

## Investigation of the association between vertical skeletal patterns and the timing of failure of temporary anchorage devices

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### Abstract

Temporary anchorage devices (TADs) have become increasingly popular as orthodontic treatment measures for anchorage or distal movement of molars. However, TAD failure is a major limitation, and the aim of this study was to examine the effects of various factors on the timing of TAD failure. This study included 467 TADs implanted on the buccal side of the molar region in 197 patients undergoing orthodontic treatment. The relationship between failure and sex, age, jaw (maxilla or mandible), side (left or right), Frankfort mandibular plane angle (FMA), point A-nasion-point B angle (ANB), overbite, and overjet was examined. The time (number of days) until failure was also investigated. The failure rates were significantly higher in men compared to women (23.9% vs. 13.6%;  $p$ -value = 0.024), and in the mandible compared to the maxilla (28.2% vs. 11.8%;  $p$ -value < 0.001). A significant difference by age-group was also observed ( $p$ -value < 0.029), with the failure rates being highest among patients aged  $\geq 30$  years (29.8%). Approximately half (47.6%) of the maxillary failures occurred by day 120, and more than half (58.1%) of the mandibular failures occurred by day 60. Moreover, the failure rate by day 120 was higher in the maxilla when the FMA was smaller. The failure rates of TADs implanted on the buccal side of the molar region were influenced by sex, age, and location (i.e., mandible or maxilla). Failure tended to occur more rapidly and readily in mandibular compared to maxillary implants. Moreover, when considering the vertical skeletal pattern, failure rates < 120 days after implantation tended to increase when the FMA decreased.

**Key words:** Temporary anchorage devices (TADs), failure rate, failure timing, self-drilling types, FMA

### Introduction

Temporary anchorage devices (TADs) were recently recognized as being an effective form of orthodontic treatment and have become increasingly popular since. TADs implanted in the jaw can serve as fixed anchorage devices for orthodontic treatments that do not rely on patient cooperation<sup>1,2</sup>, such as distal movement and intrusion of molars<sup>3,4</sup>. However, TAD failure (i.e., the need to remove a TAD because

of detachment) is a major limitation, with previous studies<sup>5–12</sup> reporting increased risk associated with factors such as proximity to or contact with the periodontium and/or tooth root<sup>5–7</sup>; application of torque during implantation<sup>8,9</sup>; increased cortical bone thickness at the implantation site<sup>9,10</sup>; and the timing of initiation of orthodontic force application<sup>11,12</sup>. In their meta-analysis of 52 studies examining factors affecting TAD failure, Papageorgiou *et al.*<sup>13</sup> found that implantations in the mandible were associated with a significantly higher rate of failure when compared to the maxilla.

However, studies examining factors affecting TAD failure have differed considerably in the type and number of TADs, implantation methods, and treatment protocols used, making objective evaluation of these outcomes challenging. Furthermore, the relationship between failure timing and other factors

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have not been investigated so far.

Therefore, the purpose of this study was to examine the effects of various factors such as sex, age, jaw (maxilla or mandible), side (left or right), Frankfort mandibular plane angle (FMA), point A-nasion-point B angle (ANB), overbite, and overjet on the timing of TAD failure. The hypothesis being tested was that TADs would exhibit failure sooner and at a higher frequency in women with larger ANBs and FMAs.

## Materials and methods

### *Patients and Samples*

This study included patients that were examined and treated by an orthodontist between April 2008 and September 2012. Informed consent was obtained from each patient prior to implantation. TADs were used as an orthodontic treatment measure for malocclusion, and all implantations were carried out by a single orthodontist at the Arishima Orthodontic Clinic in Kisarazu, Japan. All TADs were implanted into the attached gingiva on the buccal side under local anesthesia, and the area was cooled using physiological saline. The self-drilling method of implantation was the treatment of choice, and no torque-limiting screwdrivers were used in this study. Implantation using the self-drilling method was suspended if the tip of the TAD could not penetrate the surface due to increased hardness or thickness of the bone at the implantation site and/or application of excess rotational torque. In such cases, the procedure was repeated after drilling a pilot hole without a torque-limiting screwdriver. Drilling was performed midway through the procedure in 82 (17.6%) TADs. No orthodontic force was applied to the TADs for  $\geq 1$  month after implantation. Upon observation of failure, characterized by movement of the TAD, the device was considered unsuitable for orthodontic treatment and removed.

This study included five types of self-drilling TADs that are typically implanted without the need for creation of a pilot hole (Table 1 and Figure 1), and a total of 467 TADs were implanted in 197 patients.

### *Data Collection*

TAD detachment was recorded if the device failed and was removed within 750 days of implantation. The primary outcomes of interest were the effects of various factors [e.g., sex; age; jaw (maxilla or mandible); side (left or right); FMA and ANB, measured using cephalometric analysis; and overbite

and overjet, determined using model analysis] on the number of days to TAD failure. Additionally, the relationship between FMA and the TAD detachment rate was examined  $< 120$  days and  $\geq 120$  days from implantation in the maxilla and mandible, respectively.

### *Statistical Analysis*

Fisher's exact test was used to examine the association between TAD failure and the following factors: sex; jaw (maxilla or mandible); side (left and right); age ( $< 20$  years, 20–29 years, and  $\geq 30$  years); FMA ( $< 20^\circ$ ,  $20^\circ \leq \text{FMA} < 25^\circ$ ,  $25^\circ \leq \text{FMA} < 30^\circ$ ,  $30^\circ \leq \text{FMA} < 35^\circ$ , and  $\geq 35^\circ$ ); ANB ( $< 0^\circ$ ,  $0^\circ \leq \text{ANB} < 5^\circ$ , and  $\geq 5^\circ$ ); overbite ( $< 0.0$ , 0.0–1.5, 2.0–3.5, 4.0–5.5, and  $\geq 6.0$  mm); and overjet ( $< 0.0$ , 0.0–1.5, 2.0–3.5, 4.0–5.5, and  $\geq 6.0$  mm). Additionally, the number of days until failure (categorized into 30-day intervals) was examined over a period of 750 days. The Cochran-Armitage trend test was used to explore the association between FMA and failure rates  $< 120$  days and  $\geq 120$  days from implantation of the device between the second premolar and first molar (frequently used for implanting TADs) in the maxilla or mandible. All statistical analyses were performed using SAS 9.3 software (SAS Institute Inc., Cary, NC, USA).

### *Ethical Approval*

This retrospective study was approved by the Ethics Committee of the School of Dentistry at Showa University (Tokyo, Japan; approval no., 2013-017).

### *English Proofreading*

This manuscript was proofread by Editage (www.editage.jp).

## Results

### *Types of TADs*

Five types of TADs with diameters and lengths ranging from 1.3 to 1.6 mm and 5.0 to 8.0 mm, respectively, were used in this study. Type A TADs were used in 336 (71.9%) patients, while Type B were used in 79 (16.9%) patients. The smallest possible diameter of each TAD type was used to minimize risks associated with placement of the device in the interdental space. Type A TADs with a length of 6.0 mm were the most commonly used, accounting for 314 (67.2%) implantations (Table 1).

### *Influence of Different Factors*

This study included 197 patients, of which 41 (20.8%) were male and 156 (79.2%) were female.

Table 1. Number/rate of failure by type of TAD\*

Type of TADs												
	Type A				Type B	Type C	Type D	Type E			Total	
Brand	AbsoAnchor				ACR	ORLUS	Dual Top	OSAS				
Manufacturer	Dentos Inc.				BioMaterials Korea Inc.	Ortholution Co., Ltd.	Jeil Medical Corp.	Dewimed Medizintechnik GmbH				
Country of manufacture	Korea				Korea	Korea	Korea	Germany				
Type	Self drilling				Self drilling	Self drilling	Self drilling	Self drilling				
Diameter (mm)	1.4				1.3	1.6	1.6	1.6				
Length (mm)	6	7	8	6.7.8 Total	6.5	6	6	5	6	5.6 Total		
Frequency (number)	314	19	3	336	79	26	22	1	3	4	467	
Percentage (%)	67.2	4.1	0.6	71.9	16.9	5.6	4.7	0.2	0.6	0.9	100	
Number of Failures (number)	45	5	1	51	10	4	6	1	1	2	73	
Proportion of Failures (%)	9.6	1.1	0.2	10.9	2.1	0.9	1.3	0.2	0.2	0.4	15.6	
Failure less than 120 days (number)	29	3	0	32	8	1	1	0	0	0	42	
Failure less than 120 days (%)	6.2	0.6	0	6.9	1.7	0.2	0.2	0	0	0	9.0	
Failure after 120 days (number)	16	2	1	19	2	3	5	1	1	2	31	
Failure after 120 days (%)	3.4	0.4	0.2	4.1	0.4	0.6	1.1	0.2	0.2	0.4	6.6	

\*TADs indicates Temporary anchorage devices.

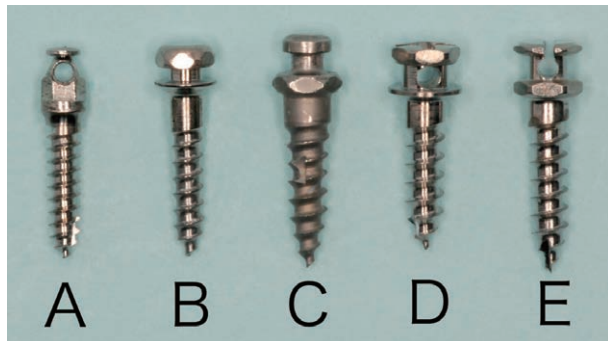


Fig. 1. Types of orthodontic temporary anchorage devices (TADs).

The overall mean age of the patients at the time of implantation was 20 years and 2 months (range: 12 years and 5 months to 47 years and 1 month), while the corresponding values by sex were 20 years and 6 months and 20 years and 1 month in men and women, respectively (Table 2). A total of 467 TADs were implanted, of which 92 (19.7%) were in men and 375 (80.3%) in women. The overall failure rate was 15.6% (73/467), and women received a greater number of TADs (80.3%, 375/467) compared to men (19.7%, 92/467).

Fisher's exact test was used to determine the association between TAD failure and various

demographic and clinical factors, and the findings have been presented in Table 2. Significant differences in failure rates were observed by sex [males: 23.9%, females: 13.6%;  $p$ -value = 0.024]; jaw [mandible: 28.2%; maxilla: 11.8%;  $p$ -value < 0.001]; and age group [ $\geq 30$  years: 29.8%; 20–29 years: 13.7%; < 20 years: 14.2%;  $p$ -value = 0.029].

#### Association between FMA and Failure Rate

The failure rates on the left and right sides were 17.8% and 13.6%, respectively, although this difference was not statistically significant. The highest failure rates were observed in the groups with the smallest FMA ( $\leq 20^\circ$ ; 21.8%), largest overbite ( $\geq 6$  mm; 26.3%), and overjet of 0–1.5 mm (23.6%), while the lowest failure rates were observed in the groups with the largest FMA ( $\geq 35^\circ$ ; 9.5%) and a tendency toward open bite (overbite  $\leq 0$  mm; 6.7%). However, Fisher's exact test showed that the differences between the various FMA, ANB, overbite, and overjet groups were not statistically significant.

Figure 2 plots the number of days after implantation against the cumulative failure rate. The combined cumulative failure rate for the maxilla and mandible tended to increase substantially until approximately day 120, after which smaller increases

Table 2. Association between demographic and clinical variables and failure rate

Factor	Subgroup	Failure rate		Fisher's exact test p value
		Percentage	Relative frequency	
Total		15.6%	73/467	
Sex	Male	23.9%	22/92	0.024*
	Female	13.6%	51/375	
Jaw	Maxilla	11.8%	42/357	< 0.001***
	Mandible	28.2%	31/110	
Side	Right	13.6%	33/242	0.251
	Left	17.8%	40/225	
Age in years	< 20	14.2%	46/325	0.029*
	20–29	13.7%	13/95	
	≥ 30	29.8%	14/47	
FMA (°)	< 20	21.8%	12/55	0.368
	20 ≤ FMA < 25	14.1%	14/99	
	25 ≤ FMA < 30	13.1%	17/130	
	30 ≤ FMA < 35	18.4%	26/141	
	≥ 35	9.5%	4/42	
ANB (°)	< 0	15.1%	11/73	0.894
	0 ≤ ANB < 5	15.2%	39/257	
	≥ 5	16.8%	23/137	
Overbite (mm)	< 0.0	6.7%	1/15	0.428
	0.0–1.5	14.2%	22/155	
	2.0–3.5	18.2%	29/159	
	4.0–5.5	13.4%	16/119	
	≥ 6.0	26.3%	5/19	
Overjet (mm)	< 0.0	17.4%	4/23	0.344
	0.0–1.5	23.6%	17/72	
	2.0–3.5	14.7%	14/95	
	4.0–5.5	12.0%	10/83	
	≥ 6.0	14.4%	28/194	

\*p < 0.05; \*\*p < 0.01; \*\*\*p < 0.001; FMA: Frankfort-mandibular plane angle; ANB: A point–nasion–B point angle

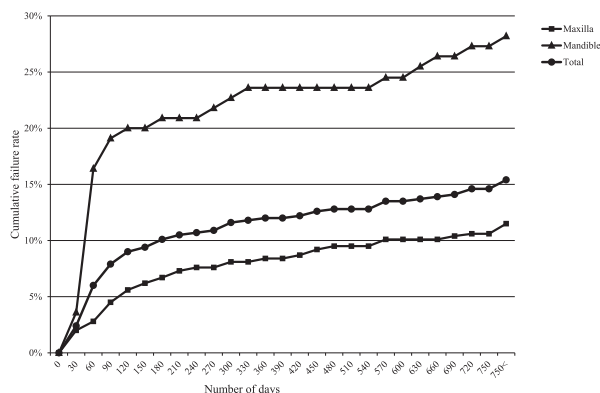


Fig. 2. Number of days after implantation plotted against the cumulative failure rate.

were observed. The final combined failure rate for the maxilla and mandible was 15.4%. The final failure rate and cumulative failure rate in the maxilla on day 120 were 11.5% and 5.6%, respectively, suggesting that approximately half (48.8%) of all maxillary failures had occurred by this point in time. For the mandible, the final failure rate and cumulative failure rate on day 60 was 28.2% and 16.4%, respectively, suggesting that 58.1% of all mandibular failures had occurred by this point in time. These results indicate that failure occurred earlier and more frequently in the mandible compared to the

Table 3. Association between the Frankfort mandibular plane angle (FMA) and failure rate up to day 120

Jaw	FMA (°)	Failure rate		Cochran-Armitage test p value
		Percentage	Relative frequency	
Maxilla	< 20	14.7%	5/34	0.005**
	20–25	6.5%	4/62	
	25–30	2.4%	2/82	
	30–35	1.2%	1/83	
	≥ 35	3.3%	1/30	
Mandible	< 20	37.5%	3/8	0.057
	20–25	23.5%	4/17	
	25–30	9.1%	1/11	
	30–35	10.5%	2/19	
	≥ 35	0.0%	0/2	
Total	< 20	19.0%	8/42	0.001***
	20–25	10.1%	8/79	
	25–30	3.2%	3/93	
	30–35	2.9%	3/102	
	≥ 35	3.1%	1/32	
	All	6.6%	23/348	

\*p < 0.05; \*\* p < 0.01; \*\*\* p < 0.001

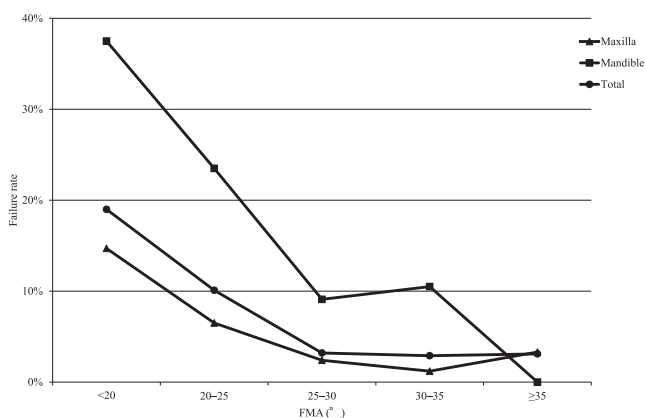


Fig. 3. Association between the Frankfort mandibular plane angle (FMA) and the failure rate before day 120.

maxilla. The 30-day failure rate of maxillary TADs tended to gradually stabilize after day 120, whereas that of the mandible tended to stabilize after day 60. However, even during these stable periods, the failure rates tended to be slightly higher in the mandible compared to the maxilla.

Table 3 and Figure 3 show the association between the five FMA groups and failure of a TAD placed between the second premolar and first molar by day 120. The Cochran-Armitage trend test indicated a significant correlation between the FMA groups and the combined maxillary and mandibular failure rates

( $p < 0.001$ ), with the latter increasing as the former decreased. The failure rate was particularly high (19.0%) in 42 patients with an FMA < 20°. Similar tendencies were observed in the maxilla and mandible separately, although the differences between the FMA groups were statistically significant only in the maxilla ( $p = 0.005$ ).

Table 4 and Figure 4 show the association between the five FMA groups and failure of TADs implanted between the second premolar and the first molar after day 120. Smaller FMAs were associated with higher failure rates up to day 120, after which this association was no longer observed. Moreover, larger FMAs tended to be associated with higher failure rates in the maxilla after day 120, while no correlation between the FMA groups and failure rates after day 120 were observed in the small number of TADs placed in the mandible.

## Discussion

In this study, the failure rates of TADs implanted on the buccal side of the molar region were significantly higher in males compared to females, the mandible compared to the maxilla, and in patients > 30 years of age. Approximately half of all failures occurred by day 120 in the maxilla and by day 60 in

Table 4. Association between the Frankfort mandibular plane angle (FMA) and failure rate after day 120

Jaw	FMA (°)	Failure rate		Cochran-Armitage test p value
		Percentage	Relative frequency	
Maxilla	< 20	6.9%	2/29	0.24
	20–25	1.7%	1/58	
	25–30	11.3%	9/80	
	30–35	8.5%	7/82	
	≥ 35	10.3%	3/29	
Mandible	< 20	0.0%	0/5	0.956
	20–25	7.7%	1/13	
	25–30	0.0%	0/10	
	30–35	5.9%	1/17	
	≥ 35	0.0%	0/2	
Total	< 20	5.9%	2/34	0.239
	20–25	2.8%	2/71	
	25–30	10.0%	9/90	
	30–35	8.1%	8/99	
	≥ 35	9.7%	3/31	
	All	7.4%	24/325	

\*p < 0.05 ; \*\* p < 0.01 ; \*\*\* p < 0.001

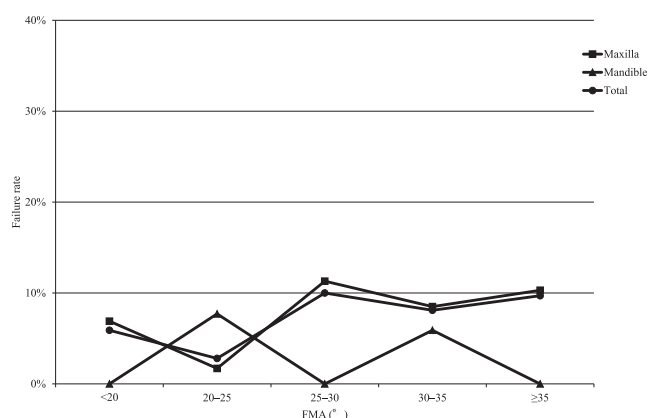


Fig. 4. Association between Frankfort mandibular plane angle (FMA) and failure rate after day 120.

the mandible. Among TADs implanted between the maxillary or mandibular second premolar and first molar, the evaluation at < 120 days after implantation showed that failure was more frequent when the FMA (i.e., the maxillofacial morphology) was small.

#### Relationship between failure rate and type of TAD

The failure rates tended to be higher for Type A (diameter :1.4 mm, length : 8.0 mm) and Type E (diameter : 1.6 mm, length : 5.0 mm, 100% ; and diameter : 1.6 mm, length : 6.0 mm, 33%) TADS, and lower for Type A (diameter : 1.4 mm, length : 6 mm,

14%) and Type B (diameter : 1.3 mm, length : 6.5 mm, 13%) TADs (Table 1).

However, differences in the number of TADs used by type necessitate further investigation to elucidate the effects of each type on clinical outcomes.

#### Failure Rate in Maxilla and Mandible

Previous studies examining TAD failure<sup>5, 8–10, 14, 15</sup> have observed significantly higher rates in the mandible compared to the maxilla<sup>5, 14</sup>, and this was supported by a recent meta-analysis by Papageorgiou *et al.*<sup>13</sup> that also reported a difference in failure rates between the former (19.3%) and the latter (12.0%). The findings of the current study were in agreement with this, with significantly higher failure rates being observed in the mandible (28.2%) compared to the maxilla (11.8%). Factors that may have contributed to these differences include variations in bone structure such as alveolar cortical bone thickness and mineral density<sup>16–18</sup>. Previous studies examining the alveolar bone structure in the molar regions of the maxilla and mandible reported thicker cortical bone<sup>16, 17</sup> and higher mineral density<sup>18</sup> in the latter. However, further investigation of the association between TAD failure rates and cortical bone thickness and density is necessary in order to elucidate the mechanism of action.



Figure 2 shows the findings of the evaluation of time elapsed between implantation and failure and the cumulative failure rates for TADs in the maxilla and mandible. Approximately half (47.6%) of the TADs in the maxilla failed within 120 days of implantation, while more than half (58.1%) of those in the mandible failed within 60 days of implantation. Similar to Wiechmann *et al.*<sup>15</sup>, these findings suggest that failure tends to occur earlier and more frequently in the mandible compared to the maxilla.

#### *Relationship between Failure Rate and Sex*

Although some studies suggested no significant differences in TAD failure rates between men and women<sup>8-10, 11, 14</sup>, others reported observing a significantly higher rate in men<sup>19</sup> and this was in agreement with the findings of the present study. The cortical bone between the second premolar and first molar (where TADs are often implanted) is typically thicker in men compared to women and in the mandible compared to the maxilla<sup>16</sup>. Maki *et al.*<sup>20</sup> found that men also exhibit higher bone density compared to women and this can differ with the oral cavity site. Therefore, the higher failure rates observed in men can be attributed to the presence of thicker and denser cortical bone, leading to application of excess torque during implantation.

#### *Relationship between Failure Rate and Age*

The meta-analysis by Papageorgiou *et al.*<sup>13</sup> observed no significant differences in failure rates by age, and this was in agreement with several studies that reported similar findings<sup>8, 11, 14, 19</sup>. In contrast, others reported observing higher failure rates in patients aged < 20 years when compared to those aged ≥ 20 years<sup>21, 22</sup>. Motoyoshi *et al.*<sup>21</sup>, in their study including minors, compared TAD failure following application of orthodontic force immediately and ≥ 12 weeks after transplantation and found that the latter was associated with lower incidence rates. In the current study, the failure rates in patients aged < 20 years and 20–29 years were 14.2% and 13.7%, respectively, indicating very slight differences between the two groups that could potentially be attributed to the application of force after a period ≥ 1 month (frequently 2–3 months) instead of immediately. Despite this delay in force application, the failure rate was highest among patients aged ≥ 30 years (29.8%) compared to the other age groups (< 20 years: 14.2%; 20–29 years: 13.7%), and this finding was inconsistent with the absence of age-related differences and higher failure rates in patients aged

< 20 years reported by previous studies<sup>11, 22</sup>.

Du *et al.*<sup>23</sup> used quantitative computed tomography to examine age-related changes in the mandible and found that the volumetric bone mineral density (vBMD) increased with age in the 20–29, 30–39, and 40–49 year age groups but decreased in the 50-year age group. The correlation between vBMD and age was statistically significant ( $r = 0.15$ ,  $p\text{-value} > 0.01$ ), and this could potentially explain the differences in failures rate between the maxilla and mandible to some extent.

#### *Relationship between FMA, Time from Implantation to Failure, and Failure Rate*

Evaluation of failure rate by FMA showed no significant differences when the time to failure was not taken into consideration. However, evaluation of the same taking time elapsed between implantation between the second premolar and first molars and failure using the Cochran–Armitage trend test showed that the rates by day 120 were significantly higher when the FMA was smaller in the maxilla and mandible combined as well as individually, and this was particularly true for FMA < 20°. No such differences between FMA groups were observed when examining failure rates after 120 days, suggesting that failure of TADs implanted between the second premolar and first molar by day 120 is more likely to occur in patients with smaller FMAs compared to those with larger FMAs.

The nature of the relationship between vertical mandibulofacial morphology and failure remains unclear, with some studies<sup>12, 24</sup> reporting a significant association and others observing the opposite<sup>11, 19</sup>. However, these previous studies failed to classify the total number of cases by the time elapsed between implantation and failure, and the findings of the current study suggest that evaluation of TAD failure rates in specific post-implantation time periods may provide new insight.

Masumoto *et al.*<sup>25</sup> classified patients into three vertical skeletal pattern groups and found that the thickness of the cortical bone closest to the TAD implantation site between the first and second mandibular molars was greater when the FMA was smaller, while Maki *et al.*<sup>26</sup> suggested that bone density varied with muscle strength. Low-angle mandibulofacial morphology is often associated with stronger muscles and denser cortical bone. In contrast, Tachibana *et al.*<sup>27</sup>, in their study using 2.0-mm-thick cortical bone samples obtained using self-drilling or predrilling methods (where pilot holes

no larger than the appropriate diameter are prepared) on pig ribs, found that microcracks occurred in the area surrounding the TADs upon application of excessive torque during implantation. However, no microcracks were observed in the surrounding cortical bone when using samples that were 1.2-mm-thick, irrespective of the method used (self-drilling or predrilling), suggesting that the thickness and mineral density of the cortical bone increased as the FMA decreased. Higher bone density is more prone to excessive torque application during implantation, resulting in microdamage in the area surrounding the TADs. This, in turn, may prevent osseointegration between the TAD and the surrounding bone, resulting in a higher frequency of failure at an early stage (i.e., < 120 days after implantation). However, larger FMAs may delay failure, even when the self-drilling method is used, as the cortical bone is thin and excessive torque application during implantation does not readily occur preventing subsequent microdamage. However, further research is warranted to test this hypothesis in the future.

In conclusion, the risk of TAD failure at an early stage following implantation can be minimized by utilizing computed tomography to estimate the actual thickness of the cortical bone at the implantation site using the FMA and/or other maxillofacial morphological data. A predrilling method involving preparation of a pilot hole with an appropriate diameter should be used where necessary, and a torque-measuring screwdriver can be used for adjustments in case of excess torque application during implantation. Adequate attention to bone quality, predrilling, and appropriate torque application must be ensured when implanting mandibular TADs in males over 30 years of age with small FMAs.

The current study used five different TADs and no torque-limiting screwdrivers during implantation, preventing elucidation of the association between the various types of devices and implantation torque and failure rate. Future studies should explore the relationship between TAD failure rate, type, and torque applied during implantation.

### Conflict of interest

The authors report no conflicts of interest.

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