Biomechanics of Removable Partial Dentures

Biomechanical Considerations
Possible Movements of Partial Denture Self-Assessment Aids

Removable partial dentures by design are intended to be removed from and replaced into the mouth. Because of this, they are not rigidly connected to the teeth or tissues, which means they are subject to movement in response to functional loads such as those created by mastication. It is important for clinicians providing removable partial denture service to understand the possible movements in response to function and to be able to logically design the component parts of the removable partial denture to help control these movements. The following biomechanical considerations provide a background regarding principles of the movement potential associated with removable partial dentures, and the subsequent chapters covering the various component parts describe how these components are designed and how they are used to control the resultant movements of the prostheses.

Biomechanical Considerations

As Maxfield stated, “Common observation clearly indicates that the ability of living things to tolerate force is largely dependent upon the magnitude or intensity of the force.” The supporting structures for removable partial dentures (abutment teeth and residual ridges) are living things and are subjected to forces. In consideration of maintaining the health of these structures, the dentist must consider direction, duration, and frequency of force application, as well as the magnitude of the force.

In the final analysis it is bone that provides the support for a removable prosthesis, that is, alveolar bone by way of the periodontal ligament and bone of the residual ridge through its soft tissue covering. If potentially destructive forces can be minimized, then the physiologic tolerances of the supporting structures are generally capable of withstanding these forces without physiologic or pathologic change. To a great extent, the forces occurring through a removable prosthesis can be widely distributed, directed, and minimized by the selection, the design, and the location of components of the removable partial denture and by development of harmonious occlusion.

Unquestionably, the design of removable partial dentures requires mechanical and biologic considerations. Most dentists are capable of applying simple mechanical principles to the design of a removable partial denture. For example, the lid of a paint can is more easily
McCracken's removable partial prosthodontics

Fig. 4-1 Scientists today recognize six simple machines: lever, wedge, screw, wheel and axle, pulley, and inclined plane. $F$, Fulcrum.

Fig. 4-2 Lever is simply a rigid bar supported somewhere between its two ends. It can be used to move objects by application of force (weight) much less than weight of object being moved.

Fig. 4-3 Distal extension removable partial denture will rotate when force is directed on denture base. Differences in displaceability of periodontal ligament, supporting abutment teeth, and soft tissues covering residual ridge permit this rotation. It would seem that rotation of denture is in combination of directions rather than unidirectional.

The longer the handle, the less effort (force) it takes. This is a simple application of the mechanics of leverage. By the same token, a lever system represented by a distal extension removable partial denture can magnify the applied force to the terminal abutments, which is most undesirable.

Tylman correctly stated, "Great caution and reserve are essential whenever an attempt is made to interpret biological phenomena entirely by mathematical computation." However, an understanding of simple machines should enhance our rationalization of the design of removable partial dentures to accomplish the objective to preserve oral structures. A removable partial denture can be, and often is, unknowingly designed as a destructive machine.

Machines may be classified into two general categories: simple and complex. Complex machines are combinations of many simple machines. The six simple machines are lever,
Fig. 4-4 There are three classes of levers. Classification is based on location of fulcrum, $F$; resistance, $R$; and direction of effort (force), $E$. Examples of each class are illustrated.

$$\text{Effort arm \overline{AB}}$$

$$\text{Resistance arm \overline{AC}}$$

$$\text{Mechanical advantage} \ MA = \frac{\text{Effort arm}}{\text{Resistance arm}}$$

Fig. 4-5 Length of lever from fulcrum, $F$, to resistance, $R$, is called resistance arm. That portion of lever from fulcrum to point of application of force, $E$, is called effort arm. Whenever effort arm is longer than resistance arm, mechanical advantage is in favor of effort arm, proportional to difference in length of the two arms. In other words, when effort arm is twice the length of resistance arm, 25-pound weight on effort arm will balance 50-pound weight at end of resistance arm.

The gross movement of the denture may be small, the potential exists for detrimental leverlike forces to be imposed on abutment teeth, especially when servicing (that is, relining) the prosthesis is neglected over a long period. There are three types of levers: first, second, and third class (Fig. 4-4). The potential of a lever system to relatively magnify a force is illustrated in Fig. 4-5.

A cantilever is a beam supported only at one end and can act as a first-class lever (Fig. 4-6). A cantilever design should be avoided (Fig. 4-7). Examples of other leverlike designs, as well as suggestions for alternative designs, to avoid or to minimize their destructive potential are illustrated in Figs. 4-8 and 4-9.

A tooth is apparently better able to tolerate vertically directed forces than off-vertical, torquing, or near horizontal forces. This characteristic is observed clinically and was substantiated many years ago by the work of...
Fig. 4-6 Cantilever can be described as rigid beam supported only at one end. When force is directed against unsupported end of beam, cantilever can act as first-class lever. Mechanical advantage in this illustration is in favor of effort arm.

Fig. 4-7 Design often seen for distal extension removable partial denture. Cast circumferential direct retainer engages mesiobuccal undercut and is supported by distoclusal rest. This could be considered a cantilever design, and it may impart detrimental first-class lever force to abutment if tissue support under extension base allows excessive vertical movement toward the residual ridge.

Fig. 4-8 Potential for first-class lever action exists in this Class II, modification 1, removable partial denture framework. If cast circumferential direct retainer with a mesiobuccal undercut on right first premolar were used, force placed on denture base could impart upward and posteriorly moving force on premolar, resulting in loss of contact between premolar and canine. Tissue support from extension base area is most important to minimize lever action of clasp. Retainer design could help accommodate more of an anteriorly directed force during rotation of the denture base in an attempt to maintain tooth contact. Other alternatives to first premolar design of direct retainer would be tapered wrought wire retentive arm that uses mesiobuccal undercut or just has buccal stabilizing arm above height of contour.
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Fig. 4-9 Illustration A uses bar type of retainer, minor connector contacting guiding plane on distal surface of premolar, and mesio-occlusal rest, to reduce cantilever or first-class lever force when and if denture rotates toward residual ridge. B, Tapered wrought-wire retentive arm, minor connector contacting guiding plane on distal surface of premolar, and mesio-occlusal rest. This design is applicable when distobuccal undercut cannot be found or created or when tissue undercut contraindicates placing bar-type retentive arm. This design would be kinder to periodontal ligament than would cast, half-round retentive arm. Again, tissue support of extension base is key factor in reducing lever action of clasp arm. Note: Depending on amount of contact of minor connector proximal plate with guiding plane, fulcrum point will change.

Box and Synge* of Toronto. It seems rational that more periodontal fibers are activated to resist the application of vertical forces to teeth than are activated to resist the application of off-vertical forces (Fig. 4-10).

Again, a distal extension removable partial denture rotates when forces are applied to the artificial teeth attached to the extension base. Because it can be assumed that this rotation must create predominantly off-vertical forces, location of stabilizing and retentive components in relation to the horizontal axis of rotation of the abutment becomes extremely important. An abutment tooth will better tolerate off-vertical forces if these forces accrue as near as possible to the horizontal axis of rotation of the abutment (Fig. 4-11). The axial surface contours of abutment teeth must be altered to locate components of direct retainer assemblies more favorably in relation to the abutment’s horizontal axis (Fig. 4-12).


Fig. 4-10 More periodontal fibers are activated to resist forces directed vertically on tooth than are activated to resist horizontally (off-vertical) directed force. Horizontal axis of rotation is located somewhere in root of tooth.
Fig. 4-11 A, Fencepost is more readily removed by application of force near its top than by applying same force nearer ground level. B, Retentive (buccal surface) and reciprocal (lingual surface) components (mirror view) of this direct retainer assembly are located much nearer occlusal surface than they should be. This represents similar effect of force application shown in top figure of illustration A.

POSSIBLE MOVEMENTS OF PARTIAL DENTURE

Presuming that direct retainers are functioning to minimize vertical displacement, rotational movement will occur about some axis as the distal extension base or bases either move toward, away, or horizontally across the underlying tissues. Unfortunately, these possible movements do not occur singularly or independently but tend to be dynamic and all occur at the same time. The greatest movement possible is found in the tooth-tissue-supported prosthesis because of the reliance on the distal extension supporting tissue to share the functional loads with the teeth. Movement of a distal extension base toward the ridge tissues will be proportionate to the quality of those tissues, the accuracy and extent of the denture base, and the total functional load applied. A review of prosthesis rotational movement that is possible around various axes in the mouth provides some understanding of how component parts of removable partial dentures should be prescribed to control prosthesis movement.

One movement is rotation about an axis through the most posterior abutments. This axis may be through occlusal rests or any other rigid portion of a direct retainer assembly located occlusally or incisally to the height of contour of the primary abutments (Fig. 4-13, A). This axis, known as the fulcrum line, is the center of rotation as the distal extension base moves toward the supporting tissues when an occlusal load is applied. The axis of rotation may shift toward more anteriorly placed components, occlusal or incisal to the height of contour of the abutment, as the base moves away from the supporting tissues when vertical dislodging forces act on the partial denture. These dislodging forces result from the vertical
pull of food between opposing tooth surfaces, the effect of moving border tissues, and the forces of gravity against a maxillary partial denture. Presuming that the direct retainers are functional and that the supportive anterior components remain seated, rotation rather than total displacement should occur. Vertical tissueward movement of the denture base is resisted by the tissues of the residual ridge in proportion to the supporting quality of those tissues, the accuracy of the fit of the denture base, and the total amount of occlusal load applied. Movement of the base in the opposite direction is resisted by the action of the retentive clasp arms on terminal abutments and the action of stabilizing minor connectors in conjunction with seated, vertical support elements of the framework anterior to the terminal abutments acting as indirect retainers. Indirect retainers should be placed as far as possible from the distal extension base, affording the best possible leverage advantage against the lifting of the distal extension base.

A second movement is rotation about a longitudinal axis as the distal extension base moves in a rotary direction about the residual ridge (Fig. 4-13, B). This movement is resisted primarily by the rigidity of the major and minor connectors and their ability to resist torque. If the connectors are not rigid or if a stress-breaker exists between the distal extension base and the major connector, this rotation about a longitudinal axis either applies undue stress to the sides of the supporting ridge or causes horizontal shifting of the denture base.

A third movement is rotation about an imaginary vertical axis located near the center of the dental arch (Fig. 4-13, C). This movement occurs under function as diagonal and horizontal occlusal forces are brought to bear on the partial denture. It is resisted by stabilizing components, such as reciprocal clasp arms and minor connectors that are in contact with vertical tooth surfaces. Such stabilizing components are essential to any partial denture design regardless of the manner of support and the type of direct retention employed. Stabilizing components on one side of the arch act to stabilize the partial denture against horizontal...

Fig. 4-13 Three possible movements of distal extension partial denture. A, Rotation around fulcrum line passing through the most posterior abutments when denture base moves vertically toward or away from supporting residual ridges. B, Rotation around longitudinal axis formed by crest of residual ridge. C, Rotation around vertical axis located near center of arch.
forces applied from the opposite side. It is obvious that rigid connectors must be used to make this effect possible.

Horizontal forces always will exist to some degree because of lateral stresses occurring during mastication, bruxism, clenching, and other patient habits. These forces are accentuated by failure to consider the orientation of the occlusal plane, the influence of malpositioned teeth in the arch, and the effect of abnormal jaw relationships. The magnitude of lateral stress may be minimized by fabricating an occlusion that is in harmony with the opposing dentition and that is free of lateral interference during eccentric jaw movements.

The amount of horizontal movement occurring in the partial denture therefore depends on the magnitude of the lateral forces that are applied and on the effectiveness of the stabilizing components.

In a tooth-supported partial denture, movement of the base toward the edentulous ridge is prevented primarily by the rests on the abutment teeth and to some degree by any rigid portion of the framework located occlusal to the height of contour. Movement away from the edentulous ridge is prevented by the action of direct retainers on the abutments that are situated at each end of each edentulous space and by the rigid, minor connector stabilizing components. Therefore the first of the three possible movements can be controlled in the tooth-supported denture. The second possible movement, which is about a longitudinal axis, is prevented by the rigid components of the direct retainers on the abutment teeth, as well as by the ability of the major connector to resist torque. This movement is much less in the tooth-supported denture because of the presence of posterior abutments. The third possible movement occurs in all partial dentures; therefore stabilizing components against horizontal movement must be incorporated into any partial denture design.

For prostheses capable of movement in three planes, occlusal rests should only provide occlusal support to resist tissueward movement. All movements of the partial denture other than those in a tissueward direction should be resisted by components other than occlusal rests. For the occlusal rest to enter into a stabilizing function would result in a direct transfer of torque to the abutment tooth. Because movements around three different axes are possible in a distal extension partial denture, an occlusal rest for such a partial denture should not have steep vertical walls or locking dovetails, which could possibly cause horizontal and torquing forces to be applied intracoronally to the abutment tooth.

In the tooth-supported denture, the only movements of any significance are horizontal, and these may be resisted by the stabilizing effect of components placed on the axial surfaces of the abutments. Therefore in the tooth-supported denture, the use of intracoronal rests is permissible. In these instances, the rests provide not only occlusal support but also significant horizontal stabilization.

In contrast, all Class I and Class II partial dentures, having one or more distal extension bases, are not totally tooth supported; neither are they completely retained by bounding abutments. Any extensive Class III or Class IV partial denture that does not have adequate abutment support falls into the same category. These latter dentures may derive some support from the edentulous ridge and therefore may have a composite support from both teeth and ridge tissues.
SELF-ASSESSMENT

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1. What elements prevent movement of the base(s) of a tooth-supported denture toward the basal seats?

2. Movement of a distal extension base away from basal seats will occur as a rotational movement or as

3. What is the difference between fulcrum line and axis of rotation?

4. Identify the fulcrum line on a Class I arch; a Class II, modification 1; and a Class IV.

5. In the treatment planning and design phase of partial denture service, the functional movements of removable partial dentures should be considered when designing the individual components of the prosthesis.

6. Forces are transmitted to abutment teeth' and residual ridges by removable partial dentures. One of the factors of a force is its magnitude. List the other three factors of a force that a dentist must consider in designing removable partial dentures.

7. The design of a removable restoration requires consideration of mechanics as well as biologic considerations. True or false?

8. Of the simple machines, which two are more likely to be encountered in the design of removable partial dentures?

9. What is a lever? A cantilever?

10. Name the three classes of levers and give an example of each.

11. Of the three classes of lever systems, which two are most likely to be encountered in removable partial prosthodontics?

12. Explain how one would figure the mechanical advantage of a lever system, given dimensions of effort and resistance arms.

13. What class lever system is most likely to be encountered with a restoration on a Class II, modification 1, arch when a force is placed on the extension base?

14. What factor permits a distal extension denture to rotate when the denture base is forced toward the basal seat?

15. Is an abutment tooth better able to resist a force directed apically or directed horizontally? Why?

16. Where is the horizontal (tipping) axis of an abutment tooth located?

17. Why should components of a direct retainer assembly be located as close to the tipping axis of a tooth as possible?