association, the Jonckheere-Terpstra test, Fisher's exact test, and the Mann-Whitney U test, and, linear regression models were also developed.

Results

The success rate of suture separation was 61.05% in male, 94.17% in female, and 79.53% in both genders. There was a statistically significant association between older age and suture nonseparation in male ($p<0.001$), but, not in female ($p=0.221$). In suture-separated subjects, there was a statistically significant trend toward a low amount of suture separation with older age subgroups in both genders ($p<0.001$), however, there was no statistically significant difference in the amount of suture separation between male and female in all age subgroups.

Conclusions

Older patients treated with MARPE, particularly in male, may have a reduced likelihood of both success in suture separation and sufficient basal bone expansion. This study demonstrates that clinicians should consider that the success rate of MARPE and the amount of suture separation may depend on chronological age and gender.

Key words: Palatal expansion technique, Orthodontic appliances, Adult, Cranial sutures

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Ji Yoon Jeon

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I. INTRODUCTION

Maxillary transverse deficiency can manifest as unilateral or bilateral posterior crossbites, as well as crowding or protrusion in the maxillary arch. Rapid palatal expanders are used for the resolution of maxillary transverse deficiency (Lagravere et al., 2005; Liu et al., 2015), mainly in children and adolescents under 15 years of age, possibly because of the gradual increase in resistance from the interdigitation of the midpalatal suture with age (Melsen and Melsen, 1982; Persson and Thilander, 1977). Radiographic confirmation of the separation of the midpalatal suture along with the midline diastema is a strong indicator of successful orthopedic expansion. Alternative surgically assisted palatal expansion has been indicated in postpubertal and mature patients (Suri and Taneja, 2008). Recently, the combined use of bone-borne miniscrews connected to hyrax expanders has resulted in successful non-

surgical orthopedic expansion in adults of various ages, including those in their 20s and 30s (Choi et al., 2016; Kapetanović et al., 2021; Lee et al., 2010; Oliveira et al., 2021). The rationale for the incorporation of miniscrews includes a possible increase in the success rate and/or safety during and after expansion to protect the buccal plate of the anchor teeth against the pressure from the hyrax expander (Seong et al., 2018). However, despite the promising outcomes in adults, the success rate and the quality of expansion related to age or gender, remain unclear.

As regards the success rate of miniscrew-assisted rapid palatal expansion (MARPE), previous studies mainly focused on young adults in their late teens or early 20s, but the number of participants was insufficient to identify a reliable pattern (Choi et al., 2016; Kapetanović et al., 2021; Oliveira et al., 2021; Shin et al., 2019). According to the meta-analysis (Kapetanović et al., 2021), the success rate of MARPE varied from 80.65% to 100% including only limited numbers of older patients within the sample size of 8 to 69; success rates of 87% in 69 young adults (Choi et al., 2016), and 71.4% in 28 adults (Oliveira et al., 2021) were reported. Regarding gender, it was demonstrated that the success of MARPE was not correlated with gender (Oliveira et al., 2021), however, in contrast, it was reported that the incidence of suture nonseparation was higher in male (Choi et al., 2016). Thus, the literature is somewhat contrasting, which might be a result of the random errors due to the small sample size with limited distribution of a wide range of chronological age or gender (Akobeng, 2016). Additionally, studies on the amount of suture separation in suture-separated patients using the suture separation ratio or its correlation with chronological age and gender are still limited.

Previous studies indicated that chronological age should be considered as an important factor of success in maxillary expansion because the maturation and articulation of the midpalatal and other circummaxillary sutures increase with age (Melsen and Melsen, 1982; Persson and Thilander, 1977). However, according to the other studies (Knaup et al., 2004; Melsen, 1975; Persson and Thilander, 1977), the maturation of the midpalatal suture starts from the posterior area with increased individual variation in interdigitation, obliteration, and ossification values, thereby the time point of complete ossification may not be proportional to chronological age. Practically, adult patients aged 27, 32 (Persson and Thilander, 1977), 54 (Knaup et al., 2004), and even 71 (Korbmacher et al., 2007) years have been reported to have no signs of fusion, and success using conventional rapid palatal expanders in adults was demonstrated (Capelozza Filho et al., 1996; Handelman et al., 2000). Moreover, it was stated that the patency of the midpalatal suture should not be considered as a sole factor for the success of orthopedic expansion, implying the role of other sutures in successful suture separation (Wehrbein and Yildizhan, 2001).

Due to the variability in the literature, ensuring expansion at a specific age or in a particular gender remains a challenge among clinicians. Although the assessment of midpalatal suture maturation has been suggested as a possible determinant for successful orthopedic expansion (Angelieri et al., 2013; Angelieri et al., 2016), it is reportedly impossible to determine obliteration using regular radiological equipment (Wehrbein and Yildizhan, 2001) because histological analysis cannot be performed in living patients, and it is barely possible to assess from a microscopic perspective even with computed tomography (CT) images. Meanwhile, the prediction of the success or the possible amount of expansion by

determining the approximate trend of nonsurgical maxillary expansion according to chronological age and gender through general macroscopic studies would be of practical support in strategic treatment planning. Thus, this study aimed to investigate the success rate and the amount of suture separation after the MARPE procedure in relation to patients' chronological age and gender.

II. MATERIALS AND METHODS

1. Subjects

This retrospective study included 227 patients with transverse maxillary deficiency who underwent MARPE treatment between January 2004 and May 2020 at the Department of Orthodontics, Yonsei University Dental Hospital, Seoul, Korea. The study protocol was approved by the Institutional Review Board of Yonsei Dental Hospital (IRB No. 2-2020-0031). Ethical approval was waived in view of the retrospective nature of the study and all the procedures being performed were part of the routine care. The investigation was performed in accordance with the Declaration of Helsinki (2013).

The inclusion criteria were as follows: maxilla-mandibular intermolar width difference less than the normal value, availability of a complete series of identifiable periapical radiographs of the maxillary central incisor and jackscrew of the appliance, no prior history of orthodontic treatment and/or orthognathic surgery, no severe dentofacial anomalies such as a cleft lip or palate, good oral hygiene, and healthy periodontal tissues.

Regardless of the chronological age and gender, under the presumption that the maxilla-mandibular intermolar width difference must be constant for normal occlusion, 8.43 ± 2.22 mm was used as the reference for normal occlusion based on a previous study on Koreans (Koo et al., 2017).

Of the 227 potentially eligible patients, 215 (95 male and 120 female) met the inclusion criteria and were selected for analysis regardless of age, gender, and success of MARPE (Fig. 1). The mean age at the start of expansion was 20.0 ± 7.3 years (range, 6-60 years; median, 19.0). The overall age and gender distribution of subjects is shown in Table 1.

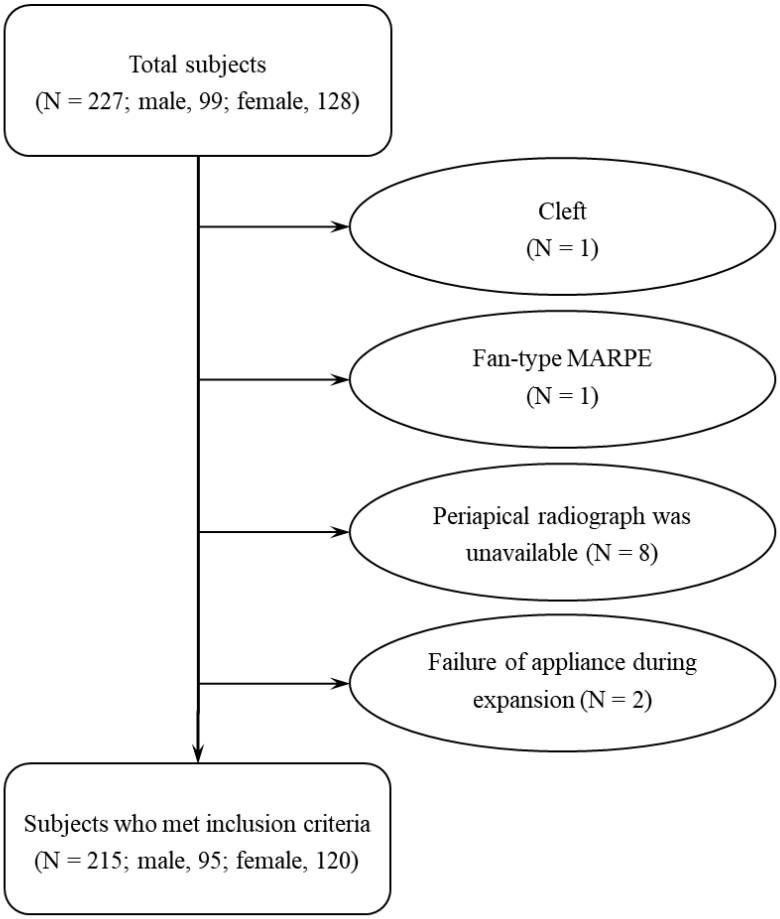


Figure 1. Flow chart of study enrollment.

Table 1. Participant characteristics.

	Total (N=215)	*Male (N=95)*	*Female (N=120)*
Age at treatment (year)	20.0 ± 7.3 [a] (range, 6-60; median, 19.0)	20.5 ± 5.4 [a] (range, 8-38; median, 21.0)	19.6 ± 8.5 [a] (range, 6-60; median, 18.5)
Age subgroup (year)			
≤15	56	17	39
16-20	71	27	44
21-25	55	38	17
26-30	19	10	9
31-35	6	2	4
36-40	4	1	3
>40	4	0	4

[a] Values are expressed as means ± standard deviations.

2. Methods

2.1 Appliance and Clinical protocol

Depending on time, two types of semi-rigid (four rigid stainless steel wire connectors with helical hooks) and rigid (two metal plates with screw holes) type MARPE appliances were used according to the development of the appliance manufacturing method. In both types, connectors for miniscrews were soldered to the base of the hyrax expander (Biomaterials Korea, Kee's Bone Expander, Seoul, Korea) to be placed on the anterior and posterior sides of the jackscrew. The maxillary first premolars and first molars were used as anchor teeth; however, the first or second deciduous molars were selected if the first premolar had not erupted. Four miniscrews (diameter 1.8 mm; length, 9.0 mm for the anterior side of jackscrew; length, 7.0 mm for the posterior side of jackscrew; self-drilled type, BMK, Ortholution, Seoul, Korea) were inserted perpendicular to the center of the helical hooks (diameter, 4.0 mm) or metal plates under local infiltration anesthesia after the MARPE appliance was placed and cemented on the maxillary dentition (Fig. 2). While using the semi-rigid type MARPE, the heads of the miniscrews were covered with light-cured resin (Transbond, 3M Unitek, St Paul, MN, USA) to connect the miniscrews with the helical hooks, minimize irritation, and improve postinsertion stability.

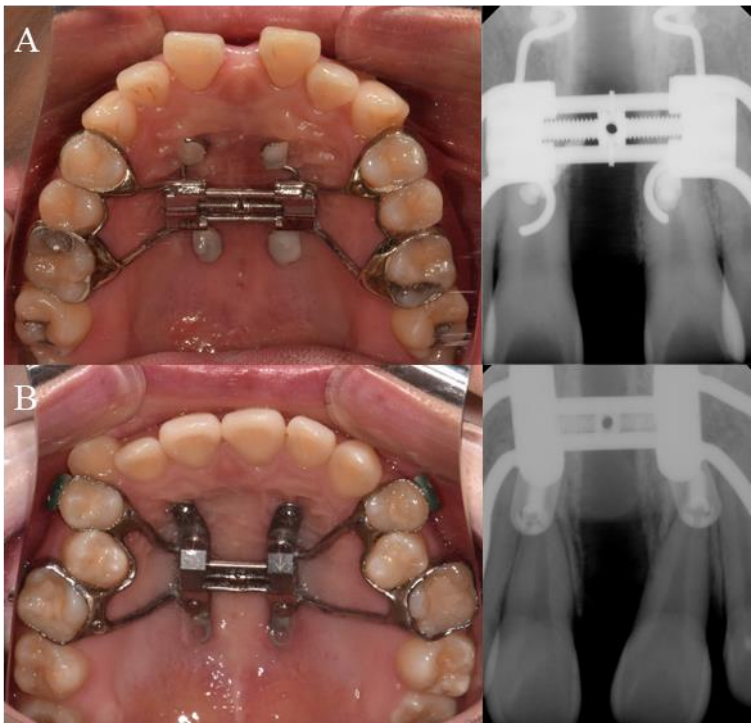


Figure 2. Miniscrew-assisted rapid palatal expansion appliances and periapical radiographs after expansion. (A) Semi-rigid type; (B) Rigid type.

The MARPE device was activated by one turn/day with one-quarter of a turn (0.2 mm/turn). During MARPE treatment, periapical radiographs of the maxillary central incisor were acquired, including the jackscrew of the MARPE device via the paralleling technique to avoid distortion of the image before treatment (T0), after 14 days of turning the screw (T1), and after active expansion (T2) in suture-separated subjects. If the suture did not separate, a periapical radiograph was not acquired at T2 (Fig. 3).

After 14 days of turning the screw, midpalatal suture separation was assessed through the periapical radiograph acquired at T1 by evaluating whether the midpalatal suture had split and the inter-sutural gap had increased compared to the periapical radiograph acquired at T0. In the case of suture nonseparation, the subject underwent a 4-week resting phase, and expansion resumed thereafter. Reevaluation of suture separation was performed after an additional 14 days of turning the screw, and expansion was discontinued if the suture was nonseparated again (Fig. 3). Active expansion was performed until the palatal cusp of either of the maxillary anchor teeth came into contact with the buccal cusp of the corresponding mandibular teeth, and was followed by a 3-6 month retention period to allow bone formation in the separated midpalatal suture and to prevent skeletal relapse.

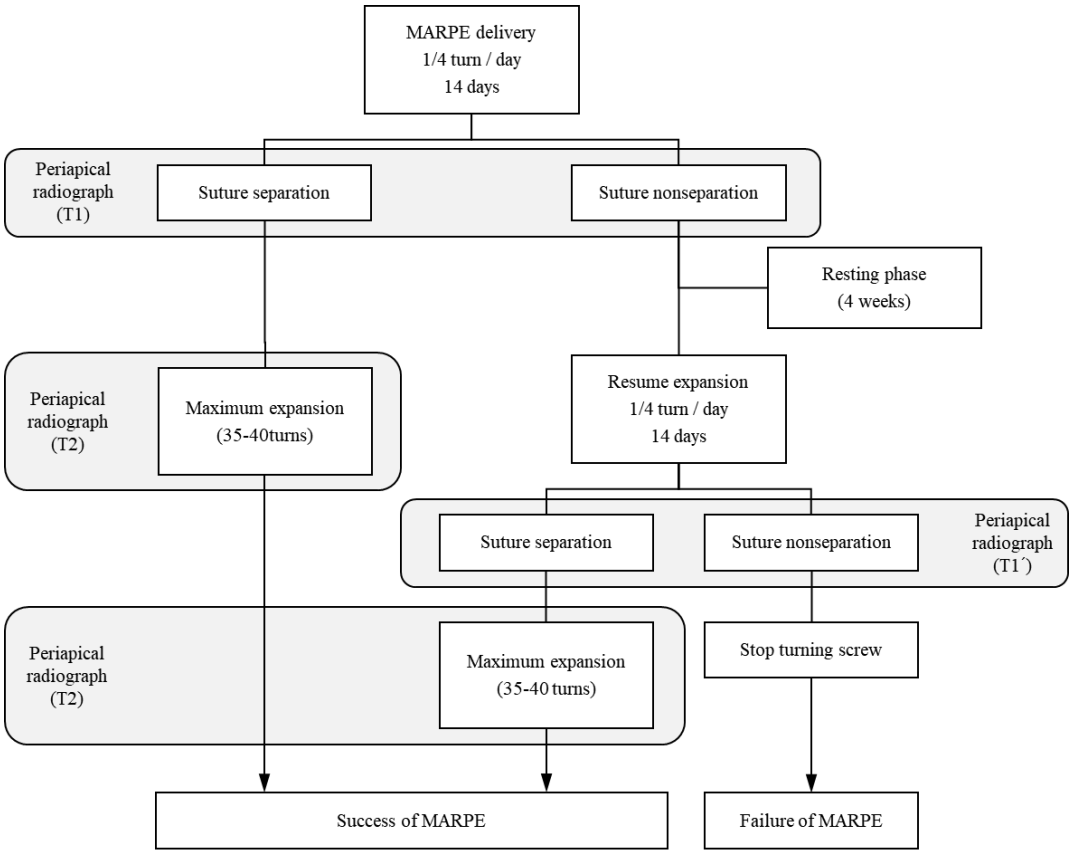


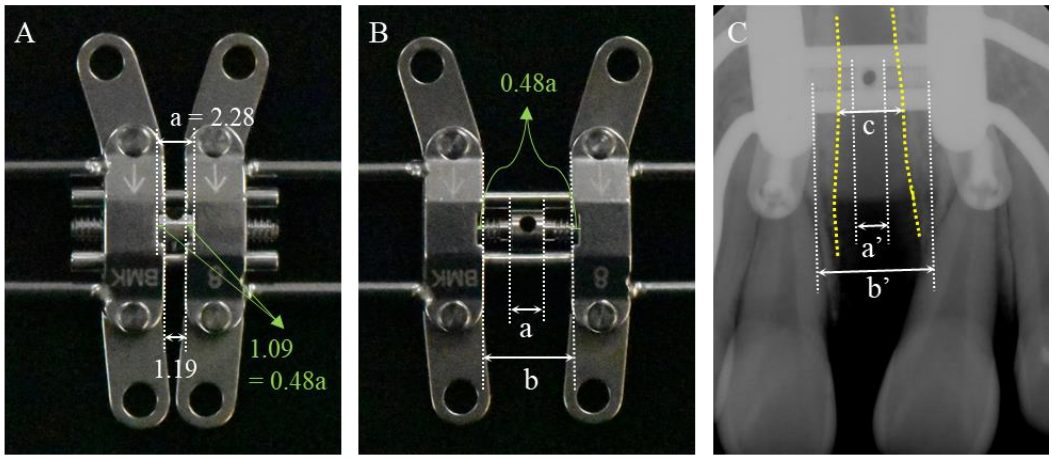
Figure 3. Allocation of success and failure in suture separation.

2.2 Measurements

In suture-separated subjects, three parameters of jackscrew expansion width, slot width, and midpalatal suture expansion width were measured in the periapical radiograph of T2 to evaluate suture expansion amount using ZeTTA PACS Viewer (Taeyoung Soft Company, Korea) by one researcher (Table 2, Fig. 4). As a standardized ratio value of the midpalatal suture expansion amount compared with the pure jackscrew expansion amount under relatively similar condition, the suture separation ratio was calculated considering the magnification ratio. Meanwhile, for subjects who were treated with rigid type of MARPE appliance, the existing initial step within the jackscrew needed calibration, and a modified equation with a calculated value of 0.48 × slot width was applied.

Table 2. Definitions of the parameters measured in the study

Measurement	Definition
Jackscrew expansion width (mm)	The shortest distance between the two points located at the anterior border of expanded jackscrew after maximum expansion on periapical radiograph (refer to Fig. 4c, measurement b').
Slot width (mm)	Slot width of jackscrew at the most anterior side on periapical radiograph (refer to Fig. 4c, measurement a').
Midpalatal suture expansion width (mm)	The shortest distance between the two points located at both cortical bone layers of separated midpalatal suture to be on the same line as jackscrew expansion width on periapical radiograph (refer to Fig. 4c, measurement c).
Suture separation ratio (%)	$\frac{\text{Midpalatal suture expansion width}}{\text{Jackscrew expansion width} - \text{Slot width}} \times 100\ (\%)$ (refer to Fig. 4)



$$\text{Suture Separation Ratio (\%)} = \frac{c}{b' - a' + 0.48a'} \times 100$$

Figure 4. Measurements of each variable (mm) and calculation of the suture separation ratio (%). (A) Calculation of the initial step (0.48a) within the jackscrew before expansion in unit of slot width; (B) Jackscrew after expansion, a : Slot width, b : Jackscrew expansion width; (C) Measurement of variables in the periapical radiograph, a' : Slot width in the periapical radiograph, b' : Jackscrew expansion width in the periapical radiograph, c : Midpalatal suture expansion width.

2.3 Reliability

All evaluations and measurements were performed by a single trained and calibrated investigator. Reproducibility was determined by comparing repeated measurements for each variable, with a 2-week interval between measurements. The intra-class correlation coefficient was greater than 0.95 for all variables measured in this study.

2.4 Statistical analysis

All statistical analyses were performed using IBM SPSS software for Windows (version 20.0; SPSS Inc., Chicago, IL, USA). A p value less than 0.05 was considered statistically significant.

The associations between age subgroup and either success of suture separation or suture separation ratio in each gender were evaluated using linear-by-linear association and the Jonckheere-Terpstra test. In each age subgroup, associations between gender and the success of suture separation were evaluated using Fisher's exact test, and the Mann-Whitney U test was applied to compare the suture separation ratio between genders.

Correlations between the suture separation ratio and age as numerical data for each gender were evaluated using the Pearson correlation coefficient. The Shapiro-Wilk test was used to determine the normality of the data distributions. With regard to the strengths of the correlations, $r>.90$ indicated a very high correlation, $.70<r<.90$ indicated a high correlation, $.50<r<.70$ indicated a moderate correlation, $.30<r<.50$ indicated a low correlation, and $r<.30$ indicated a negligible correlation (Hinkle et al., 2003). Finally, a linear regression model was developed.

III. RESULTS

1. Success rate of suture separation

Table 3 shows the descriptive statistics and associations among the age subgroups, gender, and the success of suture separation.

The overall success rate of suture separation was 61.05% in male (mean age, 20.53 years; range, 8-38 years) and 94.17% in female (mean age, 19.58 years; range, 6-60 years), which resulted in a 79.53% success rate in all subjects (mean age, 20.00 years; range, 6-60 years). However, in subjects aged older than 15 years, the success rate decreased to 53.85% in male and 92.59% in female, which led to an overall success rate of 73.58%.

The linear-by-linear association between age subgroup and the success of suture separation in each gender showed a statistically significant association between the increase in age and suture nonseparation in male ($p<0.0001$), but, not in female ($p=0.221$).

Fisher's exact test revealed an independent relationship between suture separation and gender in age subgroups younger than 20 years, while there was a strong association between both factors in age subgroups older than 21 years. In particular, in the age subgroup of 21-25 years, the odds of suture separation in female was 22.00 (95% confidence interval [CI]: 2.640-183.365) times that of male with suture separation.

Table 3. Descriptive statistics and associations among age subgroup, gender, and the success of suture separation

Age subgroup		Success of suture separation			Success rate (%)		
		Sep	Nonsep	Subtotal	Each gender	*p* *(Fisher's exact test)*	Each age subgroup
6-15Y (N=56)	M	16	1	17	94.12	0.501	96.43
	F	38	1	39	97.44		
16-20Y (N=71)	M	22	5	27	81.48	0.248	88.73
	F	41	3	44	93.18		
21-25Y (N=55)	M	16	22	38	42.11	**<0.0001******	58.18
	F	16	1	17	94.12		
26-30Y (N=19)	M	4	6	10	40.00	**0.011***	68.42
	F	9	0	9	100.00		
31-35Y (N=6)	M	0	2	2	0.00	**0.027***	50.00
	F	3	1	4	75.00		
36-40Y (N=4)	M	0	1	1	0.00	-	50.00
	F	2	1	3	66.67		
40Y- (N=4)	M	0	0	0	-	-	100.00
	F	4	0	4	100.00		
Total (N = 215)	M	58	37	95	61.05	-	79.53
	F	113	7	120	94.17		
p *(Linear by linear association)*	M				**<0.0001******		
	F				0.221		

Sep, Number of samples with suture separation in each age subgroup and gender; Nonsep, Number of samples with suture nonseparation in each age subgroup and gender; Subtotal, Number of samples in each age subgroup and gender; Each gender, Success rate of each gender in each age subgroup (%); Each age subgroup, Success rate of each age subgroup (%); M, Male; F, Female.
Bold values indicate the results that are statistically significant (*p<0.05; **p<0.01; ***p<0.001; ****p<0.0001).

2. Suture separation ratio

Among the 215 included subjects, the suture separation ratio was evaluated in 171 (58 male and 113 female) subjects whose midpalatal suture was successfully separated. The suture separation ratio of each gender was normally distributed, as assessed by the Shapiro-Wilk test (male p=0.289 and female p=0.501).

In both genders, the Jonckheere-Terpstra test indicated a statistically significant trend towards a low suture separation ratio in older age subgroups (T_{JT}=242.00, z=-4.858, p<0.0001 in male; T_{JT}=1158.00, z=-6.047, p<0.0001 in female) implying that despite the relatively similar condition of non-surgical maxillary expansion, the midpalatal suture expansion amount decreased with increasing chronological age.

Additionally, as numerical data, Pearson's correlation revealed a statistically significant moderate degree of negative correlation between chronological age and the suture separation ratio (r=-.615, n=58, p<0.001 in male; r=-.515, n=113, p<0.001 in female). A linear regression model incorporating both rigid and semi-rigid type appliance established that age could statistically significantly predict the suture separation ratio in both genders (Fig. 5a). In male, age accounted for 37.8% of the explained variability in the suture separation ratio, and the regression equation was as follows: predicted suture separation ratio = 102.879 – 2.660×age (p<0.001). In female, age accounted for 25.8% of the explained variability in the suture separation ratio, and the regression equation was as follows: predicted suture separation ratio = 76.253 – 1.206×age (p<0.001). With regard to the type of appliance, statistically significant regression models similar to the overall results of the subject population were drawn except for male with rigid type appliance (Fig. 5b, c). In both types of MARPE appliances, it was observed that the slope of the

regression model in male was twice as greater as that in female, implying that the amount of suture separation is associated with chronological age, and is considered somewhat irrelevant to the appliance.

In terms of gender, the Mann-Whitney U test indicated no statistically significant difference between the male and the female in all age subgroups (Fig. 6).

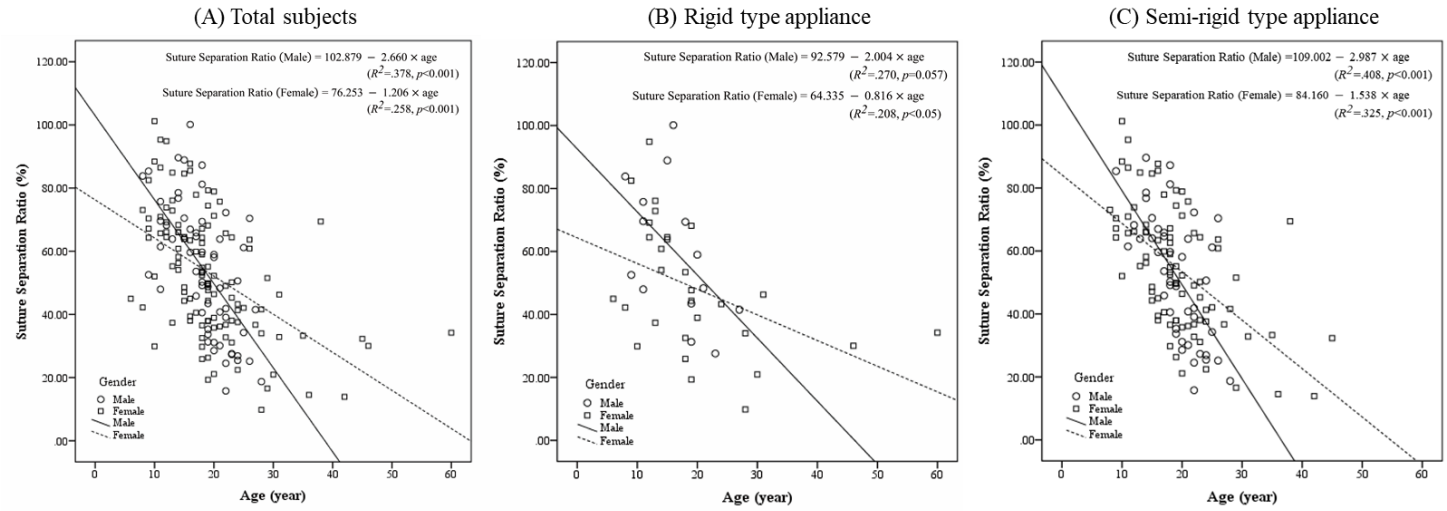


Figure 5. Analysis of linear regression between age (year) and the suture separation ratio (%) in male and female. (A) Total subjects; (B) Rigid type appliance; (C) Semi-rigid type appliance.

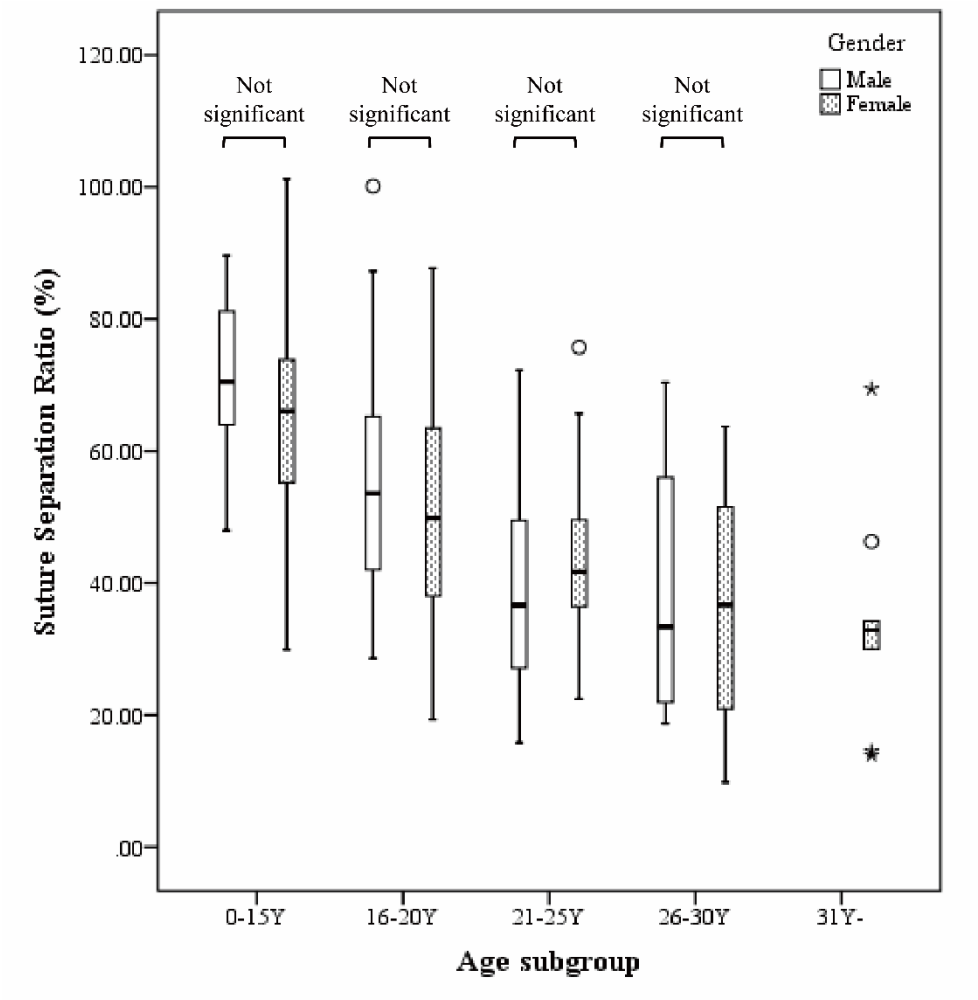


Figure 6. Changes in the suture separation ratio (%) according to age subgroup in male and female.

IV. DISCUSSION

This study investigated the distribution and correlation of chronological age and gender with the success rate and suture separation ratio after the MARPE procedure. Our results revealed an apparent age-related difference between the male and the female in terms of the success rate of MARPE, and a significant correlation was found between chronological age and suture separation ratio.

As the use of the orthopedic appliances for nonsurgical maxillary expansion increases, efforts have been made to determine the presence of midpalatal suture maturation in order to predict the success of treatment (Angelieri et al., 2016; Oliveira et al., 2021; Shin et al., 2019). However, several histological and micro-CT studies have indicated that chronological age and gender are not reliable parameters of midpalatal suture maturation (Angelieri et al., 2017; Knaup et al., 2004; Korbmacher et al., 2007; Persson et al., 1978; Persson and Thilander, 1977; Wehrbein and Yildizhan, 2001).

Histologically, the initiation of midpalatal suture obliteration differs from that of other sutures within the skull, which has been described as a continuous process that starts from the suture margins (Cohen, 1993; Persson et al., 1978). Single bony islands of acellular and inconsistently calcified tissue, located within the suture or protruding as a small bone spicula from the suture margins, initiate the ossification process (Cohen, 1993; Persson et al., 1978). In addition, it was observed that midpalatal suture maturation starts from a broad and Y-shaped infantile stage and proceeds to the tortuous and interdigitated shape of the adolescent stage (Melsen, 1975). Until now, however, it is not possible to determine whether there exists any

obliteration area in each living individual since histological evaluation cannot be conducted by just reading radiographic images even with CT.

Furthermore, although the detailed mechanism and direction of midpalatal suture obliteration are known, the exact timing varies greatly among individuals (Angelieri et al., 2017; Knaup et al., 2004; Persson and Thilander, 1977). According to the study using CBCT (Angelieri et al., 2017), neither chronological age nor gender and the maturational stages of the midpalatal suture had significant association. However, a significantly higher bone density was observed in the sagittal dimension of the midpalatal suture in the middle-aged group than in the youngest and oldest age groups, whereas the obliteration index in the frontal plane exhibited substantial inter-individual variation and was independent of age (Korbmacher et al., 2007). Such individual differences in suture obliteration may also occur under the influence of hormonal, genetic, and mechanical factors (Persson et al., 1978).

In addition to the histological characteristics of the midpalatal suture, mechanical resistance from the craniofacial complex and circumaxillary sutures occurs when the maxillary basal bone is subjected to attempted expansion. Therefore, predicting the success of MARPE by considering only the obliteration of the midpalatal suture may yield different results from the actual clinical findings. Previous studies stated that the reason for the failure of nonsurgically assisted rapid maxillary expansion was increased rigidity of the facial skeleton in relation to the fusion of various combinations of zygomaticotemporal, zygomaticofrontal, and zygomaticomaxillary sutures (Bell and Epker, 1976; Lines, 1975).

With regard to the biomechanical effects of rapid maxillary expansion on the craniofacial structures, several finite element method studies were conducted

(Gautam et al., 2007; Işeri et al., 1998; Provatidis et al., 2008). It was reported that high stress levels were observed in the canine and molar regions of the maxilla, lateral wall of the inferior nasal cavity, and zygomatic and nasal bones, with the highest stress concentration at the pterygoid plates of the sphenoid bone in the region close to the cranial base (Işeri et al., 1998); both tensile and compressive stresses of variable magnitude were present along the same suture, particularly in the zygomaticomaxillary, zygomaticotemporal, and zygomaticofrontal sutures (Gautam et al., 2007); the zygomaticomaxillary suture influenced the response of the craniofacial complex to the expansion forces, and the sagittal suture at the level of the frontal portion of the midpalatal suture plays an important role in the degree and manner of maxillary separation (Provatidis et al., 2008).

The mechanical stress generated from rapid maxillary expansion may function as mechanical resistance, and the absolute magnitude of the induced stress depends greatly on bone elasticity and the patient's age (Gautam et al., 2007). Previous studies stated that the sutures of juvenile skulls absorb significantly higher bone strain than those of adults under equivalent orthopedic load, and the juvenile bone is generally less stiff than in adults, indicating that the same mechanical stress might cause different biological effects on immature and mature facial skeletons (Oberheim and Mao, 2002; Zioupos and Currey, 1998); even after active skeletal growth is completed, further maturation occurs in the circumaxillary suture sites (Melsen and Melsen, 1982). Further, since bone mass distribution is distinguished between the male and the female due to gender-based differences such as periosteal expansion and endocortical apposition in bone maturation during puberty, the absolute values for parameters of bone strength are higher in male for a given cortical bone mass (Hart et al., 2017; Schoenau et al., 2001). Such changes in skeletal stiffness in both the craniofacial complex and circummaxillary sutures and

the maturation of bone and/or sutures according to chronological age or gender may influence skeletal resistance during maxillary expansion, which can affect success rates or result in varying amounts of suture separation even after the success of suture separation.

In this study, the overall success rate of MARPE was 79.53% which was observed to be low compared with that of the meta-analysis (Kapetanović et al., 2021) or previous studies on Koreans (Choi et al., 2016; Shin et al., 2019). Although the specific cause is uncertain, it is assumed to be the result of a relatively high proportion of older patients and male. In terms of gender-based difference, the success rate of MARPE was higher in female within every age subgroup at 92.59%, while that of male aged over 15 years decreased to 53.85%. In patients aged over 20 years, gender and the success of suture separation were statistically significantly associated. A statistically significant increase in the probability of suture nonseparation with increasing age was observed in male, and there were no successful cases in male aged over 30 years. This suggests that midpalatal suture maturation may not be related to chronological age or gender; however, from the perspective of skeletal stiffness or maturation in the craniofacial complex, there is a possibility that the midpalatal suture separation may be related to these factors.

Additionally, by evaluating the midpalatal suture expansion compared to the jackscrew expansion under the condition of a relatively similar mechanical stress applied to the maxilla, it was found that the difference in the suture separation ratio between genders in the same age subgroup was statistically insignificant. However, the increase in chronological age was statistically significantly associated with a decrease in the suture separation ratio. According to the linear regression model incorporating both rigid and semi-rigid type appliance, the rate of change in the

suture separation ratio as age increased was 2.21-fold greater in male (-2.660) than in female (-1.206). The analogous tendency was also observed in each type of MARPE. Therefore, it can be suggested that even if maxillary expansion by MARPE is successful, since resistance to expansion and the amount of skeletal expansion may change with chronological age or gender, treatment at a young age, particularly in male, would be advantageous not only for increasing the success rate of MARPE but also for achieving more skeletal expansion. Also, surgically assisted rapid palatal expansion could be considered as an effective alternative in certain patient groups, such as male aged over 30 years.

Meanwhile, although it was a minority, some of the subjects in this study were evaluated as nonseparation after the first 14 days of expansion; however, they were reevaluated as suture separation after the resumption of expansion following the 1 month resting phase. It is presumed that despite the failure of the midpalatal suture separation in the initial stage of expansion due to suture obliteration, the biological activity of the area increased during the resting period and suture separation was successful after the resumption of expansion. According to the previous study, it was demonstrated that the number and activity of osteoclasts, inflammatory cytokines, and chemokines significantly increased during the first month of expansion force application, and the bone density of the midpalatal suture was significantly decreased in the initial reaction of suture widening when transverse force was applied for the expansion of the midpalatal suture in rats (Alikhani et al., 2019). Taken together with the findings of this study, even if suture separation fails at the initial stage of expansion, it is assumed that if the subject undergoes a catabolic phase through the resting phase for approximately 1 month, firm suture obliteration may resolve to loose interdigitation through several biological reactions and the suture can be separated upon the resumption of expansion.

This study had a few limitations. First, the present study used a suture separation ratio calculated based on the values measured from a two-dimensional periapical radiograph to evaluate skeletal expansion. Although many recent studies have utilized CT images for three-dimensional analysis, there are ethical problems involved in acquiring CT images in a routine manner for all patients. Therefore, in the use of a periapical radiograph, the paralleling technique and consistent methodology were used to minimize the possibility of measurement errors due to image overlapping, distortion, and enlargement. Second, because of the retrospective and clinical nature of this study, the age distribution was somewhat unequal and the variety of transverse discrepancy in subjects resulted in a relatively heterogeneously controlled degree of expansion. To surmount the limitations of the two-dimensional analysis and to investigate the relevance between the success rate of MARPE and amount of suture separation with various clinical variables, such as anteroposterior and vertical skeletal patterns in addition to chronological age and gender, future case-controlled studies are warranted.

V. CONCLUSION

Our findings suggest that the non-surgical maxillary expansion using MARPE may be a good approach for patients with transverse discrepancy; however, the success rate of MARPE and the suture expansion amount may depend on chronological age and gender. This study demonstrates that MARPE treatment in older patients, particularly in male, may result in a reduced likelihood of both success in suture separation and sufficient basal bone expansion followed by an unfavorable outcome of orthopedic expansion, which suggests the possible need for the surgical approach.

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국 문 요 약

연령 및 성별에 따른 비수술적 상악골 확장의 성공률과 확장 비율

<지도교수: 이 기 준>

연세대학교 대학원 치의학과

전 지 윤

본 연구는 구개확장 치료가 필요한 환자를 대상으로 미니스크류 보강형 급속 구개확장 (miniscrew assisted rapid palatal expansion; MARPE) 치료 시, 연령 및 성별에 따른 성공률과 골격적 확장 비율의 분포 및 상관관계를 알아보기 위해 후향적으로 시행되었다.

MARPE 치료를 받은 환자 215명을 대상으로 확장 후 (T1) 상악 전치부 치근단방사선사진을 촬영하여 정중구개봉합의 이개를 평가하였고, 봉합이 이개된 171명의 환자에서 최대 확장을 시행한 후 (T2) 상악 전치부 치근단방사선사진을 촬영하여 봉합 이개 비율을 분석하였다. 환자의 연령은 15세 이하, 16-20세, 21-25세, 26-30세, 31-35세, 36-40세, 41세 이상으로, 성별은 남성, 여성의 subgroup으로 분류하였다. 통계 분석으로 선형 연관성, Jonckheere-Terpstra 검정, Fisher의 정확한 검정, Mann-Whitney U 검정을 시행하였으며 선형 회귀 모형을

도출하였다.

본 연구 결과, MARPE의 전체 성공률은 79.53% 이었으며 남성에서 61.05%, 여성에서 94.17%로 나타났다. 남성에서는 연령의 증가와 정중구개봉합 이개의 실패 사이에 통계적으로 유의미한 연관성이 관찰되었으나 ($p<0.001$), 여성에서는 관찰되지 않았다 ($p=0.221$). 또한 각 연령의 subgroup 내에서 성별과 정중구개봉합 이개의 성공 여부는 20세 이하에서는 통계적으로 유의미한 연관성을 보이지 않았으나 21세 이상부터는 통계적으로 유의미한 연관성을 보였다. MARPE가 성공한 환자에서 두 성별 모두 연령이 증가함에 따라 통계적으로 유의미하게 봉합 이개 비율이 감소하였으나, 모든 연령의 subgroup에서 남성 및 여성 사이의 봉합 이개 비율에 있어 통계적으로 유의미한 차이는 관찰되지 않았다. 또한 도출된 선형 회귀 모형에 따르면 장치의 종류와 무관하게 여성에서보다 남성에서 연령의 증가에 따른 정중구개봉합 이개량 감소를 나타내는 기울기가 약 2배 크게 나타났다. 결과적으로, 특히 남성에서 MARPE를 높은 연령군에 적용할 때 정중구개봉합 이개의 성공 확률과 기저골의 충분한 확장에 대한 가능성이 감소할 수 있으며 양호한 악정형적 확장 치료의 결과를 기대하기 어려울 수 있다.

핵심이 되는 말: 구개 확장치료, 교정 장치, 성인, 두개 봉합