Biomechanical aspects of reinforced implant overdentures: a systematic review

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ABSTRACT

Purpose. The purpose of this systematic review was to investigate the effect of the reinforcement on the mechanical behavior of implant overdenture (IOD) bases and its cumulative biological effect on the underlying supporting structures (implants and residual ridge).

Material and methods. The required documents were collected electronically from PubMed and Web of Science databases targeting papers in English with denture base reinforcement for IOD in order to recognize the principal outcomes of reinforcement on the mechanical and biological properties of overdenture. Such biological outcomes as: strains on implants, peri-implant bone loss, residual ridge resorption, and strain on the residual alveolar ridge.

Results. A total of 269 citations were identified. After excluding any repeated articles between databases and the application of exclusion and inclusion criteria, only 13 publications fulfilled the inclusion criteria. Three publications investigated the mechanical properties of fiber and/or metal-reinforced implant overdenture while another 3 articles investigated the effect of metal reinforcement on stress distribution and strains transmitted to the underlying implants. In addition, 3 in vitro studies investigated the effect of metal reinforcement on overdenture base strain and its stresses. Stress distribution to the residual ridge and strain characteristics of the underlying tissues were investigated by 2 in vitro studies. Five clinical studies assisting the clinical and prosthetic maintenance of metal-reinforced IOD were included. Data concerning the denture base fracture, relining, peri-implant bone loss, probing depth, and implant survival rates during the functional period were extracted and considered in order to evaluate the mechanical properties of the denture base, residual ridge resorption and implant preservation rate, respectively.

Conclusion. The use of a denture base reinforcement can reduce the fracture incidence of IOD by enhancing its flexural properties and reducing the overdenture base deformation. Strains on the

underlying supporting structures of overdenture prosthesis including dental implants and the residual ridge can be decreased and evenly distributed by using a metal reinforcement.

1. INTRODUCTION

Implants are well-known for improving retention, stability and masticatory function of edentulous patients. Implant overdenture (IOD) is a reliable well-accepted treatment option used to overcome the functional deficiencies associated with conventional dentures and to enhance residual ridge preservation (Melescanu Imre et al., 2011). Various attachment systems are available for IOD which can be divided according to their shape into splinted types such as bars with different cross-sections and solitary types which include locators, balls, and telescopes (Barão et al., 2009).

Despite the benefits of overdenture treatment, mechanical and biological complications such as denture base fracture, looseness of attachment, implant fracture, bone loss, and peri-implant tissue inflammation can be encountered (Vahidi and Pinto-Sinai, 2015). These complications may be due to the lack of sufficient inter-arch space, the type of antagonistic arch, the type of occlusion, and the difference in the degree of displacement between supporting structures under occlusal force. (Gupta et al., 2015)

Stress transmission under occlusal forces differs considerably between an IOD and a conventional complete denture (Fontijn-Tekamp et al., 2000). The abutments occupy a part of the denture base space. Moreover, they behave as a fulcrum of rotational movement under functional forces and cause a concentration of high stresses in the housing area (Gonda et al., 2007). The degree of rotation and stresses transferred from the overdenture base to the implant seem to be affected by the attachment systems and the geometric anatomy of the residual ridge (Jo and Dong, 2015). Although vertical and horizontal stresses are delivered, the horizontal stress is considered to be more harmful to the implant and the surrounding bone (Yoo et al., 2017). An excessive load beyond the physiologic limits may cause an implant fracture and/or bone loss around the implants and subsequent implant failure (Chrcanovic et al., 2018; Chrcanovic et al., 2017; Hsu et al., 2012).

Denture bases can be reinforced with metal (Yoshida et al., 2016), carbon fibers (Sipahi et al., 2006), polyethylene fibers (Narva et al., 2005), and glass fibers (Vallittu, 2018). In all of the methods used to reinforce the denture bases, the reinforcing material should adhere well to the denture base material and should be located close to the fracture initiation point. Reinforcement can be used to improve the flexural properties and prevent fractures of IOD (Gibreel et al., 2018).In addition, it improves stiffness and decreases denture base deformation (Gonda et al., 2007).

Ridge resorption occurs by compressive stresses transmitted to the underlying bone (Maruo et al., 2010). Rigid metal reinforcement has been reported to reduce stresses under the denture base and distributes masticatory forces more evenly on the underlying residual alveolar ridge (Gonda et al., 2013). Moreover, strains on the underlying implants could be minimized by using metal reinforcement for the IOD base (Takahashi et al., 2017).

Therefore, the aim of this systematic review was to investigate the effect of the reinforcement on the mechanical behavior of IOD bases and its cumulative biological effect on the underlying supporting structures (implants and residual ridge).

2. MATERIAL AND METHODS

2.1 Focus question

The (PIO) question to be focused on was "How does the reinforcement affect the mechanics and biomechanics of overdenture treatment in terms of denture base, implants, and residual ridge?

2.2 Search strategy

The necessary documents were collected electronically from the PubMed, and Web of Science databases. Additional hand searching of the databases was done as well as further reading of the bibliographies of the relevant publications. The keywords for the search and the strategy are represented in Table 1.

Focus question	**How does the reinforcement affect the mechanics and biomechanics of overdenture treatment in terms of**

	denture base, implants and residual ridge?
Search strategy	
Population	#1 Overdent*
Intervention	# 2 ((((((((enforc*) OR reinforc*) OR strength*) OR metal) OR nylon) OR rubber) OR glass) OR fiber*) OR carbon
outcome	#3 (((((((((((((((stress) OR strain) OR deformation) OR load) OR mechanic*) OR strength) OR fracture) OR bone preserv*) OR bone maintain*) OR ridge preserv*) OR bone height) OR maintain*) OR biomechanic*) OR compress*) OR tensile) OR impact) OR abrasive
Combined	#1 AND #2 AND #3

Table 1. Search strategy developed for PubMed and modified properly for other databases.

2.3 Eligibility Criteria

The published studies had to meet the following criteria: (i) type of study (clinical study or in vitro study); (ii) type of intervention (placement of denture base reinforcement for IOD); and (iii) principal outcomes (flexural strength, fracture resistance, fracture load, denture base strains or deformation, strains on implants, peri-implant bone resorption, implant survival, stress distribution, residual ridge preservation, and residual alveolar ridge resorption).

2.4 Inclusion and exclusion criteria

The in vitro and in vivo studies dealing with the reinforcement of IOD were screened. The studies included were in English and with an approachable full text. Studies related to fixed dental prostheses and tooth supported overdentures were not screened. Case reports and studies related to abnormal conditions like maxillofacial studies, articles not written in English, and/or missing full texts were excluded.

2.5 Screening and selection

The titles and abstracts of all the articles were screened by 3 authors (MG, FM, NE), and the full- text articles were reviewed by 2 authors (MG, AK) independently. An agreement was reached by consensus between the two reviewers, and if necessary, a third reviewer (MS) was consulted. Kappa values were 0.84 and 0.83, indicating a high agreement. After screening, some articles were excluded because of the lack of data relevant for the evaluation. Existing citation bibliographies were examined for any further articles related to the topic that could be added. Figure 1 represents the flow of screening procedures.

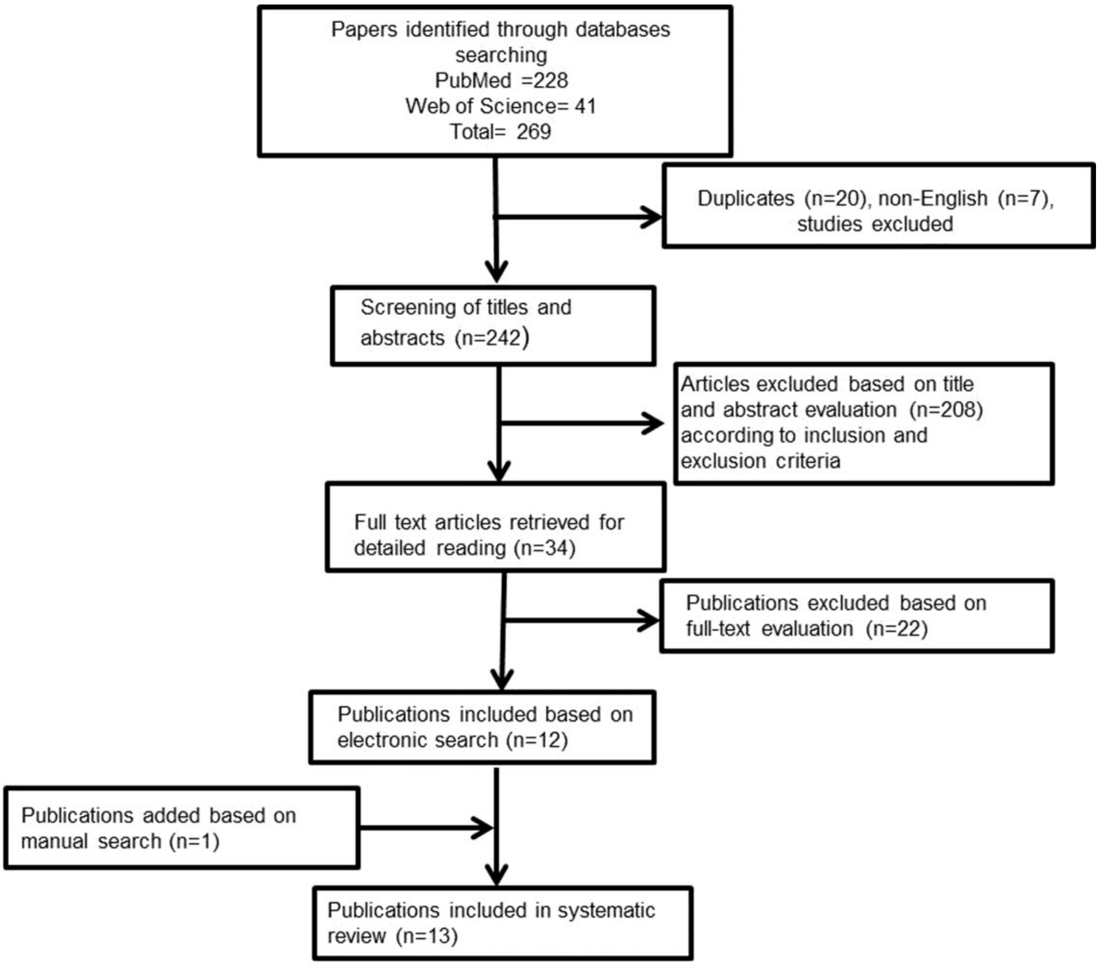

Figure 1. Flow of screening procedures

2.6 Data extraction

After completion of the search strategy, the following characteristics were tabulated from the final selected articles (n= 13): Author name and year of publication, study type, reinforcement material and form, prosthesis type, prosthesis material, attachment type, investigated parameter, investigation method, and the effect of reinforcement (Table 2). Due to the variability of outcomes measurement and methodology in the included publications, quantitative statistical meta-analysis was not possible therefore, data were descriptively analyzed.

Author and year	**Study type**	**Reinforcement material**	**Reinforcement form**	**Experimental situation**	**Material of prosthesis**	**Investigation parameter and method**	**Anchorage incorporated**	**Results in brief**
Gibreel et al., 2018	In vitro	E-glass fiber	Silanated bidirectional fiber weaves (2 or 4 layers) placed either above, adjacent, or above and adjacent to the metal housing	Specimens simulating IOD	Auto-polymerized acrylic resin	Static flexural strength, flexural modulus, and flexural strain	Locator attachment	Results revealed a significant difference only in flexural strength values among the control group (92.4 ± 14 MPa) and the 2 subgroups: 4L-A (116 ± 7.3 MPa) with 4 layers of glass fiber above the housing and 4L-A+4L-N (117.1 ±6 MPa) with 4 layers above and 4 layers adjacent to the housing A significant effect only came from the number of the reinforcing layers and not their location
Rached et al., 2011	In vitro	Metal (Stainless steel) Non-metal (E-glass, polyethylene braids and polyaramid fibers)	Stainless steel bar (BS), or mesh (SM) Unidirectional E-glass fibers (GF) or mesh (GM) Woven Polyethylene braids (PE) Polyaramid fibers (PA)	Specimens simulating IOD prosthesis Two investigated spaces for reinforcement: 2.5 and 1 mm and 7 test groups	Light-polymerized acrylic resin	Dynamic and static loading capacity	Ball attachment.	The number of failures under fatigue and static loading of glass fiber, polyethylene , and polyaramid specimens differed significantly from the control group and SM one For the 2.5 mm space groups, the same reinforcements also exhibited higher static load means than the control For the 1.0 mm space groups under static load, no significant differences were

								detected among the control and the reinforced groups
(Fajardo et al., 2011)	In vitro	E-glass fiber	Mesh	Specimens simulating IOD prosthesis with different thickness (1.5 or 3 mm) with and without a reinforcement	Heat polymerized acrylic resin	Fracture loads (N)	Simulated abutments	The addition of E-glass fibers significantly increased the fracture load values of simulated implant overdenture even with thin acrylic resin sections No interaction between the fiber mesh and the thickness The increase in the fracture load was similar when adding E-glass fibers or increasing the acrylic resin thickness
Takahashi et al., 2017	In vitro	Cast metal (Co-Cr)	Residual ridge reinforcement only or together with a palatal bar	Maxillary experimental IOD supported by 2, 4, or 6 implants	Auto-polymerized acrylic resin	Strain gauge analysis aimed to evaluate the effect of reinforcement on the underlying implants strain in various locations and numbers To compare IOD with and without a reinforcement	Healing abutments	Reinforcement of maxillary implant overdentures decreased strains on the underlying anterior and posterior implants regardless of the denture design and implant configuration compared to the non-reinforced bases Non-significant decrease in stresses for premolar implants Palatal bar reinforcement decreased the strain most on the anterior and molar implants but not significantly
Takahashi et al., 2016	In vitro	Metal (Co-Cr)	Residual ridge reinforcement only or together with a palatal bar.	Maxillary experimental IOD on 2, 4, or 6 implants	Auto-polymerized acrylic resin	Strain gauge analysis aimed to evaluate the effect of reinforcement on	Healing abutments	Significant decrease on the labial and palatal sides strain levels of the reinforced palateless dentures The labial strain levels of the reinforced

						maxillary implant overdenture bases strain with and without palatal coverage in a variety of implants configuration (number and location)		palateless dentures in most of the implant configurations were similar to the dentures with palatal coverage Reinforcement may prevent prosthetic and implant complications.
Takahashi et al., 2015	In vitro	Cast metal (Co-Cr)	Over the residual ridge and the tops of the copings: with and without palatal bar Over the residual ridge and the sides of the copings : with and without palatal bar	Maxillary IOD on 2 copings	Auto-polymerized acrylic resin	Strain gauge analysis aimed to evaluate the effect of reinforcement on the strains within an IOD base	Dome shaped copings	Reinforcement significantly decreased strains in the canine, middle, and posterior midline areas When comparing reinforcement over the tops of the copings versus reinforcement at the sides of the copings, top reinforcement significantly reduced strains on the denture base in the canine positions when the first premolar was loaded No significant differences were found with versus without palatal reinforcement
Kazokoğlu and Akaltan, 2014	In vitro	Cast metal (Co-Cr-Mo)	Framework with or without posterior palatal bar	Maxillary overdenture with a horseshoe design supported by 4 implants	Autopolymerizing acrylic resin	Strain gauge analysis of the strain transmitted to the implants and the edentulous ridge anteriorly and posteriorly by locator, bar and	MDC resilient telescopic retainers (n=5), ball (n=5) and round bar (n=5).	Strains around the implants and on the edentulous ridges produced by the three different types of attachments were not significantly different either with a rigid or less rigid major connector (with or without posterior palatal bar reinforcement) Stress distributions around the implants with the ball attachments were

						ball-retained implant overdentures The effeciency of a rigid major connector to reduce the strain levels was investigated		different from those of the MDC and bar attachments No interaction was found among the palatal bar, the strain gauges, and the attachment type
Slot et al., 2016	In vivo (Randomized controlled trial)	Cast metal (Co-Cr)	Framework	Maxillary overdenture with limited palatal coverage supported by 4 or 6 implants	Heat-polymerized acrylic resin	Clinical and radiographic evaluation.	Milled bar with distal extensions	Evaluation period: 5 years Implant survival rates: 100% for the four implants groups and 99.2% for the six implants group Mean marginal bone resorption: 0.50 ± 0.37 mm in the four implants group and 0.52 ± 0.43 mm in the six implants group. Overall overdenture survival rate: 100% Mean probing depth : 4.3 ±1.0 mm for the four implants group and 3.4 ± 0.9 mm for the six implants group
Zou et al., 2013	In vivo (prospective study)	Cast metal	Framework	Maxillary overdenture without palatal coverage supported by 4 implants	Heat-polymerized acrylic resin	Clinical, radiographic, and prosthetic maintenance assessment	Rigid bar (n=10), rigid telescopic (n=10), and locators (n=10).	Evaluation period: 3 years No overdenture fractures (n=0) Denture margin adaptation (n=4) and rebasing (n=2) Implant survival rates: 100% Mean probing depth : 3.3 ± 0.7 mm for the bar group, 3.2 ±0.8 mm for the telescopic group, and 3.4 ±0.5 mm for the locator group Mean peri-implant bone loss levels: 1.0

								± 0.6 mm for the bar group, 0.9 ± 0.3 mm for the telescopic group, and 0.9 ± 0.4 mm for the locator group
Kiener et al., 2001	In vivo (retrospective study)	Cast metal	Framework	Maxillary overdenture with a horse shoe design supported by 3, 4, 5 or 6 implants	Heat-polymerized acrylic resin	Prosthetic maintenance assessment	Splinted: U-shaped Dolder bar with cantilever extension (n=34) Unsplinted: telescopes or ball attachments either on 2 or 4 implants (n=7)	Mean observation time: 3.2 years (min. time: 12 months, max. time: 96 months) Overall implant survival rate: > 95.5 % Fractured dentures (n = 0) Denture relining (n = 2) Enhancement of mechanical properties and stability of the dentures by reinforcement
Weinländer et al., 2010	In vivo (prospective study)	Metal	Framework	Mandibular IOD retained by 4 implants	Heat polymerized acrylic resin	Implant, peri-implant outcomes, and prosthodontic maintenance assessment.	Design 1: resilient non-reinforced overdenture with ovoid bar on 2 implants (n=24) Design 2: resilient non-reinforced overdenture with ovoid bar on 4 implants (n=25) Design 3: rigid reinforced overdentures with anterior milled bar and posterior cantilevers on 4 implants	Evaluation period: 5 years Implant functional survival rates: 100% for the three tested designs Denture margin adaptation (n = 17 for design 1; n = 23 for design 2; and n = 7 for design 3 Denture rebasing (n = 21 for design 1; n = 14 for design 2; and n = 3 for design 3) Overdenture fracture (n = 4 for design 1; n = 8 for design 2; and n = 0 for design 3) Mean peri-implant bone loss (mm) (1.9 ± 0.6 for design 1; 1.8 ± 0.6 for design 2; and 1.7 ± 0.7 for design 3) Mean probing depth (3.2 ±1.3 for design 1; 3.1 ±1.5 for design 2; 3.0 ±1.4 for design 3)

							(n=27).	
Ceruti et al., 2006	In vivo (retrospective study)	Cast metal	Framework	Mandibular IOD without buccal and lingual acrylic flanges retained by 2 implants	Heat-polymerized acrylic resin	Maintenance assessment	Experimental group: ball with the matrix cemented to the framework (n=6) Control group: ball without frame work (n=6)	Mean evaluation period: 8 years Experimental group: a 100% implant survival rate and no relining (n= 0) Control group: a 100% implant survival rate and relining was carried twice (n= 2)
Amaral et al., 2018	Finite element analysis	Metal (CO-Cr)	Framework	Mandibular single-IOD	Heat polymerized acrylic resin	Stress distribution in a single-implant-retained mandibular overdenture with and without a reinforcement	Stud attachment Two IOD models: model A without metal reinforcement; model B with metal reinforcement	Using a metal framework reinforcement for a single-IOD decreased the tensile stresses through the anterior area of the denture base by almost 62% when compared with the non-reinforced overdenture model (8.7 MPa and 22.8 MPa, respectively) Both models (with and without a reinforcement) exhibited similar stress values on the attachments, implants, and bone

Table 2. Articles included in systematic review

3. RESULTS

The primary search conducted until 14 August 2018 resulted in 228 articles from PubMed, and 41 articles from the Web of Science. A total of 269 publications were initially identified. Twenty-seven articles were excluded because 20 articles were duplicates and 7 articles were not in English. In addition, 208 articles were excluded after the screening of the titles and abstracts based on the inclusion and exclusion criteria. Twenty-two articles were excluded based on full-text screening and 1 publication was added manually. Finally, 13 publications (n=13) were included in the current review (Fig. 1).

The involved articles included 5 clinical studies, 3 studies on maxillary (Kiener et al., 2001; Slot et al., 2016; Zou et al., 2013) and 2 on mandibular IOD (Ceruti et al., 2006; Weinländer et al., 2010). Additionally, 1 finite element analysis study on mandibular overdenture (Amaral et al., 2018) and 7 in vitro studies were included. Within the included In vitro studies, 3 reports tested IOD simulating specimens (Fajardo et al., 2011; Gibreel et al., 2018; Rached et al., 2011) while the other 4 studies used maxillary IOD fabricated on models (Kazokoğlu and Akaltan, 2014; Takahashi et al., 2017; Takahashi et al., 2016; Takahashi et al., 2015). (Table 2)

In terms of the investigated parameters, 3 In vitro studies investigated the flexural properties of metal and /or fiber-reinforced implant overdentures as follows: the first study (Gibreel et al., 2018) investigated the static load bearing capacity of IOD in terms of flexural strength, flexural modulus, and flexural strain; the 2nd study (Rached et al., 2011) investigated the fatigue and static loading capacity of IOD; and the 3rd one (Fajardo et al., 2011) investigated their fracture load values. Furthermore, 3 In vitro studies (Amaral et al., 2018; Takahashi et al., 2016; Takahashi et al., 2015) investigated the effect of metal reinforcement on overdenture base strain and stress distribution. Amaral et al. evaluated the stress distribution in a single-implant-retained mandibular overdenture with and without a reinforcement on implants, denture base, attachment, and peri-implant bone (Amaral et al., 2018). Takahashi et al. evaluated the denture base strains for maxillary implant overdentures with and without palatal coverage in a variety of implants configuration in one study (Takahashi et al., 2016) while in the other study they compared between the top and the side reinforcement of the copings with the presence and absence of a palatal bar reinforcement for the two-implant supported maxillary overdentures with a palatal coverage (Takahashi et al., 2015).

Three studies (Amaral et al., 2018; Kazokoğlu and Akaltan, 2014; Takahashi et al., 2017) investigated the effect of metal reinforcement on stresses and strains transmitted to the underlying implants. Kazokoğlu and Akaltan evaluated the strain values transmitted to the implants and the edentulous ridge anteriorly and posteriorly with three types of attachment and with two designs of major connectors with different degree of rigidity (Kazokoğlu and Akaltan, 2014). Takahashi et al. evaluated the effect of metal reinforcement on the underlying implants strain in various locations (anterior, premolars, and molars) and numbers (2, 4, and 6) (Takahashi et al., 2017).

Five clinical studies were found to assess the prosthetic maintenance of the metal-reinforced implant overdentures and to meet the inclusion criteria. From these studies, one was a randomized clinical trial (Slot et al., 2016), 2 were retrospective studies (Ceruti et al., 2006; Kiener et al., 2001), and 2 were prospective studies (Weinländer et al., 2010; Zou et al., 2013). Data about denture base fracture, relining, rebasing, peri-implant bone loss, probing depth, and implant survival rates during the functional period were extracted and considered for evaluating the mechanical properties of the denture base, residual ridge, and implant preservation respectively.

Regarding the material of reinforcement, 3 studies (Fajardo et al., 2011; Gibreel et al., 2018; Rached et al., 2011) used a fiber reinforcement while 11 studies (Amaral et al., 2018; Ceruti et al., 2006; Kazokoğlu and Akaltan, 2014; Kiener et al., 2001; Rached et al., 2011; Slot et al., 2016; Takahashi et al., 2017; Takahashi et al., 2016; Takahashi et al., 2015; Weinländer et al., 2010; Zou et al., 2013) used a metal reinforcement.

Publication reporting on the flexural properties of reinforced IOD showed that the fatigue and/or static flexural properties of IOD can be increased significantly when using metal reinforcement (Rached et al., 2011), E-glass fiber reinforcement (Gibreel et al., 2018; Fajardo et al., 2011; Rached et al., 2011), woven polyethylene braids, and polyaramid reinforcements (Rached et al., 2011) on the top surface of attachment system. Moreover, these mechanical properties are not significantly affected by the space available for reinforcement placement (Rached et al., 2011). No denture base fracture was encountered in the involved clinical studies which used a metal reinforcement for long term observation periods ranging between 3 to 8 years (Kiener et al., 2001;

Slot et al., 2016; Weinländer et al., 2010; Zou et al., 2013). Metal reinforcement placed over the residual ridge and the top of the coping successfully minimized labial and palatal overdenture base strains for palateless overdentures. The labial strain levels of reinforced palateless dentures were quietly similar to the dentures with palatal coverage (Takahashi et al., 2016). Moreover, it decreased strains in the canine, middle, and posterior midline areas for maxillary IOD especially when placed on the top of the copings (Takahashi et al., 2015). Using the metal framework reinforcement decreased the tensile stresses through the anterior area of the denture base for single-implant-retained overdenture by almost 62% when compared with the non-reinforced overdenture models. The difference in the stress distribution between the reinforced prosthesis and the other one without reinforcement did not affect significantly the adjacent structures, such as the attachments, implant or peri-implant bone (Amaral et al., 2018).

Reinforcement of palateless maxillary implant overdentures decreased strains on the underlying anterior and posterior implants regardless of the denture design and implant configuration compared to the non-reinforced bases (Takahashi et al., 2017). Implant and residual ridge strains were not significantly decreased when a posterior palatal bar reinforcement was used in addition to residual ridge reinforcement (Kazokoğlu and Akaltan, 2014). Data extracted from the involved clinical studies showed that the different types of attachments and even the rigid ones such as U-shaped bars with cantilever extension, milled bars, and telescopes were used with high implant functional survival rates ranging from 95.5 to 100% for the maxillary implants supporting reinforced palateless overdentures (Kiener et al., 2001; Slot et al., 2016; Zou et al., 2013) and a 100% survival rate for those supporting mandibular metal-reinforced overdentures (Ceruti et al., 2006; Weinländer et al., 2010). Additionally, no significant changes in the probing depth and peri-implant bone levels were detected (Slot et al., 2016; Weinländer et al., 2010; Zou et al., 2013). Interestingly, the need for frequent IOD relining and adaptation was minimized when incorporating a metal reinforcement within the denture base (Weinländer et al., 2010; Kiener et al., 2001; Zou et al., 2013) even with the absence of the buccal and lingual flanges (Ceruti et al., 2006).

4. DISCUSSION

The aim of the present systematic review was to investigate the effect of the reinforcement on the mechanical behavior of IOD bases and their cumulative biological effect on the underlying supporting structures.

Overdenture base fracture in the abutment and midline areas was reported as a frequent mechanical complication associated with the overdenture treatment especially when a bar attachment was used (Chen et al., 2013; Sipahi et al., 2006). Metal frameworks were used to enhance the flexural properties of the IOD even with a small thickness of denture base resin. The maximum strengthening effect was obtained when the reinforcements were placed with their long axis perpendicular to the applied fatigue and static loading (Rached et al., 2011; Vallittu, 2018). Hence, the use of a metal-reinforced overdenture base can prevent the incidence of prosthetic fracture in clinical practice (Kiener et al., 2001; Slot et al., 2016; Weinländer et al., 2010; Zou et al., 2013).

Non-metallic reinforcement like polyethylene, polyaramid, and glass fibers were tested as alternatives for metal reinforcement because metals are heavier in weight, less esthetic, and lack bonding to acrylic denture base materials (Rached et al., 2011). Glass fibers especially resin preimpregnated types have good esthetic features and chemical bonding ability with the denture base material with the aid of the silane coupling agent (Vallittu, 2018; Yoshida et al., 2015). They were found to be effective in IOD reinforcement especially when placed on the top surface of the implant abutments (Fajardo et al., 2011; Gibreel et al., 2018; Rached et al., 2011).

Denture base deformation can cause ulcer formation and pain in the denture-bearing mucosa, residual ridge resorption, and may lead to mechanical or biological complications in the implants (Takahashi et al., 2015). Mechanical studies of overdenture base strains have reported high tensile strain levels on the overdenture surface close to the top of an implant (Dong et al., 2006; ELsyad et al., 2016). Placing the reinforcement closer to the side of these stresses was found to be effective in reducing denture base strain values and increasing its resistance against deformation than that placed on the side of compression stresses (Narva et al., 2005). The inclusion of a metal framework in the single-IOD base was proved to provide a better stress distribution rather than concentrating it as in non-reinforced denture bases without negatively affecting the other structures such as the attachment, the implant, and the peri-implant bone. Moreover, it reduced tensile stresses around the housing portion of the implant by 61.8% when compared to the non-reinforced ones (Amaral et al., 2018). This could be explained by the difference in the Young modulus (Y) of the framework and denture base materials. The Co-Cr material can sustain the load stresses transferred to it from the acrylic resin base as the former has a higher Y value (Gomes et al., 2017).

A palateless overdenture is usually recommended for patients with a hyperactive gag reflex, physiological problems, or with the maxillary torus. However, omitting the palatal aspect can adversely affect the denture base rigidity and deformation under functional loads (Ochiai et al., 2004). Therefore, metal reinforcement of palateless overdenture is recommended. Cast Co-Cr reinforcement over the residual ridge and abutments together with a palatal bar was effective in reducing labial denture base strains to almost the same levels or lower than that with palatal coverage and reinforcement. However, palatal strain values were less than the unreinforced prostheses but still higher than those recorded when a palatal coverage was used (Takahashi et al., 2016). Placing the reinforcing metal over the abutments' top and extending it to the residual alveolar ridge was more successful than side reinforcement in reducing denture base strains in the canine region. However, reinforcement placed around the abutments can be an alternative option when the space between the denture teeth and the abutment is insufficient (Takahashi et al., 2015).

Reinforcement can protect the underlying supporting structures of an IOD (Gonda et al., 2013). By improving the stiffness of the denture base, even distribution of functional forces to the residual alveolar ridge and dental implants was obtained (Żmudzki et al., 2015). Without reinforcement, high stresses are concentrated in the working side and considerably lower stresses on the balancing side due to the large deformation under occlusal forces (Gonda et al., 2013). The prostheses, the implants, and their components are affected by high occlusal loads which may lead to mechanical failure (Naert et al., 2012). Some studies have concluded that occlusal stresses beyond the biological load-bearing capacities of osseointegrated oral implants could lead to marginal bone loss or even implant failure. When implants are loaded, stresses will be transferred by the implant to the bone with the highest stress in the area near the neck of the implant where they have their first contact (Chrcanovic et al., 2018; Isidor, 2006; Naert et al., 2012). Additionally, metal fatigue will occur when the implant is exposed to a lateral bending movement during the function. Therefore, optimum stress distribution around the implant is a key factor in preserving osseointegration (Chrcanovic et al., 2018; Gupta et al., 2015; Hsu et al., 2012; Naert et al., 2012).

The risk of implant failure was observed to be higher in maxillary arches when compared to mandibular ones (Andreiotelli et al., 2010; Jemt, 2018). This may be due to the fact that the mandible has a wider cortical crest than the maxilla. However, the proportion of bone marrow was greater in the maxilla than in the mandible (Lindhe et al., 2013). Implant length could be another factor because they provide an increased initial stability and a long-term resistance to bending movements, as they are more commonly used in the anterior mandible (Chrcanovic et al., 2014). Ochiai et al found that greater load and stresses were transferred to the implants supporting a palateless prosthesis (Ochiai et al., 2004). Strain levels on the underlying anterior and posterior implants were reduced and evenly distributed when using a cast metal reinforcement over the residual ridge together with a palatal bar for maxillary overdentures (Takahashi et al., 2017). However, excluding the palatal bar revealed non-significant changes in the peri-implant strain levels with splinted or solitary attachments (Kazokoğlu and Akaltan, 2014). Rigid attachments and bar cantilevers tend to transfer a greater amount of stresses to implant fixtures (Trakas et al., 2006). However, cantilevered U-shaped bars, milled bars, and telescopes were used with high implant functional survival rates without significant changes in the probing depth and peri-implant bone levels over a long term follow up period ranging between 3 to 5 years for 4-implant supported palateless overdentures (Kiener et al., 2001; Slot et al., 2016; Zou et al., 2013) and 5 to 8 years for mandibular ones (Weinländer et al., 2010).

The hinging movement and occlusal plane instability may lead to significant bone resorption in the mandibular posterior and maxillary anterior regions (Blum and McCord, 2004). The absence of demand for denture relining is a good sign of residual ridge preservation and force distribution (Kranjčić et al., 2013). A significant lack of frequent IOD relining and adaptation was found with metal-reinforced denture bases (Kiener et al., 2001; Weinländer et al., 2010; Zou et al., 2013). Even with the absence of buccal and lingual flanges, the denture base with metal reinforcement cemented to the attachment's matrix did not require any relining procedures when compared with the control group in which a conventional overdenture base without reinforcement has been used (Ceruti et al., 2006). The idea was to provide a rigid denture stabilization with the reinforcing framework, which counters the prosthesis rotational movements and distributes stresses evenly to reduce ridge resorption without inducing excessive stresses on implants (Weinländer et al., 2010).

No data were available regarding the effect of fiber reinforcement on stresses transmitted to the underlying implants or residual ridge for IOD. Moreover, there is a lack of clinical studies evaluating the effect of IOD reinforcement on residual ridge resorption using a radiographic means of assessment. Further studies are needed to evaluate the effect of fiber reinforcement on stresses transmitted to implants and residual ridge.

5. CONCLUSION

1. The use of reinforcement can reduce the fracture incidence of an IOD by enhancing its flexural properties and reducing the overdenture base deformation.

2. Strains on the underlying supporting structures of the overdenture prosthesis, including the dental implants and the residual ridge, can be decreased and evenly distributed by the use of the metal reinforcement.
3. The most favorable position of effective overdenture reinforcements is on the residual ridge and the top of the abutments. A palatal bar may enhance rigidity and even balance the stress distribution for palateless implant-supported overdentures.

DECLARATION OF INTEREST

None: the authors have no competing interests to declare regarding the authorship, funding and publication of this article.

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