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# Temporomandibular response to early and late removal of bite-jumping devices

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SUMMARY This study was designed to monitor the amount of bone formed after 'early' and 'late' removal of bite-jumping devices and to compare it with that of normal growth. One hundred and thirty-five 35-day-old female Sprague-Dawley rats were randomly divided into seven control ($n$ = 5) and 10 experimental ($n$ = 10) groups. Appliances were fitted to position the mandible forward in the experimental groups. On day 30, the bite-jumping device was removed in two groups ('early' removal) and the rats were sacrificed on days 44 and 60. On day 44 the device was removed in one group ('late' removal) and the rats were sacrificed on day 60. The full-time wear and matched control animals were then sacrificed at different time points. Tissue sections (7 μm) were cut through the temporomandibular joint (TMJ) in the sagittal plane and stained with periodic acid and Schiff's reagent for the evaluation of new bone formation. Newly formed bone was measured using a computer-assisted image analysing system.

The results showed that, in the condyle, early removal of the appliance resulted in less bone formation when compared with that of natural growth. Late removal of the appliance resulted in bone formation similar to that of natural growth. In the glenoid fossa, the level of bone formation was similar to that of the control at early and late removal of the appliance. In conclusion, early appliance removal results in subnormal growth of the posterior condyle but not of the glenoid fossa. Increasing the length of mandibular advancement secures normal levels of mandibular growth in the post-treatment period.

## Introduction

Experimental and clinical studies have shown that full-time wear of bite-jumping devices can alter the growth of the mandible (e.g. Stöckli and Willert, 1971; McNamara and Carlson, 1979; Pancherz, 1979; Ruf and Pancherz, 1998; Pancherz and Ruf, 2000). Treatment with fixed functional appliances in patients with skeletal Class II malocclusions resulted in a more forward positioning of the mandible when compared with untreated matched controls (Graber *et al.*, 1997). However, the long-term effect of this treatment is disputed and it has been suggested that there might be a limited or preordained amount of mandibular growth that can occur in any particular patient, and that the effect of the fixed functional appliance was only a temporary acceleration of mandibular growth and adaptation, which was followed by subnormal growth (Johnston, 1999). In essence, the fixed functional appliances did not lead to a real increase in mandibular growth. Rather it hastened the mandible to reach a certain size earlier.

There has been only one long-term study with a 'matched' control and it showed that mandibular growth was insignificantly larger in the patient sample which had undergone short treatment with a headgear–Herbst appliance followed by very lengthy retention treatment with activators, compared with that in normal growth (Wieslander, 1993). However, the interpretation of follow-up data from studies on short-term treatment with the Herbst appliance followed by no or short retention, revealed that mandibular growth was enhanced during treatment, but was lower than 'normal' growth during the immediate follow-up period (Pancherz and Hansen, 1986; Nelson *et al.*, 1999, 2000). In a recent study on the effect of longer treatment with the headgear–Herbst appliance followed by retention, mandibular growth was enhanced during the initial period of treatment, thereafter normal mandibular growth was maintained during the later part of treatment and retention (Hägg *et al.*, 2001). Untreated skeletal Class II subjects demonstrated a significant forward growth of both the maxilla and the mandible, resulting in a small improvement in the overjet and jaw base relationship, respectively (Tulloch *et al.*, 1998; Feldman *et al.*, 1999). The above-mentioned reports highlight the controversy regarding the response of the temporomandibular joint (TMJ) to mandibular advancement, in particular the length of the treatment period. The inference being that a longer treatment period could allow the 'extra' bone to mature before going back to normal levels of growth.

Therefore, the purpose of this study was to monitor the amount of bone formed after 'early' and 'late' removal of bite-jumping devices, and to compare it with that of normal growth. This way, different treatment modalities could be based on sound scientific data.

## Materials and methods

The material comprised the TMJs obtained from 135 35-day-old Sprague-Dawley rats. The animals were divided into seven control ($n$ = 5) and 10 experimental ($n$ = 10) groups with bite-jumping devices cemented to the maxillary incisors (Rabie *et al.*, 2001). All animals were fed with a soft diet throughout the observation periods. The animals in the full-time wear and matched control groups were sacrificed on days 3, 7, 14, 21, 30, 44 and 60. In the experimental group, on day 30 the bite-jumping devices were removed in two groups ('early' removal) and the rats were sacrificed on days 44 and 60. On day 44 the device was removed in one group ('late' removal) and the rats were sacrificed on day 60.

Ethical approval was obtained from the 'Committee on the Use of Live Animals in Teaching and Research', no. 586-01.

### *Bite-jumping appliances*

Bite-jumping appliances made from polymethylmethacrylate with identical inclined planes were cemented to the upper incisors of the animals and induced a 3.5 mm anterior and 3 mm inferior displacement of the mandible following the method reported previously (Rabie *et al.*, 2001). The appliances were cemented in place to produce continuous mandibular advancement.

### *Tissue preparation*

In summary, after the rats were sacrificed, the heads were fixed and decalcified and embedded in paraffin. Sections of 7 μm were cut through the TMJ in the sagittal plane and stained with periodic acid and Schiff's reagent (PAS) for identification of new bone formation. Stained with PAS, the newly formed bone takes on a distinctive magenta colour (Ross *et al.*, 1995).

### *Quantitative analysis*

The amount of new bone formation was quantified at a magnification of ×360 via a computer-assisted image analysing system (Leica Q5501W, Leica Microsystems Imaging Solutions Ltd, Hong Kong SAR) with Leica Qwin Pro. (version 2.2) software. Sections were evaluated through a light microscope connected to the computer for digital analysis through a three-channel system red–green–blue colour video camera (JVC TK-1281EG) via a special B-mount adaptor.

Using this system, the features from the acquired images can be automatically selected and recognized by identifying colour, shade and contrast. Therefore, the distinction in staining density between new bone deposition and mature bone can be evaluated. The area of new bone deposition in the anterior, middle and posterior aspects of the mandibular condyle and glenoid fossa were calculated.

The new bone was formed in the erosive zone of the condyle and under the proliferative zone in the glenoid fossa. The quantification was undertaken separately for the posterior, middle and anterior regions. The amount of new bone was quantified within a fixed measurement frame.

The data were processed using the Statistical Package for Social Sciences (SPSS version 10.01, Chicago, IL, USA) for both the *t*-test and analysis of variance with the Bonferroni multiple comparison test. Thirty randomly drawn sections were used for method error analysis and the measurements on two separate occasions were compared using the formula $\pm\sqrt{(\Sigma d^2/2n)}$, where $d$ is the difference between the two registrations of a pair and $n$ is the number of double registrations. The analysis indicated no significant difference in repeated measurements ($P$ = 0.24; Table 1) of the 10 randomly drawn sections.

## Results

### *Natural growth*

Bone formation in the posterior condyle and glenoid fossa during natural growth continued to decline during the 60 days of the observation period (Figure 1). In the experimental group, bone formation was significantly higher than that of natural growth in the posterior condyle from day 14 to day 30 (Figure 1b) and in the posterior glenoid fossa from day 7 to day 30 (Figure 1a). Before and after those periods there was no significant difference in bone formation in the glenoid fossa and condyle between the control and experimental groups.

### *Early removal*

Early removal (day 30) of the bite-jumping device resulted in no significant affect on bone formation when measured on day 44 in the posterior glenoid fossa (Figure 2a). Bone formation in the posterior condyle was significantly less ($P < 0.01$) than that of the controls or the animals which still had bite-jumping devices in place (Figure 3a). Furthermore, the amount of bone formed after early removal of the appliance was insignificantly different in condyles when measured on days 44 and 60 but was significantly less in the glenoid

**Table 1** Method error for the measurement of bone formation.

| Mean of the differences ($mm^2$) | Standard deviation | $P$ | Size of method error ($mm^2$) |
|---|---|---|---|
| –0.001 | 0.002 | 0.24 | 0.0011 |

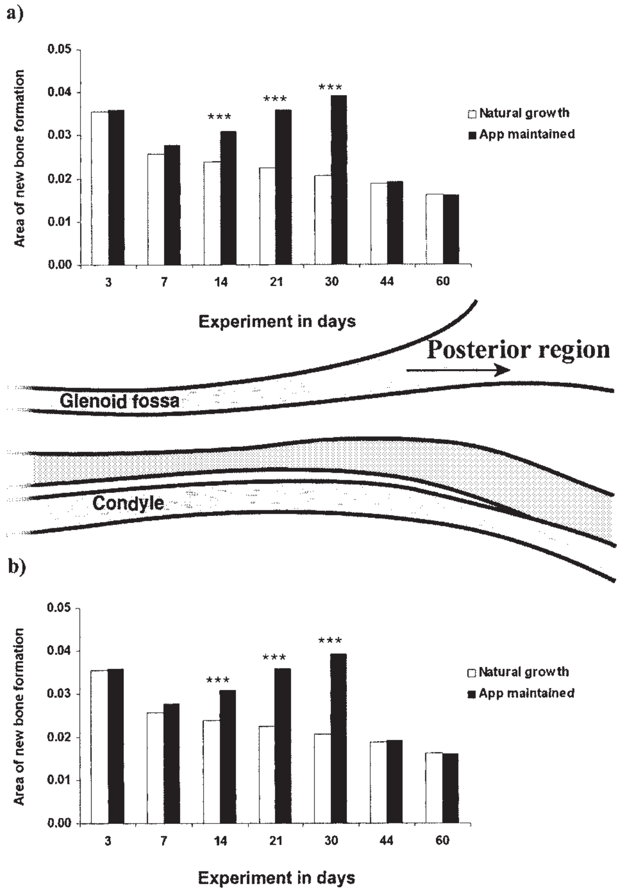


**Figure 1** Pattern of bone formation in the posterior regions of (a) the glenoid fossa and (b) the condyle during natural growth and in the experimental group with the appliance maintained throughout the experimental period (***$P < 0.001$).

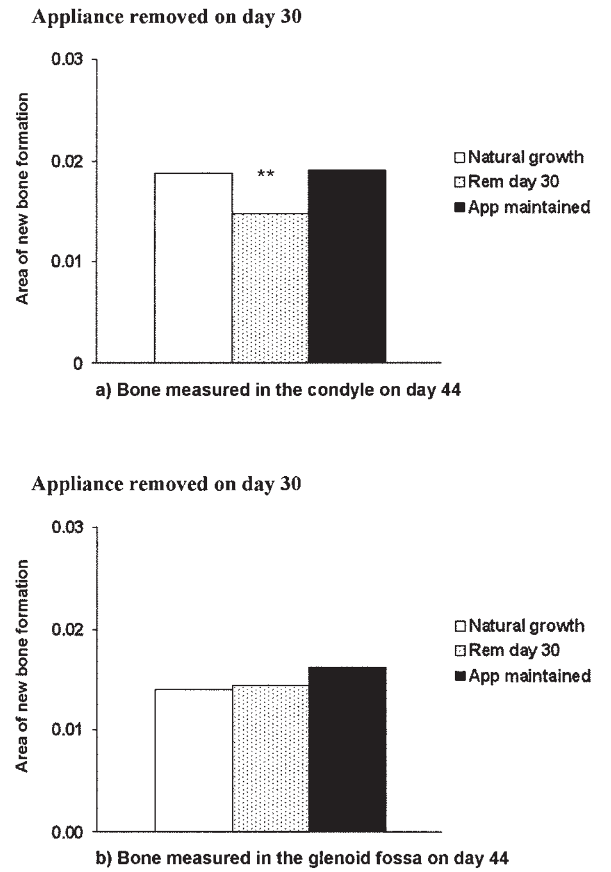


**Figure 2** Amount of bone formation on day 44 in the posterior region of (a) the condyle and (b) the glenoid fossa when the appliances were removed early on day 30, during natural growth and when the appliance was maintained.

fossa on day 60 (55.17 per cent) when compared with day 44.

*Late removal*

Late removal (day 44) of the bite-jumping device resulted in no significant difference in bone formation in either the posterior glenoid fossa (Figure 2b) or the condyle (Figure 3b) when measured on day 60 compared with that of the controls and those with bite-jumping devices or those who had 'early' removal of the bite-jumping device.

## Discussion

This study showed that early removal of the bite-jumping device resulted in lower levels of bone formation in the immediate follow-up period than those measured during natural growth (Figures 3a, 4 and 5), indicating subnormal growth during the immediate follow-up period from day 30 to day 44. This is in agreement with the clinical findings of Johnston (1999), where the effect of a functional appliance was followed by a period of subnormal growth. Interestingly, when the appliances were removed early (day 30) and levels of bone formation were followed for a longer period of time until day 60, the level of bone formation returned to that of natural growth (Figures 3b and 6). In other words, the subnormal growth was a transient stage in the immediate follow-up period, but not throughout the remaining growth period. However, in the late removal group when the appliances were maintained longer, subnormal growth did not occur after appliance removal. The explanation could be that mandibular advancement leads to changes in the biophysical environment that cause a series of cellular and molecular events that lead to bone formation in the condyles (Rabie *et al.*, 2002b, 2003) and the glenoid fossa (Rabie *et al.*, 2002a, 2003).

The matrix of newly formed bone is of the same nature as that formed during bone development and bone repair (Crofton *et al.*, 1996; Delvin, 2000). The type of collagen matrix that forms in the human condyle in situations of repair is known to be type III (Salo and Raustia, 1995). Type III collagen is the emergency type and the reason it is a good candidate for the repair

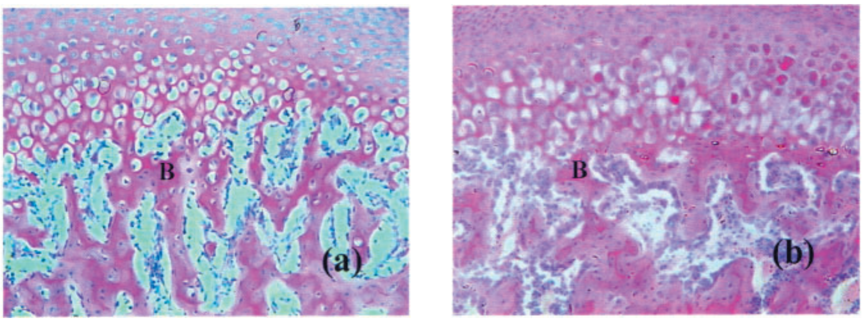


**Figure 3** Histological sections of the posterior region of the condyle on day 44 showing new bone (B) during (a) natural growth and (b) after appliance removal on day 30.

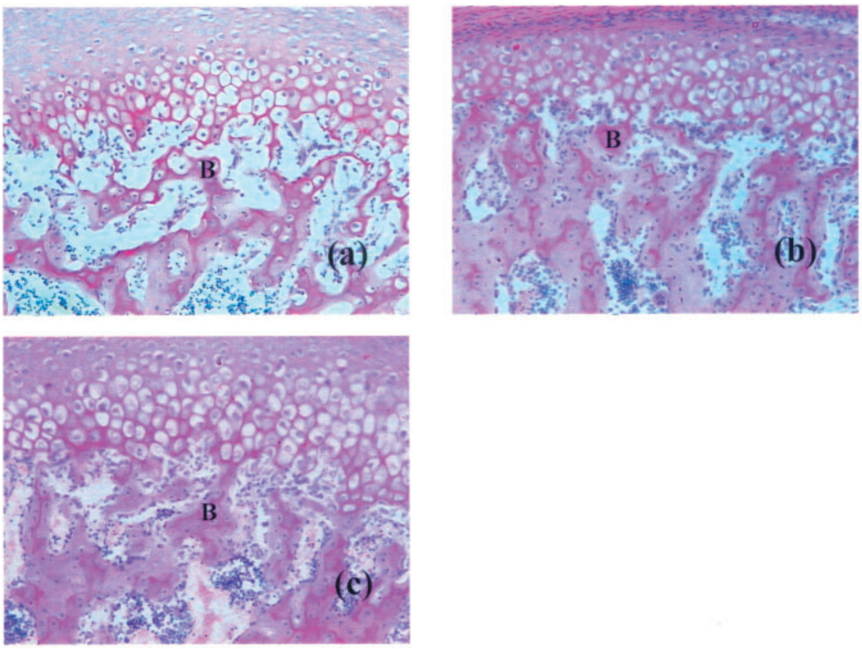


**Figure 4** Histological sections of the posterior region of the condyle on day 60 showing new bone (B) during (a) natural growth, (b) after appliance removal on day 30 and (c) after appliance removal on day 44.

of bone matrix is the weak nature of its cross-links required to stabilize the collagen molecules to form the collagen fibrils of the bone matrix. These cross-links are weaker than those present in type I collagen matrix. This makes its removal at a later stage and its replacement by the more stable type I collagen an easier process (Crofton *et al.*, 1996). Therefore, it is possible that in cases of early removal of the appliance, the process of maturation of the emergency type of bone to the more stable type I collagen matrix was not allowed to take place. It is expected, therefore, that the emergency type of bone with the inherently weak type III collagen matrix would not be stable enough to resist the forces of mastication and normal function. This could be the reason why a stage of subnormal growth is seen in the immediate follow-up period. On the other hand, by retaining the appliance longer until day 44, the levels of bone formation were similar to those seen during natural growth between days 44 and 60 (Figures 2b, 3b, 6). It is possible that keeping the appliance in longer until day 44 instead of day 30 could have allowed the emergency type III collagen to be replaced by the more permanent type I collagen matrix, which is the most stable due to its very strong cross-links (Crofton *et al.*, 1996). Therefore, the stability of the newly formed bone in the condyle and the glenoid fossa in response to mandibular advancement could be influenced by whether the clinician allows the newly formed bone to remodel to the more stable type of bone. These results lend support to clinical findings where improved results

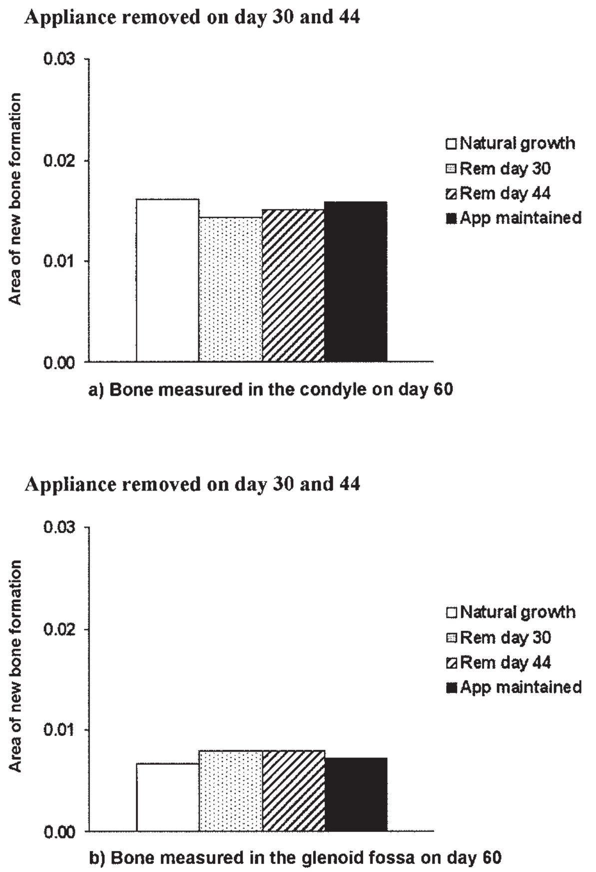


**Figure 5** Amount of bone formation in the posterior region of (a) the condyle and (b) the glenoid fossa when the appliance was removed on days 30 and 44, and also during natural growth and when appliance was maintained.

were seen in patients treated for an extended period of time with functional appliance therapy (Hägg *et al.*, 2001).

Considering the present data and those of Hägg *et al.* (2001), it is safe to recommend that the period of mandibular advancement should be increased from that commonly reported period in the literature of 5–7 months (Pancherz, 1979, 1985; Weislander, 1984) to double that period of treatment to allow for the newly formed bone to mature into more stable bone. This should offer the mandible a chance to resume growth at natural levels after the completion of treatment.

## Conclusions

Early appliance removal results in subnormal growth of the posterior condyle but not of the glenoid fossa. Increasing the duration of mandibular advancement secures normal levels of mandibular growth in the post-treatment period.

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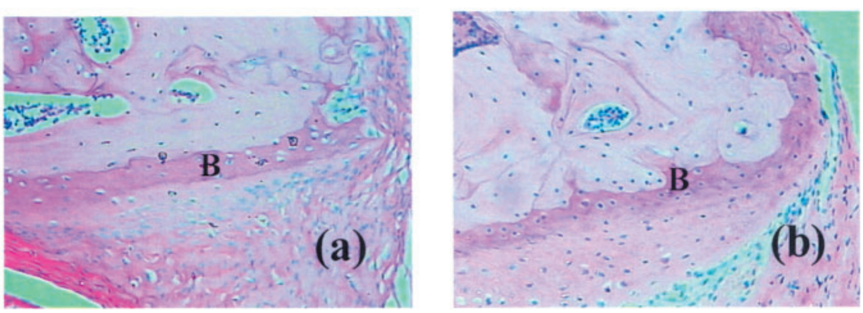


**Figure 6** Histological sections of the posterior region of the glenoid fossa on day 44 showing new bone (B) during (a) natural growth and (b) after appliance removal on day 30.

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