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Implant framework misfit: A systematic review on assessment methods and clinical complications

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Abstract

Background: The fit of implant-supported prostheses is of prime importance for the long-term success of implant therapy.

Purpose: This systematic review aimed to evaluate recent evidence on current techniques for assessing implant-framework misfit, its associated strain/stress, and whether these misfits are related to mechanical, biological, and clinical consequences.

Materials and methods: An electronic search for publications from January 2010 to October 2020 was performed using the Pubmed, Embase, Web of Science, and Cochrane Library databases with combined keywords on implant-framework misfit assessments and related clinical complications. Inclusion and exclusion criteria were applied. After full-text analyses, data extraction was implemented on current techniques of misfit assessment and the relationship between the misfit and the induced strain/stress.

Results: A total of 3 in vivo and 92 in vitro studies were selected, including 47 studies on quantifying the degree of implant-framework misfit with dimensional techniques, 24 studies measuring misfit-induced strain/stress with modeling techniques, and 24 studies using both methods. The technical details, advantages, and limitations of each technique were illustrated. The correlation between the implant-framework misfit and the induced strain/stress has been revealed in vitro, while that with the biological complications and implant/prostheses failure was weak in clinical studies.

Conclusions: Dimensional and modeling techniques are available to measure the implant-framework misfit. The passivity of implant-supported fixed prostheses appeared related to the induced strain/stress, but not the clinical complications. Further studies combining three-dimensional (3D) assessments using dimensional and modeling techniques was needed.

KEYWORDS
dimensional assessments, implant framework, misfit, modeling assessments, strain, stress, three dimensional

1 | INTRODUCTION

It is widely accepted that dental implant is a reliable and predictable solution for oral rehabilitation of partial and complete edentulous patients.[1] Nevertheless, the misfit between implants and the prosthesis has been considered to be one of the risk factors triggering various mechanical and biologic complications that might compromise the long-term success of implant therapy.[2] Regardless of the conventional or digital workflow, fabrication errors and distortions, especially in the complete-arch reconstructions, are still inevitable.[3] Laboratory data showed that the vertical discrepancy of short and long-span implant frameworks was 7 μm and 23 μm, respectively,[4] while a long-term clinical study revealed that the average marginal gap of the implant-supported full-arch prosthesis was significantly more at around 150 μm.[5] Despite a wide range of misfit observed in different laboratory and clinical studies, it is generally assumed that the "acceptable" threshold of misfit ranges from 10 ∼ 150 μm.[6] However, this threshold is not supported by substantial scientific evidence. To date, there is no international consensus on the exact level of misfit to be considered clinical acceptable for implant frameworks, as well as the definition of "passive fit" from a biomechanical perspective.

In this systematic review, the term "misfit" was defined as the dimension of clearance between components that is too tight or too loose or unevenly distributed between the mating surfaces.[7] Regarding different distortion patterns occurred within implant frameworks, 3 types of misfit have been categorized: vertical misfit, horizontal misfit and angular misfit.[8] Vertical misfit is the discrepancy along the vertical plane (*Z*-axis), which is always presented as a gap. Horizontal misfit is recorded as the displacement in the horizontal plane (*X*- and *Y*-axis). Angular misfit is defined as the difference between the inclined angles of the implant/abutment and the framework cylinder. Studies showed that 39% of implant-supported prostheses had angular misfit, 32% had horizontal misfit, and only 4% had vertical misfit.[9] However, most studies focused on vertical misfits as they can be simply measured using light microscopy or scanning electronic microscopy (SEM). In contrast, evidence on the assessment of horizontal or angular misfits is very limited.

Apart from direct measurements, it has also been advocated to assess the passivity of an implant-supported framework by evaluating the misfit-induced strains in the framework. When a distorted prosthesis is tightened onto the implant abutments, all components in the assembly deform to bring each other closer. Strain represents the degree of deformation of a material under loading, while stresses denote the tendency to resist such deformation. Strain gauges analyses (SGA) and finite element analyses (FEA) are current popular methods for assessment of misfit-induced strain/stress. However, framework distortion is a complex issue that is notoriously difficult to provide a full picture of strain distribution in the framework using a handful of SGs. On the other hand, FEA is not only able to analyze a complex mechanical model but can also predict its behavior under different simulated scenarios. The validity of FEA results, due to the belief of garbage in, garbage out (GIGO), have always been challenged.[10]

The ultimate goal of implant-framework misfit studies is to correlate the misfit with clinical consequences. It seems that the existing assessment methods demonstrate various shortcomings that valid and reliable conclusions are yet to be drawn, thereby to correlate or predict clinical complications of implant therapy.[11] In the past, clinical methods, such as finger pressure, visual inspection, tactile sensation and panoramic radiography, and laboratory methods, including microscopy and SEM, have been used to assess the misfit but they have been criticized to be crude, insensitive and not reproducible.[12] With the advancement of technology, better techniques are now available. Therefore, this systematic review aimed to (a) appraise the recent laboratory and clinical assessment methods for implant-framework misfit; (b) to reveal if misfits are related to mechanical, biological and clinical consequences.

What is known:
There are many available methods for assessing the implant-framework misfit. Whether the misfit inducing strain/stress in the implant system and contributing to clinical complications are unclear.

What this study adds:
Advantages and disadvantages of different 2D/3D dimensional and modeling techniques including post-processing algorithms for measuring the implant-framework misfit are delineated. The misfit is related to the induced strain/stress but its relationship with clinical consequences is weak.

2 | MATERIALS AND METHODS

This systematic review was conducted following the PRISMA (Preferred Reporting for Systematic Reviews and Meta-Analyses) guidelines.

2.1 | Search strategy

A literature search was conducted for obtaining English publications published from Jan 1, 2010, to Oct 20, 2020. Pubmed, EMBase, Web of Science and Cochrane Library were electronically searched for articles evaluating implant-framework misfit. The Review manager software (version 5.4.1, The Cochrane Collaboration, 2020) was used to compose the manuscript. The following combination of keywords was used: (implant supported) AND (framework* OR abutment*) AND

TABLE 1 Article selection criteria

Inclusion criteria	Exclusion criteria
• Peer-reviewed journals published from 2010 to 2020 in English.	• Case reports, reviews, including systematic reviews.
• Articles measured implant-framework misfit and its related mechanical consequences or clinical events.	• Articles on tooth-supported or removable prostheses.
• Implant-framework should involve at least two implants.	• Articles without detailed methodology and/or misfit results.

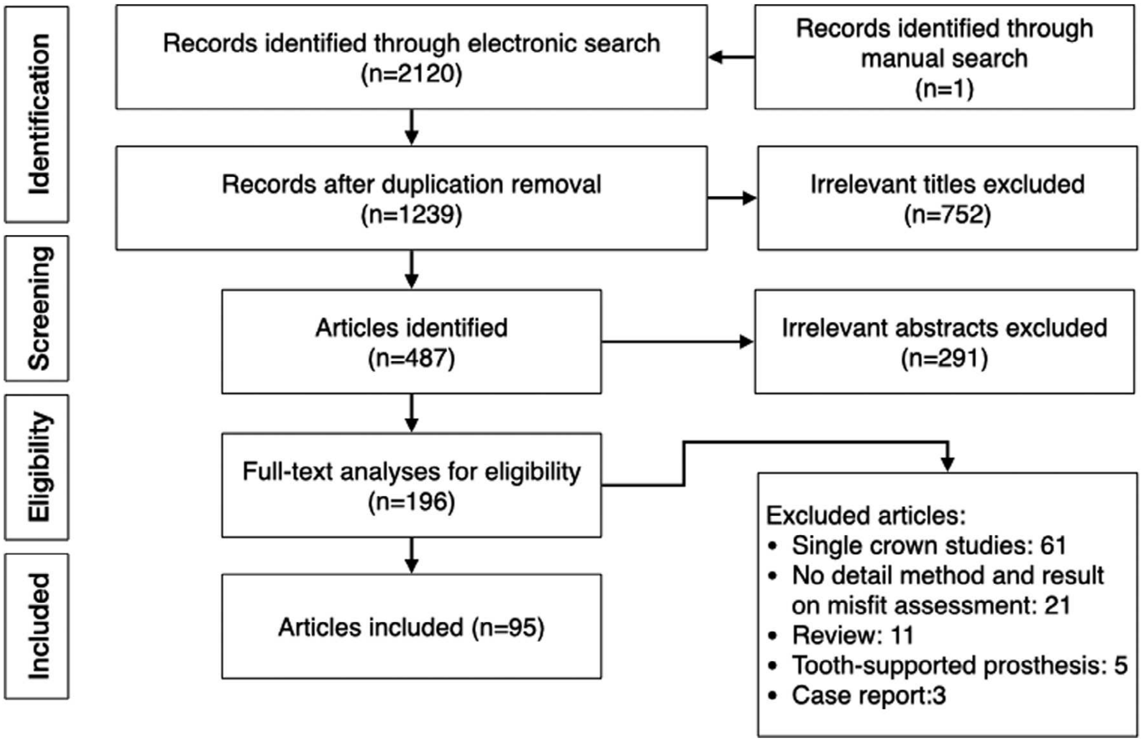

FIGURE 1 Searching strategy and results

(misfit OR ill-fitting OR passivity OR fit OR implant-abutment gap OR "passive fit") AND (2010-present). The electronic search was complemented by a manual search of the reference list of all included publications. The inclusion and exclusion criteria are shown in Table 1.

2.2 | Selection of studies and data extraction

The search process is shown in Figure 1. Article selection was completed in three stages. In the first stage, the screening was performed according to the relevance of the titles. If insufficient information could be acquired from the title, the article would be included in the next stage for further confirmation. In the second stage, full abstracts were obtained for further screening. If the decision could not be made based on the abstract, the paper would be selected for full-text reading. Finally, all remaining abstracts were examined based on the inclusion and exclusion criteria before their full texts were obtained. Full texts of the included publication were analyzed, and the relevant data on implant-framework misfit assessment were extracted. In particular, methodology details, advantages, disadvantages and the accuracy of the misfit assessment, and significant findings of the included studies were analyzed. The search and selection was done by the same reviewer (Y Pan).

2.3 | Quality assessment

The assessment of risk of bias was performed for the in vivo studies, using the Cochrane Collaboration's tool and the Newcastle-Ottawa Scale (NOS).[13,14] No assessment scale was available for the quality assessment of in vitro studies.

3 | RESULTS

Initially, 2120 published manuscripts were obtained from the electronic search (Pubmed: 570, EMbase: 859, Cochrane library: 89 and Web of Science: 603). One study was obtained from the manual search of the reference list. After removing duplications, 1239 studies were screened, and irrelevant publications were excluded. 196 abstracts were considered eligible for full-text review. 101 articles were further excluded after analyzing the full text. A total of 95 articles (3 in vivo and 92 in vitro) finally met the criteria and were included in the present study (Figure 1).

3.1 | In vivo studies

Only 3 in vivo studies were included in this review, including 2 retrospective studies[5,15] and 1 randomized clinical trial (RCT).[16] The risk of bias was assessed to be high for all 3 studies (Table 2). Their main findings were shown in Table 3. In the 2 retrospective studies, the measurement of the misfit was either performed by the intraoral scanner or panoramic radiography. Both revealed an insignificant correlation between the framework misfit and marginal bone loss or implant/prostheses failure although one study showed a slightly higher risk of screw-related adverse events in the misfit group. Regarding the RCT,

TABLE 2 Risk of bias of the in vivo studies

RCT[a]	Karl et al., 2016	
Item	**Authors' judgment**	**Descriptions**
Adequate sequence generation?	Yes	"Randomization was done by an independent individual based on enrolment numbers and a group randomization protocol."
Allocation concealment?	Unclear	No mention of concealment.
Blinding?	Unclear	No mention of study personnel or participants being blind.
Incomplete outcome data addressed?	Yes	One patient was excluded for malfunction of the strain gauge.
Free of other bias?	Yes	It appeared no other bias.
Risk of bias	High	
Retrospective[b]		
Item	**Jokstad et al., 2015**	**Slauch et al., 2019**
Selection		
Is the case definition adequate?	Yes, with independent validation.	Yes, with independent validation.
Representativeness of the cases?	Consecutive or obviously representative of cases.	Consecutive or obviously representative of cases.
Selection of controls?	No description.	No description.
Definition of controls?	No description.	No description.
Comparability		
Comparability of cases and controls on the basis of the design or analysis?	No mention.	No mention.
Ascertainment of exposure?	Secure record.	Secure record.
Same method of ascertainment for cases and controls?	Yes	Yes
Non-response rate	No description.	No description.
Risk of bias	*High*	*High*

[a]According to the Cochrane Collaboration's tool.
[b]According to the Newcastle-Ottawa Scale (NOS).

SGs were attached on the implant framework intraorally to assess the strain level. It was concluded that the passivity of fit of multiunit restorations seemed not to be as critical as previous thought for maintaining osseointegration of dental implants.

3.2 | In vitro studies

The 92 included studies were categorized according to the methodologies applied in the implant framework fit assessment. Two streams of studies were identified: dimensional and modeling measurements. Dimensional measurement is defined as the quantified discrepancy between the prosthesis and implant abutments while modeling measurement evaluates the mechanical effect of an ill-fitted prosthesis on the screws, implants and surrounding structures. Among the selected 92 studies, 47 solely used dimensional techniques while 23 investigated only with modeling techniques. Twenty-two combined at least two assessments or related one measurement to the clinical outcome.

3.3 | Dimensional assessments

In the included publications, more than half (27 out of 47 articles) described the implant-framework misfit with 2D measurements, such as vertical (31 articles)[4,17-45] and horizontal gaps (4 articles) at the margin,[18,43,44] as well as internal gaps between the mating surfaces (4 articles),[19-21,46] by stereomicroscope and SEM in different experimental conditions (one-screw test and definitive-fit test). Besides, 18 articles demonstrated the implant framework misfit with 3D measurements,[6,18,22,38,42,45,47-58] including the volumetric discrepancy[58] and spatial deviation in *X*-, *Y*-, and *Z*-axis.[6,45,47,48,50,51,54-56] The 3D data acquisition was usually performed by optical or tactile scanning,[42,56-58] computerized tomography (CT),[6,18,22,52,53,59] and coordinate measuring machine (CMM).[22,38,47-51,54-56] The advantages, disadvantages and accuracy of different acquisition methods are listed in Table 4. Following the reconstruction of the virtual model, the 3D discrepancy was often computed by an inspection software with various data processing algorithms (Table 5). In most of the studies, the framework was virtually mounted onto the abutments with the "best fit" position of the 3D models, using the least square method (Lsq),[6,22,42,45,48,49,51-53,56] zero method,[54] or orthogonal 3-2-1 method.[55] The one-screw test usually used at chairside can also be mimicked on the computer screen through aligning the distal virtual implant and abutment, namely "lofting."[58]

3.4 | Modeling assessments

SGA, FEA, photoelastic stress analysis (PSA), and reverse torque test of retaining screws have been documented in the included publications for assessing misfit-induced strain/stress. Descriptives, advantages and limitations of the techniques are listed in Table 6. Within the 23 articles solely used modeling assessments, 10 investigated with

TABLE 3 Characteristics and main findings of included in vivo studies

Article	Number of implants	Study design	Edentulous region	implants	Prostheses	Methods	Outcome measurements	Conclusions
Slauch et al., 2019	Mandible: 44 Maxilla: 138	Retrospective	Complete-arch	NA	Acrylic resin	Panoramic radiographs	Vertical gap; Early implant or prostheses failure.	95.8% early implant survival rate among implants with misfits; 84.8% early prostheses survival rate among implants with misfits; None of the clinical variables analyzed were significantly associated with the misfit status.
Jokstad et al., 2015	Mandible:150	Retrospective	Mandible Complete-arch	NA	Acrylic, Ag-Pd, Pd-Ag, Au type IV casting	Intraoral and laboratory scanning + best fit algorithm	Average misfit; Marginal bone loss; Prevalence of screw loosening or fractures; Implant or prostheses failure.	The effect of implant-framework misfit up to 230 μm on the long-term clinical outcomes appears to be minor, apart from a slightly higher risk of screw-related adverse events; The correlation between framework misfit and marginal bone loss was weak.
Karl et al., 2016	40	RCT	3-unit	Straumann	High-noble alloy casting	SGA	Mean absolute strains	Bone adaption around statically and dynamically loaded implants occurred, causing a decrease in misfit strain evoked by non-passively fitting prostheses.

TABLE 4 Advantages and disadvantages of 3D techniques to evaluate the implant-framework misfit

3D acquisition	Method	Output	Advantages	Disadvantages	Accuracy
Coordinate measuring machine (CMM)	1. Implant abutments and framework cylinders are measured independently; 2. The mating surfaces are touched by the probe to record point coordinates; 3. The data points are aligned into regular geometric shapes; 4. The center points of the aligned shapes are defined to represent abutments or framework cylinders.	Coordinates (*XYZ*)	Highly precise, reproducible and easily standardized by computer numerical control (CNC).	1. Using the center point to represent the component may lose details. 2. The probe cannot access subtle structures and undercuts. 3. Time-consuming and expensive.	+++
Optical scanning	1. Implant abutments and framework cylinders are measured independently; 2. Digitalize the surfaces by laser, structured light, or tactile probe; 3. Reconstruction of 3D models.	Point cloud	1. Easy and fast. 2. Allow full 3D reconstruction with details.	1. The point clouds transferred into STL format for further 3D comparison may affect the accuracy. 2. Deep undercut, too dull/ bright surfaces are difficult to acquire. 3. Scanning results may be affected by light reflection and scattering.	+
Computed Tomography (CT)	1. The implant framework is fixed on the implant abutments; 2. Scan the entire implant assembly by x-ray. 3. Reconstruction of 3D models.	DICOM	1. Components are physically connected instead of 3D reconstructed 2. Inspect internal connection and structures without destroying the framework. 3. Accurate, repeatable and able to detect subtle structures.	1. Radiation. 2. Artifacts, accuracy depends on material density and size being measured. 3. Time-consuming and expensive.	++

SGA,[16,60-69] 1 with PSA,[70] 1 with reverse torque test,[71] and 11 with FEA.[10,72-81] All 11 studies established the FE model with 2 implants (five overdentures, seven 3-unit frameworks), while no FEA study was found on complete arch prosthesis supported by multiple implants. Most of the FEA studies introduced levels of predetermined misfit into the FE models to calculate the resulting stresses concentrated in the implant system, including screws, framework, implants and peri-implant bone (cortical and cancellous bone). The artificially induced misfit ranged from 5 ~ 300 μm on the vertical plane[73,75-78,81] and 10 ~ 200 μm on the horizontal plane.[10,72,74,79,80] Besides, vertical bone loss (1.4 mm),[74] unilateral angular misfit (100 μm)[81] and axial/off-axial forces (100 ~ 200 N)[75,81] were also simulated in different studies. Within the 10 SGA studies, five studies built the model with 2 implants (3-unit),[16,60,65-68] two with 3 implants (5-unit),[64,69] and three with 4 implants (complete-arch).[61-63] Most studies obtained the readings after full-tightening of the retaining screws, while 1 article conducted the measurement under extra loading of 0 ~ 200 N.[68] SGs were attached either on the peri-implant simulant or on the framework.

3.5 | Combined assessments

Twenty-two articles combined at least two techniques to correlate implant-framework misfit and mechanical/biological/clinical consequences, including strain/stress in the mechanical components and peri-implant bone (21 articles)[72,82-101] and bacterial counting (1 article).[102] Within the 21 in vitro studies, 2D assessment using microscopy or SEM has been associated with PSA (5 studies),[85,88,89,91,92] SGA (7 studies),[82-84,86,93,100,101] FEA (3 studies),[96,97,99] and reverse torque test (2 studies).[87,90] Two studies combined 3D assessments (optical scanner) with SGA[94,95] and another 2 studies combined SGA and FEA.[72,103] One study indicated an inverse relationship between the vertical misfit and reverse torque of the prosthesis screw.[87] A PSA study[92] claimed a positive correlation between the marginal misfit and peri-implant stress, while the other 2 PSA studies[85,89] found no relationship between them. Three SGA studies found vertical misfit positively correlated with peri-implant[83] and framework strains.[82,100] Two other studies showed no correlation between vertical misfit and strains within the framework or the implants.[86,93] A study tried to correlate the fatigue behavior of the prosthesis to the vertical misfit with the aid of FEA, but no direct relationship was found.[96]

4 | DISCUSSION

The accurate fit of implant-supported prostheses is of prime importance for the long-term success of implant therapy.[104] The pipeline of

TABLE 5 Post-processing algorithms for misfit calculation

Algorithms	Methods	Outputs
Least square method	Superimposing the virtual framework to the theoretically best possible fit on the master model, with the shortest center point distances to those of the implant abutments at the same time.	1. *X*-, *Y*-, *Z*-displacement 2. 3D distance 3. *X*/*Z*, *Y*/*Z* angle 4. Intersecting distance between implants
Zero method	1. Superimpose the center point of the framework cylinder at one extreme of the arch on the corresponding implant abutment in all coordinates (*XYZ*); 2. Place the center point of the cylinder at the other end of the arch on the corresponding implant abutment in the *Y* and *Z* planes; 3. Place the center point of the cylinder at the most anterior on the corresponding implant abutment in the *Z* axis.	
Orthogonal 3-2-1 method	1. Superimpose the center point of the framework cylinder at one extreme of the arch on the corresponding implant abutment in all coordinates (*XYZ*); 2. Place the center point of the cylinder at the most anterior on the corresponding implant abutment in the *Y* and *Z* planes; 3. Place the center point of the cylinder at the other end of the arch on the corresponding implant abutment in the *Z* axis.	
Lofting	Superimpose the center point of the most distal cylinder of the virtual framework onto that of the corresponding virtual implant abutment.	Volumetric discrepancy
Maximum-fit for marginal discrepancy	1. Create a plane by picking the first 3 points of contact on the implant abutment (reference); 2. Create the framework cylinder center point; 3. Measure the plane-to-point perpendicular distance between the center point and the reference plane.	Vertical gap

research on implant framework misfit starts from quantifying the degree of misfits, followed by evaluating the misfit-induced strain/stress, to predictions of the risk of adverse events and longevity of the related prostheses. However, it is unsuccessful so far because (a) reliable methods to assess the misfit are currently unavailable; (b) a clear relationship between the misfit and the resulting strain/stress has not been substantiated, and (c) consensus on the clinical threshold of tolerable misfit has not been reached. To the best of the authors' knowledge, this systematic review is the first to summarize methodologies documented in scientific literature published in the past decade on the implant framework misfit and review whether they could link the misfit with the clinical complications. The most important finding is that the present assessments have been significantly advanced compared to those conducted before 2010 when digital devices such as CMM, optical scanners and CT were not available.[12] The development of reverse engineering software and post-processing algorithms is also a significant leap for analyzing the digital data. Meanwhile, modeling measurements, particularly SGA and FEA, have been further optimized to delineate the complex picture of misfit-related mechanical consequences. In the in vitro studies, the misfit was found related to the induced strain/stress, while the in vivo studies indicated the correlation between the misfit and the clinical consequences, including marginal bone loss, screw-related adverse events, and implant/prostheses failure, was weak.

4.1 | Definition of passive fit

Before investigating the framework misfit, a clear definition of "passive fit" is needed. It was once described as the level of fit that did not cause any related clinical complications in the long-term.[80] However, this definition was entirely hypothetical as neither sufficient

TABLE 6 Advantages and disadvantages of modeling assessments of the implant framework misfit

Data acquisition	Method	Location	Output	Advantages	Disadvantages
Strain gauge analyses SGA	Sensors are attached onto the tested surfaces; Fix the framework; Electronic signals are created as deformation detected.	Peri-implant structures Framework Abutments	Strains (μ)	Quantitatively measure local strains. Easy to operate in laboratory. Possible to operate intra-orally.	Limited to flat surfaces. Sensitive to locations, directions, room temperature and humidity.
Photo-elastic stress analyses PSA	The test implants are embedded in a special photo-elastic resin; Fix (and load) the framework; Inspect through a polariscope and record with a digital camera.	Peri-implant structures	Color scale Stress (MPa) fringe order (FO)	Effective and reliable. Based on real implant components; Enable both qualitative and quantitative evaluations; Suitable for complicated implant geometry, long-span framework and dynamic loading conditions;	Depends on photo-elastic cast fabrication with high technique sensitivity; Color-pattern interpretation can be very subjective.
Reverse torque test	A digital torque meter is used to loosen the screws with other screws tightened.	Retaining screws	Torque (Ncm)	Enable evaluations under dynamic and static conditions; Easy to operate intra-orally; Non-destructive.	Test results can be influenced by the mechanical properties of the screw, framework and peri-implant bone.
Finite element analyses FEA	Original model is established based on clinical data; Define material properties; Predetermine misfits; Magnitude and location of stress is computed.	Peri-implant structures Framework Implant Screws	Von Mises stress Maximum principal stress	Precise estimate of the level of stress quantitatively with detailed distributions; Fast and low-cost; Easy to change material properties and modify the model. To simplify complicated dental situations.	Results are highly sensitive to the assumptions and boundary conditions.

clinical evidence on the misfit-related complications nor effective clinical method to detect such misfits was available. Subsequently, the engineering definition of fit has been introduced, which referred to the relative looseness (clearance) or tightness (interference) of the mating parts, and that affects the motion of the parts or the force between them after assembling. There are four grades of fit classified from loose to tight: sliding fit, transition fit, interference fit and force fit.[7] The sliding fit is characterized by having a small clearance at the interface to allow free assembling, which meets the clinical requirement for retrievability of implant-supported prostheses. From transition fit to force fit, the mating surfaces are assembled with increasing pressures and hence they could not move/slide. On this basis, "passive fit" can be defined as a degree of interface clearance falls in the range of sliding fit, but not too loose or too tight. Most clinical and laboratory studies assessed the clearance fit by measuring distance and volume between the implant components.[53,58] This review used the term "misfit" as a dimensional parameter to describe the non-passively fitting condition based on the above definition. On the other hand, the "passive fit" has also been proposed as a condition that does not exert any stress/strain on preloaded implants.[6] Perfect "passive fit" in screw-retained prostheses can never be reached, since frameworks always deform even in optimal fit conditions.[82] Framework strain is an inevitable consequence of tightening screws. Therefore, some authors have suggested revising the strain-free "passive fit" definition.[105] In summary, the descriptions mentioned above about "passive fit" are empirical and poorly understood.[12]

4.2 | Dimensional measurements

The classic analogue techniques, such as SEM and stereomicroscope, have long been used in previous studies for direct examining the marginal and internal gaps after sectioning the framework.[19-21] They have limitations in measuring 3D discrepancies and angular misfits.[72] For any modern digital dimensional measurements, it entails three phases including data acquisition, virtual assembling/alignment followed by measurement.

4.3 | Data acquisition

With the rapid development of 3D data acquisition techniques, the implant components can be digitally acquired by CMM, CT, and optical/tactile scanner. Among all, CMM, always serves as a reference in previous studies, because of its high precision (±2 μm) with minimal disturbances by device vibration, surrounding environment and tested material.[106,107]

The second most accurate machine is industrial CT, which has been extensively used for non-destructive measurements. The X-ray can penetrate the framework and detect microgaps along the entire interface with an accuracy of $9 \sim 11.3$ μm.[6,59] Nevertheless, X-ray scatters and artifacts generated from the metal components often hinder the precise delineation of margin and inner structures.[108]

Optical scanners have shown variable accuracy, ranging from 5 to 30 μm for the laboratory scanners[109-111] and 11.9 to 304 μm for the intra-oral scanners (IOS).[112] Since the misfit of implant frameworks to be detected might be very small in the order of microns, most laboratory scanners seem fit for the purpose but not the IOS.

4.4 | Virtual assembling/alignment

Various alignment methods have been used to match 3D data of implant components and framework before analysis is done in the reverse engineering software. The Lsq method is the most widely used in many studies, which aligns the central points of the implant abutment to the framework with the shortest distances.[55] Alternative methods such as "orthogonal 3-2-1 method" and "zero method" using different algorithms were applied in other studies. However, the "virtual alignment" based on 3D reconstructed models should be interpreted with caution. First, in the virtual world, 3D models are aligned without consideration of physical contact or constraints. Therefore, the aligned models can penetrate each other that is clinically unfeasible, and the misfit is often underestimated. To overcome this limitation, new algorithms have been developed in which a tripod contact situation between the framework and master model was created.[56] Second, in clinical practice, the implant framework does not just "seat" on the implants but is screw-tightened under a recommended torque. The one-screw test has been accepted as a standard way to evaluate misfits clinically.[15] If the screw on the terminal abutment is fully tightened without detecting a marginal gap at the other sites visually or by dental probes, the prosthesis will be regarded as clinically acceptable.[6,113] Accordingly, Almasri and co-workers[58] advocated a CAD process, named "lofting", to simulate the one-screw test virtually. A distinct advantage of this algorithm is that the vertical/horizontal misfit over the other implants measured from the virtual aligned prosthesis can be validated in vivo. On the other hand, some studies have used the "definitive fit test" with both screws over the terminal implants tightened instead before the misfit is assessed.[22,25,32,34,44] A study showed that the mean vertical gap of complete-arch zirconia frameworks would be reduced from 107 μm to 5 μm if the one-screw test was changed to the definitive-fit test for misfit assessment.[45] Other studies also found that vertical gaps up to 500 μm could be closed if all retaining screws were tightened.[6] Therefore, for the definite fit test, measuring the dimension of the residual gap seems not a reliable method as various components in the implant assembly are deformed under stress, and the misfit would be underestimated. Instead, as the definite fit is the final clinical condition of screw-retained prostheses attached to the abutments/implants, measuring the induced stress/strain level appears more representative to the degree of misfit.

4.5 | Modeling assessments

Modeling techniques are broadly used in the engineering science for analyzing and predicting material behavior and intricate stress-strain pattern under loading. They are considered to be complementary to the dimensional techniques by assessing the effect of the misfit from a mechanical angle of view.[12]

4.6 | Virtual modeling

FEA is a numerical method that can be used to explore the misfit-related stress in the implant assembly and peri-implant structures by inputting pre-determined values of vertical, horizontal and angular misfit into the FE models. Studies showed vertical misfit induced more stress in the superstructures (framework, screws and veneering material) than in the infrastructures (implant and peri-implant bone)[80] because the residual vertical gap, acting as a stress-breaker, hindered the stress transferring toward the implants and their surroundings.[78] Compared to the vertical misfit, stresses induced by the horizontal misfit were found to be more evenly distributed across the entire system.[79] It was reported that a predetermined horizontal misfit of 10 to 200 μm could induce stresses of 38 to 810 MPa and 33 to 660 MPa in the gold alloy framework and the cortical bone respectively.[74] On the contrary, another study estimated the level of misfit required to produce a known strain around the peri-implant structure.[103] The result indicated that a horizontal misfit of 36 μm, a vertical misfit of 79 μm or an angular misfit of 0.083° could create a similar level of strain. The results imply that overload of peri-implant bone may be more easily caused by the angular misfit, followed by the horizontal misfit, while the vertical misfit seems less damaging.

Although FEA is a versatile way to analyze misfit using simulation models, its validity and clinical relevance have always been questioned.[98] Four limitations of the FEA have been noticed: (a) Some simple FE models are far from clinical reality, for example, using homogenous peri-implant bone, considering implants are simple cylinders without threads, and so forth; (b) Mechanical data such as cortical/cancellous bone for the FE model might vary much among individuals or not be available; (c) Assumption of 100% transmission of stresses distributed along the interfaces (prostheses-abutment interface, abutment-implant interface and bone-implant interface) is unrealistic; (d) Results are not clinically verified.[98]

4.7 | Laboratory modeling combined with dimensional measurements

Different laboratory techniques have been used to analyze misfit-induced mechanical consequences such as deformation of implant components measured by strain gauges, stress pattern around implants using photoelastic material, and reverse torque of prosthetic screw. They were mostly performed and collaborated with the dimensional findings of misfit to substantiate the relationship between the misfit and the strain/stress within the implant system. This review included 22 such studies, most of which investigated the correlation between the laboratory modeling data with the vertical misfit only.

4.7.1 | Framework and implants

The SGA is the only available technique to assess strains within the framework and implants with high accuracy and sensitivity. Two studies found no correlation between the vertical misfit and strains within the 5 implant-supported complete-arch framework[86,93] while another study revealed a direct relationship in the 2 implant-supported 3-unit framework.[82] It should be noted that the latter study used the peak-to-peak amplitude of strain as the primary outcome instead of the mean absolute strain that other studies had used.[60] The rationale was that because the induced strains did not increase linearly when the vertical gap was being closed during screw tightening, measuring the peak-to-peak amplitude revealed the overall strain as well as its level of fluctuation in relation to the misfit and minimized the risk of underestimating the effect of misfit.[105] It must be emphasized that current findings of SGA were based upon simplified scenarios (3-unit) and misfit. For those comprised of multiple implants in non-linear position and angulation with complex loading conditions, the relationship between misfits and strains may become more complicated.

4.7.2 | Peri-implant bone

PSA and SGA have been extensively used to evaluate peri-implant strains induced by misfits. Strain gauges have a physical limitation, and hence they could only measure strain changes in a broad area. On the other hand, PSA is capable of examining specific sites along the implant-bone interface. Besides, instead of giving a single reading only, a complete stress pattern can also be visualized using PSA. Therefore, PSA is considered to be an effective technique to evaluate peri-implant strains.[70] Among the included articles, 5 studies combined the PSA with 2D assessment of vertical misfits, in which 4 studies with a small sample size of $1 \sim 5$ did not show a correlation between the vertical misfit and peri-implant strain.[85,88,89,91] Only 1 study with a larger sample size (n = 10) revealed a positive correlation.[92] Besides, as the peri-implant structure distortion is always multi-dimensional, the quantitative PSA could not show the stress direction and hence it is regarded as a limitation.[48] To address this issue, Abduo and colleagues[60] proposed placing uniaxial SGs around the implant, which showed compression or tension stress distributions in each direction. They also showed a high positive correlation between vertical misfits and crestal bone strains. Two other studies assessed the misfit in 3D using optical scanners and found a significant association with the induced strains in each direction using SGA.[94,95] The above studies indicate that 3D measurements demonstrated with X-, Y-, Z-vectors are more likely to reveal the potential relationship.

4.7.3 | Retaining screw

If there are misfits in the implant framework, the optimal preload of implant prosthetic screw after tightening could not be achieved.

Bhering and co-workers[87] reported a moderate negative correlation between the vertical misfit and the reverse torque of prosthesis screws in implant-supported prostheses. The result agreed with the FEA study that the mechanical components in implant assembly with vertical misfit were being stressed.[80]

4.8 | Relationship between the misfit and clinical complications

In the last decade, clinical studies regarding implant framework misfit were fundamentally lacking. Only three clinical studies were included in this review, reporting none or weak correlations between the level of misfit and early/long-term implant/prostheses failure, as well as the mechanical complication and biological response. Compared to the in vitro studies, the controversial findings of the clinical studies might be due to the (a) lack of high-precision 3D intraoral assessing devices; (b) heterogeneity of included implant prostheses such as type, number, length, size, position, and distribution of implants as well as design and material used; (c) Uncontrolled confounding variables including gender, age, periodontal condition, occlusion and parafunctional habits. For example, one study found no significant association between the early implant failure and misfit of immediate provisional implant-supported prostheses,[15] in which the misfit level was assessed by panoramic radiographs. Another long-term retrospective study[5] showed a higher incidence of screw loosening/fracture in the ill-fitting implant frameworks, but no undesirable effects on marginal bone loss were found. IOS is a promising tool to acquire 3D images at the chairside and allow efficient 3D comparisons between the implants and framework. Nevertheless, the results of this study might not be reliable since the misfit measurements were made by an IOS with substantial scanning errors.[114] Previous studies showed that the intraoral scanning error (trueness) for a single tooth was only 6 to 45 μm, but for the complete dentate arch, it was significantly larger (70 ∼ 155 μm) and for complete edentulism, the distortion was more than double (63 ∼ 253 μm).[114,115] There is one randomized clinical trial using SGA to monitor strain fluctuations within the implant-supported bar intraorally. The strain level of the misfit prostheses was shown to be significantly higher than the fit ones during insertion. However, after 6 months, bone adaption was found, and the strains in the misfit framework were reduced.[67] The SGA is the only modeling technique that can be operated intraorally although the accuracy could be affected by unfavorable humidity and temperature in the oral cavity.[60] Therefore, in future studies, a standard clinical protocol, such as using rubber dam, might be helpful to control the experimental environment for intraoral SGA.

Besides, there are currently no methods to assess the strains in the peri-implant bone intra-orally. It is considered to be estimated by importing the intraoral SGA data of implant frameworks into the simulated FE models.[103,116] The estimated peri-implant strain/stress can then be further assessed whether it is clinical tolerable or not as bone strain >2500 μm/m has been considered to be overloading.[105]

4.9 | Limitations

There were only 1 RCT and 2 retrospective in vivo studies included in this review with relative low quality. Insufficient evidence was available to draw solid conclusions to bridge the gap between dimensional and modeling data of the misfit with the clinical complications. More studies employing 3D measurements of the misfit and the induced strain/stress are needed. Besides, the searching and selection of the literatures have been done by only one author, which might involve bias in the procedures.

5 | CONCLUSIONS

Within the limitation of this systematic review, the following conclusions can be drawn:

1. Dimensional and modeling techniques are available to measure the implant-framework misfit.
2. The relationship between the implant-framework misfit and the induced strain/stress has been revealed in vitro.
3. The relationship between the implant-framework misfit and the clinical consequences seemed weak.
4. Further studies combining 3D assessments using dimensional and modeling techniques was needed.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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