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‘Pump Handle Effect’ in RPD Design- A Review

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Abstract

A major biomechanical phenomenon in the construction of removable partial dentures (RPDs), the pump handle effect primarily affects Kennedy Class I and II distal-extension prostheses. The denture base rotates around a fulcrum, usually made up of distal rests, as a result of the remnant ridge tissues' compressibility under occlusal force. The abutment teeth are subjected to torquing stress during this rotation, which increases the risk of cavities, diminished retention, ridge resorption, clasp deformation, mobility, and patient discomfort. Because of the robust abutment support, the effect is negligible in tooth-supported Class III and IV RPDs. In addition to stress-breaking clasps, implant support, and modified cast procedures, mitigation depends on the positioning of mesial rests in RPI and RPA systems to move the fulcrum and permit clasp disengagement. As such very scanty literature is available on the effects of ‘Pump Handle Effect’ on RPD designs. This review paper elaborately discusses the role of pump handle effect and how to modify the RPD design.

Keywords: RPD Design; Biomechanical Principles, Pump Handle Effect

Introduction

In distal-extension RPDs (Kennedy Class I and II), a biomechanical phenomenon known as the "pump handle" occurs as the prosthesis revolves around a fulcrum, putting undesired torquing pressures on the abutment teeth. In tooth-tissue-supported RPDs, where the abutment teeth offer support and retention and the denture base rests on the compressible residual ridge, this effect is most noticeable. One important tactic to lessen this effect is the inclusion of a mesial rest in designs such as the RPI (Rest, Proximal Plate, I-bar) and RPA (Rest, Proximal Plate, Akers clasp) systems. [1,2]

Knowing the Effect of the Pump Handle

Because soft tissues are more compressible than relatively stiff abutment teeth, a distal-extension RPD that rotates tissueward (towards the remaining ridge) under occlusal force is said to have the pump handle effect. [1-3]

The most distal rests on the abutment teeth usually form the fulcrum line, which serves as a pivot point. The clasp assembly puts torquing stresses on the abutment teeth when the prosthesis revolves around this fulcrum due to occlusal forces provided to the denture base (when chewing, for example).

This rotation mimics the movement of a pump handle, in which the clasp arms raise or torque the abutment as the denture base slides tissueward, possibly freeing the tooth or causing damage to periodontal structures.

Repercussions:

Increased strain on abutment teeth, which might cause periodontal disease or movement. Decreased retention as a result of distortion or disengagement of the clasp and discomfort or irritated tissue as a result of the denture base moving too much. [4]

Factors Contributing to the Pump Handle Effect:

Distal Rest Placement: The fulcrum line is positioned closer to the edentulous ridge when rests are positioned on the distal aspect of abutment teeth. This increases the rotational pressures and torquing on the abutment during occlusal loading. [4-6]

Tissue Compressibility: When the soft tissue of the remaining ridge contracts under strain, the denture base might spin more than the parts that are supported by the teeth.

Clasp Design: The pump handle effect is exacerbated by rigid clasps (such as traditional circumferential clasps) that engage deep undercuts without disengaging during rotation.

Role of the Mesial Rest in Eliminating the Pump Handle Effect

A crucial part of the RPI and RPA systems, the mesial rest is positioned on the mesial aspect of the abutment tooth in a strategic manner to change the fulcrum line and reduce torquing pressures. Below is an explanation of its function in removing the pump handle effect: [1-6]

1.Shifting the Fulcrum Line:

Mechanism: In contrast to a distal rest, the fulcrum line is positioned farther from the edentulous ridge when the rest is placed on the mesial face of the abutment, such as the mesial marginal ridge of canines or the triangular fossa of molars. As a result, the lever arm between the denture base and the rest is longer. [7]

Effect: The mesial rest permits the clasp (I-bar in RPI or Akers clasp in RPA) to slide downward and release from the undercut when occlusal pressures induce the denture base to rotate tissueward. The pump handle effect is essentially eliminated by this disengagement, which stops torquing forces from reaching the abutment tooth.

Biomechanical Advantage: By rerouting occlusal forces along the abutment tooth's long axis, the mesial rest lessens torquing or lateral stresses that can cause the tooth to become unstable.

2.Stress-Breaking Action:

RPI System: Because of its flexibility and gingival approach, the I-bar clasp encounters a mesiobuccal undercut

and is intended to disengage during tissueward rotation. This is made possible by the mesial rest, which positions the fulcrum to minimize stress on the abutment by allowing the I-bar to slide out of the undercut. [1-3, 7-10]

RPA System: The Akers clasp is stiff above the height of contour, yet it engages a mesial undercut. By ensuring that the clasp's retentive tip disengages during rotation, the mesial rest keeps the abutment from experiencing torquing stresses.

Effect: The abutment is shielded from damaging forces by the stress-breaking action of both systems, which is made possible by the mesial rest. This eliminates the damaging effects of the pump handle effect. [1,2,8,10]

3.Improved Load Distribution:

Occlusal forces are more uniformly distributed between the remaining ridge and the abutment tooth thanks to the mesial rest. The rotational movement of the denture base is better regulated by placing the rest mesially, which lessens the pump handle effect and excessive pressure on the abutment.

4.Finite Element Analysis (FEA) Evidence: The elimination of the pump handle effect is confirmed by studies, like those by Rungsiyakull et al., which show that the mesial rest placement in RPI and RPA designs significantly reduces stress concentrations in the periodontal ligament and supporting bone of the abutment when compared to distal rest designs [3].

5.Enhanced Prosthesis Stability:

In RPI and RPA systems, the mesial rest and proximal plate work together to guide the prosthesis' insertion and removal process and stabilise it while it is in use. As a result, the pump handle action is lessened by undesired rotating movements.

Clinical Relevance: Increased stability lessens the detrimental effects of rotation on abutment teeth while also improving patient comfort and retention.

Comparison with Distal Rest:

A distal rest increases the lever arm's force on the abutment during tissueward rotation by bringing the fulcrum closer to the edentulous ridge. Torquing forces are increased as a result, intensifying the pump handle impact. In contrast, the mesial rest shifts the fulcrum to permit clasp disengagement, rerouting stresses to the remaining ridge and safeguarding the abutment. [11-13]

Limitations:

The success of the mesial rest is dependent on precise surveying to guarantee clasp release and appropriate dental preparation (e.g., sufficient rest seat depth).

To obtain the intended effect, the mesial rest may need additional adjustments (such as recontouring or restorative operations) in cases of extreme abutment tilting or insufficient mesial undercuts. [14-16]

Consequences of Improper Management of the Pump Handle Effect

Abutment Tooth Mobility and Loss:

Mechanism: The movement of the denture base around a distal fulcrum causes the pump handle effect to produce torquing stresses on abutment teeth. The periodontal ligament (PDL) experiences lateral and rotational stresses as a result of these forces, especially when rests are positioned distally. Over time, this increases tooth movement. [17-20]

Consequences: Prolonged stress can eventually result in tooth loss or loosening by weakening the PDL and causing bone resorption around the abutment. This is particularly important for abutments whose periodontal support is impaired.

Cecconi et al. provided evidence that clasp designs with distal rests or other stress-breaking systems transmit larger torquing forces, hence improving abutment mobility [6]. According to Bergman's review, poorly built RPDs exacerbate tooth mobility by promoting periodontal degradation [9].

Periodontal Damage: Mechanism: Inflammation, gingival recession, and bone loss around abutment teeth might result from the periodontal tissues being traumatised by the torqueing forces from the pump handle effect. Furthermore, excessive denture movement can cause plaque buildup, which would further jeopardise periodontal health. [19,20]

Consequences: Abutment teeth may become less long-lasting and require extraction due to gingival irritation, pocket formation, and increasing periodontal disease. This is especially troublesome for those who already have periodontal disease.

Evidence: Individuals with less-than-ideal oral hygiene are more susceptible to gingivitis and periodontal disease when their RPD is poorly designed, including when rotational forces are not adequately managed. According to Ogunrinde et al., uncontrolled rotational forces indirectly aggravate gingival inflammation, which is exacerbated by incorrect main connector designs. [18].

Decreased Stability and Retention:

Mechanism: Excessive rotation of the denture base due to the pump handle effect results in clasp disengagement or deformation. Rigid clasps that do not release during rotation, like those seen in conventional distal rest designs, for instance, may deform and become less effective at engaging undercuts. [18-20]

Consequences: Patients experience discomfort, chewing difficulties, and frequent dislodgement as a result of prosthesis instability brought on by loss of retention. Reduced patient compliance and prosthesis abandonment may result from this.

Evidence: According to Stone's research on clasp retention, in certain situations, designs such as the Akers clasp (used in RPA) offer superior retention than I-bar clasps; nevertheless, rest placement errors, such as distal rests, impair retention because of excessive rotation. [17] Kim stresses the need for bracing and support to reduce denture movement, which is interfered with by the pump handle effect if left unchecked. [19]

Residual Ridge Resorption: Mechanism: Excessive tissueward rotation of the denture base causes the pump handle action to increase pressure on the residual ridge. Resorption may be accelerated by this unequal force distribution, which may over compress the underlying bone and soft tissues. [20]

Repercussions: The denture base's fit is changed by progressive ridge resorption, which increases instability, decreases support, and necessitates periodic prosthesis relining or remaking. In cases of long-span distal extension, this is especially bad.

Evidence: Leupold et al. discovered that ridge resorption in distal-extension RPDs is caused by incorrect denture base adaptation, which is made worse by rotating stresses [16]. According to Sajjan's research on modified cast procedures, inadequate tissue support raises the likelihood of resorption, which is exacerbated by the pump handle effect. [20]

Mechanism of Patient Discomfort and Functional Impairment: The prosthesis moves significantly due to uncontrolled rotation from the pump handle effect, which irritates and sores the tissue and makes mastication difficult. Patient confidence may also be impacted by the cosmetic effects of a loose or unstable denture. [11,13]

Consequences: Patients' willingness to utilise the prosthesis may be decreased if they suffer from pain, discomfort, or mucosal ulcers. Nutrition and quality of life may be jeopardised by functional constraints, such as trouble chewing sticky meals.

Evidence: Poor RPD design, particularly an inability to manage rotational pressures, causes patient discomfort and lowers prosthesis adoption, according to Davenport et al. [10] According to Eachempati et al., functional and aesthetic dissatisfaction in RPDs is a result of biomechanical mismanagement. [14]

Mechanism of Clasp Deformation or Fracture: Particularly in stiff designs or when clasps are not made to disengage during rotation (such as distal rest with hard clasps), the repetitive torquing stresses from the pump handle effect can stress clasp arms above their elastic limit.

Consequences: While fracture makes the prosthesis non-functional and necessitates repair or replacement, clasp deformation decreases retention. Both patient annoyance and treatment expenses rise as a result.

Evidence: Inappropriate clasp and rest designs raise stress concentrations, which causes clasp fatigue or failure, as demonstrated by Itoh et al., using FEA.[8] According to Stone's research, if mesial rests are not used in conjunction with rigid clasps, such as the Akers clasp in RPA, to reduce rotational stresses, the clasps are more likely to deform. [17]

Restorative Failure and Caries:

Mechanism: Excessive movement of the pump handle action can lead to microgaps between the abutment teeth and the prosthesis, which encourages the formation of cavities and plaque retention. Furthermore, existing restorations (like as crowns or fillings) may be stressed by torquing forces, which could result in their collapse. [16]

Consequences: While restorative failures require extra dental treatments, raising the complexity and cost of

treatment, increased caries risk jeopardises the integrity of the abutment.

Proof: According to Ogunrinde TJ et al., poorly built RPDs raise the risk of root caries because they cause plaque to remain, which is made worse by uncontrolled denture movement. [18]. According to Eachempati et al., poor biomechanical design is a contributing factor to dental cavities and restorative issues. [14]

Strategies to Mitigate the Pump Handle Effect

In order to avoid these outcomes, the pump handle effect needs to be controlled by appropriate RPD design, as described below:

Placing mesial rests, as in RPI and RPA systems, reduces torquing pressures by moving the fulcrum line away from the edentulous ridge and enabling clasps to disengage during tissueward rotation [1, 2, 11].

Designs for Stress-Breaking Clasps: Stress transmission to abutments is reduced by hard clasps that are intended to disengage, such as the Akers clasp in RPA, or flexible clasps, such as the I-bar in RPI [3, 8].

Implant Assistance: By reducing denture rotation, implants in the posterior edentulous ridge improve stability and lessen the impact of the pump handle [7].

Modified Cast Techniques: By reducing tissueward movement and minimising rotating forces, selective pressure impressions improve denture base adaption. [19]

Digital Design (CAD/CAM): Accurate surveying and the placement of clasps using digital tools guarantee the best possible undercut engagement and stress distribution, which lessens the influence of the pump handle. [15] The longevity and effectiveness of the RPD are jeopardised when these tactics are not used, leading to the issues mentioned above.

Abutment tooth movement, periodontal injury, decreased retention and stability, residual ridge resorption, patient discomfort, clasp deformation, and caries or restorative failure are all consequences of failing to control the pump handle effect in distal-extension RPDs. To avoid these issues and guarantee long-term prosthesis performance, proper management is crucial. This includes the use of digital manufacturing, implant support, altered cast processes, stress-breaking clasp designs, and mesial rest insertion. [14,17]

The "pump handle" effect is seen in removable partial dentures (RPDs) and is mostly linked to particular Kennedy categories because of their functional and anatomical traits.

Kennedy Classifications and the Pump Handle Effect

Because of their distal-extension arrangements, Kennedy Class I and Kennedy Class II partial edentulous conditions are where the pump handle effect is most noticeable. The denture base in these classes of tooth-tissue-supported RPDs depends on the compressible residual ridge and the abutment teeth for support, which results in rotational forces that produce the pump handle effect.

Bilateral Distal-Extension, or Kennedy Class I:

Bilateral edentulous regions that are posterior to the remaining natural teeth and lack posterior abutment teeth for support are included in this classification. Bilateral residual ridges and anterior or premolar abutment teeth support the RPD.

Effect of Pump Handle: Because the remaining ridge is more compressible than the stiff abutment teeth, the denture base rotates tissueward under occlusal force. The fulcrum line occurs near the edentulous ridge when supports are positioned distally on abutment teeth, which increases rotation around this fulcrum. As a result, the abutment teeth experience torquing stresses that mimic a pump handle's action. [1-5]

Mechanism: The clasp arms (if not made to disengage, such as with distal rests) apply lateral or torquing stresses to the abutments when the distal-extension base goes lower, which may cause mobility, periodontal injury, or decreased retention.

Evidence: Because of the lengthy lever arm of the distal-extension base, the pump handle effect is a major concern in Class I settings, requiring the installation of mesial rests to reduce torquing pressures, as highlighted in Kratochvil's groundbreaking work on the RPI system [11]. Class I RPDs with distal rests show greater stress on abutments because of rotating forces, according to Itoh et al.'s finite element analysis (FEA).[8]

Kennedy Unilateral distal extension, or class II:

In this classification, the contralateral side has a tooth-bounded or fully dentate arch, but the unilateral edentulous area is located posterior to the remaining natural teeth. The remaining ridge on one side and the abutment teeth next to the edentulous area support the RPD.

Pump Handle Effect: A fulcrum line is formed through the distal rests as a result of the distal-extension base rotating tissueward under occlusal force, same like in Class I. The pump handle effect results from torquing forces applied to the abutment teeth next to the edentulous area by this rotation. Because of the stable contralateral arch, the effect might not be as noticeable as in Class I, but it is nonetheless important if left unchecked. [11]

Mechanism: Torquing and possible periodontal injury are exacerbated when the unilateral distal-extension base rotates around a distal fulcrum, increasing stress on the abutment, especially when hard clasps or distal rests are utilised.

Evidence: Class II RPDs are susceptible to rotating forces because of their distal-extension structure, according to Stewart et al. Designs such as RPI or RPA that have mesial rests help to reduce the pump handle effect. [4] Distal-extension designs (Classes I and II) produce larger abutment stresses when rotational forces are uncontrolled, according to a FEA study by Rungsiyakull et al. [3]

Kennedy Less Common Class III and IV: Described as a unilateral edentulous region with anterior and posterior tooth boundaries that supports teeth on both ends. [4,5]

Pump Handle Effect: Because the RPD is completely tooth-supported, which reduces rotational forces, the pump handle effect is not usually seen in Class III. The prosthesis is stabilised by the presence of posterior

abutments, which inhibit tissueward rotation.

Evidence: Davenport et al. stress that because tooth-bounded RPDs (Class III) have secure support from several abutments, they are less likely to experience rotational problems. [10]

Kennedy Class IV, or anterior extension, is characterised by a single anterior edentulous area that crosses the midline and is frequently held up by posterior teeth.

Pump Handle Effect: Because the edentulous region is normally tooth-supported and rotational forces are negligible until the anterior extension is long and unsupported, the pump handle effect is uncommon in Class IV. Though rare, a modified pump handle effect could happen if the design resembles a distal-extension scenario (for example, with lengthy anterior spans).[11]

Evidence: Compared to distal-extension designs, Class IV RPDs are less likely to experience rotational stresses since they are mainly tooth-supported, according to Eachempati et al. [14]

Why the Most Affected Classes Are I and II:

Tooth-Tissue Support: Classes I and II have a support difference that encourages rotation under occlusal stress because they rely on both compressible soft tissues and stiff teeth. [5]

Distal-Extension Configuration: The lengthening of the lever arm due to the lack of posterior abutments increases rotational forces at the fulcrum, particularly when distal rests are used.

Clasp and Rest Design: By failing to disengage during rotation, conventional designs with inflexible clasps and distal rests intensify the pump handle effect by transferring torquing pressures to abutments. [1,2]

Strategies for Management:

Mesial Rest Placement: This technique allows clasp release and lowers torquing pressures by moving the fulcrum line away from the edentulous ridge in RPI and RPA systems. [1, 2]

Stress-Breaking Clasps: Disengaging Akers clasp (RPA) or flexible I-bar (RPI) designs reduce the transmission of stress. [3, 8]

Implant Support: The prosthesis is stabilised with implants in the posterior ridge, which lessen rotation. [7]

Modified Cast Techniques: Reduce tissueward movement by improving denture base adaption [20].

Due to their tooth-tissue support, which encourages rotation around a distal fulcrum under occlusal stress, Kennedy Class I (bilateral distal-extension) and Class II (unilateral distal-extension) RPDs are the main examples of the pump handle effect. Because of their tooth-supported stability, Class III (tooth-bounded) and Class IV (anterior extension) are not usually affected. To lessen the impact in Classes I and II, proper management using mesial rests, stress-breaking clasps, implants, or enhanced imprint techniques is essential. [18-20]

Conclusion

Because the denture base rotates around a distal fulcrum under occlusal force, the pump handle effect is a basic biomechanical problem in removable partial denture (RPD) design that mainly affects Kennedy Class I and II distal-extension prostheses. Abutment tooth mobility, periodontal disease, ridge resorption, clasp deformation, decreased retention, cavities, and patient discomfort can all result from this rotation, which is fuelled by the compressibility of remnant ridge tissues. Its uniqueness to tooth-tissue-supported designs is demonstrated by the fact that it is absent from tooth-supported Class III and IV RPDs. To lessen these negative effects, strategic measures are essential. These include implant support, stress-breaking clasps, mesial rest placement in RPI and RPA systems, and modified cast procedures. By increasing load distribution and design accuracy, contemporary innovations like CAD/CAM precision and flexible materials like PEEK further improve control over the pump handle effect. In distal-extension RPDs, maintaining abutment integrity, guaranteeing prosthesis stability, and improving patient outcomes all depend on the efficient treatment of this impact.

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