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A Comparative Micro-topographic Study of the Buccal Enamel of Different Tooth Types

C. RYE MATTICK B.CH.D., F.D.S. (ORTH.), R.C.S., M.SC., M.ORTH., R.C.S.
University Dental Hospital, Higher Cambridge Street, Manchester, UK

ROSS S. HOBSON B.D.S., F.D.S., R.C.S., M.D.S., M.ORTH., R.C.P.S
The Dental Hospital, Richardson Road, Newcastle-upon-Tyne, UK

Abstract. *The aim of this study was to perform an* in vitro *examination of the etch pattern achieved on the orthodontic bonding area (OBA) of different tooth types, and to compare the extent and definition of etch achieved. Six examples of each permanent human tooth type were studied. These were collected from adolescents. A standardized etch regime was employed on the OBA and the etch pattern examined under the scanning electron microscope. The degree of definition of etch achieved on every third enamel prism was evaluated. Results showed that the extent of etch achieved decreased toward the distal end of each arch and was significantly less on the first molars (covering <2% OBA) than on the incisors (covering >90% OBA). It was also noted that the degree of definition became poorer towards the distal end of the arches and was worst on the mandibular molars.*

It is suggested that the etched enamel morphology of different tooth types could affect composite resin bond strengths. Consequently, this feature could effect the clinical survival of orthodontic brackets and contribute to the higher failure rate of brackets on posterior teeth.

Index words: Acid-etched Enamel, Bond Failure, Bracket Failure, Enamel Micro-topography, Orthodontic Bonding Area (OBA)

Introduction

Clinical experience suggests that orthodontic brackets bonded directly with composite resin are extremely reliable. This, despite the fact that some authoritative studies have cast serious doubt on such an assumption. Newman (1978) for example quotes a failure rate as high as 26 per cent. Although more recent familiarity of use and continued development of composite resins has improved the situation, O'Brien *et al*. (1989) still found a 15 per cent clinical failure rate. Brackets bonded to posterior teeth are generally accepted to be less reliable than those on the anterior, a greater failure rate being noted on second premolars than incisors and canines (Kinch *et al*., 1988) This is particularly so for molar attachments (Sonis and Snell, 1989).

Comparative failure rates between bonds on the maxillary and mandibular dentition are less distinct, although most studies show a trend towards a higher failure rate for mandibular attachments (Gorelick, 1977; Newman, 1978; Zachrisson and Brobakken, 1978).

Many theories have been proposed to explain these trends in bond failure:

- Prismless enamel tends to be more common, and to a greater depth, on posterior teeth (Whittaker, 1982) and such enamel is considered to produce an 'inferior' etch pattern (Kodaka *et al*., 1991).
- During etching, the bonding areas of posterior teeth are thought more likely to become contaminated with salivary proteins (Hormati *et al*., 1980), or to be adversely affected by higher levels of humidity (Mardaga *et al*., 1982).
- The bases of posterior brackets may have poorer adaptation to tooth surfaces. This results in an uneven composite layer with inferior mechanical properties (Evans and Powers, 1985).
- Molar regions are exposed to greater masticatory forces (Zachrisson, 1977; Kinch *et al*., 1988; Johnston *et al*., 1996). This is particularly so for the mandibular dentition (Zachrisson, 1977).
- There may be a difference in the etch pattern of anterior and posterior teeth (Johnston *et al*., 1996).

A key factor in bonding is the enamel to composite interface. There have therefore been numerous studies of etched enamel surface, including many reports of Scanning Electron Microscope (SEM) observations. However, published reports are not always comparable one with another because of inconsistencies in the type of teeth studied, the source of specimens, the specific surfaces examined or the practical techniques applied. Most workers seem not to have considered the desirability of adopting either standardized materials or procedures.

Indeed, no previous work has presented a thorough and systematic comparison of the micro-topography of the acid-etched buccal surfaces of every tooth type. This study addresses that issue, because it seems plausible that there could be a direct correlation between the nature of the etch achieved on the bonding area of different tooth types, and the consequent reliability of the bonding process.

The aim of this research was therefore to devise a valid method of visually appraising the morphology of etched buccal surfaces, in order to determine whether the micro-topography of etched enamel could provide an explanation

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for the observed differences in bond failure rate on different tooth types.

Materials and Methods

Materials

The teeth used for this comparative study comprised 72 extracted, erupted and clinically sound teeth. Six examples each of maxillary and mandibular central and lateral incisors, canines, first and second premolars and first molars were studied. Donor patients were aged 12–20 years. They were of Caucasian origin and life-long residents of Newcastle upon Tyne (an area with a 1 ppm optimized fluoridated water supply). The *in vitro* technique adopted throughout this study simulated, as far as possible, typical *in vivo* clinical procedures.

The Straight Wire Orthodontic Appliance has been widely adopted, and the brackets for this system are bonded onto the centre of the buccal clinical crown, covering an area of 4×4 mm. The enamel surface covered by such an attachment will be referred to subsequently as the Orthodontic Bonding Area (OBA).

Practical Procedures

The OBA of each tooth was polished with a pumice and water slurry (20 seconds), rinsed with distilled water (20 seconds) and dried in warm air. Thirty-seven per cent phosphoric acid (Right On etchant®) was then applied to the OBA with a sponge pledget (30 seconds), and the crown again washed with distilled water (30 seconds). The preparation was concluded by drying the tooth in a warm air oven (37°C) until the tissues were fully desiccated. Finally, the etched surface was sputter-coated with a 15-nm layer of gold. The centre of the OBA of each tooth was then examined with a SEM and 20 sequential photomicrographs covering the OBA were prepared from each specimen. These were used to construct a 1-m^2 montage of contiguous images, each with a final magnification of $\times 500$.

These high-resolution composite micrographs were used to determine and subsequently compare the etch-pattern of every tooth specimen. A 3-point comparative scale was devised to categorise the different observable grades of etched enamel. This stratagem was modified from those originally proposed by Silverstone *et al*. (1975), Galil and Wright (1979) and by Brannstrom *et al*. (1982). The scale adopted distinguished between the following clearly and consistently recognisable types of surface etch (see Figure 1).

- *Well defined:* outline of individual enamel prisms clearly visible.
- *Poorly defined:* spectrum of intermediate surface irregularities.
- *Unetched:* relatively smooth enamel surface.

No previous published research has described the surface distribution of etches of different definitions or qualities. It was therefore necessary to ascertain the potential distribution range of etch quality so that a sufficiently sensitive sampling method could be developed. Seven composite micrographs were selected at random for a pilot study. A transparent acetate sheet was placed over each and the perimeter of every discrete patch of differentially etched enamel (according to the above three categories) was traced. A Kontron MOP Videoplan computer package was used to calculate the relative surface area occupied by each

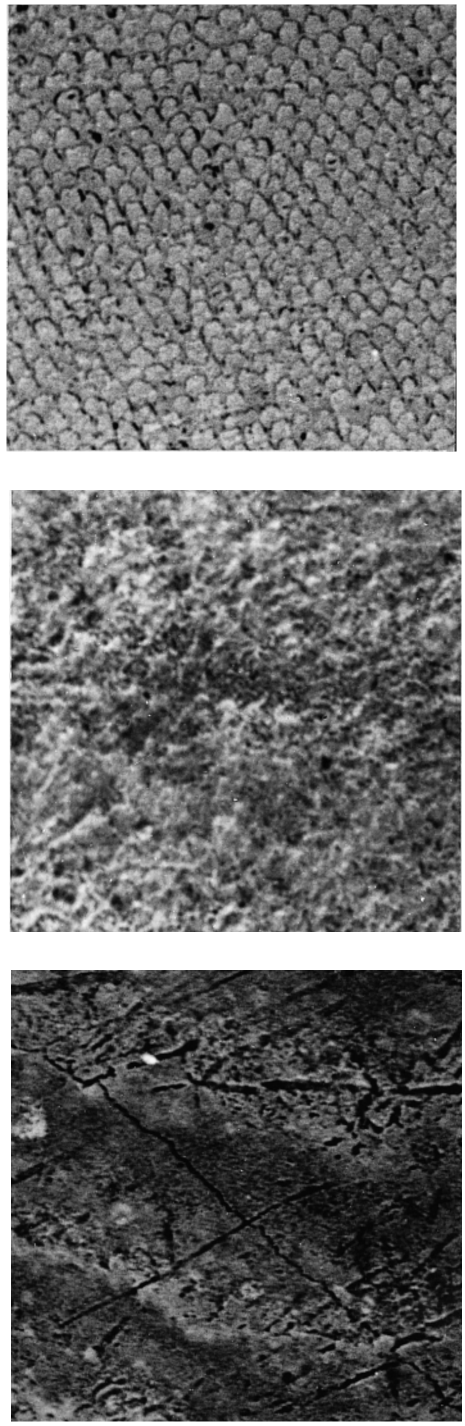

FIG. 1 Three-point scale for determining the quality of enamel etch. (a) 'Well defined' etch: a surface with 'optimal' irregularities, where the outline of the enamel prisms are clearly visible and continuous. (b) 'Poorly defined' etch: a spectrum of surface irregularities which are indisputably visible, but not markedly distinctive. (c) 'No etch': relatively smooth enamel, apparently unaffected by acid etchant.

type of etch. The mean values for the seven pilot teeth revealed that the 'pilot OBA' achieved 6·05 per cent surface coverage of 'well defined' etch, 89·50 per cent showed 'poorly defined' etch, and 4·27 per cent remained unetched.

The Sampling Regime

The technique of histometry (Anderson and Lowe, 1982; Hobson, 1989) was used to sample all the composite micrographs. This method involves assessing a predetermined number of points within a sample to provide an accurate picture of the whole. A regular grid is placed over a specimen (the micrograph) and at each intersection graded. The number of intersections lying on a particular feature is proportional to the relative area occupied by that feature within the whole sample area. The pilot study indicated the mean percentage areas that one might expect to be occupied by each etch type. The sampling method used must therefore be sufficiently sensitive to identify a feature occupying only 4·27 per cent of the surface area. The binomial distribution was applied (after Anderson and Lowe, 1982), to calculate the number of intersection points that must be studied in order to identify a feature occupying only 4·27 per cent of the surface area:

$$Pi = [Pe \cdot (100 - Pe)] / (SE)^2$$

where: Pi is the number of sampling points (the unknown), Pe is the smallest percentage area of feature (4·27 per cent), and SE is the standard error (selected to be 5 per cent).

A standard error of 5 per cent was chosen arbitrarily and would establish a 95 per cent confidence interval, for the pilot study results. The calculated value of Pi (i.e. the number of intersections to be assessed for each OBA) was 8960 and resulted in more than half a million reference points being assessed by eye in the course of the research. A sampling grid, produced on clear acetate sheet (1 m^2), with 8960 intersections, was placed over each composite micrograph, and all intersections were then classified, according to etch type. Each intersection covered a point on the composite micrograph that was separated on the 'actual' tooth surface from the next intersection by just 20 μm. Therefore, the topography of the enamel etch was ultimately assessed at every third enamel prism, for every tooth specimen.

A Student *t*-test and one-way analysis of variance (ANOVA) were applied to the amassed data. ANOVA was used to detect differences in the types of etch achieved, whilst the location of the differences was determined by *t*-tests; between individual tooth types, between the anterior and posterior teeth and between maxillary and mandibular teeth.

Reliability of the Sampling Procedure

It was essential to confirm the reproducibility of applying both the proposed 3-point scale of classification and the method of calculating the proportion of OBA surface exhibiting each identifiable grade of etch. This was achieved in each case by examining six randomly selected composite micrographs on two different occasions, separated by not less than 2 months, and comparing the results for conformity. Data from the error study was used to calculate the 95 per cent confidence interval. The results of the error study found no significant difference between the two counts, and also that differences between teeth, with respect to the surface area covered by a particular etch type were significant (at a 5 per cent level), only if greater than 7 per cent.

Results

*Comparison of the **Quantity** (Mean Area) of Etch Achieved on the OBA of Different Tooth Types*

There were considerable differences between the etch-patterns achieved on the OBAs of different tooth types, but there were also large variations within groups of similar teeth. As only relatively few specimens (72) could be examined most of the comparisons that might be made from the observations must be viewed with caution (Table 1).

The quantity of etch achieved between the different tooth type groups was significantly different ($P = 0{\cdot}007$). The composite micrographs of all teeth were etched over at least 50 per cent of their surface, with values ranging from 54 per cent (lower first molar-mean) to 97 per cent (lower central incisor mean).

TABLE 1 *A numerical comparison of the (mean) percentage areas and types of etch achieved on the orthodontic bonding areas (OBA) of every tooth type*

	Tooth type					
	6 (range, SD)	5 (range, SD)	4 (range, SD)	3 (range, SD)	2 (range, SD)	1 (range, SD)
Quantity						
Total % area of OBA affected by etchant						
Maxilla	80·0 (38–96, 23·7)	80·8 (38–93, 11·3)	56·3 (34–82, 20·7)	79·6 (41–96, 22·5)	95·4 (94–100, 5·5)	74·0 (19–98, 29·6)
Mandible	54·3 (32–82, 25·0)	76·0 (62–96, 12·4)	90·4 (74–98, 11·3)	91·8 (78–99, 9·1)	88·6 (65–98, 13·4)	96·7 (86–100, 6·1)
Quality						
% Area occupied by No-Etch						
Maxilla	20·0 (4–62, 23·6)	19·2 (7–62, 11·3)	43·7 (23–66, 20·7)	20·4 (4–59, 22·5)	4·6 (0–14, 5·5)	26·0 (2–81, 29·6)
Mandible	45·7 (18–67, 25·0)	24·0 (4–38, 12·4)	9·7 (2–26, 11·3)	8·3 (1–22, 9·1)	11·0 (2–35, 13·4)	3·3 (0–14, 6·1)
% Area occupied by Poorly Defined Etch						
Mazilla	62·5 (37–79, 13·9)	66·3 (36–88, 10·2)	47·5 (32–67, 13·3)	45·5 (19–74, 29·3)	53·0 (8–90, 37·9)	44·5 (19–65, 16·6)
Mandible	53·8 (32–82, 25·2)	66·2 (53–74, 8·2)	77·8 (67–89, 10·2)	55·8 (6–80, 27·5)	77·2 (62–89, 11·5)	63·3 (63–76, 12·0)
% area occupied by Well Defined Etch						
Maxilla	17·5 (1–27, 11·0)	14·5 (2–44, 12·6)	8·8 (0–20, 8·7)	34·1 (4–76, 32·6)	42·1 (4–93, 42·3)	29·6 (0–60, 25·3)
Mandible	0·5 (0·1–1·1, 0·5)	9·8 (1–27, 10·6)	12·6 (2–30, 12·6)	36·0 (2–92, 34·1)	11·5 (3–30, 10·9)	33·4 (23–56, 13·6)

The more extensive etches (covering around 90 per cent of the surface area) were achieved on four mandibular tooth types (incisors, canines, and second premolars), but only one maxillary tooth type (lateral incisor).

The maxillary dentition has a slightly larger area of unetched surface (22 per cent total surface) than the mandibular (17 per cent total surface), although this is not statistically significant ($P = 0{\cdot}17$).

Anterior teeth etched over a significantly greater mean area than posterior teeth ($P = 0{\cdot}0062$). This trend is particularly marked in the maxilla ($P = 0{\cdot}0068$). This characteristic is apparent from Figure 2.

The tooth with the least area of etched enamel was the mandibular first molar (mean 54 per cent). This figure was considerably less than the mandibular mean of 83 per cent, or the overall mean for the entire dentition of 80 per cent.

Comparison of the ***Degree of Definition*** *of Etch Achieved on the OBA of Different Tooth Types*

Although there is a significant difference between the 12 tooth types with respect to the quantity of etch achieved (by ANOVA), the variations in the degree of definition attained are less significant ($P = 0{\cdot}11$). However, some distinct trends were noted. Of particular note is the prevalence of 'poorly defined' etch on all tooth types. This is contrary to the classical, clearly defined etch commonly illustrated in text books. There are considerable variations in the extent of the 'well defined' etch achieved both between and within tooth type groups. The results obtained on individual tooth specimens ranged from a maximum 93 per cent surface coverage by 'well defined' etch for a single maxillary lateral incisor (mean for this tooth type is 42 per cent), to a minimum 0·1 per cent 'well defined' etch for a single mandibular first molar (mean 0·5 per cent).

Anterior teeth display a significantly greater area of 'well defined' etch ($P = 0{\cdot}006$).

It appears that maxillary teeth generally display more 'well defined' etched surfaces: Although the mean area of OBA etched on maxillary teeth is marginally smaller than for mandibular teeth (78 and 83 per cent, respectively) a greater proportion of the maxillary tooth is etched to a higher definition (25 per cent of total etch, compared to 20 per cent for the mandible).

Visibly etched enamel presents a heterogeneous mass of 'partially' and 'well' defined etch patterns. The proportion

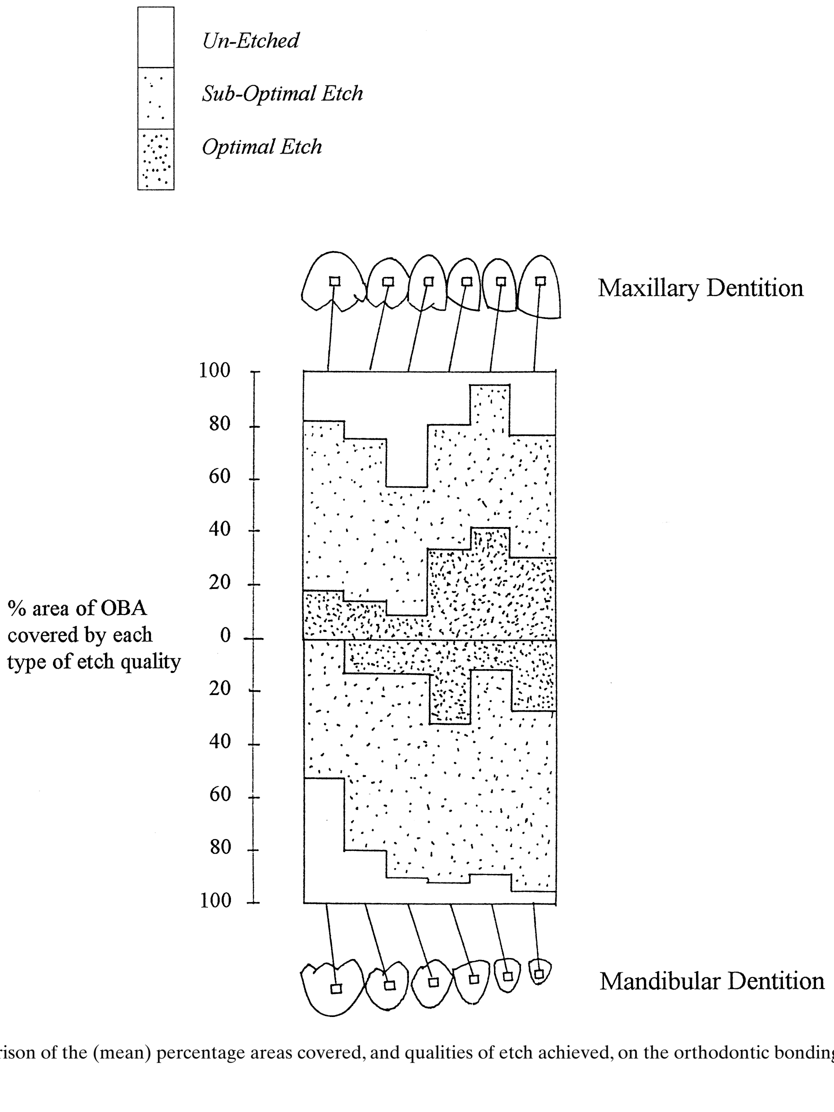

FIG. 2 A visual comparison of the (mean) percentage areas covered, and qualities of etch achieved, on the orthodontic bonding area (OBA) of each tooth type.

of etch which is 'well defined' varies throughout the dentition. In the upper labial segment 'well defined' etch accounts for 55 per cent of the total area of etching. This is twice that found in the lower labial segment (27 per cent). Both these figures are in striking contrast to the 11 per cent achieved on upper and lower premolars.

The mandibular first molar exhibited the least amount of 'well defined' etch (0·5 per cent), in addition to being the tooth that achieved the least overall quantity (54 per cent) of etch on the OBA.

Discussion

Many published texts, for example Oliver (1986), state that the 'well defined' (classical) etch is the predominant etch pattern. However, this investigation revealed that this is not always the case. The presence of substantial areas of unetched tooth surface supports the findings of Futatsuki *et al*. (1995). Li *et al*. (1994) found significant and unpredictable differences in the mineral composition across the surface of similar tooth types. This could be expected to affect acid solubility and may be reflected in the large standard deviations within the sample groups in this study. This is illustrated in Figure 3, showing the mean etch achieved for each tooth type and the large associated 95 per cent confidence intervals.

Clinical Implications

The precise pattern of acid-etching achieved on individual teeth is both heterogeneous and erratic, and this unpredictable characteristic alone might explain the apparently capricious failure of bonded brackets.

This study shows, for the first time, that both the quantity and nature of the etch achieved varies within the dentition. The extent and definition of etch significantly deteriorates progressively towards the posterior aspect of both jaws. The more frequent loss of posteriorly applied brackets suggests that the particular microtopography of the etched enamel surface of any tooth affects the efficacy of the bonding process.

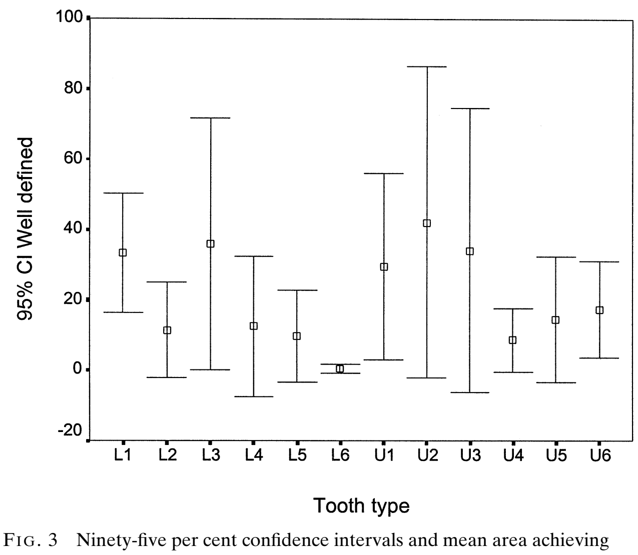

FIG. 3 Ninety-five per cent confidence intervals and mean area achieving optimal etch on each tooth type. Wide within-sample ranges result in wide confidence intervals.

For lower first molars only about half (54 per cent) of the OBA is actually etched and of that less than 1 per cent to a high definition. The higher failure rate of attachments bonded to the lower first molars, which is usually attributed to salivary contamination during bonding and/or excessive occlusal forces, may therefore result from the inherently poor quality and quantity of etched enamel.

The reported clinical failure rate of orthodontic brackets is generally greater in the mandible (Gorelick, 1977; Newman, 1978). In this study, the lower teeth were seen typically to be etched over slightly greater surface areas than the upper teeth. Nevertheless, a smaller proportion of mandibular surfaces demonstrate 'well defined' prisms. This suggests that the quality of etch is of significance with respect to bonding efficacy.

Implications for Bond Strength Research

The variability of etched tooth surfaces revealed by this work has important implications for research into *in vitro* orthodontic bond strength. Such studies are frequently adopted to test the efficacy of newly developed adhesive materials. However, because of the considerable variability in both the extent and magnitude of the etch achieved on individual teeth, and between tooth type groups, researchers should no longer assume that any one tooth type is representative of the dentition as a whole. Fox *et al*. (1991) proposed standardization of such studies by limiting testing exclusively to premolar teeth. Such a limitation should reduce variability in results. However, care would be needed in extrapolating the results to teeth other than premolars.

Brackets pre-coated with composite resin are currently receiving interest (Bearn *et al*., 1995). One might envisage a future limited range of brackets pre-coated with composite resins tailor-made for specific tooth types. This could reduce both the incidence of posterior bracket failure and the accidental iatrogenic damage of the better etched labial teeth during de-bonding procedures.

Experimental Limitations and Assumptions

Throughout this investigation it was assumed that the gender of the donors, the time elapsed since the eruption of the specimen teeth, and the short length of storage-time (up to 6 months) would have had little or no effect on the enamel surfaces. It was further assumed that the findings were typical and therefore representative of the teeth of any young persons, particularly those of Newcastle-upon-Tyne. The technique adopted for systematically sampling the SEM micrographs was objective. The assessment of the definition of etch was subjective, but was shown to be consistent and valid.

It was presumed that a 3-point scale of classification was a sufficiently sensitive tool to adequately characterise the enamel surfaces studied. However, it was noted (subjectively) that the degree of definition of etch, within the broad category of 'poorly defined', appeared to deteriorate on progressing distally along the tooth series. It is possible that a more discriminatory (e.g. a 5-point scale) might produce less equivocal results.

A relatively small number of teeth (72) were available for this study and the variations in the microtopography between apparently similar specimens was great. A study using a larger sample of teeth is needed to confirm the conclusions.

Conclusions

1. The 12 human tooth types achieved significantly different quantities and definitions of etch.
2. The OBAs of anterior teeth etch over a significantly greater surface area than those of posterior teeth.
3. The area of 'well defined' etch is significantly greater on anterior teeth.
4. Mandibular teeth present a slightly greater area of etched enamel than maxillary, but the etch has a 'poorer' definition than that found on maxillary teeth.
5. Lower first molars are the least well etched teeth, in terms of both quantity and definition. Bonding to this tooth type should be avoided, except when banding is contraindicated.
6. Because of the considerable variability in both the quantity and quality of the acid-etched surfaces of virtually all teeth, researchers studying the bonding of brackets should no longer assume that any one tooth type, perhaps least of all the previously favoured premolar, is representative of the dentition as a whole.

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