Skeletal and dental response to rapid maxillary expansion with 2- versus 4-band appliances

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Purpose: Bonding a rapid palatal expansion (RPE) appliance to the 2 first molars has been proposed as an equivalent to the conventional 4-band RPE appliance. However, the dentoskeletal response to this treatment has not been evaluated. Material: Twenty-eight subjects (aged 8-20 years) who required maxillary expansion were matched by age and randomly assigned to either a 2-band or a 4-band RPE group. Skeletal and dental responses were measured from standardized anteroposterior cephalometric and occlusal radiographs and dental casts before treatment (T1), at the end of expansion (T2), and at 1 year postexpansion (T3). Results: At T2, suture expansion was 2.5 times greater and arch perimeter was 6-fold larger in the 4-band than in the 2-band group. Both appliances displayed the typical "V" expansion of the suture and "reverse V" expansion of the dental arch. At T3, remineralization reduced the suture opening by 75%, but 95% to 99% of the dental reaction was maintained. The 2-band group demonstrated a significant inverse age-dependent correlation \( r = -0.795 \), with treatment failure beyond 12 years of age, whereas the 4-band group was age-independent. Conclusions: The greater the skeletal resistance, the smaller the sutural response but the greater the dental response to RPE therapy. Four-band RPE is indicated when severe anterior crowding is accompanied by a tapered arch form, and 2-band RPE is recommended in the mixed dentition when mild crowding occurs with posterior constriction. (Am J Orthod Dentofacial Orthop 2005;127:483-92)
result in the above-mentioned pattern of expansion with any tooth-borne appliance. Therefore, it might be more appropriate to place an expansion device near the source(s) of anatomic resistance (ie, zygomatic buttresses).20,21 Theoretically, this should cause a more uniform pattern of palatal expansion.

Matteini and Mommaerts22 supported this hypothesis when they reported the results of palatal expansion performed after surgical distraction of the articulations of the posterior aspect of the palate. They performed distractions at the level of the second premolar along with pterygomaxillary disjunction and found that parallel expansion of the maxillary buccal segments occurred. However, when the disjunction was not performed, greater expansion was observed in the anterior part of the maxilla.22

Dental effects of RPE therapy are related to skeletal reaction and force dissipation.23,24 Separation of the palatal shelves first results in the temporary formation of a diastema. The spatially unequal effects of the appliance are eventually expressed as buccal tipping of the posterior dentition when strains built up in the craniofacial structures are expressed.25,26

The effect of the appliance on the midpalatal suture has been reported to vary with age. A greater response to RPE therapy has been reported in younger subjects, whereas in older subjects the appliance becomes increasingly less effective, to the point where no sutural expansion takes place. This has been correlated with the increase with age of bony intercalations along the midpalatal suture line. It is thought that this osseous interlocking, and perhaps synostosis of the midpalatal suture, causes a mechanical resistance to the actions of the expansion device.27-29

The purpose of this study was to investigate and compare the skeletal and dental effects of conventional 4-band and 2-band (attached to the first permanent molars only) RPE devices. The objectives were to determine whether the latter device mimics the mechanism of action of the former, more-established appliance, to quantify the skeletal and dental responses to each of these appliances, and to qualitatively compare the effects of each appliance design with the other.

**MATERIAL AND METHODS**

Twenty-eight patients aged 8 to 20 years with maxillary transverse deficiencies being treated at the Orthodontic Department of the University of Tel-Aviv School of Dental Medicine were age-matched and randomly divided into 2 equal groups. The first group underwent palatal expansion with a 4-band device, consisting of fixed bands on the maxillary first permanent molars and premolars, connected on each side by a rigid bar, with both sides connected to each other by extensions from the hyrax screw (Dentaurum, Pforzheim, Germany) (Fig 1, A). The second group received treatment with a 2-band RPE appliance with the same type of hyrax screw as the 4-band appliance group fixed to the first permanent molars by soldered rigid extensions (Fig 1, B).

All subjects were instructed to activate the RPE appliances at 12-hour intervals, by a quarter turn of the hyrax screw (0.24 mm). Activation was discontinued when the posterior crossbite reverted to a slight scissors-bite in the first molar region. At this time, the hyrax screw was fixed with brass wire or cold-cure acrylic and left intraorally as a passive device for 3 months.

Documentation was made at 3 times: T1, pretreatment; T2, at end of RPE activation (ie, posttreatment); and T3, T2 + 1 year (ie, postretention). Edgewise appliances were placed during T3.

Records taken for data collection were standardized occlusal (Oralix 65 S, Philips, Monza, Italy) and anteroposterior (Orthoralix SD Ceph, Monza, Italy) radiographs and dental casts (Fig 2). Individually fab-
Ricated customized removable jigs were constructed from .021 × .025-in stainless steel archwire for placement at the time of radiographic exposure. These were formed in an “L” shape, which terminated in a circle or diamond shape toward the vestibularly directed end of the left and right jigs, respectively. These were inserted into the archwire slots of the molar bands to act as radiopaque landmarks for examining radiographic data (Fig 2, D).

The maxillary occlusal radiograph was used to evaluate linear and volumetric changes in the transverse dimension of the midpalatal suture (Fig 2, A, B). This was carried out at 3 transecting levels across the midpalatal suture: Sut 1-1: suture width at the interincisal level (bilaterally, between the 2 central incisors, along point prosthion); Sut 3-3: suture width at the intercanine level (bilaterally, along the distal wall of the maxillary canines, or the mesial wall of the first
RESULTS

There was an overall significant increase in all variables within each group from T1 to T2. Midpalatal suture width increased at the canine level (Sut 3-3) from 0.47 ± 0.26 mm to 1.6 ± 1.03 mm in the 2-band group and from 0.28 ± 0.1 mm to 2.82 ± 1.37 mm in the 4-band group. Overall, suture width increased 3 to 4 fold in the 2-band group and 9 to 10 fold in the 4-band group (Table I).

Expansion of the suture decreased progressively from the interincer to the intermolar levels in both groups. In the 2-band group, the suture expansion at the interincer level (Sut 1-1 = 1.45 ± 1.45 mm) was greater than the intercanine suture expansion (Sut 3-3 = 1.14 ± 1.07 mm), which was greater than the intermolar suture expansion (Sut 6-6 = 0.81 ± 1.09 mm) (Table II).

The greatest transverse change of the dental arch was in intermolar width. A major and significant arch perimeter increase was found in the 4-band group (6.38 ± 4.44 mm) compared with the 2-band group (1.05 ± 5.15 mm) (Table II). In addition, the molar underwent a buccally directed inclination, with expansion of 20.07° ± 24.19° and 14.08° ± 11.80° in the 4-band and 2-band groups, respectively (Table II).

From T2 to T3, both groups demonstrated a decrease in suture width, except for the 6-6 region of the 2-band group (Table I). In the 4-band group, all suture regions underwent significant decreases in width. This occurred in the 2-band group only in the 1-1 region and the overall suture area.

Dental changes during the retention period mirrored but were less than the decrease in the suture. Only the decrease in intermolar width in the 4-band group was significant (Table I). The arch perimeter increased further in the 2-band group, whereas it remained unchanged in the 4-band group. In addition, the buccal

### Table I. Change in occlusal radiograph, dental cast, and anteroposterior radiograph measurements for 2-b RPE and 4-b RPE groups at T1 (pre-expansion), T2 (postexpansion) and T3 (postretention)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>2-b RPE</th>
<th>P (T1 vs T2)</th>
<th>P (T2 vs T3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sut 1-1 (mm)</td>
<td>0.63 ± 0.37</td>
<td>2.07 ± 1.50</td>
<td>1.11 ± 1.13</td>
</tr>
<tr>
<td>Sut 3-3 (mm)</td>
<td>0.47 ± 0.26</td>
<td>1.6 ± 1.03</td>
<td>1.16 ± 1.52</td>
</tr>
<tr>
<td>Sut 6-6 (mm)</td>
<td>0.38 ± 0.20</td>
<td>1.2 ± 1.03</td>
<td>1.28 ± 2.36</td>
</tr>
<tr>
<td>Sut area (mm²)</td>
<td>6.35 ± 3.18</td>
<td>34.09 ± 28.8</td>
<td>10.47 ± 4.52</td>
</tr>
<tr>
<td>Mod 1-1 (mm)</td>
<td>17.18 ± 3.50</td>
<td>18.81 ± 3.74</td>
<td>18.60 ± 2.44</td>
</tr>
<tr>
<td>Mod 3-3 (mm)</td>
<td>28.83 ± 5.33</td>
<td>31.04 ± 1.94</td>
<td>31.75 ± 2.43</td>
</tr>
<tr>
<td>Mod 6-6 (mm)</td>
<td>41.50 ± 4.65</td>
<td>46.96 ± 5.51</td>
<td>45.50 ± 3.81</td>
</tr>
<tr>
<td>Mod perim (mm)</td>
<td>72.74 ± 6.28</td>
<td>73.18 ± 4.77</td>
<td>75.73 ± 6.59</td>
</tr>
<tr>
<td>JigR-JigL (mm)</td>
<td>55.38 ± 5.66</td>
<td>58.91 ± 7.06</td>
<td>63.59 ± 8.30</td>
</tr>
<tr>
<td>Jig angle (°)</td>
<td>-3.67 ± 17.75</td>
<td>10.42 ± 19.3</td>
<td>-0.82 ± 14.08</td>
</tr>
</tbody>
</table>

deciduous molars or first premolars); Sut 6-6: suture width at the intermolar level (bilaterally, along the mesial wall of the maxillary first molars); Sut area: area of the suture between Sut 1-1 and Sut 6-6.

The dental casts were used to measure transverse linear changes between the left and right quadrants of the dental arch. This was carried out by measuring the changes in length of cross-palate transecting lines corresponding to those measured from the occlusal radiograph with a Digimatic Electronic Caliper (Mitutoyo, Kanagawa, Japan) with 0.03-mm accuracy and 0.01-mm resolution (Fig 2, E): Mod 1-1: distance between the distal edges of the central incisors; Mod 3-3: distance between the cusp tip of the canines; Mod 6-6: distance between the central pit of the first molars; Mod perim: arch perimeter from right to left mesial aspect of the first molars.

The anteroposterior cephalometric radiographs were used to evaluate transverse changes of the apical base of the maxilla, as well as angular changes of orientation of the molars. The metallic jigs, fabricated as noted above, were placed for these purposes (Fig 2, D): JigR-JigL: the distance between the right and left jigs; Jig angle: the angle formed between the right and left jigs.

Data were statistically analyzed with the unpaired *t* test and analysis of variance with repeated measurements. Correlation between age and expansion of the suture was determined by Pearson’s product-moment coefficient of correlation. To establish the reliability of linear, angular, and volumetric measurements, the coefficient of variation for each type of measurement was calculated. The coefficient of variation of replicated measurements was low for linear measurements (Mod 1-1 = 1.7%) and moderate for the angular (Jig angle = 7%) and area measurements (Sut area = 10.5%).
showed an increase in interjig distances but decreases in jig angulations. Therefore, both groups showed an increase in interjig distances but decreases in jig angulation (Table I).

Radiographic examination of the midpalatal suture at T3 showed that suture-related measurements did not return to T1 values. The differences measured at T3 were significantly different from those at T1. Furthermore, these differences were greater in the 2-band group but not significantly different from the 4-band group (Table II).

Changes from T1 to T3 in arch perimeter were greater in the 4-band group (6.28 ± 4.23 mm). However, changes in molar angulation were found to be greater in the 4-band group (6.86° ± 17.96°) (Table II).

### Correlation

Pearson’s product-moment coefficient of correlation was used to examine the association between patient age and expansion of the suture across the canines (Sut 3-3) at T2. A highly significant and inverse correlation was found in the 2-band group ($r = -0.795$, $P \leq .0001$) (Fig 3, A). In contrast, a nonsignificant low correlation ($r = -0.081$) was found for the 4-band group (Fig 3, B). A suture expansion of more than 1.5 mm measured across the canines at T2 did not occur in any patient older than 12 years (46%) in the 2-band group, whereas this amount of expansion was observed in all patients in the 4-band group, except for a 20-year-old patient (92%).

### Table I. Continued

| Sut 1-1 (mm) | 1.45 | 3.12 | 0.88 | 0.003** | 0.003*** |
| Sut 3-3 (mm) | 2.82 | 2.32 | 0.61 | 0.003*** | 0.003*** |
| Sut 6-6 (mm) | 5.93 | 14.46 | 11.33 | 0.003*** | 0.003*** |
| JigR-JigL (mm) | 28.50 | 48.58 | 16.97 | 0.003*** | 0.003*** |
| Jig angle (°) | 14.80 | 14.83 | 4.92 | 0.020* | 0.187 |

* $P \leq .05$; ** $P \leq .001$; *** $P \leq .0001$.

### Table II. Comparison between groups for changes from T1 to T2 (pre- to postexpansion) and total change from T1 to T3 (pretreatment to postretention)

| Sut 1-1 (mm) | 1.45 | 3.12 | 0.88 | 0.003** | 0.003*** |
| Sut 3-3 (mm) | 2.82 | 2.32 | 0.61 | 0.003*** | 0.003*** |
| Sut 6-6 (mm) | 5.93 | 14.46 | 11.33 | 0.003*** | 0.003*** |
| JigR-JigL (mm) | 28.50 | 48.58 | 16.97 | 0.003*** | 0.003*** |
| Jig angle (°) | 14.80 | 14.83 | 4.92 | 0.020* | 0.187 |

* $P \leq .05$; ** $P \leq .001$; *** $P \leq .0001$. 

However, changes in molar angulation were found to be greater in the 4-band group (6.86° ± 17.96°) (Table II).
Both groups displayed the same type of “V”-shaped midpalatal suture expansion (ie, the greatest amount of opening was anteriorly directed, with convergence of suture opening in the posterior aspect of the palate. This response agrees with previous studies of palatal expansion\textsuperscript{1,12,23,24,30} but refutes the hypothesis that when the force(s) caused by an RPE appliance are applied near(er) the area of greatest resistance to maxillary expansion, a more parallel separation of the midpalatal suture occurs. These findings support the concept that parallel opening of the suture is possible when RPE therapy is accompanied by surgical disjunction of the pterygomaxillary processes, as has been previously reported.\textsuperscript{22,31,32}

Each appliance caused palatal expansion; however, their effects differed. The 4-band appliance produced up to a 2-fold greater expansion of the midpalatal suture than the 2-band version. This agrees with the findings of Lamparski et al.\textsuperscript{5} even though they reported that the effects of the appliances differed from each other by only 24%, which is a fraction of the difference noted in this investigation.

In the 2-band group, the contributions by skeletal and orthopedic change due to RPE therapy were 90%, 52%, and 16% in the incisor, canine, and molar regions, respectively (T2), which were probably caused by an increase in skeletal resistance to expansion in the more posterior aspect of the maxilla. This suggests that strains built up in the craniofacial complex during RPE therapy are first expressed as separation of the anterior aspect of the midpalatal suture, with the posterior “unzipping” of the suture with time.\textsuperscript{18} The greater magnitude of the skeletal responses to the 4-band RPE force system was probably due to force delivery in the anterior aspect of the palate, where resistance to expansion is more easily overcome (the suture anterior to the incisive canal ossifies very late in life).\textsuperscript{33} Subsequently, the resistance provided by the posterior region of the maxilla also yields as the palate “unzips.”\textsuperscript{31}

In contrast, the more posteriorly applied force delivery system of the 2-band appliance was less effective because it had to simultaneously overpower both the posterior and the anterior sutural resistance of the maxillary complex. This could explain the difficulty in achieving successful RPE therapy in more mature patients, in whom intercalation and ossification of the midpalatal suture do not easily permit the zipper-like separation of its halves.

Further differences in the effects of each appliance design are shown in each skeletal and dental response. The canine, immediately adjacent to an abutment tooth in the 4-band design, showed a 9:1 skeletal/dental ratio of expansion, whereas in the 2-band design, where the canine is 3 dental units from the RPE device, it was 1:1. Of even greater significance was the measured response at the first molar, which is the sole abutment in the 2-band group. Here the skeletal expansion was half that measured in the 4-band group. Across all 3 levels at which the palate and dental arch were measured to detect changes in the transverse dimension, the percent-

**FIG 3.** Correlation diagram of patient age versus increase in intercanine suture width (Sut 3-3) at T2. **A,** For 2-band RPE, highly significant and inverse correlation ($r = -0.795, P \leq .0001$) was found between age and suture expansion; dotted line indicates threshold value of 11.8 years of age, beyond which suture opening was less than 2 mm. **B,** For 4-band RPE, nonsignificant low correlation ($r = -0.081$) was found, indicating no age dependency up to 17 years of age.
age of skeletal expansion as part of the total expansion was greater in the 4-band RPE group than in the 2-band group by a mean ratio of 2.32:1 (Table III).

**Table III.** Extent of skeletal response from total response (dental and skeletal) at T2 and magnitude of increased response in 4-b RPE compared with 2-b RPE for skeletal and dental parameter

<table>
<thead>
<tr>
<th></th>
<th>2-b RPE</th>
<th>4-b RPE</th>
<th>Ratio 4-b RPE/2-b RPE (for T2-T1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sut 1-1</td>
<td>90</td>
<td>119</td>
<td>2.15</td>
</tr>
<tr>
<td>Sut 3-3</td>
<td>52</td>
<td>91</td>
<td>2.22</td>
</tr>
<tr>
<td>Sut 6-6</td>
<td>16</td>
<td>36</td>
<td>2.58</td>
</tr>
<tr>
<td>Sut area</td>
<td>1.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mod 1-1</td>
<td>1.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mod 3-3</td>
<td>1.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mod 6-6</td>
<td>1.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mod perim.</td>
<td>6.08</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dental effects

This investigation showed that, as reported in previous studies, the posterior dentition undergoes the greatest expansion as a result of RPE therapy, with a gradually decreasing effect toward the anterior aspect of the dental arch.5,5 Whereas the midpalatal suture responds with greater expansion at the anterior aspect of the palate, the reverse “V” pattern of dental expansion was related to an anteroposterior progressive increase in skeletal resistance.

Therefore, mechanical loading across the midpalatal suture tends to be expressed as suture separation in the anterior part of the palate, where skeletal resistance is least. However, articulations of the posterior aspect of the palate with other craniofacial bones produce greater resistance to palatal expansion in this area. Strain stored in these craniofacial structures, related to the increased resistance to expansion, results in greater dental movements of the posterior dentition. Hence, dissipation of forces created by the RPE appliance which do not cause skeletal changes necessarily are expended on the dentition.

In this study, when skeletal resistance was minimal (ie, across the incisor region), a significant skeletal and sutural response (eg, 2-band RPE = 90%) with almost no dental compensation was observed. In the midarch (canine region), with an increase in skeletal resistance, half of the response was sutural (eg, 2-band RPE = 52%) and half dental. Across the molar region, where maximal skeletal resistance occurs, minor sutural (eg, 2-band RPE = 16%) and major dental responses contributed to the total expansion.

The small dental response in the anterior region might also be related to the stretching of the transseptal collagen fibers in this region. Rapid separation of the incisors would be met by stretching of these fibers, creating resistance to the tendency of the central incisors to move laterally. This is seen clinically with the convergence of the clinical crowns of the central incisors toward the developed diastema and its closure with time when active expansion is terminated.1,34

Of further significance was the finding that the 4-band group showed up to a 6 times greater increase in arch perimeter than the 2-band group. This is probably because of the different arch forms established by each appliance. The 4-band group showed a much more significant transverse increase in the anterior region of the maxillary dentition (and suture) than the 2-band group. Thus, an arch form that was broader in this aspect was found in the 4-band group, accounting for the difference in arch perimeter measurements.

The effect of RPE therapy (T1-T2) on molar position was found to be that of buccal crown tipping (14°-20°), which correlates with the findings of previous studies.34-37 If only pure tipping of the molars had been the result of RPE therapy, the JigR-JigL distance would have decreased proportionally to the buccal crown tipping because jig measurements were made from their superior ends located toward the molar root apices. However, the concomitant increase in the interjig distance during T1-T2 was due to a combination of actual repositioning of the palatal shelves and lateral molar movement in the alveolus.38 When tooth movement becomes the most significant response to expansion, care should be taken not to cause alveolar fenestration or dehiscence of the molar buccal roots through the cortical plate. In addition to the potential periodontal defect this might cause, it has been associated with root resorption.39-41

**Effect of time**

The midpalatal suture lost up to 75% of its increased area due to expansion 1 year after RPE therapy (T3). Nevertheless, the dentoskeletal relapse was minute (≤5%). These results can be interpreted as relapse of the palatal shelves (medial migration) or mineralization of the distracted suture. Comparison of the skeletal and dental relapses would seem to imply that the latter interpretation is correct, because suture width decreases from T2 to T3.
were 47% and 75% in the 2-band and 4-band groups, respectively, but the corresponding dentoskeletal relapse was 3% in the 2-band group and 5% in the 4-band group. Thus, if the reduction in suture width was due to medial collapse of the maxillary horizontal shelves, then the dental interarch measurements should decline proportionately to the suture width. Because this was not the case (Fig 4), it can be surmised that the reduction in suture width was due to remineralization.17,18,42,43 Furthermore, this remineralization can be understood to have occurred at a faster rate in the 4-band group because suture expansion (T2) was 3 times greater than in the 2-band group, but, at T3, this measurement was more or less equal in both groups. This response could be related to elevated cell recruitment and extracellular mineralized matrix deposition in this group, which might reflect the significance of the orthopedic influence of the 4-band appliance.42,44-47

In addition, the buccal tipping of the first molars, produced by the lateral forces of the RPE device,
returned to pre-expansion values 1 year after the end of appliance activation. This transient response\textsuperscript{11} was associated with an increase in the interjig distance, which, as previously stated, increases the hazard of proximity between the buccal molar roots and the buccal cortical plate.\textsuperscript{38,48,49}

**Effect of age**

The chronologic age of the subjects was found to have a direct influence on the efficacy of the 2-band RPE appliance. Even though, on average, slightly younger subjects made up the 2-band group (12.27 ± 2.49 years vs 14.83 ± 2.14 years in the 4-band group), greater skeletal responses were found in the 4-band RPE group.

With 1.5 mm of expansion across the canine region accepted as a minimal response to gauge clinical success of the RPE appliance, it was found that in the 2-band group no subject older than 12 years had this response (Fig 3). In the 4-band group, only one 20-year-old patient did not have this minimum change, and all patients up to age 17 years had a positive correlation to treatment. This finding might reflect some upper age limit to RPE therapy, perhaps related to suture ossification, which has been previously reported.\textsuperscript{27,28,43}

**CONCLUSIONS**

1. At T2, both appliances displayed a typical “V”-shaped suture expansion (Sut1-1 > Sut 3-3 > Sut 6-6), whereas the dental arch expansion showed a “reverse V” pattern (Mod 1-1 < Mod 3-3 < Mod 6-6). The inverse skeletal and dental responses are related to a progressive anteroposterior increase in skeletal resistance limiting midpalatal suture expansion posteriorly while effecting greater dental expansion in the same region.

2. By T2, the suture width increase was 3 times greater in the 4-band group than the increase seen in the 2-band group across all measured landmarks. The 4-band RPE arch perimeter was 6-fold greater than with 2-band RPE.

3. During the retention period (T2-T3), remineralization accounted for nearly all of the re-establishment of midpalatal suture dimensions.

4. The buccal crown tipping (14°-20°) of the molars caused by RPE activation (T1-T2) is transitory. However, root proximity to the buccal cortical plate is a potential risk and might cause fenestration, dehiscence, or root resorption.

5. The 2-band group demonstrated an age-dependent correlation. The 2-band appliance failed to cause significant suture opening in patients older than 12 years. Therefore, it is recommended for use in young, mixed dentition patients with mild crowding or unilateral posterior crossbite.

6. The 4-band RPE was independent of age in subjects 9 to 17 years old. Therefore, it is recommended as the appliance of choice for patients older than 12 years or patients with severe arch length deficiency, bilateral crossbites, or a tapered arch form.

7. It is recommended that patients approaching or more than 20 years of age be radiographically examined for evidence of midpalatal suture patency to avoid untoward side effects of RPE therapy. This would be an indication for supplementing RPE therapy with surgical preparation and is highly recommended with the use of the 2-band appliance.

**REFERENCES**


