

Implant Bio-mechanics for Successful Implant Therapy: A Systematic Review

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ABSTRACT

Background: Dental implants are considered the best treatment option for replacement of missing teeth due to high survival rates and diverse applications. However, not all dental implant therapies are successful and some fail due to various biological and or/mechanical factors. The objective of this study was to systematically review primary studies that focus on the biomechanical properties of dental implants in order to determine which biomechanical properties are most important for success of dental implant therapy. **Materials and Methods:** An electronic database search was performed using MEDLINE (PubMed), EMBASE, Google Scholar, and CAB Abstracts. Six principal biomechanical properties were considered to prepare the search strategy for each database using key words and Boolean operators. Human and animal studies (observational studies, trials, and *in vitro* studies) were included in this review. Human studies that were considered eligible needed to have subjects above 18 years who received permanent restorations after implant surgery and followed up for at least 6 months after receiving permanent restorations. Studies with subjects who had absolute contraindications at the time of dental implant surgery were excluded. **Results:** In total, 28 studies were included in the review after application of the eligibility criteria; 18 *in vitro* studies, 5 cohort clinical studies, 3 animal studies, and 2 nonrandomized trials. Six *in vitro* studies assessed loss of preload, five *in vitro* studies assessed fatigue strength, four assessed implant abutment connection design, and one assessed implant diameter. Two nonrandomized trials assessed torque and six observational studies assessed the effect of cantilevers. Gold alloy coating of abutment screws resulted in higher preload values followed by titanium alloy coating and gold coating; there was a difference in preload values between coated and uncoated screws when tightened repeatedly. Preload values decreased as a function of time with majority of preload loss occurred within 10s of tightening. The 8-degree internal conical implant performed better than the internal hex design. Higher rate of complications (porcelain chipping, de-cementation) was observed in the cantilever groups in studies. **Conclusion:** Biomechanical properties of implants like preload, torque, cantilever design, implant abutment design have profound effects on the survival rates of dental implants. With limitations, this review provides some important parameters to consider for successful implant therapy.

KEYWORDS: *Biomechanics, cantilever, implant, preload, screw*

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INTRODUCTION

The use of dental implants is considered as the best treatment option for treating partial or complete edentulism and replacing single missing tooth in the anterior and posterior regions of the mouth.^[1] High survival rates for dental implant supporting single crowns or fixed partial prosthesis have been reported; however, systematic reviews of the literature have also identified a variety of the complications associated with dental implants and prosthesis superstructures.^[2,3] These complications are broadly classified into biologic, technical, and esthetic.^[4] Biological complications affect the tissue supporting the dental implant while the mechanical complications affect the structural integrity of the implant and/or abutment of prosthetic superstructure. One of the most commonly reported biological complication is peri-implantitis and peri-mucositis. Common technical complications include veneering material or framework, loss of retention, and screw loosening.

Despite the fact that majority of these complications does not threaten the survival of dental implants, management can be time consuming and requires additional financial resources for the patient and the clinician and may even affect the patient's quality of life. To avoid or minimize the chance of occurrence of these complications, it is important to avoid known risk factors during the initial planning of the implant therapy.^[5] The common approach of systematic reviews with a focus on risk factors associated with implant and implant-supported prosthetic compactions is the comparison of failure/complication rates to be expected with various types of implant characteristics and/or reconstructions.^[6,7] There are, however, many variables that the clinician should consider such as implant connection system, torque applied, and abutment screw material that can be influenced in terms of the biomechanical yield of the implant prosthesis.

This study will systematically review primary research studies that have tested the bio-mechanical properties of dental implants. The aim was to address the role of bio-mechanical factors and which biomechanical factors are most advantageous for successful implant therapy in the restoration of missing teeth. The main outcome of this review is to determine what bio-mechanical factors are most critical for implant success.

MATERIALS AND METHODS

This systematic review is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline.^[8] An electronic database search was performed for journal articles

published in English, from database inception to December 2019, on MEDLINE (PubMed), Google Scholar, EMBASE, CAB Abstracts. A separate search strategy was prepared for each database using key words and Boolean operators. For the preparation of the search strategy, seven principal biomechanical factors were considered. Systematic reviews, editor letters, reviews, abstracts, short communications, books, and dissertations were not considered eligible. The type of studies considered eligible was: (1) Observational studies—prospective and retrospective. (2) Intervention studies (trials)—on humans and animals. (3) *In vitro* studies. These studies are a mix of laboratory experiments conducted on models, observational and intervention studies on animals, and partially or completely edentulous patients. Where human studies are being reviewed, the following eligibility criteria were followed.

INCLUSION CRITERIA

1. Completely or partially edentulous patients above 18 years of age
2. Patients who received permanent restorations after implant surgery
3. Patients who had been followed up for at least 6 months after receiving permanent restoration

EXCLUSION CRITERIA

1. Patients who had any absolute contraindication to dental implants at the time of implant surgery

Two independent reviewers screened titles and abstracts. After considering inclusion and exclusion criteria, full-text articles were selected. Studies were eliminated based on the eligibility criteria of study design and participants. After reading complete texts, studies were evaluated against eligibility criteria again and data were extracted from the final selected studies. Divergences between two reviewers were solved through discussion or through consensus with the intervention of third reviewer. The following data were extracted from the selected studies: authors, year of publication, study design, implant characteristics, prosthesis characteristics, cantilevers extension and location, opposing dentition, type of abutment, screw type and material, main outcome measures, and values. After data extraction, considering the heterogeneity in terms of outcomes and measures proceeding with a meta-analysis was not considered appropriate. The results are presented using descriptive synthesis in the form of tables and text.

Tools to assess the quality and risk of bias for *in vitro* studies could not be identified; so, this assessment was performed only for nonrandomized intervention

studies in humans and animal models. The risk of bias of the included experimental *in vivo* studies was assessed using SYRCLE's risk of bias tool.^[9] Six types of bias (selection, performance, detection, attrition, reporting, and other biases). The score "yes" indicates a low risk of bias, "no" indicates a high risk of bias, and "?" indicates an unclear risk of bias. Following authors' recommendations, we have not calculated a summary score for each individual study; however, a simple counting of all the domains that scored high for the risk of bias is provided. We initially planned to use the Cochrane Collaboration's risk of bias assessment ROBII tool to assess risk of bias for randomized studies. However, none of the included studies fell into this category. The studies involving humans were observational studies; so, for quality assessments, Newcastle–Ottawa Scale (NOS) scale was used instead).^[10] Assessment was performed independently by two reviewers, and eventual disagreements were solved through discussion or through consultation with a third author.

RESULTS

STUDY SELECTION AND DESCRIPTION

Of the 234 titles resulting from the online search, 59 studies were selected for full-text review after abstract screening. In total, 28 full-text articles were included in the review for data extraction and analysis, 18 *in vitro* studies, 5 cohort clinical studies, 3 animal studies, and 2 nonrandomized studies of interventions. The results of the methodological quality and risk of bias for observational and animal studies are presented in [Supplementary Tables 1 and 2], respectively. Figure 1 displays details of the selection process used to identify the included publications.

Six different outcomes were considered: loss of preload, fatigue/mode of failure, stress distribution, removal torque values, optimal torque generation, and biological/technical complications. On the basis of the outcome, six *in vitro* studies assessed the influence the loss of preload for screw abutment (four studies) and prosthetic screw (two studies) [Table 1]. The variable considered for the abutment screw was screw surface modification and dry lubrication while for the prosthetic screw the variable was loss of preload with time after clinical use or several hours after tightening of a new screw. In the majority of cases, the screws were exposed to a sequence of tightening and loosening, before measure performance. The laboratory specimens were not subject to loading test, only in one case the measures were performed in screws that have been subject to clinical masticatory functional load. Six *in*

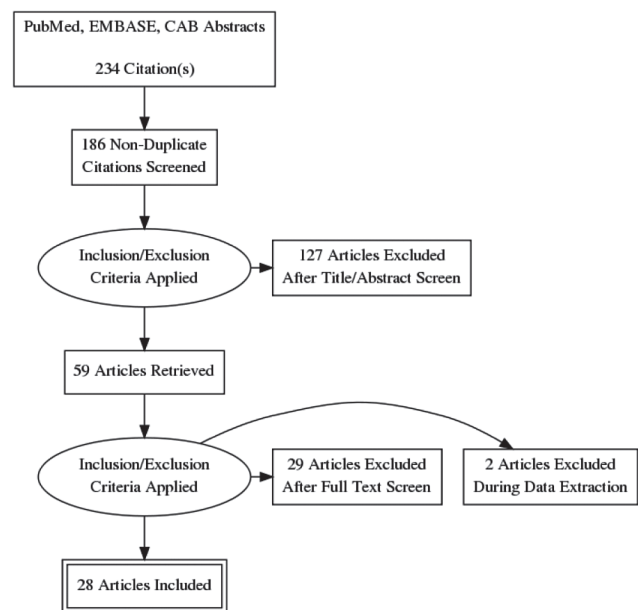


Figure 1: PRISMA flow diagram of literature search and selection process. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses

vitro studies considered the factors that might influence the reduction in removable torque after mechanical and technical stress application [Table 2]. Five *in vitro* studies were included that considered the influence of different factors on fatigue strength. Four studies assessed the influence of implant abutment connection design and one the implant diameter on fatigue and mode of failure under different loading conditions. Either static or cyclic loading was applied, consisting of different force values and the number of cycles [Table 3]. Two nonrandomized studies assessed the variability of optimal torque delivered based on the torqueing method [Table 4]. Six observational studies assessed the effect of cantilever presence and characteristics, loading conditions, and prosthesis misfit on technical and biological complications [Table 5].

The included studies were grouped according to six specific biomechanical factors:

1. Abutment screw material/surface modification
2. Prosthetic screw loss of preload
4. Implant/abutment joint design
5. Torque method
6. Cantilever
6. Prosthesis misfit

ABUTMENT SCREW MATERIAL/SURFACE MODIFICATION

One *in vitro* study by Byrne *et al.*^[11] determined that gold coating of the abutment screw produced higher preload values for a given torque application. Compared to uncoated analogue, the gold-coated screw resulted

Table 1: Summary of Data Extracted from Included *In vitro* Studies and variables that influence preload values

Author, year of publication	Abutment Type	Fixation Screw		Torque		Rotation angles	Removal torque (Ncm)	Preload		Main Results
		No.	Material	Value (Ncm)	Tightening episodes			Values (N)	Measure	
Byrne <i>et al.</i> , 2006	Prefabricated abutments	10	TA ^a	35	1 st 2 nd 3 rd	-	NA	142.5; 140.1; 142.0	Strain gauge and recorded via a digital readout.	All screws showed decrease in preload with the number of times tightened. GA-ti, fixed to the prefabricated abutment and to the cast-on abutment showed higher preloads for the 1 st and 2 nd 3 rd tightening episodes, respectively.
		10	GA ^a	35	1 st 2 nd 3 rd	-	NA	134.0; 124.4; 124.5		
		10	GA-ti ^a	35	1 st 2 nd 3 rd	-	NA	386.0; 295.0; 266.6		
Stuker <i>et al.</i> , 2008	Cast-on abutments	10	TA ^a	35	1 st 2 nd 3 rd	-	NA	233.0; 242.9; 242.0		Statistically significant differences in preload values among the three groups.
		10	GA	35	1 st 2 nd 3 rd	-	NA	194.0; 173.4; 163.3		
		10	GA-ti ^a	35	1 st 2 nd 3 rd	-	NA	353.0; 357.3; 332.4		
Haack <i>et al.</i> , 1995	Prefabricated gold hex abutments	10	TA ^a	30.07±0.28	-	-	18.75±1.89	37.03±5.69	Strain gauges	No relation was seen between elongation and number of tightening/loosening cycles
		10	GA ^a	30.07±0.28	-	-	17.64±1.12	131.72±8.98		
		10	TA-ti ^a	30.07±0.28	-	-	16.43±1.33	97.78±4.68		
Cantwell & Hobkirk 2004	Standard abutment	5	TA ^a	20	5	-	-	381.5 ± 72.9	Preload was determined by measuring elongation	Significant preload loss over time
		5	GA ^a	32	5	-	-	468.2 ± 57.9	Strain gauge	
		5	GA ^b	20	-	-	-	319.6± 88.0		
Al Jabbari <i>et al.</i> , 2008	Standard abutment	10	GA ^b	10	-	-	-	-	X-Y plotter	There was a reduction of the preload values as the number of years in service increased
		75	GA ^b	10	-	-	-	-		
		20	TA ^a	20 and 32	5	10.2 ± 1.8 and 17.0 ± 3.1	-	478.3 ± 250.4 and 636.1 ± 336.6	Torque removal	
Martin <i>et al.</i> , 2001	Standard abutment	20	GA ^a	20	5	11.1 ± 1.7 and 18.0 ± 2.0	-	576.8 ± 205.3 and 833.8 ± 206.9	used as to indirectly calculate	Gold-coated screws produced preload values and titanium coated screw greater rotational angles than the conventional screws.
		20	GA-ti ^a	20	5	17.4 ± 1.8 and 29.0 ± 2.5	-	596.8 ± 101.2 and 1015.3 ± 191.2		
		20	TA-ti ^a	20	5	21.2 ± 3.1 and 38.1 ± 8.7	-	470.2 ± 117.0 and 877.1 ± 191.1		

TA titanium alloy; GA gold alloy; GA-ti gold coated; TA-Ti surface treated titanium; NA non available; NR non reported;

^aabutment screw

^bprosthetic screw

Table 2. Summary of Data Extracted from Included *In vitro* Studies and variables that influence torque values

Author, year of publication	Implant		Abutment	Fixation screw	Level of misfit (µm)	Torque (Ncm)	Thermal stress	Mechanical stress	No. of Cycles	Experimental groups	Outcome
	Connection	Material /Length									
Farina <i>et al.</i> , 2014	-	-	-	Tia and Ga	NA	10 and 20	NA	150 N, 90°, 1 Hz	~9×10 ⁶	Two groups tightening and both screws with the 2 nd technique	Under loading conditions the RTVs increased for both screws with the 2 nd technique
Xia <i>et al.</i> , 2014	-	3.7/13	20° angle abutment	-	NA	24, 30, 36	NA	30 N and 300 N, 15 H	5×10 ⁶	Four groups based on the torque and one control non loaded	A statistical significant difference RTVs between the unloaded and loaded groups
Yeo <i>et al.</i> , 2014	External hex	Grade 4 Ti	Straight Ti	Ti	1.4–3.8 Na	30	4° and 60° 60seconds at each temperature	NA	2×10 ³	7 groups according to screw length	There was no significant difference RTVs before and after thermocycling as the screw length increases
Yousef <i>et al.</i> , 2005	-	4.0/10	Standard and custom	-	Na	NR	NA	300 N 90°	5×10 ⁴	NA	Description of changes in the screw joint occurring as a result of simulated occlusal load.
Ebrahim <i>et al.</i> , 2002	-	3.75/10	7 mm standard	Ga	100 and 175	NR	NA	298 N, 90°, 1 Hz	Three groups based on level of prosthesis misfit and one control group ^b	There was statistical significant difference in the RTV levels between two experimental groups and the control group	No subjective clinical signs of screw instability or loosening were observed
Cibirka <i>et al.</i> , 2001	External hexagon and circular	Ti	custom 25° angulated loading platform	Ga	-	32	The temp was maintained constant at 37°C	Dynamic loading 20 and 200 N	Three groups based on the vertical height, or degree of fit tolerance of the implant abutment interface	Three groups based on the vertical height, or degree of fit tolerance of the implant abutment interface	No subjective clinical signs of screw instability or loosening were observed

Ti Titanium; Tia Titanium alloy; Ga gold alloy; NA non applicable; NR not reported; C control group; RTVs removable torque values; N newton; Hz hertz

^aControl group has not undergone mechanical loading

^bControl group without vertical discrepancy between the implant-supported complete denture and the terminal abutment.

Table 3: Summary of Data Extracted from Included *In vitro* Studies and variables that influence fatigue and mode of failure of IAC

Author, year of publication	Material	Implant Diameter / Length	Implant-abutment interfaces	Connection width/length	Torque (Ncm)	Loading test	Point of force application	Outcome
Norton 2000	Ti	4.5/15	AstraTech Uni-abutment 11° Internal conical	NR	25	Static bending test Force 0–500 N Velocity 1 mm/min,	4 mm from the implant-to abutment junction	Joint design influenced the observed mode of failure.
Boggan <i>et al.</i> , 1999	TiA	4.1/14 4 and 5/NR	ITI Straumann abutment 8° Internal conical External and internal connection Custom-designed abutment	NR/1–1.7	35 30	Static and cyclic compressive bending tests	NR	5 mm diameter implant was stronger in both static and fatigue conditions as measured by fatigue failure.
Hansson <i>et al.</i> , 2000	TiA	3.4/11.6–12	Flat top fixture-abutment interface Conical fixture-abutment interface	NR	NR	1000 N	Two different load cases were used for the flat top interface and for the conical interface.	The implant with the conical interface can theoretically resist a larger axial load than the implant with the flat top interface.
Steinebrunner <i>et.</i> , 2008	Ti	4.5 and 5/ NR	6 different designs; straight and tapered internal and external hex, internal cylindrical with cam-slot fixation	2.8–3.4/0.6–5.4	20–45	Dynamic loading 120N 1,200,000 cycles at 1Hz	3.5mm away from the crown's occlusal center and 2 mm lateral movement	Statistically significant difference existed between groups with different connection designs.
Khraisat <i>et al.</i> , 2002	Ti G4	4/10	Hex mediated-butt joint	3.3/3	32	Cyclic load of 100 N 1,800,000 cycles	Perpendicular to the long axis of the implant system assembly	The second joint design performed better as resulted from fatigue strength and failure mode
Khraisat <i>et al.</i> , 2006	Ti	4.1/10 4/10	6 and 8-degree internal conical External hexagon	NR/4 NR	35 32	Cyclic load of 50N 0.25 and 0.50 × 10 ⁶ cycles	perpendicular to the long axis of the implant or 4-mm distance eccentrically	Abutment rational displacement eccentric lateral loading when compared to centric loading
Maeda <i>et al.</i> , 2007	Ti	4/15	4mm diameter abutment connection 3.25mm diameter abutment connection, assuming a platform-switching configuration	NR	NR	Static load 10 N	Periphery of abutments	In the platform switching configuration the stress concentration area was at the level of abutment or abutment screw, away from the cervical bone-implant interface.

IAC implant abutment connection; Ti Titanium; Tia Titanium alloy; G4 grade four; NA non applicable; NR not reported

Table 4. Summary of Data Extracted from Included Non-randomized Studies of Interventions and variables that influence generated torque values

Author, year of publication	Main study Variables/groups	Range of variation between target torque and experimentally values	Author s conclusions
Goheen et sl., 1994	Handheld screwdrivers 4 different mechanical torque devices	Mean values ranged form 23% to 48% below the targeted values Mean values ranged 43% above to 12% below the specified values	There is wide variation in the ability of clinicians to perceive adequate torquing forces applied to implant components. Calibrated torquing devices are mandatory if proper torquing procedures are to be accomplished.
Kanawati et al., 2009	Variability in torque force delivered with Handheld screwdrivers	NA	The study showed a varying degree of hand torquing abilities using a finger driver. Clinicians should regularly calibrate their ability to torque implant components to more predictably perform implant dentistry and use of mechanical calibrated torquing procedures for the final torquing of abutment screws.

in twice the preload at 35 N cm torque [Table 1]. The testing consisted of applying increasing torque values 10, 20, and 35 N cm on each abutment-screw assembly. The preload values were measured after application of each of the above-described torque values, after which screws were loosened completely. This procedure of screw tightening and loosening was repeated for three consecutive times. There was a difference between coated and uncoated screws when the screws were tightened repeatedly. The gold-coated screw loss preload on the second and third tightening episodes, the gold alloy screw lost preload after the second tightening with values remaining constant thereafter while the titanium alloy screw remained unchanged for the three tightening episodes. Another variable considered in this *in vitro* study was the abutment type. Two types of abutments were considered the prefabricated abutment and the cast-on abutments, consisting of a machined gold alloy cylinder to fit the implant hex and a castable plastic sleeve. The type of abutment used during testing influenced the preload values regardless of the screw type with the latter consistently was associated with higher preloads values.^[11] The preload generated by three different type of screws, gold alloy, titanium alloy, and gold-coated after application of the same torque force were compared in another *in vitro* study. The difference in preload values was significant between the three groups and the gold alloy screw presented higher preload values followed by the gold-coated and the titanium alloy screw.^[12] Moreover, statistically significant difference in the preload values was found for the gold and titanium alloy screws when these were torqued the values recommended by the manufacturer.

However, at maximum torque, titanium screw-induced stress was below the titanium yield strength, meaning that even with higher torque values the screw might still function within the material's elastic range.^[13] Surface-treated titanium, and gold alloy, and non-treated titanium and gold alloy screws were compared in another study. Surface-enhanced screws, in particular gold-coated alloy screw, generated greater preload values when compared to conventional titanium and gold alloy screws.^[14]

PROSTHETIC SCREW LOSS OF PRELOAD

Prosthetic screws were analyzed in two studies. After application of a defined torque, under standard, nonloading conditions a loss of preload was observed over time. The majority of preload loss occurred within 10s of tightening.^[15] In another study, when screws have been in use for 18–120 months, the preload values decrease as a function of time during which the screw has been in use^[16] [Table 1]. Other factors might, however, influence the preload values, such as troquing sequence, screw design abutment design, implant-abutment connection system. Considering the greatest loss of preload occurs during the initial period after torque application, torquing and retorquing can affect preload loss recovery.^[17,18] Screw presents generally with a flat head, a long stem, and a variable number of threads. It has been observed that wider screws with a long stem provide less torque loss while there is controversy^[1] about the influence of the shape of the screw head on the loss of preload.^[18] Despite abutment design has not been considered a crucial factor in the maintenance of the preload values, features such as

Table 5. Summary of Data Extracted from Included Non-randomized Studies of Interventions and the variables that influence implants clinical complications

Author	Study design	Follow-up (y)	No. patients	FDPs (no.)	No. Implants	Groups	Variables	Outcome
Halg <i>et al.</i> , 2008	Retrospective Cohort	Mean 5.3 (range 3–12.7)	54	Screw retained and cemented Fixed partial prostheses or single crowns (54)	78	Control group	Cantilever extension presence/absence	MBL, Implant and prosthesis survival rate, Biological and Technical complications
Romeo <i>et al.</i> , 2003	Retrospective Cohort	Mean 3.9	38	Screw retained and cemented Fixed partial prostheses (49)	100	NA	Cantilever length, type and opposite dentition	MBL, Prosthesis success and failure rate.
Brosky <i>et al.</i> , 2003	Retrospective Cohort	Range 7–10	13	Screw retained full arch fixed prosthesis (13)	75	NA	Length of anterior cantilever, length of posterior cantilever, and antero-posterior spread	Screw loosening
Koutouzis & Wennstrom 2007	Retrospective Cohort	5	38	Screw retained Fixed partial prostheses (42)	111	Control group	Implant axial inclination	MBL
Krekmanov <i>et al.</i> , 2007	Retrospective Cohort	5	47	Fixed partial prostheses and full arch fixed prosthesis (NR)	76	Control group	Implant axial inclination presence/absence	Cumulative implant success rates
Jemt & Book 1997	Prospective/ Retrospective Cohort	1 and 5	14	Fixed dental prosthesis (NR)	87	NA	Several parameters of prostheses misfit	MBL

FPD fixed dental prosthesis; MBL marginal bone loss; NA non applicable; NR non reported

abutment collar length has been found to influence the preload loss.^[19] With regard to the type of connection, most authors have found that internal hexagon type exhibits greater preload than external hexagonal type.^[19]

IMPLANT/ABUTMENT JOINT DESIGN

A comparison between 8- and 11-degree internal cone revealed that the 11-degree internal cone deformed before the cone joint, preventing screw fracture while the 8-degree cone fractured at the head of the screw.^[20] Another study compared two commercial implant systems to address the effect of joint design on fracture strength under cyclic loading conditions with a force applied perpendicular to the long axis of the implant system assembly. The 8-degree internal conical implant/abutment interface performed better than the hex-mediated butt joint.^[21] Six different implant systems with internal and external connection assessed for fracture strength after cyclic loading. Long internal connection and cam slott connection compared to short wither external or internal connections showed increased resistance to fracture strength.^[22,23] Cibirka *et al.*^[23] examined the effect of three different implant/abutment joint configurations differing based on the vertical height of degree of fit tolerance of the implant abutment interface and found that after cyclic loading, no difference in the de-torquing values existed between the three groups. Platform switching was compared to external hex connection to assess the effect on stress distribution using three finite element analysis. In the platform switching model, the stress level in the cervical bone area at the implant was greatly reduced however, increasing stress in the abutment or abutment screw, compared to the normal regular sized one.^[24] The conical implant–abutment interface was compared to the flat top interface to asses if the interface design affects the stress pattern at the level of marginal bone. The conical implant–abutment interface type decreased in the peak bone–implant interfacial shear stress compared to the flat top interface of the type studied.^[25]

TORQUE METHOD

Two observational studies assessed the interindividual and method imploded on the variability on the torquing force [Table 4]. When participants were asked to tighten a screw abutment with the maximum of force using a handheld screwdriver, varying degrees of torquing abilities were displayed. Considering the necessity to obtain an optimal and predictable final torque for screw abutments, it is important to monitor and calibrate the amount of force delivered.^[26] In addition, a variation between delivered torque and target torque was observed when using a handheld screwdriver and different mechanical devices. In order to obtain proper

torqueing, calibrated torqueing devices should be employed.^[27]

CANTILEVER

Three observational studies examined the effect of cantilever on the implant and prosthesis outcome [Table 5]. All studies included were retrospective cohorts involving 105 patients. Two studies examined the effects of posterior cantilever, both mesial and distal, of partial fixed and single implant supported prosthesis in the upper and lower arch. The mean duration of the observation period was 5.3 and 3.9 in the first and second study, respectively. The first study included a control group and compared the effect of cantilever presence on different outcomes. When comparisons were made for maxilla and mandible separately, no difference in the marginal bone loss (MBL) levels was found between the cantilever and control groups. A higher rate of minor technical complications was observed in the cantilever group, comprising porcelain chipping and prosthesis de-cementation.^[28] Another retrospective cohort study examined the factors that could possibly influence the outcome of the presence of cantilever in implant-supported screw-fixed partial prosthesis. The prosthesis was either screw retained or cemented and the mean length of the cantilever was 5.77 mm (5.33 mm for the mesial and 6.77 mm for the distal cantilever). The mean cantilever length in nonsuccessful cases was 6.25 mm (range 2.8 mm). The primary outcome for this was MBL. A linear relationship between the cantilever length and MBL for the cantilever nearest fixture was observed. Medium MBL (MBL) of distal cantilever prosthesis was higher than that of mesial cantilever prosthesis although the difference was not statistically significant. Mesial cantilever prosthetic reported a higher rate of prosthetic failure. No differences were observed on MBLs when the two opposite dentitions were considered; natural teeth or fixed prostheses on natural teeth vs opposite teeth with implant-supported fixed prostheses.^[29]

One retrospective cohort study assessed the influence of anterior cantilever on technical complications of full arch crew retained implant supported mandibular prosthesis supported by five implants placed in the intraforaminal region. Mean anterior cantilever length was 8.78 mm (range 5.5 to 14.4 mm), mean posterior cantilever length was 16.2 mm, and mean anteroposterior spread was 7.9 mm (range 5.2 to 12.3 mm). No significant correlation was observed between the length of mandibular anterior cantilever and screw loosening; however, the ratio of posterior cantilever to anteroposterior spread was significantly associated with screw loosening.^[30]

LOADING CONDITIONS

The effect of implant axial inclination on clinical outcomes was assessed in two observational clinical studies.^[31,32] [Table 5]. The follow-up on both clinical studies was 5 years. In one study, MBLs on axially and nonaxially positioned implants, supporting fixed partial prosthesis were considered. The implant inclination in the mesiodistal direction was moderate, and mean inclination 17.11° (range 11–30°) does not influence the implant bone level loss under functional loading conditions.^[31] The other cohort study considered either fixed partial or full arch prosthesis with implants tilted for 25–35°. There was no influence of the implant inclination on the cumulative survival rate after 5 years of functional loading of the prosthesis.^[32]

The effects of axial and nonaxial loading conditions on bone remodeling around implants was assessed in two animal models. In a dog study, axial and nonaxial loading conditions were induced by a bilaterally supported fixed partial dentures or a cantilever-fixed prosthesis supported by two implants. However, more dynamic bone remodeling observed histologically on non-axial loading during a 7 weeks period.^[33] Nonaxial loading conditions were induced by the restoration with angulated abutments in another preclinical study. After 1 year of functional loading, no differences were observed between straight and angulated abutments on surrounding bone.^[34]

PROSTHESIS MISFIT

The effect of prosthesis misfit was considered in two *in vitro* studies, one clinical study and one animal model.^[35-38] Al-Turki *et al.*^[35] in an *in vitro* experiment evaluated the effect of prosthesis misfit on screw stability. After vertical cyclic loading, significant prosthetic screw instability was observed compared with the control group. One cohort was a mixed retrospective/prospective study. One group was prospectively followed for 1 year while the second group has been wearing a prosthesis for 4 years. All the prostheses were implant-supported mandibular fixed full-arch prosthesis. Different parameter of prosthesis misfit was considered, and none of them seemed to influence marginal bone level.^[36] [Table 5]. Farina *et al.*^[37] evaluated the influence of tightening technique and prosthesis misfit after cyclic loading on torque removal. The authors concluded that the misfit decreases the removal torque values and the application of tightening and retightening increases removal torque independent of the level of prosthesis misfit [Table 2]. In an experimental animal study, vertical misfit of the superstructure had no influence on the process of osteointegration. In addition, to the level of misfit, the authors also evaluated the degree

of preload on the contact area between the implant thread and the bone, thus influencing the process of osteointegration.^[38]

OTHER FACTORS

Implant diameter

One *in vitro* study compared 4- and 5-mm diameter implants. Under both static and dynamic loading conditions, the 5-mm diameter implant was stronger as measured by fatigue failure.^[39]

Screw length

The effect of screw length on screw loosening after thermocycling was assessed in one *in vitro* study. No statistically significant difference was found between the groups with different abutment screw length and removal torque values.^[40]

Torque value

Different implant abutment specimens and different tightening torque values (24, 30, and 36 N cm) were evaluated under cyclic loading conditions. Lee *et al.*^[41] concluded that insufficient torque will lead to poor fatigue performance of dental implant–abutment assemblies and that abutment screws should be tightened to the torque recommended by the manufacture.

DISCUSSION

Torque application will result in the development of a force within the screw called preload. The screw is elongated during torque application with shank and threads being placed into tension. It is the elastic recovery of the screw that pull the abutment/prosthesis system together creating a clamping force that keep the joint system form separating. As suggested by some authors, a linear relationship exist between the tightening torque and screw preload.^[42] Greater preload values will result in a greater force required to loosen the screw. The application of an adequate torque value is of crucial importance for clinical success. Of the included studies, only one evaluated the effect of different torque applications on screw stability as measured by the removal torque. The low tightened implant abutment assembly resulted in mechanical failure after cyclical loading.^[41] On the other hand, overtightening that exceed the yield strength of the screw may lead to loss of mechanical properties of the screw due to plastic deformation.^[27] The optimum torque value may depend on several considerations that were not covered in this review. However, it was reported in two of the included studies that large interindividual variability exists when the torque force is delivered though a handheld screwdriver and that this technique will result in consistently lower torque force compared to the target values.^[26,27] The screw material significantly affects the

preload values. Independent of the magnitude of the tightening force applied, gold screws exhibited higher preload values when compared to either titanium screws or surface-treated titanium screws. When an additional group was added, surface-coated gold allows the latter exhibit higher preload values. The rationale behind modifying the screw surface by adding a solid lubricant is to decrease the coefficient of friction, thus increasing the preload value.^[43] Conflicting results were reported for repeated tightening episodes which is a common clinical situation. In one study, this resulted in a decay of the preload particularly evident for the gold-coated screw^[11] and in another study it was reported that when the same screw is fixed several times, its preload values increased.^[14] In some noncoated screws, repeated tightening removes small irregularities on surfaces, which in turn reduces the friction and increases overload.^[13] Generalizability of the results is not possible due to the small number of the included studies and the different measures of the outcome or variables that might influence the preload values such as application of different rates of torque force or torque that differed from optimal values as recommended by the manufacturer, opposing joint surfaces, abutment design, friction coefficient, and lubrication.

Six *in vitro* studies included in the present review assessed the effect of implant abutment design on force strength and mode of failure, screw loosening and instability, and the pattern of stress distribution. The systems were tested under thermic or mechanical stress (static or cyclic) conditions. There was a large variability between the included studies with regard to the interface design and characteristics precluded the possibility to make comparisons between studies. However, the type of connections that exhibited superior characteristics referred to the outcomes mentioned above were internal conical, long internal, and slot implant/abutment interface. With the platform switching model decreased the stress transfer at the level of marginal bone but more stress at the level of abutment or abutment screw.^[24] Implant-supported prosthesis with cantilever extensions are often necessary to provide occlusal support or for esthetic reasons. Mandibular and maxillary posterior cantilevers are more often investigated in *in vitro* and clinical studies. In the present review, three observational studies that addressed posterior cantilever in partial fixed prosthesis, anterior cantilever in full arch prosthesis, and the influence on implant success were included. Marginal bone loss (MBL) and implant success was not affected by the presence of the cantilever although this affected the rate of occurrence of minor technical complications.^[28] Factors such as cantilever length, type of cantilever (mesial vs distal),

and type of opposite dentition (natural teeth or tooth supported prosthesis vs implant supported prosthesis) had no influence of MBLs although more prosthetic complications were reported for mesial compared to distal cantilevers.^[29] Regarding anterior cantilever, its overall length seems to have no technical complications such as screw loosening.^[11] Besides the presence or absence of a cantilever extension, other factors such as the number of implants supporting the cantilever, the type of prosthesis, occlusal forces and occlusal scheme, opposing dentition, implant connection type, and implant to crown ration might influence the MBL and the rate of prosthetic complications.^[44] Most of these confounding factors were not considered in the included studies.

Based on the results from two clinical observational studies, no effect was found between the marginal bone level change and implant inclination, over a 5-year observation period.^[31,32] The type of implant and prosthesis material which can possibly influence the rate of peri implant bone loss were different in these two studies. Overall, the studies included in this review focused on loading conditions without considering possible confounding factors that can contribute to an increased rate of peri-implant bone loss. Conflicting results were reported based on animal experiments. However, in the study reporting possible MBL in non-axial loading conditions, excessive forces were applied which are not comparable with normal functional loading conditions in humans.^[33] Evidence for the influence of prosthesis misfit on different outcomes is based on different type of studies, in vitro, clinical and experimental animal studies. There is general agreement between studies that misfit between the implant abutment and the prosthesis superstructure, does not influence marginal bone level changes and screw instability. However, the torqueing method (tightening and retightening) increased the removal torque and the stability of the abutment screw independent of the prosthesis misfit level.^[37] For the other factors such as implant diameter, torqueing method, screw length and torque value, only one study per factor was included in this review so no definitive conclusions could be made on their influence of implant therapy outcome.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn;

- The use of lubricated abutment screws can generate higher preload values

- Internal conical implant/abutment interface performed better in strength tests under loading conditions.
- The change in marginal bone level does not seem to be influenced by the presence of prosthesis cantilever extensions. However, minor technical complications were found when a cantilever was present.
- The presence of prosthesis misfit does not influence marginal bone level and connection screw stability.
- Overall, non-axial loading conditions does not influence marginal bone level.
- Ideally, a calibrated torqueing device should be used to obtain optimal torque values.

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CONFLICTS OF INTEREST

The author declare no conflicts of interest, financial or otherwise.

AUTHORS CONTRIBUTIONS

Not applicable.

ETHICAL POLICY AND INSTITUTIONAL REVIEW BOARD STATEMENT

The present research is a cross-sectional study proposed to the Institutional Review Board (IRB) of Prince Sattam bin Abdulaziz University, Saudi Arabia (PSAU2019707).

PATIENT DECLARATION OF CONSENT

Not applicable.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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SUPPLEMENTARY MATERIAL

Supplementary Table 1. Evaluation of individual study quality with The Newcastle-Ottawa Scale (NOS) for assessing the quality of non-randomized studies in meta-analyses

	Halg <i>et al.</i> , 2008	Romeo <i>et al.</i> , 2003	Brosky <i>et al.</i> , 2003	Koutouzis & Wennstrom 2007	Krekmanov <i>et al.</i> , 2007	Jemt & Book 1997
Selection						
1) Representativeness of the exposed cohort a) Truly representative* b) Somewhat representative * c) Selected group d) No description of the derivation of the cohort	b	b	c	b	b	a
2) Selection of the non-exposed cohort a) Drawn from the same community as the exposed cohort* b) Drawn from a different source c) No description of the derivation of the non exposed cohort	a	a	c	a	a	a
3) Ascertainment of exposure a) Secure record (e.g., surgical record)* b) Structured interview * c) Written self report d) No description e) Other	a	a	a	a	a	a
4) Demonstration that outcome of interest was not present at start of study a) Yes * b) No	a	a	a	b	a	b
Comparability						
1) Comparability of cohorts on the basis of the design or analysis controlled for confounders a) The study controls for main confounders * b) Study controls for other factors * c) Cohorts are not comparable on the basis of the design or analysis controlled for confounders	- x x	x x	- x	- -	- -	- -
Outcome						
1) Assessment of outcome a) Independent blind assessment *b) Record linkage * c) Self report d) No description e) Other	a	a	b	b	d	b
2) Was follow-up long enough for outcomes to occur a) Yes *b) No	a	a	a	a	a	a
3) Adequacy of follow-up of cohorts a) Complete follow up- all subject accounted for* b) Subjects lost to follow up unlikely to introduce bias-number lost less than or equal to 20% or description of those lost suggested no different from those followed.* c) Follow up rate less than 80% and no description of those lost d) No statement	a	a	a	a	a	a
Total number of stars	7	8	6	6	6	6
Quality rating according to guideline†	Good	Good	Fair	Poor	Poor	Poor

†Thresholds for converting the Newcastle-Ottawa scales to AHRQ standards (good, fair, and poor): **Good quality:** 3 or 4 stars in selection domain AND 1 or 2 stars in comparability domain AND 2 or 3 stars in outcome/exposure domain **Fair quality:** 2 stars in selection domain AND 1 or 2 stars in comparability domain AND 2 or 3 stars in outcome/exposure domain **Poor quality:** 0 or 1 star in selection domain OR 0 stars in comparability domain OR 0 or 1 stars in outcome/exposure domain

Note: A study can be awarded a maximum of one star for each numbered item within the Selection and Outcome categories. A maximum of two stars can be given for Comparability

Supplementary Table 2. Risk of Bias of the included animal studies assessed using SYRCLEs RoB tool

	Selection bias			Performance bias		Detection bias	Attrition bias	Reporting bias	Other	Overall (# L)
	Sequence generation	Baseline characteristics	Allocation concealment	Random housing	Blinding	Blinding	Incomplete outcome data	Selective outcome reporting	Other sources of bias	
Barbier <i>et al.</i> , 1997	?	L	?	?	H	H	L	L	?	3
Celletti <i>et al.</i> , 1995	?	L	?	?	?	H	L	L	L	4
Jemt <i>et al.</i> , 2000	?	?	?	L	L	H	L	L	L	5

Note: The score 'H' indicates a high risk of bias, 'L' indicates a low risk of bias and '?' indicates an unclear risk of bias.