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Original Article

Micro-implant anchorage in adolescent orthodontics: a promising and advantageous option

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Abstract: Objective: To investigate the influence of micro-implant anchorage (MIA) on the orthodontic efficacy, safety, and oral health of adolescents. Methods: A total of 113 adolescent orthodontic patients treated during January 2019 to January 2021 were selected for study. Among them, 55 received traditional orthodontic treatment (reference group) and 58 underwent MIA (research group). The efficacy, orthodontic effect (molar displacement, upper central incisor [UCI] inclination, and convex distance differences), safety (oral infection, soft tissue edema, loose teeth, discomfort), oral health status (oral health-related quality of life [OHRQOL]), oral micro-ecological environment (detection rate of oral pathogens), gingiva-related indices (plaque index [PLI], sulcus bleeding index [SBI], and gingival index [GI]), masticatory function (bite force, masticatory efficiency), and orthodontic satisfaction were compared between the two groups. Results: The total effective rate and OHRQOL score of the research group were markedly higher compared with the reference group. Additionally, the research group reported lower molar displacement, PLI, SBI, and GI, and higher UCI inclination, convex distance, bite force, masticatory efficiency, and orthodontic satisfaction. Besides, the overall adverse reaction rate and oral pathogen detection rate were statistically lower in the research group. Conclusion: MIA is highly effective in adolescent orthodontics, significantly improving oral health, the oral microecological environment, gingival condition, masticatory function, and orthodontic satisfaction. It offers better orthodontic outcomes and higher safety.

Keywords: Orthodontics, teenagers, micro-implant anchorage, efficacy and safety, oral health status

Introduction

Dentofacial deformities are characterized by significant deviations in the maxillary-mandibular complex from the normal ratio, which can be easily detected [1]. Besides the persistent damage to patients' oral health, these deformities also negatively affect psychosocial wellbeing, particularly in adolescents [2]. This is especially prominent in adolescents with dentofacial deformities, as facial appearance can lead to a distorted self-image, as the pressure from social interactions can severely influence adolescents' self-perception [3]. Epidemiological data indicate that 83.5% of adolescents suffer from malocclusion, with higher prevalence among those with dental caries or a preference for soft-textured diets. Notably, 59.9% of high-school students express a demand for orthodontic intervention [4, 5]. Bullying due to dental appearance and dentofacial features can even lead to self-harm in teenagers [6]. To address the functional and psychological consequences of these deformities, orthodontic treatment is commonly sought [7]. Clinically, adolescents tend to have better orthodontic outcomes than adults, owing to their higher cellular responsiveness and greater ability to undergo collagen fiber transformation [8]. However, existing treatment methods face challenges, such as unstable anchorage effect and unsatisfactory efficacy. This study aims to optimize the orthodontic treatments for adolescents, with significant implications for improving postoperative recovery and quality of life of patients.

Micro-implant anchorage (MIA) is an orthodontic technique that uses bone as a direct anchor force to the jaw, minimizing unnecessary tooth displacement [9, 10]. Due to its advantages, such as small size, flexible implant site, ease of

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operation, minimal patient cooperation required, and excellent stability, MIA has gained increasing popularity among clinicians and patients in recent years [11]. MIA has demonstrated a good orthodontic effect in patients with skeletal class III malocclusion [12]. Wang et al. [13] also suggested the effectiveness of MIA in patients with unilateral posterior scissors bite. However, results from previous clinical trials on MIA in orthodontics have been mixed, likely due to variations in protocols and outcomes.

Despite extensive research on orthodontics, limited studies focus on adolescent orthodontic treatments. This study aims to retrospectively evaluate the curative effect, safety, and impact on the oral environment of MIA in adolescent orthodontics, hoping to provide a new clinical reference for the treatment of adolescent oral deformities.

Data and methods

Case selection

This retrospective study was approved by the Ethics Committee of Yongkang First People's Hospital. A total of 113 adolescent orthodontic patients who received treatment between January 2019 and January 2021 were selected for study. The reference group (n=55) received traditional orthodontic treatment, while the research group (n=58) received MIA therapy.

Patient enrollment criteria

Inclusion criteria: Patients meeting the orthodontic treatment standards; First-time orthodontic treatment; Age between 13-18; Presence of abnormal tooth alignment, buck teeth, or abnormalities in the frontal bone and/or dental arch morphology; No contraindications for surgery; Complete medical records; Willingness to participate in the study.

Exclusion criteria: Temporomandibular joint disorders or other oral diseases; Abnormal coagulation function or autoimmune deficiencies; A prior history of orthodontic treatment for dental malformations; Suboptimal oral hygiene; Congenital disorders or significant impairment of vital organ functions; History of orthodontic failure; Mental illness and communication barriers.

Intervention methods

Oral X-ray examination was performed in both groups before treatment to assess tooth arrangement, root position, and root morphology, and to determine the treatment plan.

The reference group received traditional orthodontic treatment. The procedure involved oral cleaning with 0.02% chlorhexidine and local infiltration anesthesia with lidocaine. A straight wire appliance was placed, and the appropriate traction force was applied based on the patient's tooth condition and tolerance. The straight wire appliance was worn for 8 h every day, during which oral hygiene should be maintained. Monthly follow-up visits were conducted during the 8-month treatment period.

The research group received MIA in addition to straight wire correction. The procedure involved selecting the implant site at the membrane-gingival junction, approximately 2-3 mm from the tooth root. Brass wire was used to separate adjacent teeth, and the alveolar mucosa was cut to prevent the soft tissue involvement. After implantation, an X-ray was taken again to observe the positional relationship between the tooth root and the micro-implant, as well as the surgical effect. The anchorage was maintained for 8 months.

Data collection and outcome measurements

The efficacy, orthodontic effect, safety, oral health status, oral microecological environment, gingiva-related indices, masticatory function, and orthodontic satisfaction of patients were observed and recorded.

Curative effects: Markedly effective: teeth were neatly arranged, the relationship between the teeth and molars normalized, and the anterior facial shape showed obvious improvement; Improved: Teeth were mostly aligned, the overbite and molar relationship improved, and the anterior facial shape showed noticeable enhancement; Ineffective: The above criteria were not met. The total effective rate was calculated as the percentage of patients with markedly effective or improved outcomes.

Orthodontic effects: Molar displacement, differences in upper central incisor (UCI) inclination, and convex distance were evaluated using facial cone beam CT.

Safety: The incidence of oral infections, soft tissue edema, loose teeth, discomfort, and other adverse reactions was recorded, and the overall incidence rate was calculated.

Oral health status: The Oral Health-Related Quality of life (OHRQOL) scale, with a score range of 0-56 (higher scores indicating better oral health), was used to evaluate patients' oral health after orthodontic treatment. The evaluation covered seven aspects: limited functionalities, physical disorder, psychological pain, Disabled, psychological communication, social difficulties, and psychological hindrance.

Oral microecological environment: Bacterial cultures were performed using sterilized cotton balls to collect samples from the oral walls of patients. The collected samples were cultured on BHI medium, properly processed, and diluted to measure the number of pathogenic bacteria, including cocci, spirochetes, *Fusobacterium nucleatum*, *Porphyromonas*, and *Actinobacillus actinomycetemcomitans*.

Gingiva-related indices: For the assessment of the plaque index (PLI), the tooth surface was gently scraped using a probe, and scoring was based on the quantity and thickness of the plaque, with scores ranging from 0 to 3 (higher scores indicating more pronounced plaque). Regarding the assessment of the sulcus bleeding index (SBI), a blunt-ended periodontal probe was employed to gently explore the gingival sulcus, and bleeding was observed. The total score spans from 0 to 5, where a higher score implies more severe bleeding. The gingival index (GI) was evaluated, with a total score ranging from 0 to 3. A higher score suggests a worse gingival condition.

Masticatory function-associated indicators: Bite force was measured using the MCF-8701 bite force measuring instrument. An occlusal test piece was placed on the first mandibular molar, and the patient performed 10 consecutive occlusions with 2-second intervals. Subsequently, the average value of three maximum bite forces was calculated. For the assessment of masticatory efficiency, the patient chewed 2 grams of peanuts, performing 20 chews on each side. After rinsing the mouth, the expectorated matter and residues were collected, mixed with distilled water, sieved, dried, and weighed. Masticatory efficiency was then calculated as the weight difference before and after chewing, relative to the pre-chewing weight.

Orthodontic satisfaction: A self-designed scale was utilized to evaluate patient satisfaction. A score below 60 was considered as dissatisfied, 60-80 as satisfied, and a score above 80 as highly satisfied. The satisfaction rate = (the number of highly satisfied patients + the number of satisfied patients)/the total number of cases × 100%.

In this study, the primary outcome measures included efficacy, safety profile, OHRQOL scores, oral microecological environment, and various gingival-related indices. The secondary outcome measures included molar displacement, differences in UCI inclination and convex distance, bite force, masticatory efficiency, and orthodontic satisfaction.

Statistical methods

Statistical analysis was performed using SPSS 18.0 software. Enumeration data were expressed as number of cases (percentage) (n [%]), and continuous data as mean ± standard deviation (SD ± SEM). Comparisons between groups were made using the χ^2 test for categorical data and independent samples t-test for continuous data. Significant differences were indicated by *P* values <0.05.

Results

Comparison of baseline data between the two groups

No statistically significant differences were found between the reference and research groups in terms of gender distribution, age composition, disease duration, disease classification, or family medical history (all $P>0.05$). The details are presented in **Table 1**.

Comparison of treatment efficacy between the two groups

The therapeutic effects of both groups were evaluated (**Table 2**). The total effective rate was 91.38% in the research group, significantly higher than 78.18% in the reference group ($P<0.05$). Images of two typical cases are shown in **Figures 1**, **2**.

Comparison of orthodontic effects between the two groups

The molar displacement, UCI inclination, and convex distance were measured to assess the orthodontic effects (**Figure 3**). The research

Table 1. General characteristics of the two groups

Categories	Reference group (n=55)	Research group (n=58)	t/χ^2 value	*P* value
Gender (male/female)	30/25	29/29	0.234	0.629
Age (years old)	14.80±1.64	15.05±1.70	0.795	0.428
Disease course (years)	2.91±1.27	2.53±1.74	1.320	0.190
Disease type (open-lipped and teeth-exposed/dental arch protrusion)	39/16	35/23	1.394	0.238
Family medical history (none/yes)	48/7	49/9	0.181	0.671

Table 2. Treatment efficacy in the two groups [n (%)]

Categories	Reference group (n=55)	Research group (n=58)	χ^2 value	*P* value
Markedly effective	23 (41.82)	30 (51.72)	-	-
Improved	20 (36.36)	23 (39.66)	-	-
Ineffective	12 (21.82)	5 (8.62)	-	-
Total effective rate	43 (78.18)	53 (91.38)	3.847	<0.050

Figure 1. Photos of a patient with a crowded dentition before (A) and after treatment (B).

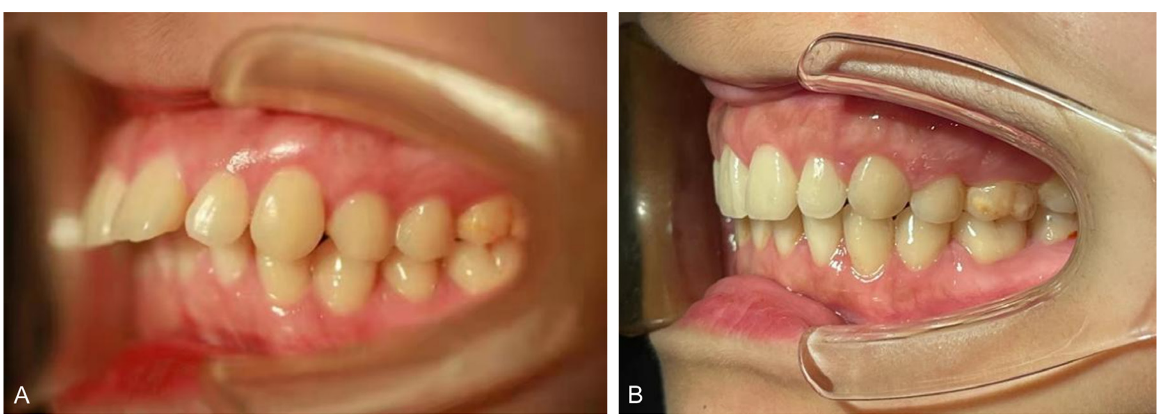

Figure 2. Photos of a patient with maxillary protrusion before (A) and after treatment (B).

group showed statistically lower molar displacement and higher UCI inclination and convex distance differences compared to the reference group (P<0.05).

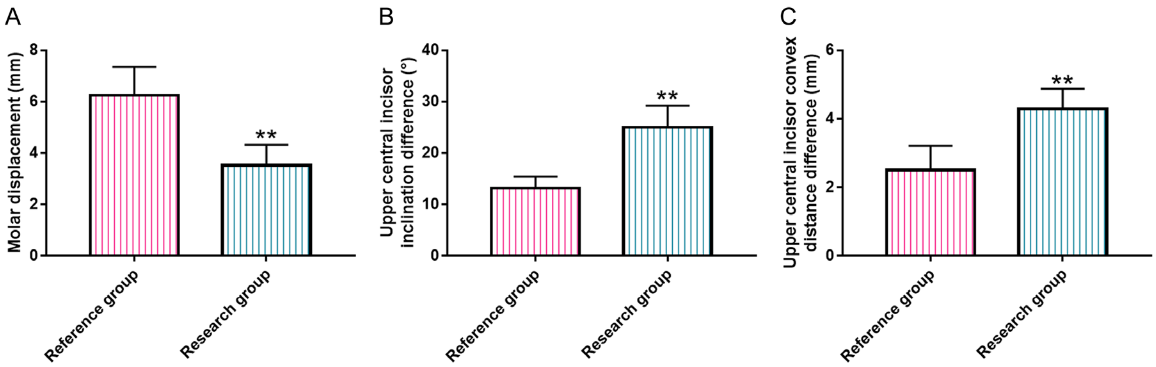

Figure 3. Comparison of orthodontic effect between the two groups. A. Molar displacement; B. Upper central incisor inclination difference; C. Upper central incisor convex distance difference. Note: **P<0.01.

Table 3. Safety profile in the two groups [n (%)]

Categories	Reference group (n=55)	Research group (n=58)	χ^2 value	*P* value
Oral infection	5 (9.09)	1 (1.72)	-	-
Soft tissue edema	5 (9.09)	2 (3.45)	-	-
Loose teeth	4 (7.27)	1 (1.72)	-	-
Discomfort	6 (10.91)	1 (1.72)	-	-
Total incidence	20 (36.36)	5 (8.62)	12.611	<0.001

Comparison of safety profiles between the two groups

Adverse events, including oral infection, soft tissue edema, loose teeth, and discomfort, were evaluated (**Table 3**). The total incidence of adverse events in the research group was 8.62%, notably lower than 36.36% in the reference group (P<0.05).

Comparison of oral health status between the two groups

Patients' oral health status was assessed using the OHRQOL scale, which evaluates seven aspects: limited functionality, physical disorder, psychological pain, disability, psychological communication, social difficulties, and psychological hindrance (**Figure 4**). The research group showed significantly higher OHRQOL scores in all seven aspects compared to the reference group (P<0.05).

Comparison of oral microecological environment between the two groups

The oral microecological environment was evaluated by detecting pathogenic bacteria, including cocci, spirochetes, Fusobacterium nucleatum, Porphyromonas, and Actinobacillus actinomycetemcomitans (**Table 4**). The research group exhibited significantly lower bacterial counts for all five pathogens compared to the reference group (P<0.05).

Comparison of gingival conditions between the two groups

Gingival health was assessed using PLI, SBI, and GI indices. The research group had significantly lower PLI, SBI, and GI scores compared to the reference group (P<0.05, **Table 5**).

Comparison of masticatory function between the two groups

Masticatory function, measured by bite force and masticatory efficiency, was significantly higher in the research group compared to the reference group (P<0.001, **Table 6**).

Comparison of orthodontic satisfaction between the two groups

The orthodontic satisfaction rate was significantly higher in the research group compared to the reference group (P<0.05, **Table 7**).

Discussion

Oral deformities, which encompass jaw abnormalities, dental malalignment, dental arch dis-

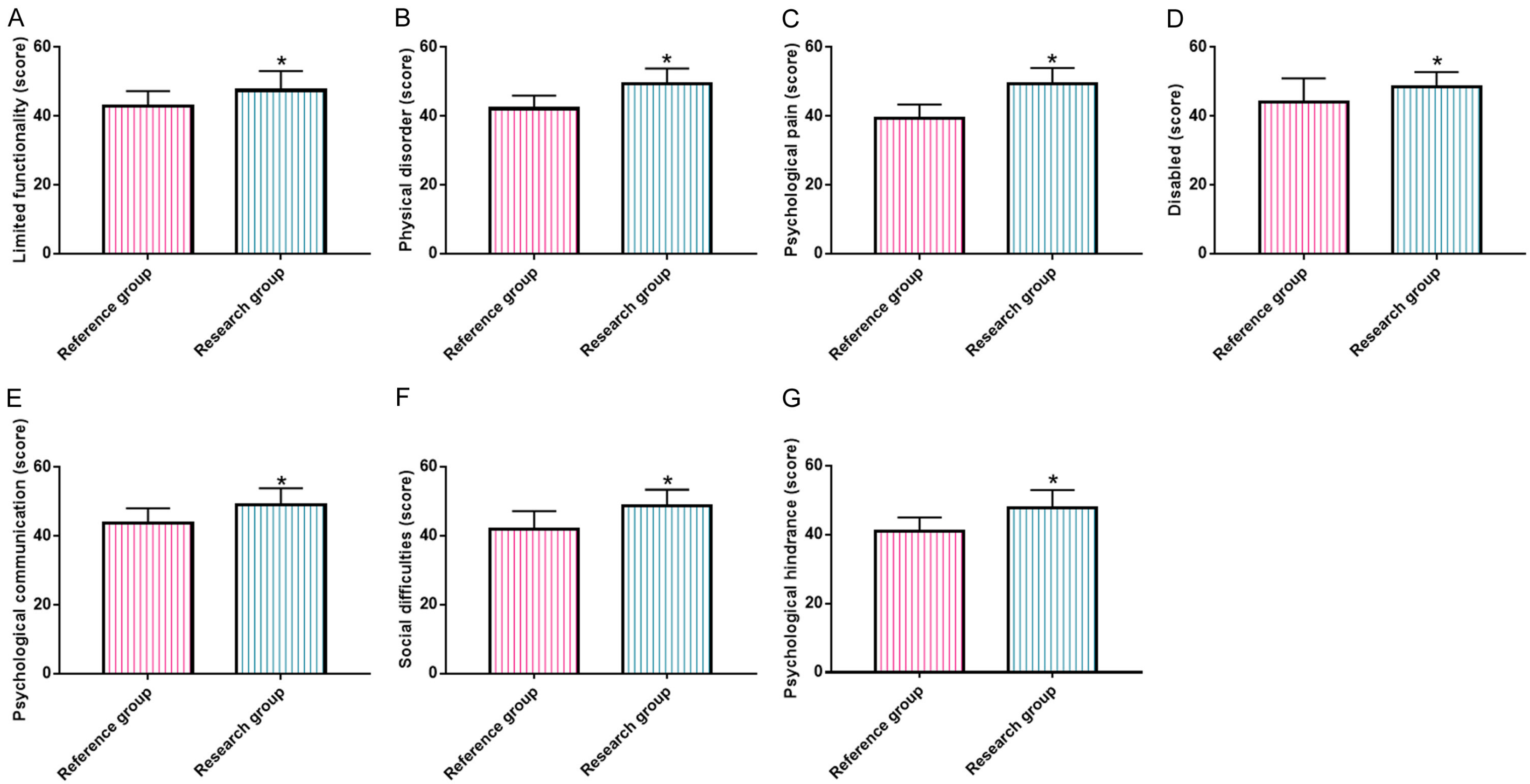

Figure 4. Comparison of oral health status between the two groups. A. Limited functionalities; B. Physical disorder; C. Psychological pain; D. Disabled; E. Psychological communication; F. Social difficulties; G. Psychological hindrance. *P<0.05.

Table 4. Oral microecological environment in the two groups [n (%)]

Categories	Reference group (n=55)	Research group (n=58)	χ^2 value	*P* value
Cocci	28 (50.91)	16 (27.59)	6.459	0.011
Spirochetes	13 (23.64)	5 (8.62)	4.753	0.029
Fusobacterium nucleatum	21 (38.18)	12 (20.69)	4.178	0.041
Porphyromonas	14 (25.45)	6 (10.34)	4.425	0.035
Actinobacillus actinomycetemcomitans	22 (40.00)	12 (20.69)	5.004	0.025

Table 5. Gingival conditions in the two groups

Categories	Reference group (n=55)	Research group (n=58)	t value	*P* value
Plaque index (points)	0.98±0.59	0.71±0.56	2.496	0.014
Sulcus bleeding index (points)	0.91±0.70	0.53±0.57	3.172	0.002
Gingival index (points)	1.29±0.57	0.84±0.70	3.735	<0.001

Table 6. Masticatory function in the two groups

Categories	Reference group (n=55)	Research group (n=58)	t value	*P* value
Bite force (IBS)	131.65±17.50	149.69±18.53	5.314	<0.001
Masticatory efficiency (%)	75.04±8.24	88.95±5.35	10.698	<0.001

Table 7. Orthodontic satisfaction in the two groups

Categories	Reference group (n=55)	Research group (n=58)	χ^2 value	*P* value
Highly satisfied	27 (49.09)	35 (60.34)		
Satisfied	18 (32.73)	20 (34.48)		
Dissatisfied	10 (18.18)	3 (5.17)		
Total satisfaction	45 (81.82)	55 (94.83)	4.692	0.030

location, are usually attributed to both congenital factors and the oral environment [14, 15]. Dentofacial deformities, a primary concern for adolescent oral health, can have significant physical and psychological impacts. Adolescents are in a critical period of rapid physical development and psychological self-shaping, making timely intervention crucial to prevent long-term adverse effects on their well-being [16, 17]. In recent years, increasing attention has been paid to adolescents' oral health problems. However, the stability of anchorage in current orthodontic treatments directly influences treatment outcomes and can lead to adverse reactions [18]. This study aimed to explore better orthodontic treatment options for adolescents, with a focus on micro-implant anchorage (MIA).

In this study, a total of 113 adolescent orthodontic patients were divided into the reference group (traditional orthodontics) and the research group (MIA treatment) according to their treatment methods. The total effective rate of adolescent orthodontic patients in the research group was significantly higher compared with the reference group (91.38% vs. 78.18%), indicating that MIA significantly improves treatment efficacy. MIA offers several advantages in clinical applications. First, its small diameter enhances comfort and promotes better patient compliance. Second, MIA demonstrates a higher orthodontic force-bearing capacity, effectively reducing the risk of displacement and ensuring the stable and predictable outcomes. Third, the procedure is relatively simple, which shortens treatment time and minimizes the risk of injury. Fourth, the micro-implant anchorage can be removed after treatment without the need for anesthesia, reducing patient discomfort. Fifth, MIA does not affect the patient's appearance, improving both treatment acceptance and aesthetic satisfaction [19, 20].

We evaluated the orthodontic effects of the two methods by measuring molar displacement, UCI inclination difference, and UCI convex distance. The research group showed evidently higher UCI inclination and convex distance differences, along with lower molar displacement, indicating that MIA not only improves orthodontic outcomes but also reduces unnecessary molar displacement, while increasing the inclination difference and convex difference of UCI. This is consistent with the study of Wahabuddin et al. [21] on MIA for orthodontic traction. In terms of safety, the incidence of oral infections, soft tissue edema, loose teeth, and discomfort was lower in the research group compared to the reference group. The overall adverse event rate was significantly lower in the research group (8.62% vs. 36.36%), indicating MIA's improved safety profile for adolescent orthodontic patients. This finding aligns with Wang et al.'s study on MIA in Angle Class II malocclusion cases [22].

Next, we evaluated oral health from seven dimensions (limited functionalities, physical disorder, psychological pain, disabled, psychological communication, social difficulties, and psychological hindrance, etc.). The research group showed better improvements in all aspects, demonstrating that MIA is more effective than traditional orthodontics in improving patients' oral health. Guo et al. [23] also indicated that the choice of orthodontic appliance can affect adolescents' oral microbial status, so we evaluated the oral microecological environment. As expected, the research group had a lower number of oral pathogenic bacteria, demonstrating that MIA helps improve the oral microenvironment. This favorable outcome can be attributed to MIA's reduced impact on the oral cavity compared to traditional strong anchorage systems. The compact size of the implant also makes it easier for patients to maintain oral hygiene, reducing the surface area where bacteria can accumulate and thereby lowering the detection rate of pathogenic bacteria [24].

Additionally, we found that MIA significantly reduced the scores of PLI, SBI, and GI, thereby improving patients' gingival health. Furthermore, MIA is conducive to enhancing the bite force and masticatory efficiency, leading to better masticatory function. This improvement can be attributed to the long-term malformation of teeth in adolescent patients prior to treatment. Food residue, which often remains in the oral cavity due to malaligned teeth, can cause gingival deterioration and impair masticatory function. However, MIA treatment helps prevent the accumulation of food residue by better aligning the teeth, improving both dental condition and occlusion, which in turn boosts masticatory efficiency [25].

In terms of orthodontic satisfaction, MIA intervention also showed a more prominent advantage, as evidenced by the higher orthodontic satisfaction in the research group. Previous studies have proposed various optimized alternatives for adolescent orthodontic treatment. For example, Gänzer H et al. [26] suggested that an oral irrigator incorporating microburst technology offers effective cleaning for adolescent patients, particularly for those who struggle with using interdental brushes, thus maintaining better oral hygiene during treatment. Jiang Y et al. [27] reported on the remarkable outcome of the 3D visualization-based modified anterior maxillary segmental distraction osteogenesis in treating maxillary hypoplasia in adolescents with cleft lip and palate, achieving excellent curative results with a low complication rate of 8.33%.

Conclusion

To sum up, MIA demonstrates remarkable efficacy in adolescent orthodontic patients. It not only improves patients' oral health and the oral micro-ecological environment, but also effectively reduces adverse events, enhances treatment safety, and improves the gingival condition, masticatory function, and orthodontic satisfaction. These benefits make MIA a promising treatment option for the rehabilitation of adolescent orthodontic patients, warranting clinical promotion. However, this study has certain limitations that need to be addressed. For example, the accuracy of the research results could be improved by expanding the sample size, as only 113 cases were included in this study. Additionally, aesthetic evaluations of patients after treatment can also be supplemented to determine a more aesthetically effective treatment plan. Future research will aim to address these areas for improvement.

Disclosure of conflict of interest

None.

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