Scientific Report
A new super elasto-plastic Ti alloy-GUMMETAL- simplify treatment procedure,

Clinical use of GUMMETAL

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Introduction

The number of adults in Japan who choose to undergo orthodontic therapy is increasing. However, some people, despite knowledge of what beautiful teeth they could have, do not undergo orthodontic therapy because of the unpleasant prospect of having uncomfortable orthodontic appliances in their mouth for a long period of time. We have improved brackets and other orthodontic hardware, and any required tooth movement can now be achieved in less time. A better knowledge of bone metabolism has helped us to improve our therapeutic techniques. Despite many improvements in therapeutic techniques and materials, we have not yet found the ultimate solution.

Two disadvantages of active orthodontic therapy that are yet to be overcome are acute pain and root resorption. Due to limitations associated with the application of orthodontic force, orthodontists had to use light-wire methods using round-wire with loops and rectangular thin-wire. However, these types of wire have been avoided because it is difficult and time-consuming to custom-bend the wire into the shape needed for each patient. In order to keep the technique simple, we have continued to study a variety of straight-wire methods, despite the strong orthodontic force that results from the use of straight orthodontic wire.

For ideal clinical treatment, we need 1) high-level three-dimensional control of the movement of the teeth; 2) simple appliances; and 3) efficient continuous gentle force. I would like to talk about the materials and methods that will allow us to achieve all of these three goals.

Orthodontic wire and new materials

At the most elemental level, orthodontic wire provides the primary force to move teeth. This has remained unchanged throughout the history of orthodontics. Gold-alloy wire, the first wire used in the early days of multi-bracket orthodontic therapy, was eventually supplanted by other alloys. Stainless-steel wire played an important role before giving way to a cobalt-chrome alloy (Co-Cr) manufactured by RMO®, which became the de facto standard. For a long period of time starting in the Tweed era, the pace of improvement in orthodontic therapy was very slow, because there simply were no alternative materials capable of surpassing the inherent limitations of Co-Cr wire. For a revolution in orthodontics, our predecessors had to wait until 1977 which brought the advent

Table.1　Key characteristics of several conventional biocompatible metal alloys and GUMMETAL.

Metal for dental use	Conventional metal	Main elements	Young's modulus GPa	Tensile strength MPa
Noble metal	12%Au-Ag-Pd alloy	Au-Ag-Pd	>250	900
Stainless steel	SUS316	Fe-Cr-Ni-Mo	200	860
Co-Cr alloy	ASTM F562	Co-Cr-Ni-Mo	170	1000
Titanium	Pure Titanium	Ti	102	270
Ni-Ti alloy	Nitinol	Ti-Ni	105	700
α+β Titanium alloy	ASTM F136	Ti-Ai-V	85	860
Ti-Nb alloy	**GUMMETAL**	**Ti-Nb-Ta-Zr**	**45**	**1100**

(Cr,Ni,V are cytotoxic)

of wire made of titanium alloys. Advances in metallurgy and processing technology led to the development of these alloys.

Pure titanium and its alloys are the best materials for many dental applications at the present time. The use of titanium alloys in many dental products, including orthodontic wire, metal-based dentures, and dental implants, has surged because of their biocompatibility and because of other useful characteristics of titanium alloys. One alloy in particular, that contains equal amounts of nickel and titanium, known as Ni-Ti, is super-elastic, has shape memory, and is very suitable for use as orthodontic wire. Ni-Ti wire significantly simplifies the beginning phase of active treatment and at the same time eliminates excessive orthodontic force. Because of its continuous orthodontic force delivery and unique hysteresis characteristics, it simplifies the therapeutic regimen, reduces or eliminates acute pain, and shortens the duration of treatment. Unfortunately, however, these characteristics of super-elasticity and hysteresis reduce the formability of Ni-Ti wire and make it almost impossible to bend. For this reason, Ni-Ti wire is used only in the first phase of orthodontic treatment. It is too difficult to bend it into the shape needed for the three-dimensional control of individual tooth movement during the middle and final phases of therapy. Up to the present time, these last two phases have required wire made of stainless steel or Co-Cr.

Several years ago β titanium wire joined Co-Cr alloy, stainless steel, and Ni-Ti alloy in the stable of materials used as orthodontic wire. Titanium alloys are designated as α or β depending on the arrangement of atoms at room temperature. The use of β titanium alloys has expanded because they are more flexible than steel and can hold a bend (Fig. 1, 2).

Development of GUMMETAL wire

A new titanium alloy, given the name GUMMETAL®, was developed in 2003 in Japan at the Metallurgy Research Section of Toyota Central R & D Laboratories, Inc. GUMMETAL is the world's first alloy that combines an extremely low value of Young's modulus with extremely high strength. Producing an alloy of conventional metal materials with this combination of characteristics was thought to be impossible. Three magic numbers were necessary: Ti 25%mol (Ta+Nb)-Zr-O,(i) a compositional average valence electron number (e/a) of around 4.24,(ii) a compositional bond order (Bo) of around 2.87,and (iii) a d-electron orbital energy (Md) of around 2.45eV.

GUMMETAL has these characteristics:
1) Its Young's modulus is about 40 GPa while at the same time its tensile strength is about 1000 MPa.
2) It is super-elastic; its ductility is about 10 times greater than conventional metals. It has similar super-elastic character as NiTi.
3) Micrographs of GUMMETAL show the interwoven filamentary structure (Fig. 2) that results from the cold-working of the alloy during the manufacturing process.
Easy to do plastic deformation without any dislocation of crystal architecture is the main feature of GUMMETAL.
4) GUMMETAL does not have stress-induced martensitic transformation like NiTi alloy; this superelastic deformation is true elastic deformation without hysteresis.
5) Its behaviors are curved to and from the yielding point. (it is the only metal that does not follow Hooke's law, Fig. 3).
6) Because of the dislocation-free deformation mechanics, there is no work-hardening by forming.
7) All the constituent atomic elements of the alloy are biocompatible and non-toxic.

These are important requirements of orthodontic wire.

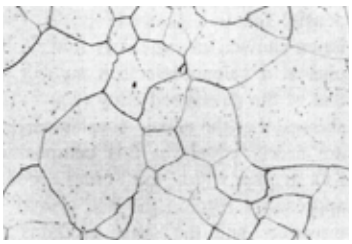

Fig.1

Structure of common metal

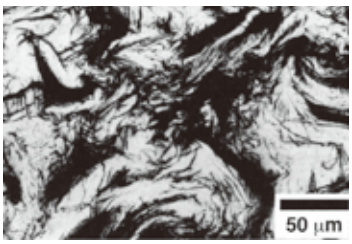

Fig.2

The micrograph shows the filamentary structure of GUMMETAL. This structure is produced as a result of being cold-worked during the manufacturing process.

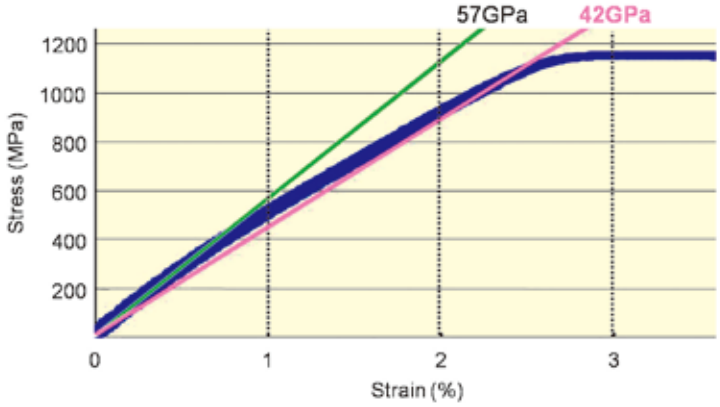

Fig.3

Unique elasticity of GUMMETAL. The value of Young's modulus for GUMMETAL is not constant, but takes on different values in different regions of the stress-strain curve.

We have adapted GUMMETAL wire for use in orthodontic therapy because it allows the period of active treatment to be shortened. GUMMETAL wire is able to maintain its advantagous characteristics by avoiding high-temperature processing and instead using cold-working processes for diluting and wire-drawing. In addition, the coefficient of friction of the surface of the wire was optimized so that friction between the wire and brackets is 1／2 of other β titanium wires.

GUMMETAL orthodontic wire

These are the characteristics of GUMMETAL wires directly related to orthodontic use:

1) Flexible and super-elastic
2) Easier to bend than other titanium alloy wire
Even easier to handle than Elgiloy®
3) High in spring-back effect, yet no hysteresis
Easily controls orthodontic force
4) Contains no nickel and no heavy metals, thus, it is non-toxic
5) Not susceptible to work-hardening, thus almost no breakage inside the mouth
6) Low coefficient of friction, thus, it is suitable for sliding mechanics

Not only is it good as a substitute for Co-Cr or stainless wire, but GUMMETAL can increase the efficiency of treatment, can simplify treatment, and can allow a considerable shortening of the duration of treatment (Fig. 5). There are various ways to provide 3-D control of teeth during active treatment with the multi-bracket method. Vertical control, including the uprighting of teeth, is an important factor in establishing a functional and stable occlusion. There are many methods for moving teeth with GUMMETAL, but I would like to talk discuss active torque during vertical control, which is recognized as a difficult challenge. I will use actual cases to illustrate the concepts.

In order to control the molars at the very beginning of active treatment, three-dimensional control of tooth movement is necessary. Since the center of resistance of a tooth is almost always different than the position of the bracket on that tooth, there is a risk of introducing an unintended inclination of the tooth while moving it. It is better to control torque with rectangular wire from the earliest phase of treatment.

However, it is physically difficult to attach the wire to the brackets at the beginning of active treatment if you are using Co-Cr or stainless steel wire. While it is possible to attach Ni-Ti wire, it is almost impossible to bend Ni-Ti wire into the shape best suited to the therapeutic goal. GUMMETAL is not only more flexible than Ni-Ti wire but it can also be bent freely. Rectangular GUMMETAL wire can be formed into the desired curvature that provides the appropriate active torque. These characteristics make it possible to design simple treatment plans that produce swift results and provide the shortest route to the therapeutic objective.

Straight wire methods use a variety of innovative bracket designs. The feature that requires the most attention is the slot inclination. However the number shown is the passive torque that reflects the ideal tooth-axis inclination at the finishing phase but does not aim to set active torque for uprighting or vertical control of the teeth that is the main goal of active treatment. As we all know, every case of malocclusion takes a different form. The treatment plan must be tailored to the individual patient, and the amount of vertical control needed depends on the circumstances of the case. In addition, the bucco-lingual inclination of the tooth axis of molars varies, and ideally we can adjust the therapeutic torque of the wire.

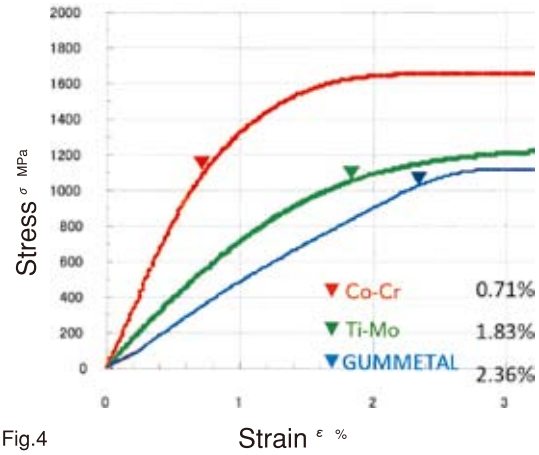

Fig.4
Stress Strain Curve

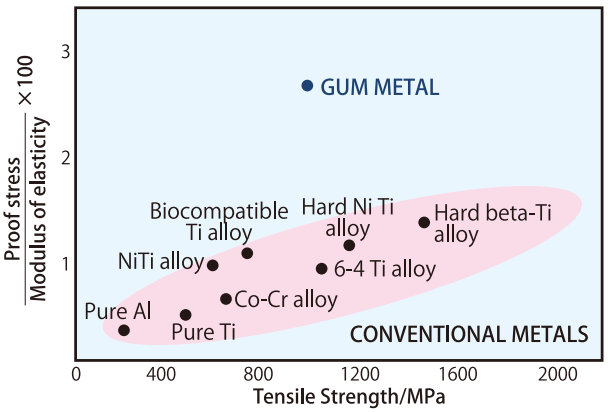

Fig.5
For alloys with a broad range of tensile strengths, the ratio of proof stress to the elastic modulus is fairly uniform. This plot shows that the value of this ratio for GUMMETAL is much higher than those of many other conventional alloys.

A case of Angle Class I malocclusion with crowding

First we need to resolve the underlying causes of the existing disharmonies and discrepancies. Uprighting the molars is the first priority. The most important treatment objective is to remove the cause of the malocclusion. In this case, crowding of anterior teeth and prognathism are the result of the malformation of the dental arch. We begin therefore by treating this malformation. In other words, aligning should be started after we have created sufficient space by expanding the dentition and uprighting the molars (Figs. 6-1, 6-2, 6-3, and 6-4). Otherwise, anterior teeth become flared out and hard to retract. It is not too much to say that the greatest cause of failure in orthodontic cases with premolar extraction is over-hasty leveling. With excellent technique, it is possible to reduce treatment time by moving all teeth at the same time. It is possible to move anterior teeth easily if there is sufficient space, so establishing the occlusion of molars should be done first.

Most patients are only interested in resolving the anterior crowding of the teeth. When that has been largely accomplished, they tend to lose motivation for treatment and they ask that the orthodontic appliances be removed as soon as possible. For that reason, it is better for both patient and orthodontist to start stabilizing and aligning the anterior teeth only toward the end of therapy. We may say that successful treatment of Angle Class I malocclusion depends on resolving the discrepancy at the end of the active treatment.

It is desirable to start active treatment by uprighting the molars, which is the priority of the Angle Class I treatment either with or without extraction. We add the compensation curve to the wire to resolve the strong Curve of Spee to level the occlusal plane, while at the same time inhibiting unexpected buccal inclination on the molar region and anterior teeth flare out by giving the suitable lingual crown torque depending on the strength of Curve of Spee. GUMMETAL wire is super-elastic, easy to modify and has a very low value in Young's modulus . It can be applied for the first phase of treatment, it gives constant gentle force, and the wire does not have to be changed when the therapy moves to the next phase.
(Figs. 7-1, 7-2, 7-3, 7-4, 7-5, and 7-6)

Angle class Ⅰ malocclusion with crowding "En bloc" movement

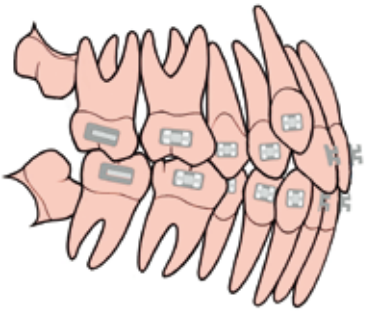

Fig.6-1

In cases like the one shown here, the teeth are mesially inclined and the third molars prevent the uprighting of the teeth. Before beginning active treatment, the third molars must be extracted to create sufficient space for uprighting teeth.

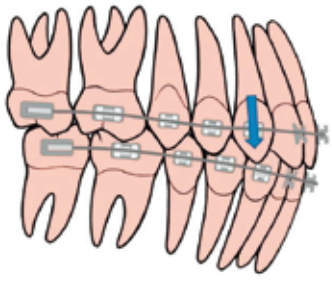

Fig.6-3

Step 3 is to staighten all bends. Then check the intercuspation. At the same time, align the anterior teeth and complete the functional occlusion.

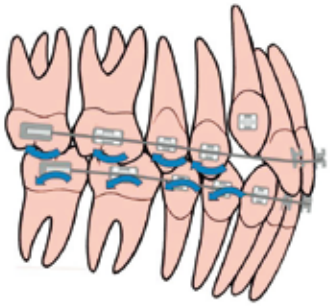

Fig.6-2

This diagram illustrates the beginning of step 2. Start "en bloc" movement of the dentition using .018 x .022 GUMMETAL with a tip-back angle of approximately 30° and active torque of approximately 20°.

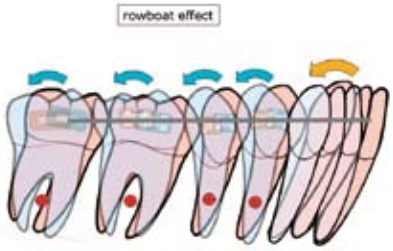

Fig.6-4

The rowboat effect of the lateral teeth prevents the flare-out of anterior teeth. The uprighting of lateral teeth all at the same time causes them all to move distally, preventing the flare-out of anterior teeth, which sometimes become inclined lingually.

Case 1. Angle class I malocclusion with crowding 24y6m female

Fig.7-1

This slide shows the case of a female, age 24 years 6 months, whose initial diagnosis was Angle Class I with crowding. These photos were taken at the time the orthodontic appliances were first applied. The mesial inclination and mesial rotation are evident. The wire is Φ .016" nickel-titanium. The Φ 0.25 mm GUMMETAL open coil seen here is a prototype. No brackets were bonded to the mandibular anterior teeth.

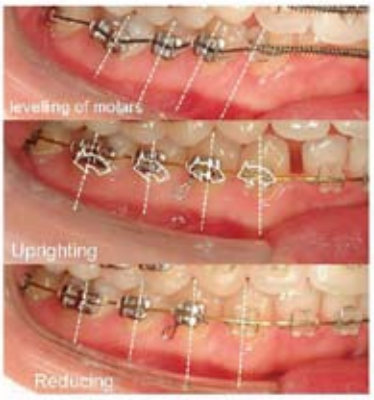

Fig.7-2

Row boat effect derived from uprighting the molars creates working space in the region of the anterior teeth.

Fig.7-3

These photos show the dentition at the time the appliances were removed. The duration of active treatment was 8 and half months.

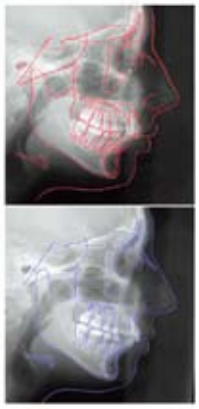

Fig.7-4

We eliminated the discrepancy without changing the position of the mandible or the inclination of anterior teeth, neither of which needed to be changed.

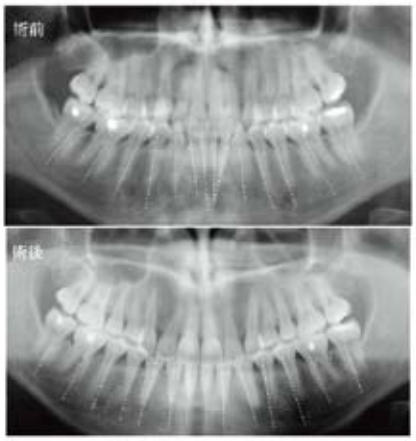

Fig.7-5

Panoramic radiographs before and after treatment. They show that therapy with GUMMETAL wire can effectively not only upright molars but also parallelize dental roots.

Fig.7-6

Three facial views before and after treatment.

A case of Angle Class II malocclusion with open-bite

In most cases of open-bite the face is a dolichofacial type. In this case, the molars and premolars are mesially inclined and the molars are over-erupted, and there is a molar discrepancy. The third molars should be extracted to resolve the discrepancy. The whole molar region can then be uprighted "en block."

It is important to prevent an opening rotation of the mandible here. In this case the smallest wire we used was .018" x .022". When GUMMETAL was in the ideal arch, the active torque was appropriate for the amount of tip-back bend. GUMMETAL wire is very flexible, so it was easy to insert the full-size wire in the brackets.
(Figs. 8-1, 2, 3 ; Figs. 9-1, 2, 3, 4, 5, 6, 7)

Angle class Ⅱ malocclusion with open bite "En bloc" movement

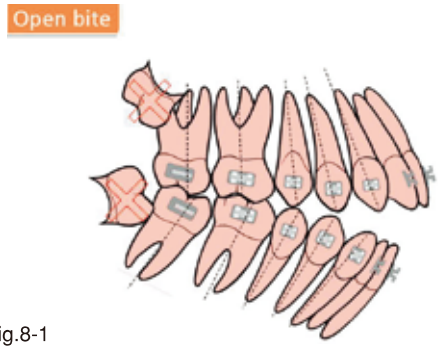

Fig.8-1

In almost all cases of open-bite, all teeth are mesially inclined because of a discrepancy of the molars. The discrepancy must be eliminated by extracting third molars before beginning active treatment.

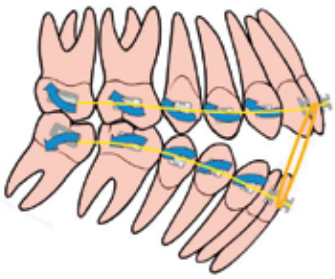

Fig.8-2

Use elastics between upper and lower anterior teeth to oppose the force on the anterior teeth and to suppress flare-out. At the beginning of the "en bloc" movement, start with a tip-back bend of 45° and an active torque of 30° . Then adjust later as needed.

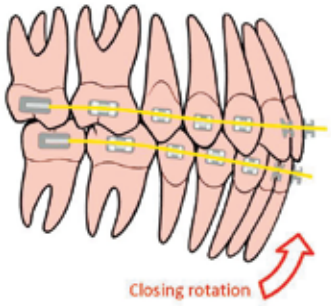

Fig.8-3

This slide shows the uprighting of molars en bloc, which causes a closing-rotation of the mandible.

Case 2 Angle class Ⅱ malocclusion with open bite 24y3m female

Fig.9-1

A case of open-bite (with marked dolichofacial type), age 24 years and 3 months, diagnosed as Angle Class II Division I, backward rotation of mandible, and labially inclined incisors
According to the Tweed analysis, the treatment plan should include extracting the premolars because the calculated total discrepancy is -16.8mm, based on the labial inclination of the anterior mandibular teeth. However, in detailed observations, we noted that the dental arch was narrow, the maxillary teeth were lingually inclined, and there was noticeable mesial inclination of maxillary and mandibular lateral teeth. Adequate space may be gained by improving these conditions.

Fig.9-2

Φ .016" nickel-titanium wire was used to level the teeth in both the maxillary and mandibular arches. For lateral expansion of maxilla, a Mulligan's over-lay arch with Φ 0.9-mm GUMMETAL straight wire was added. By uprighting the lingual inclination, the arch was expanded laterally.

Fig.9-3

Photographs of the dentition after the orthodontic appliances were removed at the end of therapy. The duration of treatment was 1 year 2 months.

Fig.9-4

Photographs show that the lingual inclination and marked mesial inclination of molars were corrected.

Fig.9-5

Pre- and post-treatment facial photographs show the improvement of the profile.

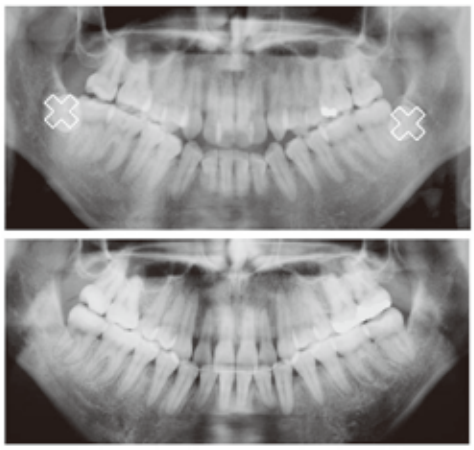

Fig.9-6

Pre- and post-treatment panoramic radiographs show the distal movement of teeth and parallelization of dental roots.

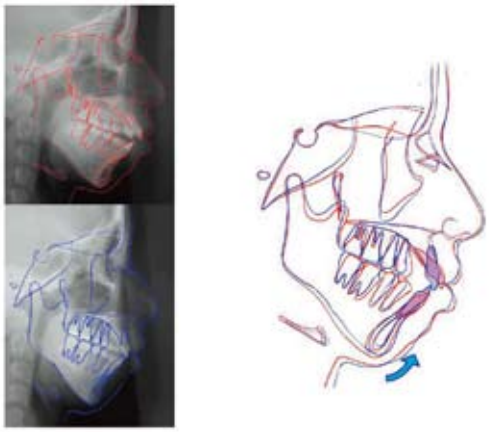

Fig.9-7

Therapy improved the overbite and overjet as a result of the closing-rotation of the mandible.
The superimposition of the cephalograms show that with torque control of maxillary incisors and the final result was esthetic.

Conclusion

The vertical control of teeth, including uprighting, is important in order to establish functional occlusion and to prevent regression after active treatment is finished. GUMMETAL wire extends the range of applicability of rectangular wire because the amount of active torque transmitted to a given tooth in a given phase can easily be adjusted by the orthodontist to the value that provides the most suitable continuous orthodontic force. The Young' s modulus of GUMMETAL is lower than that of NiTi, so it is possible to apply it without alignment. The length of active treatment is much shorter than with other archwire, since we are able to start vertical control coupled with active torque from the early phase of treatment. This is especially effective for patients who have a deep overbite or an open-bite, because vertical control can be done at the same time as active torque, thus shortening active treatment time. In addition, since we do not need to change the wire after leveling, it eliminates the discomfort and risk of root resorption that accompanies the process of replacing the wire. Because of these considerations, GUMMETAL simplifies and shortens active treatment, to the benefit of all.

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