

## Review Article

# Review of Implant Support for the Distal Extension Removable Partial Dentures

Li Shue<sup>1</sup>, Richard J. Miron<sup>2,3</sup>, and Zhang Yufeng<sup>2,3\*</sup><sup>1</sup>Department of Stomatology, Huazhong University of Science and Technology, China<sup>2</sup>The State Key Laboratory Breeding Base of Basic Science of Stomatology (Hubei-MOST), Wuhan University, China<sup>3</sup>Department of Oral Implantology, Wuhan University, China**\*Corresponding author**

Zhang Yufeng, Department of Oral Implantology, Wuhan University, 237 Luoyu Road, Wuhan 430079, China, Tel: 8613437295043; Email: hustunion@126.com

Submitted: 24 October 2016

Accepted: 20 November 2016

Published: 22 November 2016

## Copyright

© 2016 Yufeng et al.

## OPEN ACCESS

## Keywords

- Dental implant
- Removable partial denture
- Implant-supported removable partial denture
- Distal extension removable partial denture

**Abstract**

Partially edentulous patients with missing premolars and molars have been conventionally rehabilitated using the free-end removable partial dentures (RPDs). With the advancements in implant dentistry, the benefits of implant-retained/supported mandibular implant overdentures relative to conventional mandibular dentures with bilateral extensions (Class I Kennedy) have now been extensively investigated with well-documented long-term clinical studies. Two prominent advantages of implant-retained mandibular dentures are additional prosthetic retention and stability. This review article highlights the numerous factors affecting the retention and stability of RPDs and demonstrates their advantages over conventional mandibular removable dentures.

**ABBREVIATIONS**

RPD: Removable Partial Denture; IARPD: Implant-Assisted Removable Partial Denture; ISRPD: Implant-Supported Removable Partial Denture; FEA: Finite Element Analysis; ISRPD: Implant Supported Removable Partial Denture; TPS: Titanium Plasma-Spraying; SLA: Sandblasted and Acid-etched; SBB: Stress-Breaking Ball

**INTRODUCTION**

Many years have now passed since the free-end removable partial denture (RPD) was considered the gold standard for missing teeth [1]. Originally used to achieve primary stability, prevent tooth migration and restore patient occlusion, their main limitation is gradual ridge resorption due to pressure areas between the tooth-fibro mucosa and support system [1-3]. The continual resorption of the residual ridge negatively impacts the stability, retention and support of RPDs, thus placing patients in a loop of continual change towards inferior stability and discomfort. Furthermore, bone loss on the alveolar ridge also modifies the occlusal conditions most notably in the distal-extension of RPDs, thus further contributing to bone loss by causing premature contacts and uneven occlusal forces [4]. Kelly was one of the first to report cases of patients with an edentulous maxilla rehabilitated by a complete denture opposing a Kennedy Class I deflection lower arch [5]. In all cases, it was demonstrated that the free-end RPDs led to gradual and continual bone loss in the alveolar ridge under the base of RPDs causing changes

in the occlusal planning and thereby creating anterior teeth overload [6,7]. This condition, where overload contributes to the resorption of anterior area and changes the force and position of mandibular teeth, has since been termed 'Kelly's syndrome'.

To prevent the rotational movements of RPDs, precise attachments or telescope systems have been used on the remaining teeth, and an altered cast technique has been applied to offset different displacement between the remaining teeth and soft tissues during function [8-12]. These studies have led to the discovery and innovation of many new systems used to treat class I Kennedy deflections in the mandible [13-15]. A series of variable alternative options are presented in Table (1). All systems present their advantages and disadvantages and numerous modifications of each have been realized in order to meet patient satisfaction.

Of the listed options in Table (1), the implant-supported removable partial dentures are an alternative to traditional RPD and are now a well-accepted treatment modality [16]. The use of dental implants has become widely accepted and many studies have demonstrated that the association of RPDs with implants improves the prosthetic biomechanics, resulting in greater patient satisfaction [17-20]. Decades have now passed since implants and RPDs have been utilized in combination [15,21]. Standard RPDs were not originally designed to accommodate a posterior implant load point [22]. Due to this limitation, a potentially destructive mismatch of strain distribution was identified between the acrylic and metal framework, which was originally depicted as a

**Table 1:** Prosthetic options for Kennedy Class I/II defection.

Options	Advantages	Disadvantages	Survival rate
Removable partial denture	Low cost, less time consuming	Damage to support system(teeth and fibromucosa)[2]	71.3%-76.6% (5-year) [102]
Implant-supported removable partial denture (ISRPD)	Stable and reliable occlusion, good retention, improved satisfaction, aesthetics and function[15]	long time of procedure, more discomfort than ISFP	Implant: 93.75% RPD:100% (8-year)[103]
Implant-supported fixed prostheses(ISFP)	Easy to use, high masticatory efficiency, comfort, long life span, improved aesthetics and fuction	High cost, long time of procedure, suffer more	94.5% (5-year)[104]
Precise attachment with RPD	Stable and reliable occlusion, good retention, improved satisfaction, aesthetics and function	Dental lab-reliable, need experienced dentist, time consuming	65% (15-year)[105]

risk factor for the failure of acrylic in the material design [22-24]. More recently, investigators have studied the effects of loading a Kennedy class I implant-assisted removable partial denture (IARPD) or implant-supported removable partial denture (ISRPD) using finite element analysis (FEA) [22]. The results from this study showed that the forces on teeth showed strains mainly on the metal framework specifically on the major and minor connectors, while the implant components transferred the load directly to the acrylic base plate [22]. It was also shown by other research groups that implant support helped prevent the displacement of distal extension RPDs and decreased pressure on soft tissues, thus preventing bone loss in the alveolar ridge [3]. Furthermore, it was demonstrated that implants maintain the integrity of the vertical occlusion dimension which was a very common pattern in patients wearing conventional distal-extension removable dentures [24,25]. Thus, with numerous studies demonstrating positive long term results following implant supported RPDs, it has now been demonstrated in 15-year long-term follow-up studies that implant supported removable partial denture (ISRPD) can be used with predictable long-term results in carefully selected and well-maintained patients [18]. Patients should naturally be emphasized of their role in maintenance especially regarding implant care and a comprehensive recall system is necessary to obtain satisfactory long-term results [18].

It is also noteworthy to discuss the cost differences associated with implant-assisted RPDs versus fixed prosthesis. Blum and McCord have previously compared long term costs of both systems and demonstrated that the use of implants in RPDs is seen as a less expensive option than fixed prosthesis where numerous implants would be required with necessary crowns over restorations [17,26]. The purpose of this review article is to discuss and highlight the critical features of this implant supported restoration including the position of implants, inclination of implants, diameter and surface characteristics of implants and attachment systems of implant overdentures used in implant-supported RPDs.

## DISCUSSION AND CONCLUSION

### Position of implants in ISRPD

The challenging problem with the use of conventional RPDs is the distal rotation of the acrylic base in the free-end region of RPDs distal to the last natural tooth. Over 15 years have

now past since it was suggested to add a dental implant distal to the remaining natural dentition with the purpose of resisting rotational forces [27]. Many investigators have proposed that the additional use of implants placed distally effectively changes the Kennedy Class I or II situation to that of the Class III [3]. Due to the placement of an implant in a distal position, fewer implants are needed to achieve a successful distal extension RPD while preventing alveolar ridge bone loss over time [26].

It has previously been shown that implant placement at the residual alveolar ridge at the location of the second molar decreases the stress around teeth [28], mainly the first premolar, which was considered to improve the stress distribution and retention [29-31]. Compared with implants placed at other positions distal to the last missing tooth, it was found that implants located in the region of the second bicuspid presented the lowest value for maximum tendency for displacement of the abutment tooth when compared with other regions[32-34]. It has since been confirmed by other case reports demonstrating the benefit of placing implants at the anterior region, which were considered to fulfill the functional and esthetic requirements of the patient without jeopardizing the natural teeth [17,35-37]. On the other hand, distally-placed implants were proved to increase the displacement levels near and surrounding the support tooth which may do harm to the abutment tooth [38]. It was reported that an inadequate posterior ridge dimension could restrict implant placement to a more anterior place [23, 39]. 5-year follow-up of these cases did not reveal any type of biomechanical or functional problem [39]. Furthermore, an 8-year-follow-up study showed that the placement of implants placed anteriorly allows the maintenance of a compromised residual dentition for the support of RPDs [24]. Within the limits of these studies, it was demonstrated once again that the placement of implants adjacent to the abutment tooth showed favorable results. In the future, the patient might select to restore the edentulous ridges with fixed implant-supported restorations [23].

Of the removable prostheses used in conjunction with natural teeth, implant survival rates were found ranging from 71.3% to 83.7% in the maxilla and 83% to 100% in the mandible [40]. In one retrospective investigation with mandibular ISRPDs by telescopic double crowns, 100% survival rate of implants was observed [41]. Another retrospective study showed 95.5% survival with implants placed in both the maxilla and mandible [3]. Some differences in success rates have been observed

between the maxilla and mandible however these were mainly due to the interaction between the bone quality and quantity [42,43].

### Inclination of implants in ISRPD

There is a consensus that, the location and magnitude of occlusal forces affect the quality and quantity of induced strains and stresses in all components of the bone-implant prosthesis complex [44,45]. An axial force is considered more favorable than a bending force, which distributes stress more vertically throughout the implant to the bone obliquely and generates a high level of traction and decreases compression [46-48]. Furthermore, it has been demonstrated that straight or slightly inclined implants represent less biomechanical risks and optimized load-bearing devices [38]. Therefore, the selection of the appropriate inclination of an implant and the position of implantation are vital critical factors for long-term success [49]. Reports have documented that excessive occlusal load is generated when an implant is excessively inclined [50, 51]. This causes microcracks in the bone surrounding the implant and causes the implant fastening screw to loosen, and eventually causes fractures of the implant body [49]. In order to study the stress of implants placed in the mouth, both vertical and horizontal forces should be calculated as stress patterns seem to play an important role in cortical bone microfractures, implant fractures and/or implant failures. Theoretically, the production of torque is dependent on the position and direction of the force relative to the position of the implant and future research in this area may provide greater clinical success [52]. As such, it has been demonstrated that changing the inclination of an implant body has a considerable effect on the amount and distribution of stress along the implant bone interface and is less favorable for stress distribution [53-55]. It was found that due to effects of torque on the implant body, the compressive stresses on the side of inclination of the implant body, and tensile stresses on the other side were not even. This reflects that the force was not directed towards the long axis of the implant creating uneven distribution which in turn leads to an increase in stress magnitudes and possible future implant failure [49].

It's reported that an ISRPD associated with an implant may allow some implant inclination in distal alveolar ridge because the force distribution from implant to bone tissue is reduced in comparison to a fixed partial prosthesis which was stated above[38]. Straight or slightly inclined implants (5° and 15°) did not represent such biomechanical risks.

With respect to the retentive forces, it has previously been shown that the highest retentive force was observed when the implant was placed at a 0 degree angle. In this clinical situation, the various attachment systems were all shown to maintain the retentive forces at a 0 degree angle [56]. Whereas at a 30 degree implant inclination, implants loaded onto ball attachment systems reduced their force[57]. Similarly, systems using magnetic attachments performed significantly worst when compared to their smaller degree inclination [56,58]. Therefore, having an angled implant or abutment is less favorable for stress distribution[53] and lateral forces will be increased instead [56].

Unfortunately, it is not always possible to place implants

vertically. This may be due to the fact that some form of inclination is needed in order for the implant to be embedded in bone [59]. Nowadays an abutment with a bent neck of an implant body is commercially available, and is widely applied clinically. It may be effective for facilitating the implant/denture connection however the stress distribution on the inclined implant retains additional torque forces. Future research in this area is necessary to optimize this clinical scenario.

### Diameter and length of implants in ISRPD

It is now widely accepted that increasing the length of the implant has a great influence on decreasing the displacement and von Mises tension values. Interestingly however, increasing the diameter of the implant also has a great influence on von Mises tension values but did not influence displacement values [30]. With increases in implant diameter and length it was observed that less stress values were detected for cortical bone and more effective stress distributions for cancellous bone [60]. In cases of low bone quality, the optimum increase in the implant length and diameter should be taken into account to achieve higher primary stability [61]. With respect to implants placed for distal extension RPDs, it is recommended to maximize the length and diameter of implants [62,63]. Several studies report that the implant survival rate of ISRPDs whose implant length ranged from 8 to 13 mm was between 98-99% [15,17,64]. Other investigators have however found that the implant length did not have as much of an influence as the diameter with regard to stress distribution [65]. Interestingly, a recent systematic review has shown that short implant survival is supported by numerous clinical trials as long as the diameter is well chosen [66]. In a prospective, consecutive, controlled, time series clinical study to evaluate the change in oral health quality of life by incorporating short implants with RPD therapy, when 6 mm implants were placed in the first or second molar positions, high initial survival rates were revealed [67]. The increased diameter also reduced the tension values observed within the implant and healing abutment [68]. Recently, the advantages of using wide diameter implants have been well documented in the literature [62,65,69-71]. Variations in the length and diameter of the implant have also been the subject of much research [30]. The survival rate is decreased in cases where short length and small diameter implants were placed for anatomical reasons, and unexpectedly high forces were applied to the implant by bruxism and tooth contact habit [8].

### Surface of dental implants

A great deal of research has been placed on modifications of surface topography to improve the healing and loading protocols of dental implants [72]. In the early 90s, it was found that new bone apposition directly to the surface of implant materials was largely triggered by increased surface topography [69]. Dental implants manufacturers have developed a variety of surfaces with different compositions and degrees of roughness. Numerous reports have shown that both the early fixation and long-term mechanical stability of the prosthesis can be improved by a high roughness profile compared to the originally designed smooth surfaces [72-75]. Moderate roughness of 1-2  $\mu\text{m}$  has been advocated for successful implant bio-integration, thereby

reducing the risk of peri-implantitis and ionic exchange [76]. Various methods have been developed in order to create a rough surface and improve the osseointegration of titanium dental implants, including titanium plasma-spraying, blasting with ceramic particles, acid-etching and anodization [77-81].

Although a variety of techniques exist to increase surface roughness such as titanium plasma-spraying (TPS) [73], grit-blasting with hard ceramic particles, including alumina, titanium oxide and calcium phosphate particles and via acid-etching using HCl, H<sub>2</sub>SO<sub>4</sub>, HNO<sub>3</sub> and HF [82,83], the combination approach seems to favor the most bone formation to date. Sandblasted and acid-etched (SLA) implant surface modification has become an imperative 'gold-standard' of surface modifications while further enhance implant osseointegration [84]. A number of long term studies report a high level of success rates (96.4%-100%) following numerous years post-implantation [85-88]. Furthermore, more recently, the development of modifications to surface chemistry has shown to be an excellent contributor of bone healing. The increased surface hydroxylated titanium content and the greater spatial and functional roughness parameters improve bone to implant contact and decreases loading times [89].

### The attachment of implant overdenture in ISRPD

It is well documented that implants placed at the distal extension of the denture base will minimize the resultant denture displacement. However, there are great differences in settling during a chewing load between the implant and mucosa under the denture base [3]. To protect implants from excessive force, stress-breaking attachments have been manufactured as conventional commercial attachments [90]. The initial retention of a mandibular Kennedy class I implant-assisted removable partial denture retained by two stud attachment systems indicates its clinical predictability and performance and influences patient acceptance [91]. However, these attachments do not fully compensate for the different amount of pressure displacement of the mucosa due to individual variations [92, 93]. Many different attachments may be used to connect implants such as cover screws, healing caps, stress-breaking ball attachment and O-ring attachments. Several studies have evaluated the retention of attachments in implant-retained Overdentures [90,94-96]. The O-ring is a stud attachment that can be used to increase the retention of implant complete and partial overdentures [13]. It includes many advantages such as ease of use, low cost, and possible elimination of a superstructure bar. Its main disadvantage is its wear over time which would decrease its retention over time as well requiring future replacement [97].

Although O-ring attachments are considered the simplest attachment for clinical application, it has been shown that IARPDs with locator attachments demonstrate initial retentive characteristics almost three times greater than those with O-ring attachments [91]. Furthermore, the locator attachments have dual external and internal retentive features, self-aligning design and low vertical height [94]. For these reasons, the locator attachment may be selected as the attachment of choice in the most demanding situations where poor residual ridge anatomy may be compromised [91].

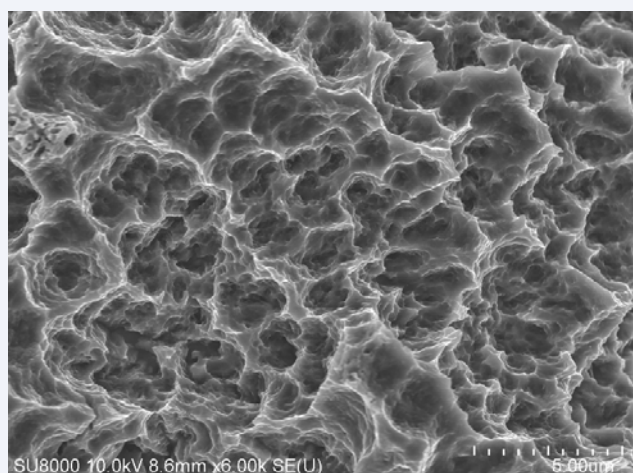
Other investigators have also been interested in the initial retention of IARPDs using various systems. Gharehchahi et al., reported that the precise selection of attachments with or without clasp assemblies may affect the clinical success of mandibular IARPDs [91]. The assembly with locator attachments and suprabulge clasps was shown to provide the highest retentive values compared to O-ring attachments with clasp designs (suprabulge, infrabulge, no clasp) or locator attachments with other clasp designs (infrabulge, no clasp). The overall implant survival was 91.6% [98]. Meanwhile, in another study the O-ring attachments assemblies revealed the lowest retentive forces [91]. The highest retentive force was also observed in the locator blue attachment, followed by the locator black, ball, flat-type and self-adjusting magnetic attachments respectively [56].

To protect implants from excessive force, stress-breaking ball (SBB) attachments have been manufactured as conventional commercial attachments. These attachment types have been shown to not fully compensate for the different amounts of pressure displacement of the mucosa in vivo [92,93]. They typically consist of a flat-top ball head male and O-ring rubber female [99]. Despite these, the advantages of SBB attachments over conventional attachments are as follows: (1) they prevent the implant from excessive occlusal force, (2) they are ready-made, (3) they show appropriate retention, and (4) they can easily be mounted on the denture base. The disadvantages of these attachments include (1) they are approximately 1mm higher than conventional ball attachments and (2) the retentive force cannot be adjusted (Figure 1).

### Future perspectives of implant in RPD

Many advances have been made over the past two decades for the application of implant RPDs. Implants over a free-end RPD were shown to result in smaller swallowed median particle size and improved nutrient than conventional RPDs [100]. As dental implants are made more and more aware by dentists worldwide, their application in RPDs is also becoming more and more prominent [101]. The position, length, diameter, surface modification, inclination and attachment of implants have all been determined parts in their success and many research activities have characterized their role in implant supported RPDs. As the number of aging people continues to rise, the use of implant supported RPDs are becoming more prominent and more research is necessary to improve patient care in this population [98]. The use of implants in class I Kennedy edentulous patients is subject to retain alveolar bone however this has not been well studied over time. Furthermore, for those patients who have lost significant bone over time by using conventional RPDs are subject to receiving bone enhancement procedures using a combination of bone grafts, membranes and/or growth factors. It remains to be investigated what effect these procedures have on overall patient satisfaction in patients following therapy in combination with future IARPD. Another area which requires attention is the cost of implant supported RPDs versus that of conventional RPDs. As dental implants become increasingly popular, their cost have also decreased with time and their increased longevity when compared to remaining natural teeth such as premolars at the distal extension of class I edentulous patients are subject to additional risk of tooth loss which would necessitate either





**Figure 1** Scanning electron microscopic (SEM) images of implant surface treated with a sandblast and acid-etched (SLA) method.

modifications to their pre-existing conventional RPDs or complete new ones. Thus, with all these issues being contributing factors to the overall costs of both systems, the total cost of providing implant overdentures is not as large as one might expect when compared to conventional RPDs.

## ACKNOWLEDGEMENTS

I'll give my great thanks to Mr Shi Dengsong for both help and support.

## REFERENCES

- Petropoulos VC, Rashedi B. Removable partial denture education in U.S. dental schools. *J Prosthodont*. 2006; 15: 62-68.
- Hummel SK, Wilson MA, Marker VA, Nunn ME. Quality of removable partial dentures worn by the adult U.S. population. *J Prosthet Dent*. 2002; 88: 37-43.
- Ohkubo C, Kurihara D, Shimpō H, Suzuki Y, Kokubo T, Hosoi T. Effect of implant support on distal extension removable partial dentures: *in vitro* assessment. *J Oral Rehabil*. 2007; 34: 52-56.
- Ozan O, Orhan K, Aksoy S, Icen M, Bilecenoglu B, Sakul BU. The effect of removable partial dentures on alveolar bone resorption: a retrospective study with cone-beam computed tomography. *J Prosthodont*. 2013; 22: 42-48.
- Kelly E. Changes caused by a mandibular removable partial denture opposing a maxillary complete denture. *J Prosthet Dent*. 1972; 27: 140-150.
- Jorge JH, Quishida CC, Vergani CE, Machado AL, Pavarina AC, Giampaolo ET. Clinical evaluation of failures in removable partial dentures. *J Oral Sci*. 2012; 54: 337-342.
- Saito M, Notani K, Miura Y, Kawasaki T. Complications and failures in removable partial dentures: a clinical evaluation. *J Oral Rehabil*. 2002; 29: 627-633.
- Kono K, Kurihara D, Suzuki Y, Ohkubo C. Pressure distribution of implant-supported removable partial dentures with stress-breaking attachments. *J Prosthodont Res*. 2014; 58: 115-120.
- Schmitt J, Wichmann M, Eitner S, Hamel J, Holst S. Five-year clinical follow-up of prefabricated precision attachments: a comparison of uni- and bilateral removable dental prostheses. *Quintessence international*. 2011; 42: 413-418.
- Ozcelik TB, Yilmaz B. An alternative procedure for positioning a prefabricated extracoronary attachment in a removable partial denture. *J Prosthet Dent*. 2008; 100: 240-241.
- Wolf K, Ludwig K, Hartfil H, Kern M. Analysis of retention and wear of ball attachments. *Quintessence Int*. 2009; 40: 405-412.
- Chaiyabutr Y, Brudvik JS. Removable partial denture design using milled abutment surfaces and minimal soft tissue coverage for periodontally compromised teeth: a clinical report. *J Prosthet Dent*. 2008; 99: 263-266.
- Pellizzer EP, Verri FR, Falcon-Antenucci RM, Goiato MC, Gennari Filho H. Evaluation of different retention systems on a distal extension removable partial denture associated with an osseointegrated implant. *J Craniofac Surg*. 2010; 21: 727-734.
- Costa MM, da Silva MA, Oliveira SA, Gomes VL, Carvalho PM, Lucas BL. Photoelastic study of the support structures of distal-extension removable partial dentures. *J Prosthodont*. 2009; 18: 589-595.
- Mitrani R, Brudvik JS, Phillips KM. Posterior implants for distal extension removable prostheses: a retrospective study. *The International journal of periodontics & restorative dentistry*. 2003; 23: 353-359.
- Romeo E, Chiapasco M, Ghisolfi M, Vogel G. Long-term clinical effectiveness of oral implants in the treatment of partial edentulism. Seven-year life table analysis of a prospective study with ITI dental implants system used for single-tooth restorations. *Clin Oral Implants Res*. 2002; 13: 133-143.
- Bortolini S, Natali A, Franchi M, Coggiola A, Consolo U. Implant-retained removable partial dentures: an 8-year retrospective study. *J Prosthodont*. 2011; 20: 168-172.
- Mijiritsky E, Lorean A, Mazor Z, Levin L. Implant Tooth-Supported Removable Partial Denture with at Least 15-Year Long-Term Follow-Up. *Clin Implant Dent Relat Res*. 2015; 17: 917-922.
- Campos CH, Gonçalves TM, Garcia RC. Implant-Supported Removable Partial Denture Improves the Quality of Life of Patients with Extreme Tooth Loss. *Braz Dent J*. 2015; 26: 463-467.
- Mijiritsky E, Lorean A, Mazor Z, Levin L. Implant Tooth-Supported Removable Partial Denture with at Least 15-Year Long-Term Follow-Up. *Clin Implant Dent Relat Res*. 2015; 17: 917-922.
- Kuzmanovic DV, Payne AG, Purton DG. Distal implants to modify the Kennedy classification of a removable partial denture: a clinical report. *J Prosthet Dent*. 2004; 92: 8-11.
- Shahmiri R, Aarts JM, Bennani V, Atieh MA, Swain MV. Finite element analysis of an implant-assisted removable partial denture. *J Prosthodont*. 2013; 22: 550-555.
- Grossmann Y, Nissan J, Levin L. Clinical effectiveness of implant-supported removable partial dentures: a review of the literature and retrospective case evaluation. *Journal of oral and maxillofacial surgery: official journal of the American Association of Oral and Maxillofacial Surgeons*. 2009; 67: 1941-1946.
- Kaufmann R, Friedli M, Hug S, Mericske-Stern R. Removable dentures with implant support in strategic positions followed for up to 8 years. *Int J Prosthodont*. 2009; 22: 233-241.
- Zitzmann NU, Sendi P, Marinello CP. An economic evaluation of implant treatment in edentulous patients-preliminary results. *Int J Prosthodont*. 2005; 18: 20-27.
- Blum IR, McCord JF. A clinical investigation of the morphological changes in the posterior mandible when implant-retained overdentures are used. *Clin Oral Implants Res*. 2004; 15: 700-708.

27. Jang Y, Emtiaz S, Tarnow DP. Single implant-supported crown used as an abutment for a removable cast partial denture: a case report. *Implant Dent.* 1998; 7: 199-204.
28. Oh WS, Oh TJ, Park JM. Impact of implant support on mandibular free-end base removable partial denture: theoretical study. *Clin Oral Implants Res.* 2016; 27: 87-90.
29. Rodrigues RC, Faria AC, Macedo AP, de Mattos Mda G, Ribeiro RF. Retention and stress distribution in distal extension removable partial dentures with and without implant association. *J Prosthodont Res.* 2013; 57: 24-29.
30. Verri FR, Pellizzer EP, Rocha EP, Pereira JA. Influence of length and diameter of implants associated with distal extension removable partial dentures. *Implant Dent.* 2007; 16: 270-280.
31. Mijiritsky E. Implants in conjunction with removable partial dentures: a literature review. *Implant Dent.* 2007; 16: 146-154.
32. Cunha LD, Pellizzer EP, Verri FR, Falcon-Antenucci RM, Goiato MC. Influence of ridge inclination and implant localization on the association of mandibular Kennedy class I removable partial denture. *J Craniofac Surg.* 2011; 22: 871-875.
33. Cunha LD, Pellizzer EP, Verri FR, Pereira JA. Evaluation of the influence of location of osseointegrated implants associated with mandibular removable partial dentures. *Implant Dent.* 2008; 17: 278-287.
34. Matsudate Y, Yoda N, Nanba M, Ogawa T, Sasaki K. Load distribution on abutment tooth, implant and residual ridge with distal-extension implant-supported removable partial denture. *J Prosthodont Res.* 2016; 60: 282-288.
35. Jackson TR. Removable partial overdentures with natural root structure and osseointegrated fixtures. *Dent Clin North Am.* 1990; 34: 711-728.
36. Amet EM. A unique method of combining teeth and endosseous implants for a stable removable prosthesis. *J Oral Implantol.* 1993; 19: 216-220.
37. Ganz SD. Combination natural tooth and implant-borne removable partial denture: a clinical report. *J Prosthet Dent.* 1991; 66: 1-5.
38. de Freitas Santos CM, Pellizzer EP, Verri FR, de Moraes SL, Falcon-Antenucci RM. Influence of implant inclination associated with mandibular class I removable partial denture. *J Craniofac Surg.* 2011; 22: 663-668.
39. de Freitas R, Kaizer OB, Hamata MM, de Resende DR, de Oliveira Fortes Kaizer R. Prosthetic rehabilitation of a bone defect with a teeth-implant supported, removable partial denture. *Implant Dent.* 2006; 15: 241-247.
40. Bryant SR, MacDonald-Jankowski D, Kim K. Does the type of implant prosthesis affect outcomes for the completely edentulous arch? *Int J Oral Maxillofac Implants.* 2007; 22: 117-139.
41. Rinke S, Ziebolz D, Ratka-Krüger P, Frisch E. Clinical Outcome of Double Crown-Retained Mandibular Removable Dentures Supported by a Combination of Residual Teeth and Strategic Implants. *J Prosthodont.* 2015; 24: 358-365.
42. Hutton JE, Heath MR, Chai JY, Harnett J, Jemt T, Johns RB, et al. Factors related to success and failure rates at 3-year follow-up in a multicenter study of overdentures supported by Branemark implants. *Int J Oral Maxillofac Implants.* 1995; 10: 33-42.
43. Suzuki Y, Osada H, Kobayashi M, Katoh M, Kokubo Y, Sato J, et al. Long-term clinical evaluation of implant over denture. *J Prosthodont Res.* 2012; 56: 32-36.
44. Mericske-Stern R, Venetz E, Fahrlander F, Burgin W. *In vivo* force measurements on maxillary implants supporting a fixed prosthesis or an overdenture: a pilot study. *J Prosthet Dent.* 2000; 84: 535-547.
45. Glantz PO, Rangert B, Svensson A, Stafford GD, Arnvidarson B, Randow K, et al. On clinical loading of osseointegrated implants. A methodological and clinical study. *Clin Oral Implants Res.* 1993; 4: 99-105.
46. Bevilacqua M, Tealdo T, Pera F, Menini M, Mossolov A, Drago C, et al. Three-dimensional finite element analysis of load transmission using different implant inclinations and cantilever lengths. *Int J Prosthodont.* 2008; 21: 539-542.
47. Sahin S, Cehreli MC, Yalçin E. The influence of functional forces on the biomechanics of implant-supported prostheses--a review. *J Dent.* 2002; 30: 271-282.
48. Cehreli MC, Iplikcioglu H. *In vitro* strain gauge analysis of axial and off-axial loading on implant supported fixed partial dentures. *Implant Dent.* 2002; 11: 286-292.
49. Watanabe F, Hata Y, Komatsu S, Ramos TC, Fukuda H. Finite element analysis of the influence of implant inclination, loading position, and load direction on stress distribution. *Odontology.* 2003; 91: 31-36.
50. Moyer BJ, Lahey PJ, Weinberg EH, Rumelhart C, Harris WH. Effects of application of metal plates to bone. Comparison of a rigid with a flexible plate. *Acta Orthop Belg.* 1980; 46: 806-815.
51. Hassler CR, Rybicki EF, Simonen FA, Weis EB. Measurements of healing at an osteotomy in a rabbit calvarium: the influence of applied compressive stress on collagen synthesis and calcification. *Journal of biomechanics.* 1974; 7: 545-550.
52. Holmgren EP, Seckinger RJ, Kilgren LM, Mante F. Evaluating parameters of osseointegrated dental implants using finite element analysis--a two-dimensional comparative study examining the effects of implant diameter, implant shape, and load direction. *J Oral Implantol.* 1998; 24: 80-88.
53. Brosh T, Pilo R, Sudai D. The influence of abutment angulation on strains and stresses along the implant/bone interface: comparison between two experimental techniques. *J Prosthet Dent.* 1998; 79: 328-334.
54. Canay S, Hersek N, Akpınar I, Asik Z. Comparison of stress distribution around vertical and angled implants with finite-element analysis. *Quintessence international.* 1996; 27: 591-598.
55. Federick DR, Caputo AA. Effects of overdenture retention designs and implant orientations on load transfer characteristics. *J Prosthet Dent.* 1996; 76: 624-632.
56. Yang TC, Maeda Y, Gonda T, Kotecha S. Attachment systems for implant overdenture: influence of implant inclination on retentive and lateral forces. *Clin Oral Implants Res.* 2011; 22: 1315-1319.
57. Gulizio MP, Agar JR, Kelly JR, Taylor TD. Effect of implant angulation upon retention of overdenture attachments. *J Prosthodont.* 2005; 14: 3-11.
58. Chen J, Tomotake Y, Watanabe M, Ishida Y, Nagao K, Ichikawa T. Telescopic magnetic attachment for implant-supported denture: evaluation of splint effect. *Int J Oral Maxillofac Implants.* 2011; 26: 657-664.
59. Hobkirk JA, Havthouls TK. The influence of mandibular deformation, implant numbers, and loading position on detected forces in abutments supporting fixed implant superstructures. *J Prosthet Dent.* 1998; 80: 169-174.
60. Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three-dimensional finite element analysis. *J Prosthet Dent.* 2008; 100: 422-431.

61. Barikani H, Rashtak S, Akbari S, Badri S, Daneshparvar N, Rohn A. The effect of implant length and diameter on the primary stability in different bone types. *J Dent (Tehran)*. 2013; 449-455.
62. Iplikcioglu H, Akca K. Comparative evaluation of the effect of diameter, length and number of implants supporting three-unit fixed partial prostheses on stress distribution. *J Dent*. 2002; 30: 41-46.
63. Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. *J Prosthet Dent*. 2001; 85: 585-598.
64. Grossmann Y, Levin L, Sadan A. A retrospective case series of implants used to restore partially edentulous patients with implant-supported removable partial dentures: 31-month means follow-up results. *Quintessence international*. 2008; 39: 665-671.
65. Himmlová L, Dostálová T, Kácovský A, Konvicková S. Influence of implant length and diameter on stress distribution: a finite element analysis. *J Prosthet Dent*. 2004; 91: 20-25.
66. Atieh MA, Zadeh H, Stanford CM, Cooper LF. Survival of short dental implants for treatment of posterior partial edentulism: a systematic review. *Int J Oral Maxillofac Implants*. 2012; 27: 1323-1331.
67. Gates WD, Cooper LF, Sanders AE, Reside GJ, De Kok IJ. The effect of implant-supported removable partial dentures on oral health quality of life. *Clin Oral Implants Res*. 2014; 25: 207-213.
68. Ding X, Zhu XH, Liao SH, Zhang XH, Chen H. Implant-bone interface stress distribution in immediately loaded implants of different diameters: a three-dimensional finite element analysis. *J Prosthodont*. 2009; 18: 393-402.
69. Termeie D, Klokkevold PR, Caputo AA. Effect of Implant Diameter and Ridge Dimension on Stress Distribution in Mandibular First Molar Sites-A Photoelastic Study. *J Oral Implantol*. 2015; 41: 165-173.
70. Misch CE. Implant design considerations for the posterior regions of the mouth. *Implant Dent*. 1999; 8: 376-386.
71. Sato Y, Shindoi N, Hosokawa R, Tsuga K, Akagawa Y. A biomechanical effect of wide implant placement and offset placement of three implants in the posterior partially edentulous region. *J Oral Rehabil*. 2000; 27: 15-21.
72. Le Guehennec L, Soueidan A, Layrolle P, Amouriq Y. Surface treatments of titanium dental implants for rapid osseointegration. Dental materials: official publication of the Academy of Dental Materials. 2007; 23: 844-854.
73. Buser D, Schenk RK, Steinemann S, Fiorellini JP, Fox CH, Stich H. Influence of surface characteristics on bone integration of titanium implants. A histomorphometric study in miniature pigs. *J Biomed Mater Res*. 1991; 25: 889-902.
74. Wennerberg A, Albrektsson T, Andersson B, Krol JJ. A histomorphometric and removal torque study of screw-shaped titanium implants with three different surface topographies. *Clin Oral Implants Res*. 1995; 6: 24-30.
75. Bächle M, Kohal RJ. A systematic review of the influence of different titanium surfaces on proliferation, differentiation and protein synthesis of osteoblast-like MG63. *Clin Oral Implants Res*. 2004; 15: 683-692.
76. Albrektsson T, Wennerberg A. The impact of oral implants - past and future, 1966-2042. *J Can Dent Assoc*. 2005; 71: 327.
77. Cunha A, Renz RP, Blando E, de Oliveira RB, Hübner R. Osseointegration of atmospheric plasma-sprayed titanium implants: Influence of the native oxide layer. *J Biomed Mater Res A*. 2014; 102: 30-36.
78. Anselme K, Bigerelle M. Statistical demonstration of the relative effect of surface chemistry and roughness on human osteoblast short-term adhesion. *Journal of materials science Materials in medicine*. 2006; 17: 471-479.
79. van Velzen FJ, Ofec R, Schulten EA, Ten Bruggenkate CM. 10-year survival rate and the incidence of peri-implant disease of 374 titanium dental implants with a SLA surface: a prospective cohort study in 1. *Clin Oral Implants Res*. 2015; 26: 1121-1128.
80. Philipp A, Duncan W, Roos M, Hammerle CH, Attin T, Schmidlin PR. Comparison of SLA(R) or SLActive (R) implants placed in the maxillary sinus with or without synthetic bone graft materials--an animal study in sheep. *Clin Oral Implants Res*. 2014; 25: 1142-1148.
81. Kang MK, Moon SK, Kwon JS, Kim KM, Kim KN. Characterization of hydroxyapatite containing a titania layer formed by anodization coupled with blasting. *Acta Odontol Scand*. 2014; 72: 989-998.
82. Novaes AB, Papalexiou V, Grisi MF, Souza SS, Taba M, Kajiwarra JK. Influence of implant microstructure on the osseointegration of immediate implants placed in periodontally infected sites. A histomorphometric study in dogs. *Clin Oral Implants Res*. 2004; 15: 34-43.
83. Cochran DL, Buser D, ten Bruggenkate CM, Weingart D, Taylor TM, Bernard JP, et al. The use of reduced healing times on ITI implants with a sandblasted and acid-etched (SLA) surface: early results from clinical trials on ITI SLA im. *Clin Oral Implants Res*. 2002; 13: 144-153.
84. Mesquita P, Gomes Pde S, Sampaio P, Juodzbalsys G, Afonso A, Fernandes MH. Surface properties and osteoblastic cytocompatibility of two blasted and Acid-etched titanium implant systems with distinct microtopography. *Journal of oral & maxillofacial research*. 2012; 3: 4.
85. Rodrigo D, Cabello G, Herrero M, Gonzalez D, Herrero F, Aracil L, et al. Retrospective multicenter study of 230 6-mm SLA-surfaced implants with 1- to 6-year follow-up. *Int J Oral Maxillofac Implants*. 2013; 28: 1331-1337.
86. Kokovic V, Jung R, Feloutzis A, Todorovic VS, Jurisic M, Hammerle CH. Immediate vs. early loading of SLA implants in the posterior mandible: 5-year results of randomized controlled clinical trial. *Clin Oral Implants Res*. 2014; 25: 114-119.
87. Oates TW, Valderrama P, Bischof M, Nedir R, Jones A, Simpson J, et al. Enhanced implant stability with a chemically modified SLA surface: a randomized pilot study. *Int J Oral Maxillofac Implants*. 2007; 22: 755-760.
88. Lethaus B, Kälber J, Petrin G, Brandstätter A, Weingart D. Early loading of sandblasted and acid-etched titanium implants in the edentulous mandible: a prospective 5-year study. *Int J Oral Maxillofac Implants*. 2011; 26: 887-892.
89. Buser D, Broggini N, Wieland M, Schenk RK, Denzer AJ, Cochran DL, et al. Enhanced bone apposition to a chemically modified SLA titanium surface. *J Dent Res*. 2004; 83: 529-533.
90. Kono K, Kurihara D, Suzuki Y, Ohkubo C. *In vitro* assessment of mandibular single/two implant-retained overdentures using stress-breaking attachments. *Implant Dent*. 2014; 23: 456-462.
91. Gharehchahi J, Asadzadeh N, Mirmortazavi A, Shakeri MT. Maximum dislodging forces of mandibular implant-assisted removable partial dentures: *in vitro* assessment. *J Prosthodont*. 2013; 22: 543-549.
92. Chen KW, Lin TM, Liu PR, Ramp LC, Lin HJ, Wu CT, et al. An analysis of the implant-supported overdenture in the edentulous mandible. *J Oral Rehabil*. 2013; 40: 43-50.
93. Slot W, Raghoobar GM, Vissink A, Huddleston Slater JJ, Meijer HJ. A systematic review of implant-supported maxillary overdentures after a mean observation period of at least 1 year. *Journal of clinical periodontology*. 2010; 37: 98-110.

94. Trakas T, Michalakis K, Kang K, Hirayama H. Attachment systems for implant retained overdentures: a literature review. *Implant Dent.* 2006; 15: 24-34.
95. Scherer MD, McGlumphy EA, Seghi RR, Campagni WV. Comparison of retention and stability of two implant-retained overdentures based on implant location. *J Prosthet Dent.* 2014; 112: 515-521.
96. Campos CH, Gonçalves TM, Rodrigues Garcia RC. Implant retainers for free-end removable partial dentures affect mastication and nutrient intake. *Clin Oral Implants Res.* 2014; 25: 957-961.
97. Winkler S, Piermatti J, Rothman A, Siamos G. An overview of the O-ring implant overdenture attachment: clinical reports. *J Oral Implantol.* 2002; 28: 82-86.
98. Ortiz-Puigpelat O, Gargallo-Albiol J, Hernandez-Alfaro F, Cabratosa-Termes J. Short-term retrospective case series of implant-assisted removable partial dentures with locator abutments. *The International journal of periodontics & restorative dentistry.* 2014; 34: 121-128.
99. Suzuki Y, Ohkubo C, Kurtz KS. Clinical application of stress-breaking ball attachment for implant overdenture. *J Prosthodont Res.* 2013; 57: 140-144.
100. Campos CH, Gonçalves TM, Rodrigues Garcia RC. Implant retainers for free-end removable partial dentures affect mastication and nutrient intake. *Clin Oral Implants Res.* 2014; 25: 957-961.
101. Al-Dwairi ZN, El Masoud BM, Al-Afifi SA, Borzabadi-Farahani A, Lynch E. Awareness, attitude, and expectations toward dental implants among removable prostheses wearers. *J Prosthodont.* 2014; 23: 192-197.
102. Kapur KK, Deupree R, Dent RJ, Hasse AL. A randomized clinical trial of two basic removable partial denture designs. Part I: Comparisons of five-year success rates and periodontal health. 1994; 72: 268-282.
103. Bortolini S, Natali A, Franchi M, Coggiola A, Consolo U. Implant-retained removable partial dentures: an 8-year retrospective study. *J Prosthodont.* 2011; 20: 168-172.
104. Muddugangadhar BC, Amarnath GS, Sonika R, Chheda PS, Garg A. Meta-analysis of Failure and Survival Rate of Implant-supported Single Crowns, Fixed Partial Denture, and Implant Tooth-supported Prostheses. *J Int Oral Health.* 2015; 7: 11-17.
105. Owall B. Precision attachment retained removable partial dentures: 1. Technical long-term study. 1991; 4: 249-257.

#### Cite this article

Shue L, Miron RJ, Yufeng Z (2016) Review of Implant Support for the Distal Extension Removable Partial Dentures. *JSM Dent Surg* 1(1): 1007.