9.2 General observations

Several observations of a general nature may be made from the data presented in Table 9.6.

No material, regardless of the etching time or test procedure, completely resisted microleakage or even confined microleakage entirely to the enamel cavity wall. Four combinations of material, etching time and test procedure successfully confined microleakage to the enamel cavity wall in 88 - 91 per cent of the surfaces examined. Of these surfaces, the percentage showing no microleakage at all (Grade 0) was between 32 and 68 per cent; the remaining surfaces showed Grade 1 microleakage.

The highest level of microleakage, in which fewer than ten per cent of the surfaces examined showed microleakage confined to the enamel of the cavity wall, was found when Concise, without Enamel Bond, was used under certain test conditions.

9.3 The Microleakage around Composite Resin Restorations placed in Unetched Cavities

The microleakage around Concise composite resin restorations that were placed in unetched cavities was examined after storage for 24 hours, ageing for 12 months and thermal-cycling.
TABLE 9.6

Summary of the microleakage results

<table>
<thead>
<tr>
<th>Percentage of surfaces with microleakage confined to enamel</th>
<th>Etching time (minutes)</th>
<th>Material</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>91</td>
<td>2</td>
<td>Concise</td>
<td>24 hr.</td>
</tr>
<tr>
<td>88</td>
<td>1</td>
<td>Estic</td>
<td>12 mths.</td>
</tr>
<tr>
<td>88</td>
<td>2</td>
<td>Concise + E.B.*</td>
<td>24 hr.</td>
</tr>
<tr>
<td>88</td>
<td>2</td>
<td>Estic</td>
<td>24 hr.</td>
</tr>
<tr>
<td>78</td>
<td>1</td>
<td>Concise</td>
<td>12 mths.</td>
</tr>
<tr>
<td>66</td>
<td>0</td>
<td>Concise</td>
<td>12 mths.</td>
</tr>
<tr>
<td>65</td>
<td>1</td>
<td>Concise</td>
<td>12 mths.</td>
</tr>
<tr>
<td>59</td>
<td>2</td>
<td>Estic</td>
<td>T.C.</td>
</tr>
<tr>
<td>47</td>
<td>1</td>
<td>Concise</td>
<td>24 hr.</td>
</tr>
<tr>
<td>47</td>
<td>2</td>
<td>Concise + E.B.</td>
<td>T.C.</td>
</tr>
<tr>
<td>39</td>
<td>1</td>
<td>Concise + E.B.</td>
<td>24 hr.</td>
</tr>
<tr>
<td>31</td>
<td>1</td>
<td>Estic</td>
<td>24 hr.</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>Estic</td>
<td>T.C.</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>Concise + E.B.</td>
<td>T.C.</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>Concise</td>
<td>T.C.</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>Concise</td>
<td>T.C.</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>Concise</td>
<td>24 hr.</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Concise</td>
<td>T.C.</td>
</tr>
</tbody>
</table>

Tests: 24 hr. - Tested after 24 hours' storage.
T.C. - Tested after thermal-cycling.
12 mths. - Tested after 12 months' ageing.

*Enamel Bond.
The results, illustrated in Figure 9.3, and presented in Tables 9.1 to 9.5, indicated that fewer than eight per cent of the surfaces examined that had been stored for 24 hours or thermal-cycled showed microleakage confined to the enamel of the cavity wall; that is, in more than 92 per cent of cases the microleakage extended beyond the enamel and onto the dentine cavity wall. This compared with the surfaces examined after ageing for 12 months in which more than 66 per cent showed microleakage confined to the enamel cavity wall.

Statistical analysis of the data indicated that the differences between restorations tested after 24 hours' storage or thermal-cycling and those tested after ageing for 12 months, in their ability to confine the microleakage to the enamel cavity wall, were significant. The null hypothesis, that there was no real difference (difference was due to chance) in the microleakage around these restorations, was disproved; in other words, in fewer than one per cent of cases the difference was due to chance (this being the level of confidence required in this investigation as described in a previous chapter). The difference in microleakage, between the restorations tested after storage for 24 hours and after thermal-cycling, was not significant; at the one per cent level of confidence, the null hypothesis was upheld.
FIGURE 9.3

The microleakage around Concise composite resin restorations placed in unetched cavities.

- Microleakage confined to the enamel.
- Microleakage in enamel and dentine.
24 hr. - Tested after 24 hours' storage.
T.C. - Tested after thermal-cycling.
12 mths. - Tested after 12 months' ageing.
FIGURE 9.3

Percentage of surfaces.
9.4 The Influence of Etching the Enamel Cavity Wall on the Microleakage

This part of the investigation compared the microleakage that occurred around a restoration when the enamel cavity wall was etched for one or two minutes, with the microleakage around a restoration placed in an unetched cavity. The material used was Concise and the restorations were tested after storage for 24 hours, ageing for 12 months and thermal-cycling, in the manner previously described.

The results, illustrated in Figure 9.4, are presented in Tables 9.1 to 9.5. When tested after storage for 24 hours, fewer than six per cent of the surfaces from restorations with unetched cavities showed microleakage confined to the enamel cavity wall, compared with approximately 47 per cent and 91 per cent for restorations with cavities etched for one minute and two minutes, respectively. These differences between the unetched and the etched cavities were significant. After ageing for 12 months, the difference in the microleakage between the unetched cavities and cavities etched for one minute before restoration was not significant. After thermal cycling, the differences in the microleakage between restorations placed in unetched cavities and those
FIGURE 9.4

The influence of etching the enamel cavity wall on the microleakage around Concise composite resin restorations

- Microleakage confined to the enamel.
- Microleakage in enamel and dentine.
24 hr. - Tested after 24 hours' storage.
T.C. - Tested after thermal cycling.
12 mths. - Tested after 12 months' ageing.
1 min. - 1 minute etch of the enamel cavity wall.
2 min. - 2 minute etch of the enamel cavity wall.
placed in cavities etched for one or two minutes were not significant. In each case, after thermal-cycling, fewer than ten per cent of the surfaces examined showed the microleakage confined to the enamel cavity wall.

9.5 The Influence of the Etching Time on the Microleakage

The influence of different etching times, either a one or a two minute application of acid-etchant to the enamel of the cavity wall, on the microleakage occurring around restorations was examined using Estic, Concise or Concise in combination with Enamel Bond. Restorations were immersed in tracer dye either after storage for 24 hours or after thermal-cycling.

9.5.1 Restored teeth were stored for 24 hours before immersion in the dye solution.

The results, presented in Tables 9.1 and 9.2, are illustrated in Figure 9.5. Following a one minute etch of the cavity before restoration, the microleakage was confined to the enamel cavity wall in approximately 47 per cent of the surfaces examined from Concise restorations, in approximately 39 per cent of the surfaces examined from restorations using Concise plus Enamel Bond and in approximately 31 per cent of the surfaces examined from Estic restorations. In contrast, for each
FIGURE 9.5

The influence of the etching time on the microleakage following 24 hours' storage.

- Microleakage confined to the enamel.

- Microleakage in enamel and dentine.

1 min. - 1 minute etch of the enamel cavity wall.

2 min. - 2 minute etch of the enamel cavity wall.

E.B. - Enamel Bond.
Percentage of surfaces.
material, after a two minute etch of the enamel cavity wall, more than 88 per cent of the surfaces examined showed microleakage confined to this wall. In the case of each of Concise, Concise plus Enamel Bond and Estic, the difference in microleakage, between a one minute and a two minute etch of the enamel cavity wall before restoration, was significant at the one per cent level of confidence.

9.52 Restored teeth were subjected to thermal-cycling, in the manner previously described, before immersion in the dye solution.

The results, illustrated in Figure 9.6, are presented in Tables 9.3 and 9.4. After thermal-cycling, both the cavities etched for one minute and those etched for two minutes resulted in Concise restorations showing microleakage extending beyond the enamel of the cavity wall in more than 90 per cent of the surfaces examined; statistically, the difference between the two results was not significant. Both Concise, used in conjunction with Enamel Bond, and Estic, following thermal-cycling, exhibited a greater percentage of surfaces showing microleakage confined to the enamel of the cavity wall when a two minute etch was used rather than a one minute etch; in the case of each material, the difference was significant.
FIGURE 9.6
The influence of the etching time on the microleakage following thermal-cycling.

- Microleakage confined to the enamel.
- Microleakage in enamel and dentine.
- 1 minute etch of the enamel cavity wall.
- 2 minute etch of the enamel cavity wall.
- E.B. - Enamel Bond.
FIGURE 9.6

Percentage of surfaces.
In summary, for the three materials investigated, cavities etched for two minutes before restoration showed significantly less microleakage (as measured by the ability to confine microleakage of the tracer dye to the enamel of the cavity wall) than cavities etched for one minute, when tested after storage for 24 hours or after thermal-cycling, with one exception. For Concise restorations (without Enamel Bond) tested by thermal cycling, the difference between etching for one minute and for two minutes was not significant; in each case, more than 90 per cent of the surfaces examined showed microleakage extending beyond the enamel of the cavity wall.

9.6 The Influence of the Type of Material on the Microleakage

This part of the investigation examined the effects on the microleakage of a difference in either the particle size or the viscosity of the composite resin.

9.6.1 To study the influence of the particle size of the inorganic filler component of the composite resin on the microleakage, the larger particle size Concise composite resin was compared with Estic (Figure 9.7). The materials
Fig. 9.7. Photographs showing the difference in particle size of a, Concise and, b, Estic composite resins, x100.
were placed into cavities etched for either one or two minutes and the restorations were subsequently immersed in dye after storage for 24 hours or after thermal-cycling. In addition, cavities etched for one minute before restoration were used to compare the two materials after ageing for 12 months.

The results for microleakage following a one minute etch of the enamel cavity wall are presented in Tables 9.1, 9.3 and 9.5, and are illustrated in Figure 9.8. When cavities were etched for one minute, the differences between Concise and Estic in their microleakage (as measured by the ability to confine microleakage of the tracer dye to the enamel cavity wall) following immersion in dye after 24 hours' storage or after ageing for 12 months were not significant. After thermal cycling, however, approximately five per cent of the surfaces examined from Concise restorations showed microleakage confined to the enamel and approximately 25 per cent of the surfaces examined from restorations using the smaller particle size Estic composite resin showed microleakage confined to the enamel cavity wall; the difference between the two was significant at the one per cent level of confidence.
FIGURE 9.8

The influence of the particle size of the composite resin on the microleakage following a one minute etch

- Microleakage confined to the enamel.
- Microleakage in enamel and dentine.
24 hr. - Tested after 24 hours' storage.
T.C. - Tested after thermal-cycling.
12 mths. - Tested after 12 months' storage.
FIGURE 9.8

Percentage of surfaces.
The results for microleakage following a two minute etch of the enamel cavity wall are presented in Tables 9.2 and 9.4, and are illustrated in Figure 9.9. When the cavities were etched for two minutes and the restorations immersed in dye after storage for 24 hours, Concise and Estic were observed to confine the microleakage to the enamel cavity wall in approximately 91 per cent and 88 per cent, respectively, of the surfaces examined; the difference between the two materials was not statistically significant. After thermal cycling, approximately nine per cent of the surfaces examined from Concise restorations showed microleakage confined to the enamel of the cavity wall compared with approximately 59 per cent of the surfaces examined from Estic restorations; the difference was statistically significant.

9.62 To study the influence on the microleakage of the viscosity of the resin component of the composite resin, Concise composite resin was compared with Concise used in combination with the less viscous unfilled resin, Enamel Bond. The materials were placed into cavities etched for either one or two minutes and the restorations were subsequently immersed in dye after storage for 24 hours or after thermal-cycling.
FIGURE 9.9
The influence of the particle size of the
composite resin on the microleakage
following a two minute etch.

- Microleakage confined to the enamel.
- Microleakage in enamel and dentine.
- Tested after 24 hours' storage.
- Tested after thermal-cycling.
FIGURE 9.9

Percentage of surfaces.
In addition, cavities etched for one minute before restoration were used to compare the two materials after ageing for 12 months.

The results for the microleakage around restorations, following a one minute etch of the enamel of the cavity wall, are presented in Tables 9.1, 9.3 and 9.5, and are illustrated in Figure 9.10. The results, following a two minute etch, are presented in Tables 9.2 and 9.4, and are illustrated in Figure 9.11. When the restorations were either stored for 24 hours, after a one minute or a two minute etching of the cavity wall, or aged for 12 months, after a one minute etching of the cavity wall, before immersion in the tracer dye, the differences, between Concise and Concise used in combination with the less viscous Enamel Bond, in their ability to confine microleakage to the enamel of the cavity wall, were not significant at the one per cent level of confidence.

When the cavities were etched for one minute before restoration and subsequent thermal cycling and dye immersion, approximately five per cent of the surfaces examined from Concise restorations showed microleakage confined to the enamel cavity wall compared with approximately 18 per cent of the surfaces examined from restorations placed using Enamel Bond which preceded the application of the Concise composite resin. When the cavities were etched for two minutes and the
FIGURE 9.10

The influence of the viscosity of the composite resin on the microleakage following a one minute etch

- Microleakage confined to the enamel
- Microleakage in enamel and dentine
24 hr. - Tested after 24 hours' storage
T.C. - Tested after thermal cycling
12 mths. - Tested after 12 months' ageing
E.B. - Enamel Bond.
FIGURE 9.11

The influence of the viscosity of the composite resin on the microleakage following a two minute etch

- Microleakage confined to the enamel
- Microleakage in enamel and dentine
24 hr. - Tested after 24 hours' storage
T.C.   - Tested after thermal cycling
E.B.   - Enamel Bond.
restorations thermal-cycled, approximately nine per cent of the surfaces examined from Concise restorations and approximately 47 per cent of the surfaces examined from restorations placed using Enamel Bond and Concise showed microleakage confined to the enamel of the cavity wall. In either one minute or two minute etching of the enamel cavity wall after thermal cycling of the restorations, the difference in the microleakage, between Concise and Concise used in combination with the less viscous Enamel Bond, was significant at the one per cent confidence level.

9.7 The Influence of Ageing and Thermal Cycling on the Microleakage

This part of the investigation examined the effects, on the microleakage occurring around restorations, of different testing procedures by comparing the results obtained after storage for 24 hours (before immersion in the dye) with results obtained either after ageing of the restorations for 12 months or after thermal cycling.

9.7.1 To study the influence of ageing — the time since placement and finishing of the restoration — four types of restorations were examined; namely, Concise placed in an unetched cavity and Concise, Concise in combination with Enamel Bond and Estic placed in cavities etched for one minute. The microleakage
occurring around restorations aged for 12 months was compared with results obtained from restorations immersed in the tracer dye after storage for 24 hours.

The results are presented in Tables 9.1 and 9.5 and are illustrated in Figure 9.12. For each type of restoration, the microleakage of the tracer dye was confined to the enamel cavity wall in a greater percentage of the surfaces examined after ageing of the restorations for 12 months than in the surfaces examined from restorations stored for 24 hours before immersion in the dye. For Concise placed in an unetched cavity, approximately 66 per cent of the surfaces examined showed microleakage confined to the enamel of the cavity wall after ageing of the restoration for 12 months, compared with fewer than six per cent of the surfaces showing microleakage confined to the enamel wall after storage of the restoration for 24 hours. Corresponding values, for the percentage of surfaces examined showing microleakage confined to the enamel of the cavity wall, for the three materials placed in cavities etched for one minute were approximately 78 per cent (12 months' ageing) and 47 per cent (24 hours' storage) for Concise, 65 per cent and 39 per cent for Concise used in combination with Enamel Bond and 88 per
FIGURE 9.12

The influence of 12 months' ageing
on the microleakage

- Microleakage confined to the enamel
- Microleakage in enamel and dentine
24 hr. - Tested after 24 hours' storage
12 mths. - Tested after 12 months' ageing
1 min. - 1 minute etch of the enamel cavity wall
E.B. - Enamel Bond.
cent and 31 per cent for Estic composite resin. In each case, the difference between the microleakage after ageing for 12 months and after storage for 24 hours was statistically significant at the one per cent level of confidence.

9.72 The influence of thermal cycling on the microleakage was examined using restorations of Concise, Concise in combination with Enamel Bond and Estic placed in cavities etched for one minute and two minutes and by using Concise restorations placed in unetched cavities. The results for the thermal-cycled restorations were compared with the microleakage occurring around restorations that were stored for 24 hours before immersion in the dye and not subjected to thermal cycling. Statistical analysis of the results compared the ability to confine microleakage of the tracer dye to the enamel of the cavity wall.

The results are presented in Tables 9.1 to 9.4 and are illustrated in Figure 9.13. With two exceptions, restorations that were thermal-cycled showed significantly more microleakage than restorations stored for 24 hours and not subjected to thermal cycling before immersion in the dye. Fewer than eight per cent of the surfaces examined from restorations of Concise
FIGURE 9.13

The influence of thermal cycling on the microleakage

- Microleakage confined to the enamel
- Microleakage in enamel and dentine
1 min. - 1 minute etch of the enamel cavity wall
2 min. - 2 minute etch of the enamel cavity wall
24 hr. - Tested after 24 hours' storage
T.C. - Tested after thermal cycling
E.B. - Enamel Bond.
placed in unetched cavities showed microleakage confined to the enamel of the cavity wall after conditions of thermal cycling or storage for 24 hours; the difference was not significant, both procedures causing a high degree of microleakage.

Concise restorations placed in etched cavities showed significantly more microleakage after thermal cycling than after storage for 24 hours. In cavities etched for one minute, approximately 47 per cent of the examined surfaces showed microleakage confined to the enamel of the cavity wall after storage for 24 hours compared with approximately five per cent showing this degree of microleakage after thermal cycling; corresponding values in cavities etched for two minutes were approximately 91 per cent and nine per cent.

Microleakage occurring around restorations of Concise used in combination with Enamel Bond, after a one minute etch, was confined to the enamel cavity wall in approximately 39 per cent of the surfaces examined after storage for 24 hours and in approximately 18 per cent of the surfaces examined after thermal cycling; in cavities etched for two minutes, values were approximately 88 per cent and 47 per cent, respectively. In other words, in cavities etched for two minutes, the microleakage of the tracer dye extended beyond the enamel
part of the cavity wall and into the dentine in approximately 12 per cent of the surfaces examined after storage for 24 hours and in approximately 53 per cent of the surfaces examined after thermal cycling. For this material, in the case of each etching time, the difference in the microleakage between restorations stored for 24 hours and restorations subjected to thermal cycling, was significant.

Estic restorations placed in cavities etched for two minutes showed significantly greater microleakage when the restorations were thermal-cycled (approximately 59 per cent of the surfaces examined confined the tracer dye to the enamel of the cavity wall) than following storage of the restoration for 24 hours (approximately 88 per cent). When placed in cavities etched for one minute, however, the difference in microleakage, between Estic restorations thermal-cycled and those stored for 24 hours, was not significant at the one per cent level of confidence; approximately 25 per cent and 31 per cent, respectively, of the surfaces examined confined the microleakage of the tracer dye to the enamel of the cavity wall.
CHAPTER 10

RESULTS - B

AN INVESTIGATION OF ETCHED ENAMEL SURFACES AND THE ADAPTATION
OF COMPOSITE RESINS

10.1 Introduction

Using the method described (8.2), etched enamel tooth surfaces and resin negatives, prepared by adapting composite resin either to etched surfaces or to the surface of a metal slab containing machined grooves, were investigated by examining photomicrographs of:

(i) Transverse sections of teeth cut with a tungsten carbide bur (10.2).

(ii) Transverse and longitudinal sections of teeth etched for one, two and four minutes (10.3).

(iii) Bevelled cavo-surface angles of transverse sections of teeth etched for one and two minutes (10.4).

(iv) The enamel tooth surface, before and after the removal of approximately 0.3mm of enamel, etched for four minutes (10.5).

(v) Transverse sections of teeth showing prismless enamel, etched for one and two minutes (10.6).

(vi) Composite resin negatives of transverse sections etched for one and two minutes, using Concise, Estic and Concise with Enamel Bond (10.7).
Concise, Estic and Concise with Enamel Bond negatives of a metal slab containing machined grooves (10.8).

10.2 Transverse sections of teeth cut with a tungsten carbide bur

Photomicrographs taken of enamel, prepared with a tungsten carbide bur, show smearing, grinding marks and debris on the freshly cut surface after washing with a water spray and drying (Fig. 10.1, a and b). The cavo-surface angle produced with this type of bur varied. Most commonly, a clean, neat margin with an angle close to 90° (Fig. 10.1, c and d) was obtained; on occasions, the margin was chipped and untidy (Fig. 10.1, e and f).

10.3 Transverse and longitudinal sections of teeth etched for one, two and four minutes

The application of 37 per cent phosphoric acid to the enamel of transverse sections of premolar teeth and longitudinal sections of incisor teeth, for one, two or four minutes, resulted most commonly in the dissolution of the prism peripheries of enamel, leaving the prism cores exposed and relatively unaffected. Less frequently, the prism cores were preferentially dissolved, leaving raised prism peripheries surrounding the depressed prism cores. The difference in solubility of the prism components was, perhaps, caused by the varying angles in which the prisms had been sectioned during preparation before exposure.
Fig. 10.1. - a, Enamel cut with a tungsten carbide bur, x300.
b, Same area, x1000.  c, Neat cavo-surface angle, x300.
d, Same area, x1000.  e, Chipped cavo-surface angle, x300.
f, Same area, x1000.
to the acid. The predominant etching pattern on these "cavity wall" surfaces contrasted with the usual etching pattern described for the enamel of the tooth surface, where the prism cores are preferentially dissolved (3.31).

Fig. 10.2 and 10.3 show the banding effect seen in enamel, taken from a transverse section of a premolar and a longitudinal section of an incisor, respectively. This banding effect was commonly noticed near the dentino-enamel junction where the prisms were cut and etched in a direction nearly parallel to the prism axes and in a direction oblique to the axes. These photomicrographs show the predominant pattern of dissolution of the prism peripheries following a one minute etch; Fig. 10.2, b and c and Fig. 10.3, b and c show the enamel prisms running almost longitudinally; Fig. 10.2, d and e and Fig. 10.3, d and e, show the prisms in more oblique section. Other, less frequently observed patterns of prism periphery dissolution following a one minute etch are shown in Fig. 10.4 and 10.5. Fig. 10.4 shows an example of some dissolution of the prism cores in addition to the loss of the prism peripheries and Fig. 10.5 shows peripheral dissolution at a very oblique angle.

The somewhat less common pattern of selective dissolution of the prism cores is shown in Fig. 10.6 and 10.7. Fig. 10.6, a and b, show the typical keyhole shape of the enamel prisms
Fig. 10.2. - a, Transverse section through enamel, etched for one minute, x100.  b, Prisms longitudinally sectioned, x300.  c, Same area, x1000.  d, Prisms obliquely sectioned, x300.  e, Same area, x1000.
Fig. 10.3. - a, Longitudinal section through enamel, etched for two minutes, x100. b, Prisms longitudinally sectioned, x300. c, Same area, x1000. d, Prisms obliquely sectioned, x300. e, Same area, x1000.
Fig. 10.4.

a

b

Fig. 10.5.

a

b

Fig. 10.4. - a, Transverse section through enamel, etched for one minute, showing prisms longitudinally sectioned, x300.

b, Same area, x1000.

Fig. 10.5. - a, Transverse section through enamel, etched for one minute, showing prisms obliquely sectioned, x300.

b, Same area, x1000.
when they are sectioned at approximately 90° to their long axes; these photomicrographs show the raised prism border defining this shape. Fig. 10.7, a and b, show an area in which there was mainly prism core dissolution; the remaining prism peripheries were exposed at an oblique angle.

Phosphoric acid applications for two minutes in most cases produced a slightly more clearly defined etched pattern than that following a one minute application. Photomicrographs of transversely cut tooth enamel are shown in Fig. 10.8; Fig. 10.8, b and c, possibly show slightly wider and deeper spaces between adjacent prism cores, where the prism peripheries or "tails" have been dissolved. The overall width of the remaining prism cores (Fig. 10.8, c and e) appeared to be marginally narrower than those following a one minute etch (Fig. 10.2, c and e). Photomicrographs of a longitudinally sectioned tooth show the prisms running longitudinally (Fig. 10.9, b and c) and illustrates dissolution of the junctional region between the prism cores and prism peripheries instead of the prism periphery dissolution which would have been expected. Fig. 10.9, d and e which show the prisms obliquely sectioned, illustrates the predominant pattern of prism periphery dissolution, where the prism cores were left
Fig. 10.6.  

- a, Transverse section through enamel, etched for one minute, showing prisms sectioned at almost 90°, x300.  
  b, Same area, x1000. 

Fig. 10.7.  

- a, Transverse section through enamel, etched for one minute, showing prisms obliquely sectioned, x300.  
  b, Same area, x1000.
Fig. 10.8. – a, Transverse section through enamel, etched for two minutes, x100. b, Prisms longitudinally sectioned, x300. c, Same area, x1000. d, Prisms obliquely sectioned, x300. e, Same area, x1000.
Fig. 10.9. - a, Longitudinal section through enamel, etched for two minutes, x100.  b, Prisms longitudinally sectioned, x300.  
c, Same area, x1000.  d, Prisms obliquely sectioned, x300.  
e, Same area, x1000.
exposed. Other examples of this etching pattern, taken from
a transversely sectioned tooth, are shown in Fig. 10.10, 10.11
and 10.12, where the enamel prisms have been sectioned in varying
degrees of obliquity, resulting in slightly different shapes of
the exposed prism cores. Some areas, however, (Fig. 10.13, a
and b) show dissolution of the prism cores in addition to that
of the prism peripheries.

A third type of etching pattern, observed in a number of
specimens, appears as a generalised dissolution of the enamel,
creating a roughened, pitted appearance, often with no resemblance
to prism structure. Examples of this are shown in Fig. 10.14,
10.15 and 10.16; in each case, although some prism structure
can be identified, the manner of dissolution was quite unlike that
shown in the previous photomicrographs.

The application of acid for four minutes, to transverse and
longitudinal sections through the enamel, produced many different
patterns of etching. One type which occurred frequently is shown
in Fig. 10.17, where the prism peripheries have dissolved leaving
the prism cores clearly exposed; this was accompanied by a
patchy distribution of destruction where small areas of the
prism cores remained slightly raised, resembling small "islands".
Other specimens showed areas where the prism peripheries had
dissolved and the prism cores could be identified together with
Fig. 10.10.  a, Transverse section through enamel, etched for two minutes, showing prisms obliquely sectioned, x300.  b, Same area, x1000.

Fig. 10.11.  a, Transverse section through enamel, etched for two minutes, showing prisms obliquely sectioned, x300.  b, Same area, x1000.
Fig. 10.12. - a, Transverse sections through enamel, etched for two minutes, showing prisms obliquely sectioned, x300.
b, Same area, x1000.

Fig. 10.13. - a, Transverse section through enamel, etched for two minutes, showing prisms longitudinally sectioned, x300.
b, Same area, x1000.
Fig. 10.14.  - a, Transverse section through enamel, etched for one minute, x300.  b, Same area, x1000.

Fig. 10.15.  - a, Transverse section through enamel, etched for one minute, x300.  b, Same area, x1000.

Fig. 10.16.  - a, Transverse section through enamel, etched for two minutes, x300.  b, Same area, x1000.
Fig. 10.17.  - a, Transverse section through enamel, etched for four minutes, showing a raised "island", x100.  b, Same area, x300.  c, Same area, x1000.

Fig. 10.18.  - a, Transverse section through enamel, etched for four minutes, showing irregular destruction, x100.  b, Same area, x300.  c, Same area, x1000.
areas of greater destruction where the prisms may have fractured during preparation of the specimens (Fig. 10.18). Fig. 10.19 and 10.20 show additional examples of the destructive capacity of the four minute etch indicating the varied and irregular nature of the surface produced.

10.4 Bevelled cavo-surface angles of transverse sections of teeth etched for one and two minutes

Acid-etching a 45° bevel of the cavo-surface angle revealed two common etched patterns. In all cases, the transversely sectioned surface of the specimens shows preferential dissolution of the prism peripheries; the bevelled surface shows, predominantly, a loss of the prism cores (Fig. 10.21 and 10.22) and, less frequently, loss of the prism peripheries (Fig. 10.23). Fig. 10.21 and 10.22 compare the effects of a one and two minute etch on this surface. The two minute etch (Fig. 10.22) appears to show slightly deeper dissolution of the prism peripheries, of the transversely cut enamel and deeper prism core dissolution of the bevelled enamel, when compared to the one minute etched surface (Fig. 10.21). In Fig. 10.21, a, the right side of the photomicrograph, shows an area of enamel which illustrates inadequate etching, after an etching time of one minute.
Fig. 10.19.  

Fig. 10.19.  
- a, Transverse section through enamel, etched for four minutes, x300.  b, Same area, x1000.

Fig. 10.20.  
- a, Transverse section through enamel, etched for four minutes, x 300.  b, Same area, x1000.
Fig. 10.21.  
a, Bevelled cavo-surface angle placed on a transverse section, etched for one minute, x300.  b, Same area, x1000.

Fig. 10.22.  
a, Bevelled cavo-surface angle placed on a transverse section, etched for two minutes, x300.  b, Same area, x1000.

Fig. 10.23.  
a, Bevelled cavo-surface angle placed on a transverse section, etched for two minutes, x300.  b, Same area, x1000.
10.5 The enamel tooth surface and the enamel surface after the removal of 0.3mm of enamel, etched for four minutes

Application of the acid etchant to the enamel of the tooth surface for four minutes produced two etched patterns. The most frequently observed pattern, illustrated in Fig. 10.24, b, shows dissolution of the crystallites from the junctional region between the prism core and the prism periphery. The less commonly observed etched pattern (Fig. 10.24, c) shows rows of raised horse-shoe shaped prism peripheries, where the prism cores have been lost, but a substantial amount of the peripheries has been irregularly retained.

The enamel surface produced by the removal of approximately 0.3mm of enamel and etched for four minutes shows a pattern of dissolution of the prism cores and the junctional area between the adjacent prism peripheries, leaving the prism peripheries slightly raised and outlining the keyhole shape of the enamel prism (Fig. 10.25). The most obvious difference, between the etched enamel surface and the etched surface after the removal of 0.3mm of enamel, was the prism core dissolution of the sub-surface enamel, instead of only junctional dissolution.
Fig. 10.24. - a, Enamel surface etched for four minutes, x300.
b, Same area, showing junctional dissolution, x1000.
c, Same area, showing acid-resistant prism peripheries, x1000.
Fig. 10.25. - a, Enamel surface after the removal of 0.3mm of enamel, etched for four minutes, x300. b, Same area, x1000. c, Same area, x3000.
10.6 **Transverse sections of teeth showing prismless enamel etched for one and two minutes**

Photomicrographs of transverse sections through enamel, taken in the region of the cavo-surface angle, show the transition from etched prism peripheries, where the prism cores were exposed, to the featureless appearance of the prismless enamel nearer the cavo-surface angle (Fig. 10.26 and 10.27). The use of the two minute etch did not essentially alter the appearance of the prismless enamel, which showed almost none of the usual prism structure.

10.7 **Composite resin negatives of transverse sections etched for one and two minutes**

10.71 **Concise resin negatives**

Photomicrographs of the Concise resin negatives indicate the ability of the composite resin to penetrate into the etched micropores; most commonly the resin flows around undissolved prism cores and replaces the lost prism peripheries. Fig. 10.28 and 10.30 show the prisms longitudinally sectioned and Fig. 10.29 and 10.31 show the prisms obliquely sectioned; in all cases, the prism peripheries have been replaced. The two minute etched specimen of longitudinally sectioned prisms (Fig. 10.30), shows raised resin ridges, where the resin penetrated between and around the remaining prism cores, to appear slightly wider in the two minute specimen than in the one minute etched specimen.
Fig. 10.26.  

a  

b  

Fig. 10.27.  

a  

b  

Fig. 10.26.  -  a, Transverse section showing prismless enamel, etched for one minute, x300.  b, Same area, x1000.  

Fig. 10.27.  -  a, Transverse section showing prismless enamel, etched for two minutes, x300.  b, Same area, x1000.
Fig. 10.28.  

- a, Concise resin negative, from enamel etched for one minute, prisms longitudinally sectioned, x300.  
- b, Same area, x1000.

Fig. 10.29.  

- a, Concise resin negative, from enamel etched for one minute, prisms obliquely sectioned, x300.  
- b, Same area, x1000.
Fig. 10.30.  

a

b

Fig. 10.31.  

a

b

Fig. 10.30.  -  a, Concise resin negative, from enamel etched for two minutes, prisms longitudinally sectioned, x300.  

b, Same area, x1000.

Fig. 10.31.  -  a, Concise resin negative, from enamel etched for two minutes, prisms obliquely sectioned, x300.  

b, Same area, x1000.
(Fig. 10.28). The resin negative of the obliquely sectioned prisms (Fig. 10.31) shows a more regular etched pattern with deeper holes between the projecting resin ridges, in the two minute etched specimen, compared with the one minute etched specimen (Fig. 10.29); this is consistent with the prism peripheries having been etched to a greater depth, leaving longer exposed prism cores, which created the deeper holes in the resin negative.

10.72 Estic resin negatives

Photomicrographs of the Estic resin negatives indicate that it also flows easily to replace the dissolved prism peripheries. Fig. 10.32 and 10.34 show the negatives of longitudinally sectioned prisms after etching for one and two minutes, respectively. The two minute etched specimen (Fig. 10.34) shows the resin ridges separated by distinctly rounded grooves which previously contained the undissolved prism cores, indicating that the resin had flowed around the circumference of the prism cores to a greater extent than in the specimen that was etched for one minute (Fig. 10.32).

The two minute etched specimen also shows better reproduction of the surface detail, and longer, finer resin projections than is seen in either the one minute etched specimen or the Concise resin negatives.
Fig. 10.32.  

- a, Estic resin negative, from enamel etched for one minute, prisms longitudinally sectioned, x300. 
- b, Same area, x1000.

Fig. 10.33.  

- a, Estic resin negative, from enamel etched for one minute, prisms obliquely sectioned, x300. 
- b, Same area, x1000.
Fig. 10.34.  

a, Estic resin negative, from enamel etched for two minutes, prisms longitudinally sectioned, x300.  

b, Same area, x1000.

Fig. 10.35.  

a, Estic resin negative, from enamel etched for two minutes, prisms obliquely sectioned, x300.  

b, Same area, x1000.
Fig. 10.33 and 10.35 show resin negatives of prisms sectioned obliquely and etched for one and two minutes, respectively. The Estic resin negatives, from obliquely sectioned enamel, show the resin replacement of the prism peripheries at a different angle from that seen in the Concise resin negatives (Fig. 10.29 and 10.31). When compared with the one minute etched specimen (Fig. 10.33), the two minute etched specimen (Fig. 10.35) shows a thickening of the resin projections, accompanied by a narrowing of the holes between them - the holes having been previously occupied by the undissolved prism cores. It appears that the etchant dissolved the prism peripheries to an even depth. The two minute etch caused the dissolution of a greater amount of the prism peripheries than the one minute etch, both in depth, which resulted in longer resin projections, and in width, which created wider resin projections with adjacent narrowed holes.

10.73 Concise and Enamel Bond resin negatives

Photomicrographs of the resin negatives made with Concise and Enamel Bond show the most clearly defined structure and surface detail of the etched prism peripheries of the three materials. Longitudinally sectioned prisms are shown in
Fig. 10.36 and 10.38, etched for one and two minutes, respectively. The two minute etched specimen (Fig. 10.38) appears to show slightly longer, finer resin projections than are seen in the one minute etched specimen. Fig. 10.37 and 10.39 show the prisms obliquely sectioned, in a manner similar to the Concise resin negatives, and etched for one and two minutes, respectively. As noted previously (10.71 and 10.72), the two minute etch of the enamel allowed deeper penetration of the resin; Fig. 10.39 shows the long, fine protrusions not seen in the one minute etched specimen (Fig. 10.37) or the Concise resin negatives (Fig. 10.29 and 10.31).

All the materials examined were capable of reproducing the lost surface detail and structure dissolved by the acid etchants. Differences between these materials in their ability to flow and penetrate the enamel were not great; however, the Concise with Enamel Bond produced the longest, finest resin protrusions with the most clearly defined surface detail, whether applied to surfaces etched for one or two minutes.
Fig. 10.36. - a, Concise and Enamel Bond resin negative, from enamel etched for one minute, prisms longitudinally sectioned, x300. b, Same area, x1000.

Fig. 10.37. - a, Concise and Enamel Bond resin negative, from enamel etched for one minute, prisms obliquely sectioned, x300. b, Same area, x1000.
Fig. 10.38. – a, Concise and Enamel Bond resin negative, from enamel etched for two minutes, prisms longitudinally sectioned, x300. b, Same area, x1000.

Fig. 10.39. – a, Concise and Enamel Bond resin negative, from enamel etched for two minutes, prisms obliquely sectioned, x300. b, Same area, x1000.
10.8 Concise, Estic and Concise with Enamel Bond negatives of a metal slab containing machined grooves

The resin negatives obtained from the adaptation of Concise to the metal slab, revealed a surface incorporating many voids or air bubbles, especially on the height of the central ridge where only a small portion of the ridge was accurately recorded. Two examples are shown in Fig. 10.40.

The adaptation of Estic showed an improved reproduction of the ridge (Fig. 10.41); although voids were still present, they were generally smaller and less frequent than in the Concise negatives (Fig. 10.40).

The use of Enamel Bond with the Concise composite resin allowed the consistent reproduction of surface detail and sharpness of the ridge, with minimum of voids (Fig. 10.42, a and b).

These findings were consistent with those for the resin negatives obtained from etched enamel surfaces; in both cases, Concise with Enamel Bond generally gave evidence of the best adaptation and reproduction, with the finest detail. In contrast, the poorest reproduction of both structure and surface detail was found when Concise composite resin was used without the Enamel Bond.
Fig. 10.40.  - a and b. Two examples of Concise resin negatives of machined grooves, x50.

Fig. 10.41.  - a and b. Two examples of Estic resin negatives of machined grooves, x50.

Fig. 10.42.  - a and b. Two examples of Concise and Enamel Bond resin negatives of machined grooves, x50.
CHAPTER 11

DISCUSSION

11.1 Introduction

Marginal leakage has been a serious shortcoming of many of the restorative materials used in Dentistry; this study has confirmed the failure of composite resins to provide a complete seal against microleakage. It is possible that "a full appreciation of the importance of marginal seal can only be achieved when marginal leakage has been eliminated" (Buonocore, 1975). Scanning electron photomicrographs, however, have shown the potential for composite resins to adapt to etched surfaces. Microleakage, when it occurs, therefore, may result from one, or a combination of factors, such as, faulty cavity preparation, the provision of an unsuitable etched pattern, less than optimal adaptation of the composite resin to the etched cavity walls, early finishing of the restoration or dimensional changes of the composite resin.

11.2 Discussion of the experimental method

All composite resin restorations examined in the microleakage study were placed in Class V box-type cavities, with a cavo-surface angle of approximately 90 degrees,
creating a butt joint between the enamel wall and the composite restoration. Although other cavity forms, such as a bevelled cavo-surface angle or a feather-edged finish of resin beyond the cavity margin (6.41), have merit, it was decided, because of the need to limit the extent of this study, to investigate microleakage in one type of prepared cavity only — the box-type of cavity was considered to have the widest clinical application.

11.21 Preparation and restoration of the Class V type cavities involved the preparation of a cavo-surface angle of 90 degrees and the elimination of all excess composite resin beyond this finishing line. Microscopic evaluation of the sectioned surfaces, however, on occasions, revealed depressions or notches at the cavo-surface angle, most probably caused by the shattering effect of the high speed tungsten carbide bur during cavity preparation. In the light of research into the finishing of cavity margins (Boyde, 1976; Lester, 1978), tungsten carbide burs used at high speed have been shown to produce the best marginal finish.

The depressions or notches at the cavo-surface angle, formed during the cavity preparation, later became filled with composite resin, creating occasional bevelled and feather-edged
finishes which were not detected when the margins were explored with a fine probe; this problem was also reported by Buonocore (1975).

11.22 The use of hand instruments was omitted from this study after consideration of reports by Boyde (1976) and Lester (1978) of their limited effectiveness. Boyde (1976) remarked that hand instruments "cut" enamel by propagating fractures which resulted in the removal of substantial amounts of enamel and created plastic deformation of the tissue under the blade, causing the enamel surface to smear, regardless of the sharpness of the hand instrument. It has been recommended that, clinically, the use of hand instruments at cavity margins should be limited to a light scraping action to assist the removal of fractured enamel and should be confined to those margins inaccessible to rotating instruments (Lester, 1978).

11.23 The advantages derived from delaying the final finishing of the composite resin restorations for at least 24 hours following setting have been discussed (6.42). However, in this study all restorations were finished approximately fifteen minutes after the composite resin had set. This particular method was adopted because it was considered that, currently, the majority of practitioners finish their composite
restorations immediately, rather than at a subsequent appointment. According to Buonocore (1975), a truly butt-jointed restoration that was well adapted at the cavity margins was seldom obtained in practice because, in attempting to remove immediately all the overlapping restorative material peripheral to the margin, the edges of the enamel or the restoration became chipped or fractured. For this reason, it has been suggested by many authors (6.42) that the majority of finishing should be delayed for at least 24 hours, in order to permit water absorption, which begins four to six hours after the insertion of the restoration, to close marginal gaps, reduce stresses in the region of the etched enamel-resin interface and to support the enamel margin during finishing.

11.24 Initial evaluation of the microleakage of the sectioned teeth used a system of assigning numbers in the range 0 to 4, that was related to the depth of penetration of the dye (7.2). Each sectioned surface was examined and designated a number on two different occasions. A comparison of the two sets of readings revealed a low rate of disagreement; as a result, the method of evaluation was considered to be reliable.

In the context of this investigation, interest was centred on the ability of the material to confine the microleakage to the enamel, where significant etched
mechanical retention could be achieved. It therefore seemed appropriate to divide the results into two groups, those exhibiting microleakage confined to the enamel (grades 0 and 1) and those where the microleakage extended beyond the enamel into dentine (grades 2, 3 and 4); this was similar to the classification used by Speiser and Kahn (1977). Because of this, factors influencing the extension of microleakage within dentine were not considered. This method of dividing the results into two groups did not conflict with the results from the two evaluations, which showed the majority of disagreements (55 per cent) to lie between grades 0 and 1 and few (15 per cent) to lie between grades 1 and 2.

Clinical sequelae of microleakage at the enamel cavity margin, including marginal staining and eventual caries are slight compared with the potential for relatively rapid irritation and damage associated with leakage beyond the enamel and onto the dentine cavity wall; microleakage into dentine may result in pulp pathology, sensitivity to stimuli and more rapid caries. The dangers associated with leakage onto the dentine surface could be substantially reduced by the use of a material which had the capacity to bond with dentine; in this regard, the future development and use of glass ionomer cements, which bond chemically with both enamel
and dentine, may be of significant clinical benefit. Currently, however, emphasis is given to maximizing retention of the composite resin to the etched enamel as a means of eliminating or reducing the marginal leakage.

11.25 As previously observed (7.2), all the surfaces exhibiting microleakage showed leakage at the gingival margin, very few surfaces showed microleakage also at the occlusal margin. Similar results were found by Going et al (1960) in their study of marginal leakage around amalgam restorations and by Tani and Buonocore (1969), Al-Hamadani and Crabb (1975), Kopel et al (1975) and Hembree and Andrews (1978) who investigated leakage around composite resins; it was regularly observed that the leakage of dyes and isotopes was greater at the gingival margin than at the occlusal or incisal margins. This increase in microleakage at the gingival margin might have been due to several factors, including the possible presence of prismless enamel in this region, the thinner bulk of enamel which made less enamel available for bonding, and the unpredictable etched patterns obtained in the cervical region.
Photomicrographs of prismless enamel, presented in the results (10.6), indicated little, or no, regular prism structure after etching because of the unidirectional crystallite orientation and the dense packing of the crystallites; this structure offers an unfavourable surface for the bonding of resins. Microleakage and scanning electron microscope findings from this study were in agreement with those of Sheykholeslam and Buonocore (1972), Gwinnett (1973, b), Buonocore (1975), Eriksen and Buonocore (1976, a) and Fuks et al (1977). Buonocore (1975) stated that "if the strength of the bond is a function of the depth of adhesive penetration into enamel, then a weaker attachment might be anticipated where 'prismless' enamel exists". The presence of prismless enamel is of clinical significance in that it has been shown to occur in the gingival one-third of a high percentage of permanent teeth (3.6). In this position it could influence successful sealing at the gingival margins of Class III and V composite restorations. It is not possible, however, to gauge clinically the thickness of the prismless layer and attempts to remove it, by grinding, bevelling or prolonging the etch time are contraindicated (Gwinnett, 1973, b).
11.3 Discussion of the tests involved in the microleakage study

The experimental techniques used in the microleakage study ranged in severity from a relatively mild test, 12 months' ageing at 37°C before immersion in the dye, to the far more severe test, thermal cycling for 100 cycles between 4°C and 60°C with an immersion time of 30 seconds at each temperature.

Potentially, 12 months' ageing at a constant temperature allowed the composite restorations to absorb water and expand against the cavity margins, thereby creating an improved marginal seal. After 12 months' ageing, each type of restoration, that is, Concise placed in an etched cavity, Concise, Estic and Concise with Enamel Bond placed in one minute etched cavities, showed significantly less microleakage than comparable restorations tested after storage for 24 hours (Fig. 9.12). This finding tended to support evidence for the role of water absorption in minimizing the microleakage around composite resin restorations. In the summary of the microleakage findings shown in Table 9.6, it may be seen that the results after 12 months' ageing are found in the upper part of the table; this indicated that, in a relatively high proportion of the surfaces examined, the microleakage was confined to the enamel. This finding, potentially important from a clinical
point of view, might be related either to problems associated 
with the preparation of the cavity and etching of the gingival 
cavity wall, to the effects of early finishing or to the 
characteristics of the composite resin itself.

Restorations examined after storage for 24 hours allowed 
inadequate time for optimum water absorption to take place. 
It is probable that microleakage results from these restorations 
tended to emphasize problems common to all the restorations, 
namely, the polymerization contraction of composite resins and 
the early finishing of the restorations. In particular, the 
results of this test confirmed the importance of etching the 
enamel cavity walls as a means of improving the initial seal 
(Fig. 9.4).

The thermal cycling test carried out in this study used 
the temperature range of 4°C to 60°C; in previous research 
(Nelson et al, 1952; Going and Sawinski, 1966; Baharloo and 
Moore, 1974; Kopel et al, 1975; Rafei and Moore, 1975; 
Hembree and Andrews, 1976 and 1978; Eriksen and Buonocore, 
1976, a and b; Eliasson and Hill, 1977; Kidd et al, 1978) 
specimens were cycled at temperatures separated by a minimum 
of 50°C within the range of 0°C to 68°C. The values for the 
temperature range and cycling times used in this study were
based on a compromise of the testing regimens of other workers. The thermal cycling technique was a relatively severe test, because first, the restorations were cycled only thirty minutes after setting of the composite resin. This allowed no time for water absorption to expand the restorations against the cavity walls, in order to improve the adaptation or to relieve the stresses caused by polymerisation contraction. Secondly, the temperature range of 4°C to 60°C was greater than that to which restorations might frequently be exposed in the mouth; it has been suggested that more realistic temperature limits, in vivo, are 15°C and 45°C (Asmussen and Jorgensen, 1978). Thirdly, the restorations in this experiment were immersed in baths maintained at each temperature for 30 seconds; this was undoubtedly longer than these temperatures could be tolerated in vivo, where exposure to temperatures of 4°C or 60°C would be limited to a few seconds. In Table 9.6, the results for thermal-cycled restorations appear in the lower part of the table, reflecting the relatively low proportion of surfaces with microleakage confined to the enamel. However, in contrast with the 12 months' ageing test, which showed the sealing ability of all the materials to be fairly uniform, the thermal cycling test, because of its severity, was able to distinguish between
different materials and different etch times. Statistical analysis confirmed that under these stressful conditions, Concise with Enamel Bond and Estic, placed in cavities etched for two minutes, provided the best marginal seal (Fig. 9.13).

The 12 months' ageing and thermal cycling tests used in this study cannot be considered directly applicable to in vivo conditions; a more clinically oriented test might involve thermal cycling, within a less severe temperature range, in association with ageing. Under these conditions it is probable that the microleakage results obtained would be less extreme than those found in this study following 12 months' ageing or thermal cycling.

11.4 Discussion of the S.E.M. investigation of etched enamel

11.4.1 The unetched enamel cavity wall

Scanning electron photomicrographs of the prepared, unetched surface of an enamel cavity wall, showed smearing of the enamel and the accumulation of debris (Fig. 10.1, a and b), which were features also noted by Provenza and Sardana (1966), Eick et al (1970), Boyde (1976), Evans and Kasloff (1976) and Barnes (1977, d). The presence of the smearing and debris would have effectively prevented close adaptation of a composite resin applied to the prepared enamel surface of a cavity wall and would have presented a surface unsuitable for mechanical
bonding, because of the lack of microspaces into which the resin could flow. In addition, in the absence of acid-etching, the presence of a film of debris at the resin/tooth interface could enhance the onset of marginal leakage and, following dissolution of the film, result in microleakage around the restoration.

The photomicrographs also showed the finish of the cavo-surface angle ranging from the most commonly seen "neat enamel margin" (Fig. 10.1, c and d), as described by Boyde (1976), to a damaged margin, with the loss of segments of enamel and fractured prisms (Fig. 10.1, e and f), which would have caused a feather-edging of the composite resin beyond the cavo-surface angle during restoration of the cavity.

11.42 The etched tooth surface

The etched tooth surface was examined to illustrate differences in the etched patterns produced when acid etchant was applied to this surface and to the prepared enamel of the cavity wall (11.44).

The study of the etched tooth surface was divided into two sections, first, the etched natural tooth surface and, secondly, the etched sub-surface enamel, which involved the removal of approximately 0.3mm of surface enamel prior to etching; this sub-surface enamel was examined in order to provide more distinct information on the effect of etching enamel prisms.
On the tooth surface, a four minute etch was required before it was possible to show a consistent etched pattern (Fig. 10.24), because the enamel of the tooth surface is much less affected by etching agents than deeper, cut enamel (Poole and Johnson, 1967) due to the presence of salivary proteins and plaque and an organic and fluoride rich layer in the surface enamel.

Etching the enamel of the natural tooth surface showed preferential dissolution of the zone between the prism cores and prism peripheries, leaving these structures slightly raised and delineating the key-hole shape of interlocking enamel prisms (Fig. 10.24, b); this appearance was in agreement with photomicrographs published by Nichol et al (1973), Jorgensen (1975) and Retief (1975, c). This pattern of etching (Fig. 10.24, b) was found covering the perikymata or grooves on the enamel surface which resulted from the emergence of the striae of Retzius. These areas (Fig. 10.24, b) were interspersed with bands or ridges (Fig. 10.24, a) known as the imbrication lines of Pickerill, which are surface extensions of the striae; because the imbrication lines were raised, they were etched to a greater extent than the grooves (Retief, 1975, a) and in photomicrographs (Fig. 10.24, c) were seen as prominent,
acid-resistant, horse-shoe shaped prism peripheries.

Photomicrographs of the etched sub-surface preparation, showed both dissolution of the crystallites from the zone between adjacent prism peripheries and dissolution of the prism cores. The remaining raised prism peripheries defined the key-hole shape of the enamel prisms and created the classical honeycomb pattern of an enamel surface cut transverse to the prism direction, then etched parallel with the long axes of the prisms (Fig. 10.25) as described by Sharpe (1967), Poole and Johnson (1967), Johnson (1971), Scott et al (1974), Buonocore (1975), Hals and Laegreid (1976) and Tyler (1976).

11.43 The variation in etched patterns

The pattern of etched enamel has been shown by many workers including Sharpe (1967), Poole and Johnson (1967), Nygaard and Simmelink (1972) and Gwinnett (1972, a) to be related to the direction of the prisms and the orientation of the crystallites to the acid attack. As previously described (11.42), when the acid attack was parallel to the long axes of the prisms, such as in the sub-surface layer of enamel, the prism cores dissolved most rapidly, creating an etched pattern that was classified by Silverstone et al (1975) as type 1 (Fig. 10.25). However, when the acid attack was perpendicular to the long axes of the prisms, which occurred frequently on the enamel cavity wall, the tails
or prism peripheries were preferentially dissolved and a type 2 etched pattern was produced (Fig. 10.2). The third type of etched pattern has been described as a generalised dissolution with random pitting (Fig. 10.24) (Buonocore, 1975; Silverstone et al, 1975).

Crystallite orientation relative to the direction of acid attack is not the only factor involved in the differential dissolution of enamel. There are other natural tendencies for variation, unrelated to crystallite orientation, which were described by Smith (1980) as being due to variations in the local composition of enamel. These variations are quite common because many workers (Gwinnett, 1971; Gwinnett et al, 1972; Sheykholeslam and Buonocore, 1972; Buonocore, 1973 and 1975; Jorgensen, 1975, a; Silverstone, 1975; Silverstone et al, 1975; Ferreira, 1976; Brannstrom and Nordenvall, 1972) have reported a considerable variation in the etched pattern obtained from enamel surfaces. The variation in etching produced by an acid on the enamel of the cavity wall indicates that clinically it is often impossible to predict the type of etched pattern obtained or its suitability for bonding.

Commonly, types 1 and 2, and sometimes type 3, etched patterns were produced, in this study, on the same enamel surface by the one acid solution. This conflicted with the claims of
Poole and Johnson (1967) and Johnson et al (1971), that the type 1 etched pattern was the result of acid action and the type 2 pattern was the result of the action of chelators. Etched enamel surfaces which showed more than one type of etched pattern were occasionally seen during this study (Fig. 3.2) and, in agreement with the findings of Jorgensen (1975, a), it was also noticed that different teeth and different portions of the same tooth exhibited different patterns of dissolution. However, the majority of the etched surfaces examined, produced patterns of dissolution which could be attributed to the direction of the prisms and the orientation of the crystallites to the direction of acid attack. This was exemplified in Fig. 10.21 and 10.22, which showed photomicrographs of a bevelled cavo-surface angle placed on a transverse section through enamel. In these photomicrographs the longitudinally sectioned prisms exhibited prism periphery dissolution and the nearly transversely sectioned prisms of the bevel region exhibited, in most cases, the prism core dissolution that is considered clinically preferable because it offers greater retention.
11.44 The etched enamel cavity wall

Enamel surfaces prepared from transverse and longitudinal sections through tooth enamel, etched for one or two minutes, showed varied patterns of etching. This was related to the exposure of the enamel prisms in a variety of planes resulting from the wavy and bending course of the prisms from the dentino-enamel junction to the enamel surface (Fig. 10.8). Where the prisms were sectioned running longitudinally or obliquely, they were etched perpendicularly to their long axes, which produced mainly prism periphery dissolution, and left the prism cores as a series of ridges separated by grooves (Fig. 10.8, b and c) or obliquely projecting prism cores (Fig. 10.10); these findings were consistent with those of Sharpe (1967), Poole and Johnson (1967), Gwinnett (1973) and Crawford and Whittaker (1977). Those areas where the prisms were sectioned transversely to the prism direction and then etched parallel with the long axes of the prisms most frequently produced a pattern of prism core dissolution and left the prism peripheries raised and intact which created the honeycomb pattern (Fig. 10.6); these results were in agreement with those of Sharpe (1967), Poole and Johnson (1967) and Johnson et al (1971).
It was suggested (Ibsen and Neville, 1974; Buonocore, 1975; Hals and Laegreid, 1976; Eriksen and Buonocore, 1976, a; Speiser and Kahn, 1977) that the etched pattern found on the enamel cavity wall and previously described as a series of ridges and grooves, was associated with possibly inferior adaptation and greater microleakage of composite resins bonded to longitudinally cut and etched enamel prisms, compared with the possibly deeper resin penetration and superior retention resulting in reduced microleakage from transversely cut and etched prisms.

11.5 General discussion of the microleakage and S.E.M. results

11.51 The effect of etching

Under the conditions of this study, microleakage was not completely eliminated by any of the materials or techniques that were investigated. This may have been the fault of any one, or more, of a number of factors, including, the cavity preparation, the etched pattern produced, the early restoration finishing time or characteristics of the particular composite resin material. However, the results were consistent with the observations of Rafei and Moore (1975), Dogon (1975), Oritz et al (1976), Hembree and Andrews (1976, b and c) and Elliasson and Hill (1977) who found that etching the walls of intracoronal cavities prior to the placement of resins reduced the microleakage.
The results conflicted with the findings of Retief (1973, b) who claimed that etching eliminated microleakage, Buonocore et al (1973), Baharloo and Moore (1974), Eriksen and Buonocore (1976, a) and Luscher et al (1977), who found no improvement in marginal sealing with etching, and Speiser and Kahn (1977) who found that acid-etching significantly increased the microleakage.

Results from this study found that etching the enamel cavity wall for one or two minutes, prior to the placement of Concise composite resin, significantly improved the marginal seal around the restorations tested after 24 hours' storage, compared with the seal around restorations placed in unetched cavities. There was little difference in the results of the restorations tested after 12 months' ageing, where all the surfaces showed a moderate marginal sealing capacity, or after thermal cycling, where all the surfaces showed a poor sealing ability (Fig. 9.4). The Concise restorations, however, were found to show greater microleakage than those restored with Estic or Concise with Enamel Bond placed in cavities etched for one or two minutes and tested after thermal cycling (Fig. 9.13). Therefore, to derive the maximum benefit from etching, Concise should be used with Enamel Bond; when used
in this way, etching the cavity wall significantly reduces the microleakage under the stresses of thermal cycling. Photomicrographs of one and two minute etched cavity walls showed the removal of the smearing and debris, previously seen on the cut enamel surface, in agreement with the findings of Barnes (1977, d), and showed dissolution of the prism components producing a surface suitable for bonding (Fig. 10.1 and 10.2).

11.52 The duration of etching

This study found that, in general, a two minute etch more successfully confined microleakage to the enamel cavity wall than a one minute etch (Fig. 9.5 and 9.6).

Results summarized in Table 9.6 showed that, of the restorations stored for 24 hours, those etched for two minutes occupied the upper part of the table, where a greater proportion of the surfaces had microleakage confined to the enamel; the one minute etched specimens were found somewhat lower in the table. The significance of this observation was confirmed by statistical analysis (9.51). These results indicated that the initial problems of inadequate sealing during the first 24 hours, probably associated with polymerisation contraction, incomplete water absorption and microscopic fracture of the enamel stressed during early finishing, may have been reduced by etching the enamel cavity wall for two minutes.
Photomicrographs of enamel cavity walls etched for two minutes (Fig. 10.8) showed a slightly greater overall dissolution, with larger spaces appearing between prism cores where the peripheries had been dissolved, compared with photomicrographs of one minute etched walls (Fig. 10.2). The difference in the depth of dissolution of prism components, between the one and two minute etched surfaces, was also clearly demonstrated in the photomicrographs of the composite resin negatives. The materials had reproduced the etched enamel prisms in different planes of section and, as a result, slightly different patterns were shown. However, broad comparisons illustrated that resin negatives of etched longitudinally and obliquely sectioned prisms showed longer, finer extensions of resin, after two minutes' etching than after one minute's etching (Fig. 10.30, 10.34, 10.38 and 10.39). Prisms sectioned more transversely showed wider, thicker resin extensions into spaces between the remaining prism cores following two minutes' etching (Fig. 10.31 and 10.35).

On the basis of this evidence, it is reasonable to conclude that a two minute etching time produced a more predictably etched surface, that allowed more uniform, deeper resin penetration, thereby increasing the resistance
to microleakage that might result from thermal and mechanical stresses.

There have been no studies, to date, in the available literature that have compared the effects of one and two minute etching times on the degree of microleakage or the adaptation of composite resins. The majority of microleakage studies carried out have used a one minute etching time. The comments of Dennison and Craig (1978), based on scanning electron microscopy and surface profile tracings, that optimum etched patterns were obtained by exposure of the enamel to 37 per cent phosphoric acid for one minute, were not supported by the results of this study.

Photomicrographs of one and two minute etched enamel surfaces compared with those etched for four minutes, illustrated the destructive capacity of excessive etching (Fig. 10.8, 10.12 and 10.18). After four minutes' etching, some areas showed prism periphery dissolution accompanied by a generalised dissolution of enamel, leaving small raised "islands", and other areas showed fracturing of remaining prism cores. On this evidence, the surface presented after four minutes' etching would be extremely porous, with many sites available for resin bonding. However, the application, at this surface of mechanical or thermal stress associated
either with the placement of the composite resin, or with polymerisation contractions during setting, or with different dimensional changes in the tooth and resin from thermal stimuli, would almost inevitably result in the collapse of some of the remaining prisms because of their fragility.

11.53 The influence of filler particle size

Although there was only a small difference between the particle size of the two materials investigated—Concise and Estic (Fig. 9.7), there was a marked difference in their performance following thermal cycling, where considerably less microleakage occurred around Estic restorations than Concise restorations after placement in cavities etched for two minutes (Fig. 9.9). It required the quite severe thermal cycling test to illustrate the difference in adaptation between the two materials that the other tests, 24 hours' storage and 12 months' ageing, could not detect.

Photomicrographs demonstrating the adaptation of these two materials to etched enamel (Fig. 10.28 to 10.35), indicated that each was capable of flowing into the etched micropores and creating an accurate negative of the surface; the Estic, however, reproduced the structure and fine surface details more precisely than the Concise.
The difference in the ability of these composite resins to adapt to the etched surface may, in fact, relate not only to the particle size but also to the viscosity and the availability of the resinous components. The smaller particle size of Estic possibly permitted a tighter packing arrangement of the particles, thereby making more of the resin component available during bonding when the monomer phase of the composite resin was sucked, by capillary action, into the etched micropores (Smith, 1980). Results from this study were consistent with the findings from studies by Jorgensen and Shimokobe (1975), McLundie and Messer (1975), Jorgensen (1975, b), Qvist et al (1977) and Brannstrom and Nordenvall (1977) who showed the ability of Concise to flow and reproduce the etched enamel. However, there are no studies in the current literature which have either assessed the adaptation of Estic composite resin or compared the microleakage occurring around restorations placed using composite resins of different particle size.

11.54 The influence of resin viscosity

Controversy has surrounded the need for, and effectiveness of, an intermediary resin of low viscosity to penetrate the acid-etched surface prior to the placement of the composite resin. Studies by numerous workers (Rafei and Moore, 1975; Dogon, 1975; Galan et al, 1975; Hembree and Andrews, 1976, c; Elliiasson and
Hill, 1977; Qvist and Qvist, 1977) have shown that acid-etching of the enamel cavity walls followed by the application of an unfilled resin, before placement of the composite resin, significantly reduced the microleakage. These findings were supported by the results of this study in which the sealing abilities of Concise and Concise with Enamel Bond were compared. It was demonstrated that those restorations in which the Enamel Bond was used showed less microleakage. However, this superiority was only evident after the restorations were subjected to thermal cycling — the most severe test used (Fig. 9.11); immersion in dye after 24 hours' storage and 12 months' ageing showed little difference in the sealing abilities of the two materials.

It would be logical to assume that the low viscosity resin would flow more easily into the microspaces; this was supported by the photomicrographs (Fig. 10.28 to 10.31 and 10.36 to 10.39) which compared the adaptation of Concise with and without the Enamel Bond. When the Enamel Bond was used, longer, finer protrusions of resin into the most deeply etched areas were observed together with an accurate reproduction of the surface detail. The findings were in agreement with those of Buonocore (1968), McLundie and Messer (1975) and Dogon (1975 and 1976) who suggested that longer tag lengths and better surface penetration
would be found with a resin of low viscosity.

Although the use of a low viscosity resin has been shown to be advantageous in improving the adaptation of the composite resin and in limiting the microleakage, it was recommended that only small amounts of this resin should be applied; it has been described as the weakest point in the acid-etch system because of the differences in the physical properties of the filled and unfilled resins (Jacobsen, 1975; Low and von Fraunhofer, 1976; Luscher et al, 1977).

It was suggested (Smith, 1980) that the improved adaptation of the low viscosity resin compared with the composite resin could be explained by the setting reaction. Once the composite resin was mixed, the setting reaction began and the viscosity of the material increased; the low viscosity resin, however, remained fluid after the completion of mixing and was capable of wetting the enamel surface and spreading more easily than the composite resin.

11.55 Adaptation of the materials to a metal surface

The use of the etched tooth surface, to compare the ability of the different materials to adapt, provided a difficult method of assessment, because of the variability of the etched enamel surface. To assess the reliability of these findings, the composite resin materials were adapted to a metal slab containing
machined grooves ranging in size from 25 to 300 micrometres. The photomicrographs of the resin negatives of this surface (Fig. 10.40 to 10.42) showed Concise with Enamel Bond most accurately to record the sharp base of the grooves, whereas, Concise alone, was least able to record the detail or sharpness (Fig. 10.40). These results were consistent with those of the resin negatives from etched tooth enamel and with the findings of the microleakage study.

11.56 The influence of ageing

It was noted that very few studies have investigated the effects on the microleakage of ageing restorations for periods greater than one week prior to testing (6.43). The results of this study supported those of Hembree and Andrews (1976, a, b and c), who indicated that marginal leakage after six months' and one year's ageing was significantly reduced or eliminated around those restorations where the enamel had been etched and coated with an unfilled resin before restoration of the cavity with the composite resin. In this study the microleakage was significantly reduced after ageing, not only for the Concise restorations placed with Enamel Bond, but also for restorations placed in unetched cavities and for Concise and Estic restorations placed in one minute etched cavities (Fig. 9.12).
The results showed that there was significantly less microleakage around these restorations after 12 months' ageing than after 24 hours' storage. The observed reduction after 12 months' ageing was consistent with the role of water absorption in tending to reduce microleakage.

11.57 The influence of thermal cycling

The results of this study indicated that thermal cycling of finished restorations caused an increase in the microleakage around all the materials when compared with restorations stored for 24 hours at a constant temperature before testing. Comparable results have been found by Tani and Buonocore (1969), Oritz et al (1976 and 1979) and Eriksen and Buonocore (1976, a) using similar experimental procedures. These results differed from those of Buonocore et al (1973) who used a cavity design which involved the feather-edging of an unfilled layer onto the surface enamel adjacent to the cavity and those of Elliasson and Hill (1977) and Kidd et al (1978) who stored their specimens for one month and one week, respectively, before thermal cycling. It is likely that, in a similar manner to ageing, the effect of storage prior to thermal cycling enabled water absorption to reduce subsequent microleakage by improving adaptation and reducing stress at the resin-tooth surface.
Findings from this study also indicated that a two minute etch produced less microleakage after thermal cycling than a one minute etch (Fig. 9.13). This finding was significant for restorations placed using Concise with Enamel Bond and Estic; both one and two minute etched Concise restorations showed marked microleakage. These results suggest that materials of lower viscosity and/or smaller particle size achieve and maintain adaptation, under the more severe conditions imposed during thermal cycling, more successfully than a more viscous or larger particle size material.
CONCLUSIONS

A review of the previous laboratory studies indicated that acid-etching the enamel cavity walls, prior to restoration of the cavity, was a successful method of reducing or eliminating the microleakage that occurred around composite resin restorations. It was noted, however, that relatively little attention had been paid to the influence, on the microleakage, of different etching times, different filler particle sizes and to the effects of ageing the restorations for a period of twelve months. It was also observed that there was some controversy concerning the effectiveness of low viscosity resins in assisting to improve adaptation and retention and to reduce microleakage.

This investigation examined the nature of the etched enamel cavity wall, alternative enamel surfaces available for the retention of composite resins, the ability of composite resins to adapt to these surfaces and the microleakage occurring, \textit{in vitro}, at the margins of composite resin restorations.

It was found that, under the conditions of this study, microleakage was not completely eliminated by any of the experimental materials or techniques. This may have been attributable to the preparation of the cavity (in particular the cavo-surface angle), the quality of the etched surface available for adaptation, problems associated with etching
the enamel of the cervical region and prismless enamel, intrinsic characteristics of composite resins influencing their ability to adapt to etched surfaces, procedures associated with the finishing of composite resins and the nature of the tests used to examine the microleakage.

Problems of some clinical importance that were not specifically examined in this study were, the type of cavo-surface angle preparation, instrumentation alternatives and the time of finishing of the composite restorations. Although many authors (6.41) have recommended the placement of a bevel at the cavo-surface angle, the composite restorations tested in this investigation were all placed in cavities prepared with a cavo-surface angle of approximately 90 degrees. It was considered that this preparation had the widest clinical application; despite its several undoubted advantages, the placement of a bevel at the entire margin of all cavities for etched composite resin restorations was considered both to be impractical and imprecise and, until the long-term benefits of acid-etching have been established, to lack adequate conservation of outline form. To approach more closely the clinical habits of most dental practitioners, the restorations examined in this study were finished fifteen minutes after the
composite had set; the advantages of delayed finishing have, however, been acknowledged (6.42).

Consistent with the findings of other research, the results indicated a pronounced tendency for microleakage to occur at the gingival margin; this may have been associated with the thinner bulk of enamel and the unpredictable etched patterns obtained in the cervical region or with the presence of prismless enamel which, upon etching, was found to produce uniform dissolution and limited random porosity creating an unfavourable surface for the bonding of resins. Clinically, it could be anticipated that the difficulties frequently experienced, either in preparing adequately the cavo-surface angle of some cavities or in finishing the final restoration in this region, would encourage failure at the gingival margin.

The results of this study confirmed that etching the enamel cavity walls, prior to the placement of the restoration, reduced microleakage when compared with restorations placed in unetched cavities.

The etched patterns observed in the S.E.M. investigation were frequently varied and unpredictable. This may have been related to the direction of the enamel prisms and the orientation of the crystallites to the acid-etchant, the wavy and bending course of the enamel prisms from the dentino-enamel junction.
to the enamel surface, the presence of prismless enamel and the local variations in composition of the enamel; of these alternatives, prism direction and crystallite orientation have been considered to exert the major influence.

The predominant etched pattern of the enamel cavity wall involved dissolution of the enamel prism peripheries, leaving the prism cores raised and exposed. This commonly produced a pattern of ridges and grooves which was considered (ll.44) to offer an inferior surface for the retention of resins compared with the surface produced by etching transversely cut prisms.

Both the scanning electron photomicrographs and the microleakage results indicated that the two minute application of acid to enamel produced a more consistently and more reliably etched surface than that obtained from the one minute etch that is commonly preferred for use in dental practice. The destructive effects of excessive etching (for example, four minutes' etching) were well demonstrated.

A composite resin of smaller filler particle size (Estic) adapted more intimately to the etched surface structure and showed less microleakage around the restorations than the larger particle size, Concise composite resin. However, the
superiority of the Estic might relate not only to the particle size but also to the viscosity of the resin component. When used with a lower viscosity, unfilled resin (as recommended), the Concise composite resin was more than comparable with the Estic in its ability both to adapt to the etched surface and to reduce the microleakage around the restorations. Although an investigation of further materials would be desirable, this limited study suggested that, when an unfilled resin has been supplied by a manufacturer (for example, in the Concise/Enamel Bond system), it should be used and that when such a resin has not been supplied (for example, in the Estic system), it is probably not necessary.

The finding, that there was less microleakage around composite restorations aged for twelve months, compared with those tested at twenty-four hours, tended to support the proposal relating to the influence of water absorption on the marginal seal.

Restorations that had been thermal-cycled, by the rather severe test used in this study, consistently showed a relatively high level of microleakage. The results obtained from the thermal-cycled restorations, however, suggested that materials of lower viscosity and/or smaller particle size achieved and maintained adaptation, during thermal cycling, more successfully than a more viscous or larger particle size material.
SUMMARY

This investigation has confirmed the potential ability of composite resins to adapt initially to etched enamel; theoretically, therefore, the use of composite resins with the acid-etch technique should be capable of preventing microleakage. The finding that a less than optimum seal was usually achieved may have been attributable to one, or more, of the factors examined in this study; these included the nature of the enamel surface to which the composite resins were adapted which was influenced by the form of the prepared cavity, the length of the etching time and the natural variation in the etched pattern on the enamel cavity walls, and the choice, and correct use of the composite resin material. Finally, as evidenced by the thermal cycling test, it must be conceded that the thermal and mechanical stresses to which clinical restorations are subjected, may, at times, exceed the intrinsic properties of either the composite resin or the acid-etched enamel-resin bond.
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