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The evolution of the M.A.R.A. appliance from analogue to digital

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SUMMARY

The Mandibular Anterior Repositioning Appliance (M.A.R.A.) is a Class II fixed functional appliance invented by Douglas E. Toll in 1991. Since then, several modifications to its design have been made. From our perspective as clinicians and long-term users, having treated approximately 1000 cases collectively, the M.A.R.A. appliance is undervalued as a highly effective Class II appliance. Its versatility in addressing individual treatment needs in Class II corrections can be likened to that of a Swiss army knife.

The simplicity of each component of the M.A.R.A. allows for easy individual adjustments, ensuring that function follows form. The optimization of the analog M.A.R.A. and its clinical reliability were informed by long-term experience, encompassing biomechanical, hygiene, and usability aspects. These insights were incorporated into the digital design process. In the past, the analog customization process in the lab was extensive and time-consuming.

The virtual design process, utilizing the OrthoApps module embedded in OnyxCeph software by Image Instruments (Germany), facilitates the implementation of patient needs. This allows for the creation of an individually tailored M.A.R.A. appliance in real-time, with instant access to the manufacturing company. Manual adjustments, once integral in the clinic, are now largely handled by computer technology. Consequently, chairside time has been significantly reduced.

The evolution of the M.A.R.A. from analog to digital has followed the principle of "less but better," aiming to understand what is relevant in use and seeking ways to improve.

Introduction

Class II malocclusion is one of the most prevalent conditions among children and adolescents, affecting 20 % to 30 % of the world's population.[1,11] This means that nearly one-third of all orthodontic treatments are dedicated to Class II corrections, reflecting a significant economic impact.

In contemporary orthodontic practice, various Class II appliances are available, with fixed functional appliances (FFAs) being widely favored due to their non-compliance nature.

Class II corrections typically involve both skeletal and dental changes, including growth modification, condylar remodeling, distalization of upper molars, retraction of upper incisors, mesialization of lower molars, and proclination of lower incisors.[8,10,15,18]

In this article, we aim to shed light on one of the most underestimated FFAs: the Mandibular Anterior Repositioning Appliance (M.A.R.A.) and its evolution from analog to digital technology.

The M.A.R.A. was introduced by D. E. Toll in 1991 to advance the mandible forward, with subsequent modifications to its design. However, its fundamental construction can be traced back to an appliance by Edward H. Angle, known as "antagonizing spur retainers".[3]

In 1998, D. E. Toll and J. E. Eckart obtained the patent for the M.A.R.A., with Ormco and AOA (Allesee Orthodontic Appliance, Wisconsin) responsible for marketing, production, and delivery. While Ormco offered a standardized prefabricated M.A.R.A. accessory kit, AOA provided customized services to orthodontists.

Although the M.A.R.A. gained popularity in the USA, particularly surpassing the Herbst appliance, the latter remains dominant in Class II treatment, especially in Germany following its rediscovery by H. Pancherz in.[13] Numerous articles have been published on the Herbst appliance, establishing its worldwide reputation.

From our perspective as clinicians and long-term users, having treated approximately 1000 cases collectively, the M.A.R.A. appliance is underestimated as a highly valuable Class II appliance. It exhibits versatility and can easily adapt to individual treatment needs. Moreover, it offers simple clinical handling, predictable treatment outcomes, and broad applicability for Class II anomalies in patients of all ages, with high patient acceptance in terms of comfort and aesthetics.[5]

We recognized the opportune moment to transition to digital technology, which allowed us to fully customize M.A.R.A. appliances independently, without reliance on any specific supplier.

The M.A.R.A. appliance: construction and function

The original M.A.R.A. appliance consists simply of four crowns or bands placed on the permanent first molars in the upper and lower jaw. The removable elbow, connected to the upper first molar, advances the

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Fig. 1. a, b: a. Components of the M.A.R.A. − a. lateral view; b. frontal view.

lower jaw with its vertical square part against the lower arm forward (see Fig. 1a and b).

These functional components of the M.A.R.A. run perpendicular to each other and are not directly connected; only intermittent forces are produced. Additionally, the elbows approach the height of the center of resistance of the lower first mandibular molar in the vertical direction when closing the bite.

The mandible is incrementally advanced forward in Class I occlusion, typically starting from the habitual occlusion by shims (1−4 mm). Every 4 to 6 weeks, the mandible is pushed forward to allow adequate time for the underlying structures and the neuromuscular system to adapt[16,17] (see Fig. 2 a nnd b).

The sweep of the elbow, which runs dorsally from its vertical part parallel to the dentition, ensures that the elbow does not slip in front of the lower arm and entrap the mandible backward (see Fig. 2a).

The M.A.R.A. is a versatility tool

The M.A.R.A. is a versatile tool for correcting both symmetrical and asymmetrical Class II malocclusions, without affecting the cant of the occlusal plane. Thanks to its simple construction, the M.A.R.A. can be easily adapted to various clinical scenarios in Class II correction and allows for combinations across different age groups. It can be utilized in the early mixed dentition phase in children, as well as in the permanent dentition phase in youth or adults.

Furthermore, the M.A.R.A. serves as an important treatment tool for upper jaw anchorage, similar to a headgear, to retract proclined upper incisors while maintaining Class I molars and counteracting the "rowing boat effect." Additionally, in cases involving extractions, the M.A.R.A. proves invaluable in preventing any loss of anchorage.

Overall, wherever Class II malocclusion exists, whether from the outset or developing during treatment from Class I, the M.A.R.A. can effectively address it through its dental and skeletal effects.[2,4,6,7,9,12,14,15]

The evolution of the M.A.R.A. − from M.A.R.A. Kit to customization in the analog era to the big bang of the digital process - time of transition

In the past, the M.A.R.A. was available in two variants. Ormco distributed the M.A.R.A. as an accessory kit from Allesee Orthodontic Appliance (AOA), while AOA offered a full-service option, providing orthodontists with prefabricated components assembled for specific patient cases. Initially, impressions or models were sent by mail, and later, copies of the upper and lower arch could be sent via facsimile. Nowadays, model scans or scans of impressions are transferred electronically.

The M.A.R.A. kit requires its own laboratory. The customization process in your own lab can be quite extensive and time-consuming. The proficiency of your technician is crucial in determining the depth of this process.

The clinical part involves standardized processes: separation with separators, fitting of the crowns or bands, bite registration and impressions (see Table 1).

We must acknowledge that digitalization disrupts established processes, and undergoing transformation is a significant challenge, always with the goal of leveraging all advantages (see Table 1). Ignoring this development carries the risk of being left behind.

Fig. 2. a, b: a. The sweep of the elbow protects that the mandible slips backwards from the starting position of the lower jaw while advancing the mandible forward. b. In the first step the mandible adapts in the new position by neuromuscular deprogramming.

Table 1
Workflow-Chart: Comparing analog and digital workflows of the M.A.R.A.

Analog A. Clinical-Preparation	Appointments	Digital Clinical- Preparation	Appointments
1. Separation of the 1st molars	1.	1. bite registration	1.
2. Crown/band fitting	2.	2. Scan	
3. Impressions		**B. CAD process**	
4. bite registration		3D models	
5. Separation of the 1st molars		MARA design	
B. Own lab process (in office/e.g. AOA)			
		D. CAM process (SLM)	
C. Clinical insertion	**3.**	**E. Clinical insertion**	2.
Company dependent: Ormco, AOA		Company independent (open source)	
Limited individualization		Full individualization	

Table 2
Preferable Class II appliance should be like a Swiss army knife i.d. an all-in-one device suitable for every purpose.

Patient expectations	orthodontist goals
no cooperation	non-compliance
invisible	easy handling
comfortable	little chairtime
short treatment time	no or less side effects
no extra appointments	stable and consistence
	projectable outcome

The future of orthodontics relies on successful adaptation to the new era of digital transformation.

First and foremost, one needs to embrace the digital spirit, which serves as the driving force behind the transformation process.

The new technology empowers us to easily respond to short technology cycles, to develop and optimize, and to employ best practices through iterative "test and learn" approaches such as design thinking. Ultimately, it reduces the time required to gain experience.

The virtual designing process facilitated by the OrthoApps module embedded in OnyxCeph software (Image Instruments, Germany) streamlines the implementation of patient needs and meets our demands for individually tailored M.A.R.A. appliances chairside and in real-time, with instant access to the manufacturing company (see Table 1).

In the short term, you receive evidence of the stability and functionality of your new construction. You can address any problems directly and easily without hesitation. Improvement occurs rapidly, accelerating your experience with leveraging your M.A.R.A. appliance sooner rather than later.

The idea

The concept revolves around creating the most advanced version of the M.A.R.A., inspired by its analog counterpart, while focusing on biomechanical properties, stability, usability, hygiene, aesthetics, and comfort to fulfill both patient expectations and orthodontist goals simultaneously (see Table 2). This is crucial and hinges on understanding the relevance of each aspect in practice. Our aim was to streamline what may seem like a straightforward fixed functional appliance (FFA) to its optimal form. In essence, the virtual design process of the M.A.R.A. adheres to the principle of "function follows form." Ultimately, the final product is much more than the mere sum of its individual components.

The design processes

The software we utilize for the design process is the OrthoApps 3D module, seamlessly integrated within OnyxCeph3TM (Image Instruments, Germany). This module empowers the creation of virtual appliances, encompassing bands, 3D objects from a user-maintained library, and 3D connecting elements. All patient records, both 2D and 3D, are securely stored within the integrated database of OnyxCeph3TM.

Here’s a general guide on how to initiate the M.A.R.A. design process in OrthoApps:

Begin by virtually designing the essential components of the analog M.A.R.A. template. This involves modifying 3D objects from the virtual

Fig. 3. a, b: Virtual tool bar of M.A.R.A. components: a. M.A.R.A. components assembled and b. breaked open in 16 necessary parts to utilize function.

Fig. 4. a-c. Three-dimensional adjustment of the lower arm. a. consider the centre of resistance (CR) – (yellow dot) b. vertical (green broken arrow) and sagittal orientation (blue arrow) of the lower arm, c. transversal orientation (red broken arrow) of the lower arm of approximately 8 mm to prevent tissue impingement.

library, including bands, bars, connectors, and other suitable elements, tailored to fit an average Class II patient case.

Define the parameters (in millimeters or percentages) for all objects, considering factors such as thickness, length, direction relative to the coordination plane, and positioning based on interspace and optimal biomechanical transmission. Additionally, prioritize considerations for hygiene, patient comfort, and invisibility.

Save the configured objects as a template toolbar, which can then be easily modified and adapted to suit any specific patient case (see Fig. 3a and b).

The virtual M.A.R.A. assembling process follows an efficient workflow.

Commencing with the bands and lingual arch. This process resembles the fitting and adaptation process in the clinic and in the lab.

Following this, the next step involves positioning the functional attachments. It's crucial to adhere to biomechanical principles as they are fundamental to the design features from the outset.

When positioning the upper and lower attachments, it's ideal to orient them as close as possible to the center of the bands, taking into account occluso-gingival, mesio-distal, and bucco-lingual space conditions (see Figs. 4a-d, 5a-c).

Begin by focusing on the lower arm. It should be positioned in three dimensions relative to the upper first molar, considering sagittal advancement and vertical direction aimed at approaching the CR (see Fig. 4a-c). The lower arm extends approximately 8 mm in the bucco-lingual direction to ensure an adequate guiding surface for the upper elbow and to minimize soft tissue impingement as much as possible (see Fig. 6b).

Fig. 5. a-c a. Upper attachment with the elbow, elbow tube and the archwire tube (sagittal and frontal view). b. adjustment of the elbow, the elbow tube and archwire tube according to the adjacent brackets (yellow circle) and lower arm (yellow broken arrow) in sagittal direction according to the habitual occlusion, c. elbow and the archwire tube are positioned under consideration of the thickness of the shims (yellow circle) and the adjacent brackets (blue broken arrow) in transversal direction.

Fig. 6. a, b: Positioning of the vertical part of the elbow in transversal, sagittal and vertical direction to the lower arm according to the target spot. a. note in the frontal view the transversal discrepancy of the horizontal part and vertical part of the elbow (yellow broken arrow) and b. note in the sagittal view that the vertical part of the elbow is extended to the bottom end of the lower arm (yellow solid line).

Fig. 7. Variable connector (square part in orange) between the horizontal and vertical part of the elbow. The yellow broken arrow marks the transversal discrepancy between the horizontal and the vertical part of the elbow.

Fig. 8. a, b: a. sufficient length of the sweep in mesio-distal direction (yellow dotted lines, blue broken arrow) to prevent slipping backwards of the upper elbow b. slight curvature of the sweep (yellow circle) to increase room for lateral movements (frontal view and dorsal view).

Next, focus on positioning the upper attachment. It should be placed vertically and transversely on the band of the upper first molar, aligning with the best-fit area in line with the adjacent bracket position or the assumed bracket line (see Fig. 5a and b).

The upper attachment consists of the elbow, elbow tube, and archwire tube.

Ensure that the elbow can freely slide in the sagittal direction. The spacing between the archwire and the spacer should be determined based on the thickness of the spacer (Scheu Dental, Germany) and the approximate distance to the upper band (see Fig. 5c).

Lastly, the refinement of positioning the upper and lower attachments occurs based on the sagittal plane of mandibular advancement. Typically, the lower arm and the elbow are initially positioned in the mesio-distal direction according to the habitual occlusion (see Fig. 5b).

This serves as the starting point for gradual advancement to prevent overloading of the underlying physical and biological structures. By adopting this approach, patients can adapt to the new appliance more comfortably and with less difficulty, reducing feelings of overwhelm. Additionally, it allows for better control of potential side effects.

Fig. 9. Lower archwire tube positioning in the sagittal and transversal view in line with the adjacent bracket slots (yellow circle).

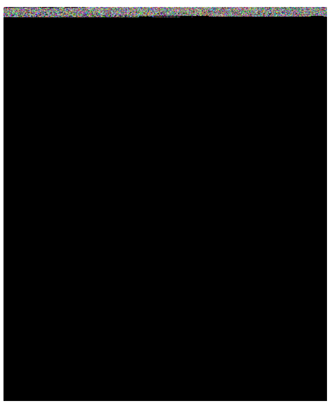

Fig. 10. Securing of the elbow in two ways horizontal (yellow arrow) and diagonal (yellow broken arrow) if reinforcement of the elbow is necessary.

It's important to consider limiting factors, such as the mesio-distal extent of the crown and the magnitude of sagittal advancement.

The vertical part of the elbow should be in touch with the guidance surface of the lower arm to obtain a sufficient bodily force transmission to the lower 1st molar (see Fig. 6a and b).

Therefore, it is necessary to extent the vertical part of the elbow to the bottom end of the lower arm with a full surface contact (see Fig. 6b).

Note that, the vertical part of the elbow in bucco-lingual direction is centered to the inwards running target spot of the lower arm (see Fig. 6b).

A connector is often needed which connects the horizontal part with the vertical part of the elbow (see Fig. a, b). The horizontal and vertical elbow components are subject to the most frequently individualization (see Fig. 7). In the analog era the elbow was manually adjusted by the torqueing tool and different pliers like three prong plier and utility plier.

A crucial functional component of the M.A.R.A. is the sweep, which is attached to the vertical elbow. Extending a sufficient length in the mesio-distal direction, it serves to prevent the upper elbow from slipping sagittally behind the lower arm and blocking mandibular movement backwards (see Fig. 8a).

The lower portion of the sweep features a slight buccally-curved contour along the dentoalveolar slope to allow for increased space during lateral movements (see Fig. 8b).

Thanks to its moderate extension, it functions akin to a snowshoe, enhancing comfort. The amount of extension required for patient satisfaction can be adjusted, with one exception - the dorsal length.

The final step in our workflow is the positioning of the lower bracket tube in line with the adjacent bracket slots (see Fig. 9).

The elbow can be secured in two ways: horizontally and diagonally.

The main connection, which runs horizontally, involves two hooks and a supporting connection that extends from an additional hook on the vertical leg of the elbow diagonally to the upper attachment (see Fig. 10).

This diagonal connection reinforces the horizontal leg within the tube. We recommend using a stainless-steel ligature 0.014 inch to ensure a secure attachment.

Reviewing the virtual appliance

After connecting and detailing all components, we review the construction in the computed result (see Fig. 11). This 3D-view reflects the virtual M.A.R.A. as it will appear in reality. All objects added to a particular component are fused, while assisting objects that create particular negative geometries on a component, such as tubes, are subtracted.

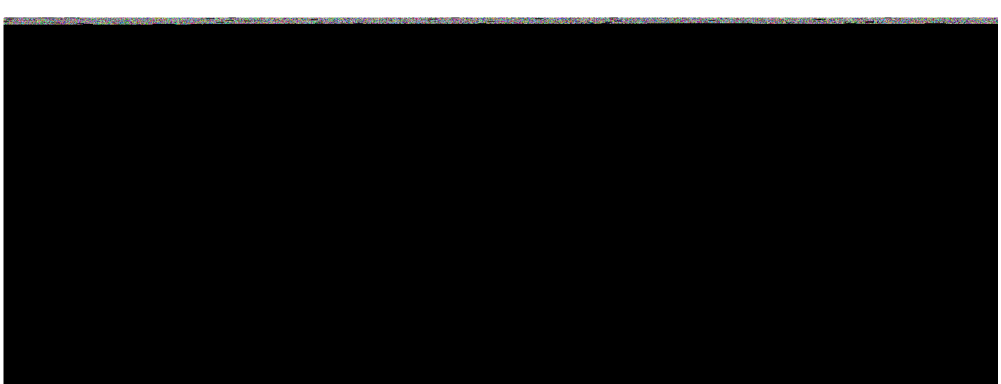

Fig. 11. Review of the computed components of the M.A.R.A.

Fig. 12. Elbows with the supporting structures on the SLM construction platform. Depending on the position of the supporting structure there is an additive layer of material between 0,1−0,3 mm.

The final step is to generate and save an STL file for export to a manufacturing company with specialized dental technicians. The virtual file can be directly transferred into a physical cobalt-chrome alloy (CoCr) object using SLM (selective laser melting) technology.

Manufacturing − SLM (selective laser melting)

In general, you can order your M.A.R.A. in three different finishing outcomes depending on the quality of refinement: non-sanded, sanded, and polished.

Selective laser melting (SLM) is a metal additive manufacturing (AM) technology designed to use a high power-density laser to melt and fuse metallic powder, such as cobalt-chrome alloy, in thin layers together to create 3D metal objects. Nowadays, it is almost used in all kinds of industries where complex geometries are produced. This innovative technique guarantees a standardized and repeatable procedure with high-quality objects regarding density, compactness, stability, and precision.

All objects are supported by multiple support structures that connect the different components of the M.A.R.A. with the construction platform. These structures are essential for printability in the manufacturing process, serving as anchors, dissipating heat, and preventing thermal warping of the parts (see Fig. 12). Afterward, the M.A.R.A. objects go through numerous further processing steps in terms of refinement, ranging from non-sanded to sanded to polished. These steps include both automated and manual labor processes. However, this process chain, from the raw product to the highly polished appliance, may compromise the accuracy of the final objects to some extent.

Check the manufactured appliance and refinement

After receiving the M.A.R.A. components from the manufacturing company, a final finishing process in your own laboratory is necessary, depending on the refinement stage (non-sanded, sanded, polished) you have ordered the M.A.R.A..

The 3D printing process causes small bumps on the inner surface of the archwire and elbow tubes, which generate friction and require post-

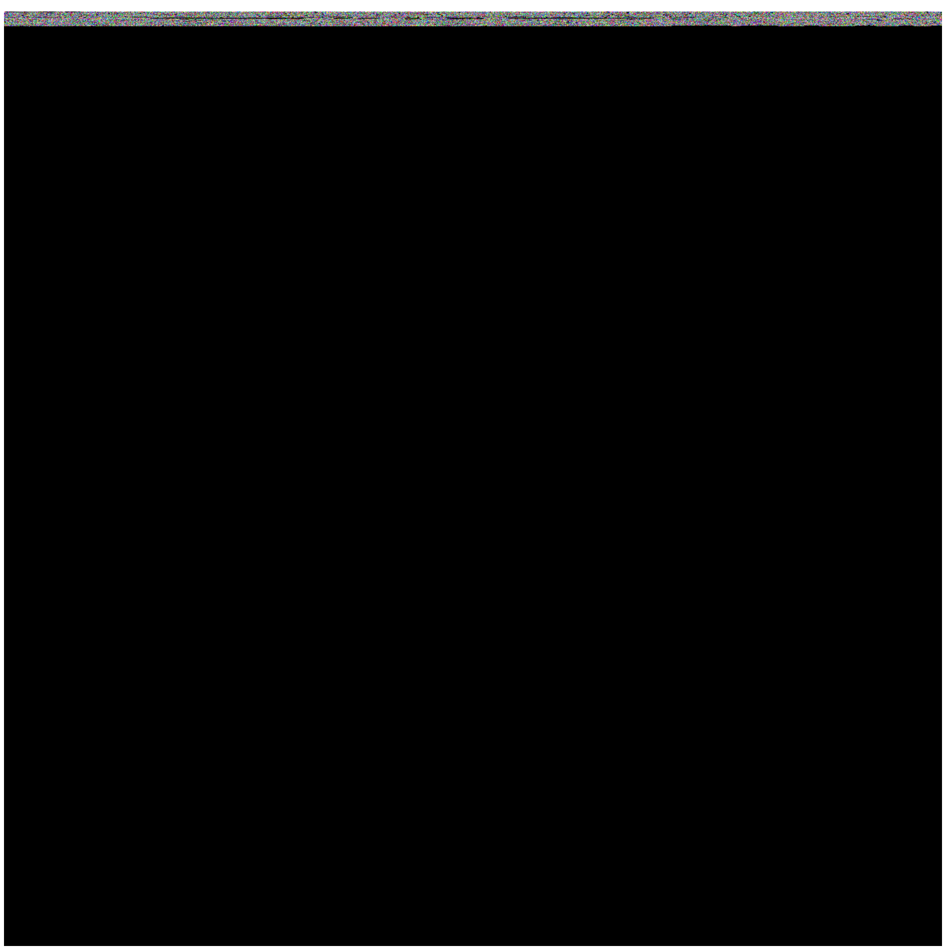

Fig. 13. a-d: Fitting of the functional elements (archwire and horizontal elbow) to the elbow and archwire tube a. removal of process dependent overhang edges on the archwire tube by the smallest rose-head burr to make the archwire move smoothly through the archwire tube (size: 0.022) b; c. using a smal conical formed carbide milling cutter to remove overhang edges on the elbow tube in terms of elbow fitting d.

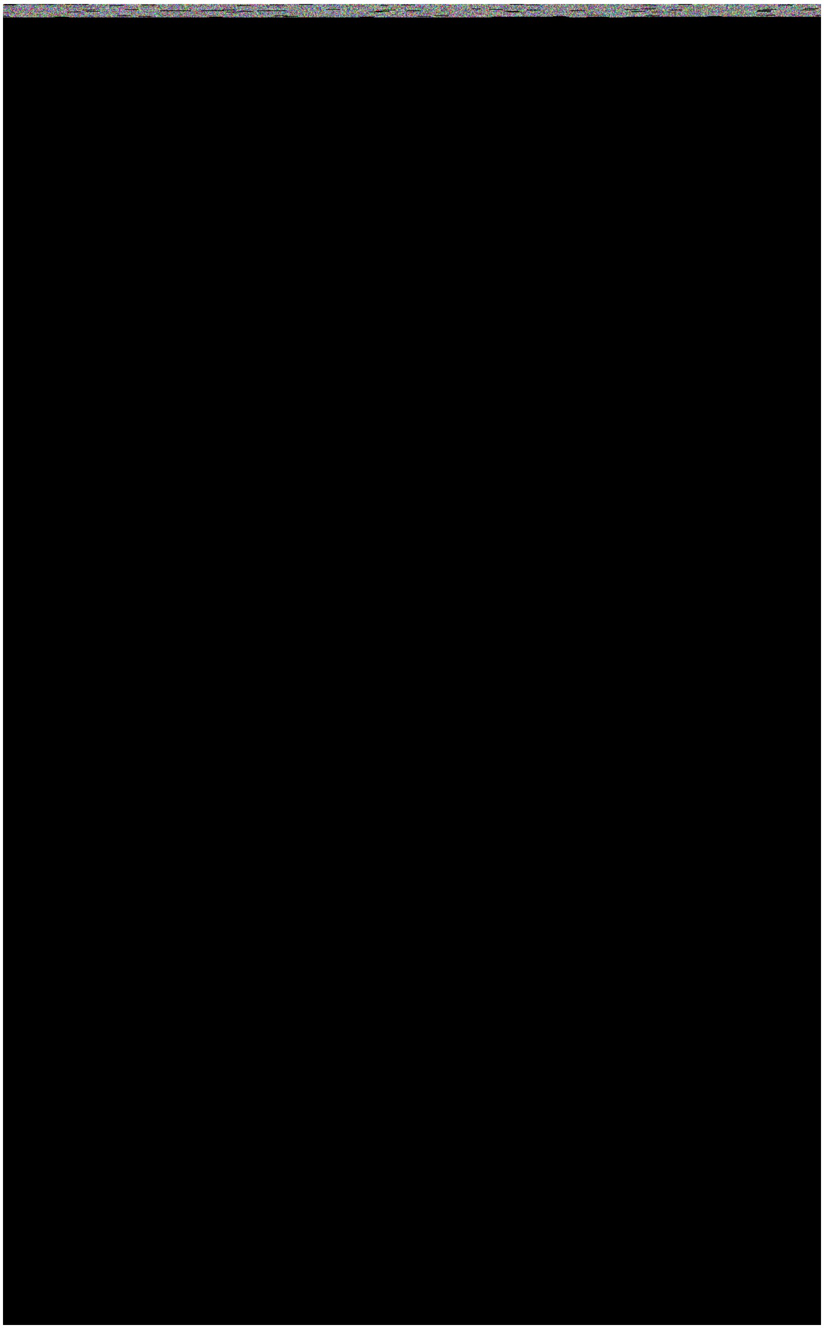

Fig. 14. a,b: a. Patient in mixed dentition directly after insertion of the customized M.A.R.A. in combination with an utility appliance in the upper arch. b. same patient after 6 month of follow up with the M.A.R.A.

processing with various rotating instruments, completed by final polishing (see Fig. 13a-d).

The final finishing processes in your own laboratory also affect the accuracy of fit of the archwire tube and horizontal elbow tube, resulting in a certain amount of play between components.

Clinical application

Engineering a new appliance to its optimum is a continual process. The significant advantage lies in the ability to promptly apply clinical experiences directly to patients. By collecting and analyzing data, orthodontists can swiftly implement findings into practice, allowing for better judgment compared to relying solely on company marketing. Continuous reassessment is essential. Rapid experience gain is a major benefit, as the appliance can be adjusted almost in real-time to match individual clinical habits. To gain evidence, it's crucial to have data independently researched. The virtual designing process of the M.A.R.A. appliance not only offers customization options but also accelerates the process from conception to the finished product (see Fig. 14a and b). Manufacturing companies provide efficient services like 24/7 STL file downloads and short production and delivery times.

Critical self-assessment

Embracing Charles Tweed's advice to "put your plasters on the table," we subject ourselves to critical self-assessment of the new technique. We contrast pros and cons regarding the application of CAD-CAM and clinical experiences.

CAD-CAM

Pros: Flexibility, independence, speed, quick implementation, adaptability, delegability, cleanliness.

Cons: Questionable precision due to process-related inaccuracies, manual post-processing necessary.

Clinical experience

Pros: Easy and fast insertion in patient cases with or without brackets, eliminates time-consuming preparations like separations of 1st molars, impressions, and quick adaptation phase.

Cons: Reduced friction between bands and teeth, limited by stiffness (alloy-related), may require prior etching with phosphoric acid in some cases.

Conclusion

The M.A.R.A. proves itself as versatile, offering clinicians a comfortable adaptation with a short learning curve. The new technology enhances productivity, improves design quality, facilitates communication through documentation, and creates a database for tailored construction needs. However, the advancement of AI technology raises concerns about job displacement, presenting both opportunities and challenges for passionate orthodontists. It's hoped that any changes in the profession will occur gradually.

Patient consent

Patient consent was obtained.

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Author contributions

All authors attest that they meet the current ICMJE criteria for authorship.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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