Stress distribution in human tooth structure can be visualized through the use of Moiré fringes, which has improved the clinical understanding of subtle compression and stress fracture presentations in teeth. Until the publication of this benchmark article, numerous fracture presentations observed clinically have been difficult to explain. Strain distribution within the tooth is related to its structure. Enamel acts as a stress distributor, transferring the load vertically to the root, and horizontally via the dentin–enamel junction (DEJ) to the dentin of the crown. A thick zone (~200 µm) in the dentin at the DEJ undergoes greater stress than the central coronal dentin.

Recently discovered structures within the occlusal surface of molars indicate that conventional cavity designs are disharmonious with the tooth’s natural mechanical stress distribution system. This understanding has resulted in the development of a discipline termed microdentistry. This philosophy urges the use of modern methods of cavity detection for early accurate minimal intervention in the cavity process to preserve internal mechanical structures within the tooth that are vital to its long-term mechanical viability.

Moiré Fringes

To understand the various presentations of tooth fracture caused by the disruption of the natural stress distribution mechanism within the tooth, the significance of the Moiré fringes must be considered. To date, stress studies that utilize polarized light have generally been conducted with plastics to show stresses that occur when loads are applied. This technique is not effective in natural dentition due to their inability to transmit light, so these studies

Figure 1. The direction of the Moiré fringes indicates the direction of the stress. Thicker zones in the fringes represent increased stress and tighter fringes indicate greater stress.

Key Words: Moiré fringes, stress, microdentistry, caries, peripheral, enamel

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have most often focused on stress distribution associated with intracoronal pins and posts. The Moiré fringes study allows the visualization of stress distribution within natural tooth structure (Figure 1). Since it has been postulated that the source of abfraction lesions is stress concentration at the cervical DEJ, the relationship demonstrated in the Moiré fringes study confirms this hypothesis. The Moiré fringes show the peripheral rim of enamel transferring occlusal load directly to the root of the tooth. Compression load in the enamel transfers via the DEJ into horizontal load in the dentin of the crown. In this transfer, a stress concentration occurs at the DEJ as it converts the vertical load in the enamel into the horizontal load in the dentin.

The DEJ is a zone approximately 200 µm thick where collagen density and mineral content are each approximately 50%, compared to a 30% collagen/70% mineral ratio in the body of the dentin. Since the DEJ is more elastic due to its greater collagen content, it allows microcompression to occur between the enamel and the dentin, which enables the enamel rim — with its high elastic modulus — to transfer a vertical load directly to the root structure. Once this initial load transfer occurs, the shear load created within the DEJ transfers into a horizontal load in the body of the crown dentin, with the stress decreasing toward the center of the tooth. This increase in load in the DEJ and decrease of stress in the central body of the dentin is evidenced in the Moiré fringes study.

Peripheral Rim Theory

Once this load distribution system is understood, the function of the enamel rim assumes greater significance. From the perspective of stress distribution, the occlusal enamel is a separate entity from the peripheral rim enamel. In simplified terms, the function of the peripheral rim can be visualized through a comparison to an inverted teacup. Several years ago, an automobile company successfully balanced a 2-ton car on four inverted china teacups. When loaded correctly, the fragile teacups were able to support significant loads and successfully transfer the load to the floor. In the same manner, the enamel

Figure 2. Delamination of the peripheral rim and occlusal enamel is apparent as a white line fracture. Note the occlusal abfraction and recurrent caries associated with stress concentration.

Figure 3. Occlusal abfraction guttering occurs between the peripheral rim and the cavity margin due to stress concentration. The compressive facets are marked in blue.

Figure 4. A subocclusal transverse oblique ridge that extends from the distolingual to mesiobuccal aspects of mandibular molars. A supporting web of enamel is connected to this structure.

Figure 5. A suspensory web of enamel in the area formerly referred to as the mesial fossae of maxillary molars. This web is also found mesially in the adjacent region formerly referred to as the marginal ridge fossae.
still support reasonable vertical compressive loads. When lateral compressive loads are applied to the rim, however, it distorts easily. Squeezed between two forces on opposite sides of the rim, an opened can becomes oval with the apex of the deformation occurring 90 degrees around the rim from the compression forces. This is a simplified image, but the effects can be observed clinically in teeth that are failing due to the presence of restorations. An occlusal cavity in a posterior tooth can cause it to flex under compressive loads on external cusp planes to an extent that the distortion in the tooth results in structural failure of the peripheral rim.

Considering tooth structure in this manner, the marginal ridge becomes a part of the peripheral rim rather than a separate morphological identity. Its significance to the overall stress distribution system increases when cavity designs are considered for the treatment of primary interproximal caries. The peripheral rim can be considered a tension ring. When a minimal MOD-type cavity is prepared in a sound tooth, the cusps spring apart approximately 10 µm, which indicates that the tooth structure is under tension. When the marginal ridge is simply a part of the peripheral rim of enamel, its removal to treat Class II interproximal caries has long-term significance for the structural integrity of the tooth.

Clinical Evidence and Significance

If the peripheral rim of enamel functions almost independently of the occlusal enamel and is able to absorb compressive loads without fracturing, a transfer of this load via the DEJ to a horizontal load in the dentin should occur. If this redistribution of the compressive load cannot be distributed through the body of the dentin due to the blocking transfers load to the root. The theory that the peripheral rim of enamel is able to support significant vertical loads becomes evident in a clinical setting. Clinicians can observe how the teeth fail in function when their stress distribution system is disrupted by cavity designs.

A simple tin can is also valuable in this discussion. Untouched, it can support significant vertical and lateral compressive loads. Even with the lid removed, it can
effect of a cavity, then one would expect to find clinical evidence of stress concentration between the peripheral rim enamel and the cavity wall. Differences in elastic modulus between the enamel and the underlying dentin could cause vertical delamination and fracturing along the DEJ. The failure of the stresses to be distributed through the dentin, due to the blocking effect of the cavity, should cause stress concentration between the peripheral rim and the cavity margin. This would have the same effect as stress concentration at the cervical enamel margin has in causing abfraction lesions. The result would be an occlusal abfraction lesion. Once the theory is understood, the clinical evidence becomes clear (Figures 2 and 3).

The preparation of cavities in tooth structure disrupts the natural load distribution and creates zones of stress concentration. The clinical presentation of this stress concentration depends primarily on two factors: the type of cavity prepared, and whether the applied load is compressive or tensile.

Conventional Extension-For-Prevention Type Occlusal Cavity
Dentin has a moderate elastic modulus, and enamel has a high elastic modulus. Between them lies the DEJ, which, due to its high collagen content, has a low elastic modulus in comparison to both dentin and enamel. While dentin can deform elastically under load (due to its moderate elastic modulus), enamel will fracture rather than deform. Once the occlusal surface of a mandibular molar has been removed for amalgam placement, the tooth begins to behave like the tin can with the top removed. First, the conventional extension-for-prevention cavity design required by amalgam removes an important occlusal cross-bracing structure — the subocclusal oblique transverse ridge in mandibular molars (Figure 4), and the maxillary molar mesial subocclusal enamel web (Figure 5). Second, amalgam provides little mechanical support when the tooth is under load.

One of the most common loads on mandibular molars is a compressive load on the outer face of the buccal cusps. As the unsupported dentin deforms under load, a

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Figure 10. Radiograph of occlusal effect caries associated with the conventional extension of the cavity in figures 8 and 9.

Figure 11. Occlusal view of posterior tooth with peripheral rim fracture.

Figure 12. Caries associated with peripheral rim fracture and the causative compression facets. Note the inverted enamel decalcification.

Figure 13. Radiograph demonstrates occlusal effect caries depicted in figures 11 and 12.
Compressive distortion in the cusps is created.\(^8,13\) The tooth becomes ovate, which places the peripheral rim enamel in the contact point areas under tension. Eventually, vertical fracturing of the enamel may occur in the marginal ridge zone of the peripheral rim. These enamel fractures are not to be confused with naturally occurring stress relief lamellae in virgin teeth. Continued flexure in this fracture can eventually result in caries propagation through the enamel crack (Figure 6). This caries presentation can best be described as “occlusal effect caries.” The interproximal caries is developing only because an occlusal cavity has been prepared in the tooth.

The proposition that preparation of an occlusal cavity in a tooth creates the potential for interproximal caries has serious significance for the development of minimal intervention microdentistry. Radiographically, this type of caries presentation is difficult to diagnose.\(^17\) Apart from a faint and diffuse graying of the contact point enamel, little enamel decalcification can be detected. Due to the lack of a conventional interproximal enamel caries marker, the dentin caries is often overlooked unless fracture has been noted at clinical examination, and the radiographs are viewed with that in mind (Figures 7 through 13). While these examples are exemplified in mandibular molars, this effect can occur in any tooth that has a compressive force applied to the cusp where a moderate-sized restoration has been placed.

### Tension Fracturing of Cusps

Vertical fracturing in the contact point area of the peripheral rim and associated caries can occur when cusps are placed under tension loads. Although the interproximal caries presentation remains the same as with compression fractures, there is generally an associated dentin fracture under the tension facet cusp. This is due to the inability of dentin to absorb tensile forces once it has been separated from the surrounding tooth structure by a cavity preparation that removed the occlusal enamel cross-bracing structures.\(^9-11\) Tooth structure is designed to absorb compressive and tension loads as a total.
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biomechanical entity and does not adapt well when this force distribution system is disrupted to any extent by conventional cavity designs (Figures 14 through 17).

Conclusions

If the preparation of an extension-for-prevention occlusal cavity can cause long-term failure of the tooth, then cavity designs must be addressed to accommodate the natural stress distribution mechanisms within the tooth. It could be necessary to conserve the occlusal cross-bracing structures of the subocclusal oblique transverse ridge and maxillary molar mesial subocclusal enamel web, and — if at all possible — to avoid the cutting of the peripheral rim of enamel. To conserve these structures, contemporary caries diagnostic techniques must be understood and utilized so that caries can be treated in its preliminary stages without unnecessary destruction of these vital anatomical entities. The utilization of magnification, caries detection dye, 18 laser caries diagnosis, 19 and minimally invasive stages without unnecessary destruction of these vital anatomical entities. The utilization of magnification, caries detection dye, 18 laser caries diagnosis, 19 and minimally invasive cavity designs utilizing air abrasion to avoid the microfracturing that occurs in enamel when cavities are prepared with high-speed rotary instrumentation are all promising new techniques. 20-23 Due to the way it selectively cuts compromised tooth structure, air abrasion allows conservation of sound tooth structure. It was this technology that allowed anatomical structures such as the subocclusal oblique transverse ridge and maxillary molar mesial subocclusal enamel web to be observed clinically. In contrast, high-speed rotary burs indiscriminately cut both sound and soundless tooth with equal ease.

In addition, for minimally invasive dentistry, the techniques and materials utilized in restoring minimal cavities should be considered. To conserve the integrity of the peripheral rim and occlusal cross-bracing structures, tunnel preparations become an appropriate treatment option when treating primary interproximal cases in posterior teeth. This approach will prevent composite fracturing of the peripheral rim and tension fracturing of cusps that occur with conventional MOD-type cavity preparations. As a consequence, the use of autopolymerizing glass-ionomer cement has to be considered when restoring this form of cavity design. 24-27 Current cavity designs and treatment concepts have evolved from a tradition based on the mechanical requirements of amalgam, often to the exclusion of the biomechanical requirements of the tooth. Only by reassessing their restorative criteria and modalities can clinicians avoid the perpetuation of the treatment cycle to which patients are currently subjected. 28-30

References

1. What is the significant conclusion from the Moiré Fringes study?
   a. Enamel has no significance in stress transfer.
   b. Dentin fails under occlusal load.
   c. Stress is evenly distributed throughout tooth structure.
   d. A tooth is a complex structure designed to effectively distribute and absorb stress.

2. What recently reported anatomical structure is significant in occlusal stress distribution?
   a. The marginal ridge.
   b. The oblique transverse ridge.
   c. The subocclusal oblique transverse ridge and maxillary molar mesial subocclusal enamel web.
   d. The dentinoenamel junction.

3. What is the biomechanical significance of the DEJ?
   a. It allows caries to spread laterally.
   b. It acts to transfer vertical load in the enamel into a horizontal load in the dentin.
   c. It causes fracturing between enamel and dentin.
   d. It has no functional significance.

4. What is the significance of the peripheral rim of enamel?
   a. It is very stable in vertical compressive load.
   b. The marginal ridge is a part of the peripheral rim.
   c. Cutting an occlusal cavity disrupts the ability of the peripheral rim to distribute occlusal loads.
   d. All of the above.

5. What is the potential effect of cutting a conventional G.V. Black extension for prevention of occlusal cavity?
   a. It has no effect.
   b. It unnecessarily cuts sound tooth structure.
   c. It has the potential to cause recurrent caries.
   d. It allows compressive flexing of the tooth resulting in peripheral rim enamel fracture and the potential for interproximal caries.

6. What is occlusal effect caries?
   a. Recurrent caries that occurs due to underextension of the cavity.
   b. Compressive distortion of the peripheral rim due to the presence of an occlusal cavity causing vertical fracture of the enamel allowing caries to establish.
   c. Failure of the occlusal restoration due to compressive loads leading to recurrent caries.
   d. Fracturing of the occlusal enamel under compressive load leading to recurrent caries.

7. What causes occlusal abfraction and peripheral rim guttering?
   a. The presence of an existing large cavity.
   b. Stress concentration between the peripheral rim and the restoration.
   c. Fracturing between the peripheral rim and underlying dentin along the DEJ.
   d. All of the above.

8. What is the difference in fracture presentation between compressive loads and tensile loads on cusps?
   a. There is no difference.
   b. Tensile loads cause horizontal fractures through dentin.
   c. Compressive loads cause cusps to fall off.
   d. Tensile loads cause occlusal abfractions.

9. Why is occlusal effect caries difficult to diagnose radiographically?
   a. There is most often minimal enamel decalcification in the fracture so it will not appear on the radiograph.
   b. X-rays will not penetrate the area.
   c. Occlusal effect caries does not exist.
   d. Fractures can easily be seen on radiographs.

10. What is required to prevent occlusal effect caries and peripheral rim fracturing?
    a. Accurate caries diagnosis.
    b. Conservation of the important anatomical structures of the peripheral rim, subocclusal oblique transverse ridge, and maxillary molar mesial subocclusal enamel web.
    c. Minimally invasive tunnel preparations to treat interproximal caries to conserve the peripheral rim.
    d. All of the above.