INFLUENCE OF ABUTMENT CONNECTIONS ON STRAIN DISTRIBUTION FOR IMPLANT-SUPPORTED 4-UNITS BRIDGE

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INFLUENCE OF ABUTMENT CONNECTIONS ON STRAIN DISTRIBUTION FOR IMPLANT-SUPPORTED 4-UNITS BRIDGE

JEKITA SIRIPRU

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BY

JEKITA SIRIPRU

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IN CLINICAL DENTISTRY AT SRINAKHARINWIROT UNIVERSITY

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The purpose of this study is to evaluate the microstrain around two non-parallel implant-supported bridges with different types of abutment connections (engaging, non-engaging and scrp) and the different positions of abutments. The four models simulating the mandibular unilateral free end were fabricated. There were eight implants (4.0 x 10 mm and 5.0 x 10 mm) were inserted in four models in the position of the second premolar (45) that paralleled the long axis and the second molar (47) that tilted 15° from the long axis to support a 4-unit zirconia bridge, according to different abutment combinations: engaging and engaging abutments (angled abutment), both non-engaging abutments, both SCRP abutments, and engaging and non-engaging abutments. Four strain gauges were mounted buccally, lingually, mesially, and distally adjacent to each implant. Applied vertical static load: 300 N. Microstrains were recorded and analyzed statistically by three-way repeated ANOVA and pairwise comparisons (α=.5). The result showed group two (non-engaging, non-engaging) showed the highest compressive microstrains (-52.975), followed by control group one (engaging, angled abutment) (-25.239), and group three (SCRP-SCRP) had the lowest compressive microstrains (-14.505), while only group four (engaging, angled abutment) had tensile microstrains (0.418). The microstrains in groups three and four were significantly lower than those in the control group (α=.5) Area 45 showed compressive microstrains (-47.06), while area 47 had tensile microstrains (+0.91), with microstrains in area 45 being significantly higher than in area 47 (α=.5) In conclusion, the type and position of the abutment connection have significantly affected microstrain at the implant-bone interface of two non-parallel implant-supported bridges. Both SCRP abutments for two non-parallel implant-supported bridges provided optimal microstrain distribution on bone.

Keyword : Microstrain, Implant-supported bridges, Abutment connection, Strain gauge

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CHAPTER 1
INTRODUCTION

Background

Implant-supported fixed dental prostheses (FDP) are a well-established treatment option for patients who are partially or fully edentulous and have evolved into a standard of care in dentistry[1]. Several data support high and long-term treatment success, as well as high patient acceptance[2]. However, factors that affect the implant-supported FDP's longevity, such as the bone quality, stress concentration, type of abutment, dimensions, and position of the implants, have been considered[3].

For implant-supported FDP, the implant number is an important factor when considering the biomechanical response that influences the masticatory stress transmitted to the bone tissue[4]. For a long span edentulous area of 4-6 teeth, the use of 2 or 3 implants is determined by the masticatory stress, occlusal scheme and bone availability[5]. This success is based on the phenomenon of osseointegration, refined surgical techniques, improved stability between implant and abutment interface (IAI), and the establishment of lifelong prophylactic efforts to avoid biologic complications and failures[6].

The stress and displacement of IAI determine clinical success. When significant stress is applied to the restoration and implant components, mechanical complications such as screw loosening and screw fracture, as well as abutment fracture, may occur. The macro-geometric shape of the implant connection (external indexed, internal indexed or cone connection), abutment types (engaging versus non-engaging), implant component materials, position of the dental implants and masticatory forces can influence stress patterns in the implant-prosthesis-bone complex[6].

Implants can be placed in correct three-dimensional (3D) position with a prosthetic-driven philosophy by using computer-assisted surgical procedures. Template-guided placement has been established as a static procedure, whereas real-time navigation is a dynamic process.[7] But template-guided placement is limited to inadequate mouth openings.[8] In the traditional method, freehand implant placement is still done. In the posterior region, the deviations between planned and actually achieved position with freehand implant placement showed the mean values and standard deviations as follows: angle 8.7 ± 4.8°, 3D deviation at the implant shoulder 1.62 ± 0.87 mm, mesiodistal deviation 0.87 ± 0.75 mm, buccolingual deviation 0.70 ± 0.66 mm, and apiocoronal deviation 0.95 ± 0.61 mm.(9) Freehand implant placement exhibits a higher level of deviation between planned and actually achieved implant positions. Moreover, bone anatomy in some areas may limit in implant angulation, such as the lingual concavity in the posterior mandible.

The design of the IAI is important because it affects the stress on the abutment screw. The engaging abutment can reduce stress on the abutment screw because it increases the contact area and decreases micromovement, which can reduce screw loosening.(10) However, the path of insertion for implant-supported multiple-unit FDP on nonparallel implants may be difficult.

Both the non-engaging abutments on the two implant-supported 3-unit FDPs are typically designed to allow the prosthesis to be inserted and removed from multiple nonparallel implants. To use engaging components, implants may not have to be perfectly parallel, but any deviation from parallelism has a minimal error rate, and the level of tolerance is determined by the connection design. Implants with long internal parallel engagement areas are the least indulgent of any deviation, whereas implants with short conical engagements are the most flexible. External connection implants are frequently selected for this reason, in part because of their short engagement area and high tolerance for nonparallel angulations.(11)

Screw and cement-retained prosthesis (SCRP) is a new concept for implant restoration that combines the advantages of both screw and cement-retained restoration. A new designed connection, SCRP abutment, has both engaging and non-engaging components in one abutment. If the implants are not parallel, the SCRP abutment provides space to compensate for the undercuts between the hex parts of the nonparallel implant.(12)

Implant-supported fixed dental prostheses are more challenging to produce because the impression must be much more precise to connect two or more implants into a single prosthesis. Therefore, the angulation of implants has become more important so that implants are never 100% parallel, passive fit is more difficult to achieve, and more technical precision is required.[13] Nowadays, there are no manufacturer guidelines for selecting the position of an engaging or non-engaging abutment to be connected to the fixture in non-parallel implant-supported FDP. Due to a lack of directly relevant scientific data, this practice is based on anecdotal evidence and the clinical experience of educators and clinicians.[14]

Strain gauge analysis has been widely used to analyze the microstrain distribution of dental implants surrounding bone. Strain gauges are used to evaluate the deformation of force subjected to an implant component.

Research question

Do the types of abutment connections (engaging, non-engaging, and SCRP) and positions of abutments affect the microstrain in non-parallel implant-supported 4-unit FDP.

Objectives of the Study

The aim of this study was to investigate the microstrain of the implant-bone interface around two non-parallel implant-supported 4-unit FDP in the posterior region with different types of abutment connections (engaging, non-engaging, and SCRP) and different positions of abutments (areas 45, 47).

Significance of the Study

The implant-supported 4-units FDP has been widely used in partially edentulous patients because of its high success rate. In the posterior region, template-guided placement does not allow for the correct position of the implant because of the limited mouth opening. Therefore, freehand implant placement is still the conventional method to use. Freehand implant placement, on the other hand, involves deviations between planned and achieved orientation. When the two implants supported 4-units FDP non-parallel, which connection of abutment should be aware. Passive fit between implant-abutment connection of any implant is the goal of prostheses placement this effect to biomechanical failure of the implant, abutment, or prosthesis complex. The purpose of this study was to investigate the microstrain of the implant-bone interface around two non-parallel implant-supported 4-unit FDP in the posterior region with different types of abutment connections (engaging, non-engaging, and SCRP) and positions of abutments (areas 45, 47).

Scope of the study

This study is a laboratory experimental design to compare the microstrain of the implant-bone interface around two non-parallel implant-supported 4-unit FDP in the posterior region with different types of abutment connections (engaging, non-engaging, and SCRP) and different positions of abutments (areas 45, 47). Strain gauges and static axial loads by universal testing machines were used to measure microstrain around the implant-bone interface.

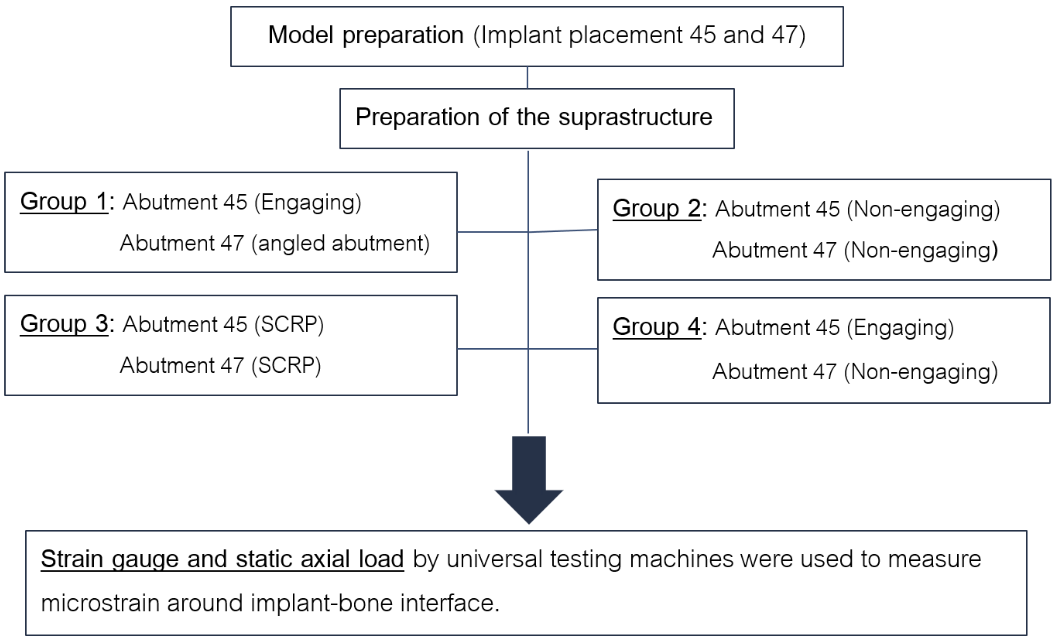

Figure 1 Scope of the study

Variable of the study

1. Independent variable: Types of abutment connection, positions of abutment
2. Dependent variable: Microstrain distribution of the implant-bone interface
3. Controlled variable: The model's size, angulation of implant, material and size of suprastructure, type of resin cement, position and axis of static axial load

Definition of term

1. Implant supported 4-unit FDP: 2 implants supported 4-units bridge.
2. Engaging abutment: The abutment has an apical hex with positioning grooves that guide the positioning of the restoration and anti-rotating.
3. Angled abutment: Angulated dental implant abutment
4. Non-engaging abutment: The abutment has not an apical hex with positioning grooves.
5. Screw and cement retained abutment (SCRP): a single abutment with both engaging and non-engaging components.
6. Microstrain: A strain expressed in term of parts per million

Hypothesis

H_0: The type and position of the abutment connection have no effect on microstrain at the implant-bone interface around two non-parallel implant-supported 4-unit FDP in the posterior region.

H_1: The type and position of the abutment connection have effect on microstrain at the implant-bone interface around two non-parallel implant-supported 4-unit FDP in the posterior region.

CHAPTER 2
LITERATURE REVIEW

In this research, the researcher has compiled documents and related research to present the following topics.

1. Engaging abutment for implant.
2. Angled abutment for implant.
3. Non-engaging abutment for implant.
4. Screw and cement-retained abutment for implant.
5. Type of retention for implant supported fixed dental prostheses (Screw retained vs cement retained prosthesis)
6. Stress distribution in surrounding bone and implant component.
7. Stress distribution in implant-supported fixed cantilever prostheses.
8. Biomechanical success and failure of implant supported fixed dental prostheses
9. Strain gauge

Engaging abutment for implant

Engaging abutments are designed to lock into the implant interface's unique anti-rotation feature (hex, star, etc.).

Figure 2 Hex interface found on Zimmer Biomet, Nobel Biocare™ and BioHorizons®. The square interface found on Straumann and the star interface found on Keystone Dental

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Use the engaging abutment with a single-unit screw-retained restoration. This procedure will lock the individual crown in the proper position. The abutment can rotate on the implant if a non-engaging abutment is used. The contact area with adjacent teeth of the crown would be the only location with any kind of anti-rotation feature.

Figure 3 An engaging abutment needs to be used for single unit crown so it can lock into the correct orientation and when a non-engaging abutment is used on a single unit, the crown can freely rotate

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For a screw-retained implant-supported 3-unit FDP, one question to consider is whether to use an engaging abutment to engage the anti-rotational feature and internal wall of one or more of the implants. There are currently no manufacturer guidelines available to assist users in making this selection. There is no peer-reviewed evidence available on engaging component selection in multiple connected units, according to a survey of the literature.(14)

An institutional protocol uses at least one engaging component for restoring implants with attached screw-retained restorations wherever practicable. The use of a single engaged abutment simplifies prosthetic positioning and seating and also intuitively transfers some of the stress from the abutment screw to the implant fixture, resulting in a different biomechanical complex. This approach is based on anecdotal evidence from clinical experience due to a lack of direct relevant scientific research. Clinical criteria are sometimes utilized to choose which implant to engage, such as implant position and angulation.(14)

By increasing the contact area for engaging abutments, the design at the implant-abutment interface (IAI) can dramatically minimize stress and strain on the abutment screw. This leads to improved load distribution, reducing both micro-movement and the risk of screw loosening. Although the stability of the prosthesis is improved by these properties of internal indexed implants and engaging abutments, the path of insertion for multiunit prostheses on nonparallel implants can be difficult.[6]

Figure 4 Engaging type IS abutment (Neobiotech, Korea)

Copied from the 2017 Neobiotech Implant System catalog.

Angled abutment for implant

In some clinical conditions, excessively resorbed bone may lead to improper implant alignment, which may result in discrepancies between the long axis of the implant and the abutment. Future prosthesis fabrication will probably face difficulties. There is an option available to overcome such problems: an angled abutment. When inserting an implant, it is appropriate to achieve a balance between prosthetic and anatomical concerns[15].

An angled abutment is often used in cases where the implant is not parallel to the adjacent teeth or the implant. Since the thickness of the bone ridge is insufficient and the patient does not want a bone graft and avoids the mandibular canal, the dentist can choose an angled abutment to correct the angle of the implant. parallel to the side teeth, giving a proper restoration contour and making it easier to insert. An angled abutment can help reduce the treatment time and cost of guided bone regeneration[16].

However, the conclusions of multiple studies[17-19] indicate that angled abutments generate greater stresses on the prosthetics they support, the adjacent bone, and the supporting implants. These increased stresses usually fall within physiological tolerances. not decreased the survival rate of implants or prostheses and do not seem to be associated with screw loosening in comparison with that of straight abutments.

Nowadays, there are a variety of prefabricated abutments on the market, depending on the manufacturer. Preangled abutments have a variety of angles from 15 degrees to 35 degrees, depending on the manufacturer, or you can fabricate custom abutments to create the appropriate contour of the restoration.

Neobiotech uses an IS-angled abutment, which can be customized by grinding. Can be positioned in 12 directions by selecting A or B, where A type angles to the edge and B type angles to the flat walled and non-engaging, with diameters of 4.5, 5.2, and 5.7, with cuff heights of 2.0, 3.0, and 4.0 mm, with an angle of 15 degrees and 25 degrees.

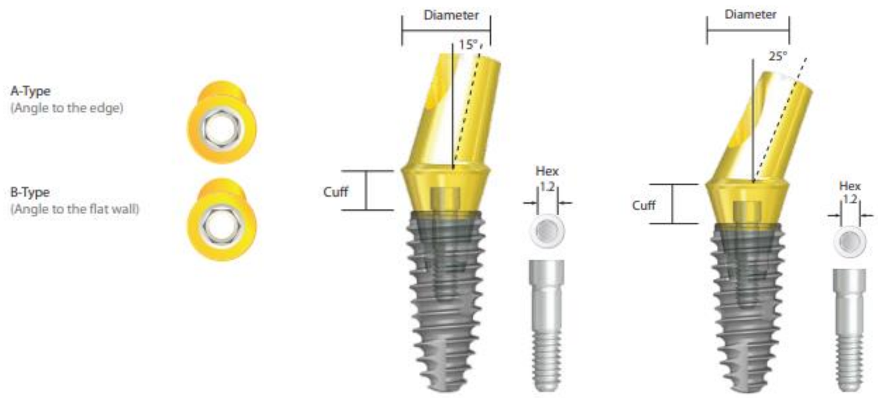

Figure 5 IS Angled abutment 15° and 25° (Neobiotech, Korea)

Copied from the 2017 Neobiotech Implant System catalog.

Non-engaging abutment for implant

Non-engaging abutments do not have this anti-rotational feature. Rather, the design does not quite interact or lock in the same way between the abutment and implant.

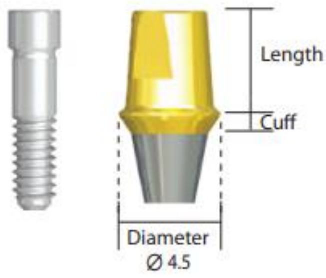

Figure 6 non-engaging type IS abutment (Neobiotech, Korea)

Copied from the 2017 Neobiotech Implant System catalog.

When two implants are not parallel, using both engaging abutments, it is difficult to achieve a passive fit of the suprastructure. Non-engaging abutments are an option to use in this situation. Because the non-engaging abutment is smooth and lacks this anti-rotational property, it can be inserted into the implant fixture in all directions to achieve a passive fit of the suprastructure.

Non-engaging abutment is the absence of an engaging part. That cannot be repositioned after preparation without a repositioning jig. Sometimes, a jig cannot be repositioned if the jig is not fit. It is more difficult to maintain the abutment in position after applying torque to the implant because the position in the oral cavity and the position in the working cast are not the same, as the position may lack passive fit of the superstructure.[20]

Figure 7 With engaging abutments, a passive fit of a screw-retained restoration may not even be possible if the implants are not completely parallel

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When two implants are placed for supporting a bridge with parallel orientation, the stock abutments with engaging connections can be used for retrievable screw-cement-retained prostheses. While nonparallel implants are placed, the engaging abutments are not retrievable due to the undercuts caused by the angulation implant. In such conditions, non-engaging abutments should be utilized, but they cannot be relocated after preparation without using a repositioning jig. However, if the jig is not exactly placed in the working cast and intraoral in the same position, or if the seating repositioning jig is disrupted by the surrounding gingiva cuff, the non-engaging abutment cannot always be replaced.[12] A screw-and-cement-retained abutment (SCRP) can be an alternative that may solve this problem with passivity and retrievability.

Screw and cement-retained abutment and prosthesis for implant

A Screw and cement-retained abutment (SCRP) is a specially designed stock abutment with a unique type of connection. In one abutment there are both engaged and non-engaged components. It has a short-engaged section that allows for abutment relocation, as well as a non-engaged section. A non-engaging figure appears in the lower half of the engaging area. The upper half of the engaging section is designed to allow each prepared abutment to be connected to its corresponding implant by a fine touch from the fixture without the use of a repositioning jig. The lower non-engaging part is designed to allow the SCRP to be retrieved like screw-retained prostheses after the multiunit suprastructure has been intraorally cemented to the abutments. It also has the ability to separate from the non-parallel implant within 20 degrees, despite the fact that it is a cement type prosthesis with a screw hole at the occlusal surface. After cementing the prosthesis with permanent cement, they can be removed by removing the screw through the screw hole, which causes the SCRP multi-abutment and prosthesis to separate from the implants as one piece. The SCRP abutments, unlike conventional engaging abutments, enable the retrieval of the entire suprastructure, even if the implants are not parallel. This is feasible thanks to the SCRP abutment's unique structural design, which includes gaps to compensate for the undercuts generated by the nonparallel implant connection.[12]

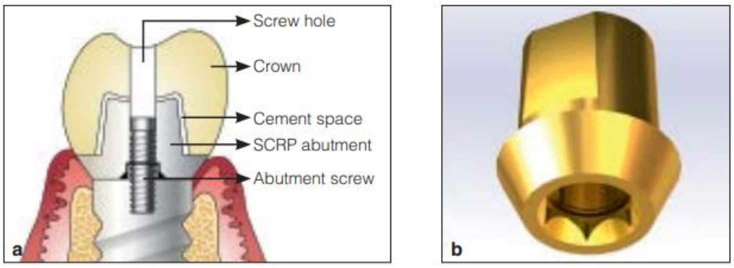

Figure 8 The components of the SCRP system.

Site Young-Ku Heo (2015), International Journal of Prosthodontics

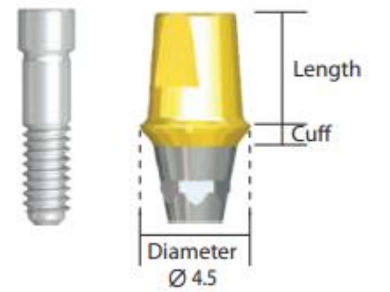

Figure 9 SCRP type IS abutment (Neobiotech, Korea)

Catalog Neobiotech implant system 2017

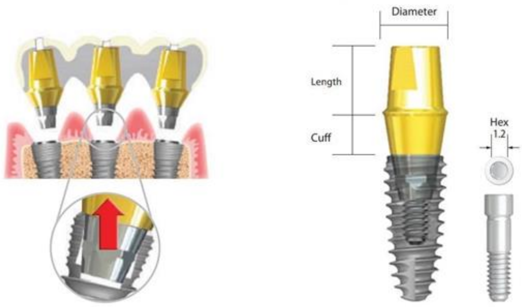

Figure 10 Abutment for screw-cement retained of the nonparallel implants

Catalog Neobiotech implant system 2017

The SCRP technique allows for the retention of the prosthetic suprastructure with any definitive resin cement, which can compensate for minor fabrication defects. As a result, even with long-span prosthesis, a passive fit can be achieved without cutting or soldering. After permanent cementation, the SCRP system's prosthesis is retrievable, allowing a clinician to unscrew and retighten the entire suprastructure as needed for repair, maintenance, or excess cement removal.[12]

In contrast, the presence of screw holes on the occlusal surface can impair the stable occlusion and esthetic component of the SCRP prosthesis. Because the SCRP is cement-retained, even if a definite cement is used, cement washout will occur over time. As a result, determining the maximum retention form of the abutment and selecting a definite cement with high strength are crucial for the SCRP system's effectiveness.[12]

As mentioned above, it is concluded that the engaging abutment is used in single-unit restoration, cement-retained restoration, and parallel implants. The non-engaging abutment is used in multiple implant restorations or in two non-parallel implants. The SCRP abutment is used for multiple implants that are not parallel and retrievable within 20° between implants.

When multiple implants are placed, implant-supported fixed dental prostheses are more challenging to produce. Engaging and non-engaging titanium bases can be used in a single prosthesis. Linkevicius T. (2019)[13] suggests using the engaging base chosen for the straightest implant, which facilitates the positioning of the prosthesis during placement, and the non-engaging base for the others. Savignano R. et al. (2021)[6] found that implant-supported FDPs with different combinations of engaging and non-engaging abutments resulted in different stress patterns in the implants and prosthesis components. The dual-engaging abutment had the best stress distribution, followed by the engaging abutment being placed in the more anterior implant position and the non-engaging abutment being placed in the more posterior implant position. Non-engaging abutments resulted in higher stress areas at the implant platform and the prosthetic screws, which exceeded the yield strength of the titanium alloy. Dogus, S. M., et al. (2011)[14] found that using an engaging abutment in a screw-retained fixed cantilevered FDP provides a mechanical advantage. Engaging the implant farthest from the cantilever when designing a screw-retained cantilever FDP increased resistance to fracture of the abutment screw so that more cycles and more force are required for failure.

Type of retention for implant supported fixed dental prostheses (Screw retained vs cement retained prosthesis)

Many clinical and laboratory processes are involved in the manufacturing of implant-supported prostheses, as are a succession of decisions about implant components, materials, and other factors. The treating clinician and technician must choose between screw and cement as a technique of retention at some point during the treatment planning process. Both of these techniques have their benefits and drawbacks, and it is the clinician's obligation to choose the most appropriate method of retention for each patient.(21)

Screw-retained implant-supported prostheses provide the advantages of reliable retrievability, a minimal interocclusal space requirement (4 mm.), and being easy to remove for hygiene, repairs, or surgical interventions. Because of the position of the screw access, screw-retained implant supported prostheses necessitate accurate, prosthetically driven implant insertion. The limitations of a screw-retained prosthesis for implant-supported 3-unit FDP are UCLA abutment fabrication by casting, which is costly and technique-sensitive; chipping of porcelain; and the access hole in the occlusal table, which may interfere with occlusion in posterior sites. Because access to the screw plays no active role in occlusion in the anterior zone, there should be no reason to avoid it.(1) When compared to cement-retained implant-supported prostheses, the manufacturing procedure for screw-retained implant supported prostheses is more technique-sensitive and demanding.(22)

Cemented restorations are less costly to manufacture because they do not require as much technical expertise as screw-retained restorations. Compensation of implant position discrepancies, easy-to-get passivity fit of IAI, improved esthetics, and optimal occlusal anatomy are all advantages of this retention type. The difficulty of removing excess cement, which has been related to the development of peri-implant diseases such as peri-implant mucositis and peri-implantitis, is a major issue with cement retention.[23]

When interarch space conditions are ideal, the height and angulation of abutments provide sufficient retention in cement-retained FDP. Prefabricated abutments with a six-degree taper frequently give optimum retention, which is three to four times that of natural tooth preparations. Even with provisional cement, this combination of taper and height provides enough retention for definitive use. To enable retrievability, provisional cementation has been recommended for implant-supported crowns and FDPs.[24] However, the lack of a marginal seal remains a disadvantage of these cements. Provisional cements can dissolve over time, resulting in microleakage and crown dislodgement.

The main benefit of screw-retained dental prostheses is the predicted retrievability that can be accomplished without destroying the FDP. The visibility of the access hole in this case aids in locating the exact position for the careful removal of the covered FDP. Polytetrafluoroethylene tape should be used to protect the abutment screw if possible. As a result, screw retention is favored in maintenance. Patients' desire for FDPs, sometimes with a full-arch or long-span design, is increasing as the population ages. Hygiene plays an important role in this situation. Even if the implant prosthesis is designed to be cleanable, it can still be difficult to keep clean. The FDP can then be removed for maintenance, which aids in the preservation of the peri-implant mucosa's health.[1]

Overall, screw-retained FDPs have various advantages over cement-retained FDPs. but attaining a passive fit when replacing multiple, nonparallel, internally indexed implants is more complex and difficult. There have been reports of retention failures, which have been attributed to misfitting at implant-abutment interface and insufficient torque applied to the prosthetic screws.[6] Although there were no statistical differences in survival rates between cement and screw-retained I-FDPs (including cantilever I-FDPs).[25]

There was no statistical difference in survival or failure rates between cement- and screw-retained implant-supported prostheses, screw-retained implant-supported prostheses had fewer technical and biologic complications overall.[23]

Stress distribution in surrounding bone and implant-supported fixed cantilever prostheses.

When thinking about the biomechanical response of an implant-supported FDP, the number of implants is an important thing to consider. This is because the number of implants may affect how the stress from chewing is transferred to the bone tissue. The use of one implant per tooth in the treatment of a 3-unit edentulous area appears to be a clinically effective option for reducing certain risk factors, including overload, but may be limited by a lack of space, poor bone quality, and vital structures (Maxillary sinus, inferior alveolar canal, and lingual concavity)[26, 27].

The transmission of occlusal load to peri-implant bone tissues has been extensively researched in vitro and in vivo, with certain affecting factors, such as occlusal bite force, bone characteristics (density and quantity), implant configuration, type of implant-abutment connection, materials, and prosthesis characteristics, carefully considered. In cases of excessive strength, the compressive or tensile stress acting at the crestal bone might produce bone resorption in response to a microtrauma affecting the bone trabeculae, depending on the characteristics of the occlusal load at the implant-abutment interface.[28]

Savignano R. et al. found that the stress distribution on implants and prosthesis components can be affected by connection design (engaging and non-engaging) and location of the abutment. Sufficient information about implant planning and implant placement in locations with various bone characteristics (bone types I-IV), is the most significant reason to examine stress distribution in abutments and microstrain in crestal bone around implants.[29]

The use of a cantilever (mesial or distal) is recommended as an alternative to surgical procedures, which add time to the treatment process along with cost and surgical morbidity. In situations of premature loss of the permanent mandibular premolar and molar teeth as a result of severe bone resorption, there may be the presence of the mental foramen and inferior alveolar canal. This situation is challenging to restore. It is important to understand variables that affect the stress distribution and success of implant cantilever prostheses, such as reducing mechanical failures, such as screw loosening and screw fracture.[30, 31] and improve the longevity of prostheses. Several studies have shown that implant-supported cantilever bridges can induce excessive stress concentrations in the supporting alveolar bone.[32, 33]

Cantilever length did have a direct influence on stress distribution, with a greater concentration of force on the cervical part of the implant[34], a minimum bone resorption increase of 0.1 mm per 1 mm increase in cantilever length[35], and an increase in the cantilever arm promoting an increase in stress concentration around the implant adjacent to the cantilever[36]. Furthermore, the length of the cantilever arm was significantly correlated with both biological and technical complications, in particular in implants that lost more than 1.5 mm of bone[37].

Alencar et al.[38] compare stress in the peri-implant bone in fixed partial prostheses with mesial and distal cantilevers when screwed or cemented retained implants: group 1 cement-retained fixed partial dentures: mesial cantilever, distal cantilever; group 2 screws-retained fixed partial dentures. mesial cantilever, distal cantilever Using axial and oblique stress, it was discovered that the distal cantilever fixed partial dentures have more stress than the mesial cantilever fixed partial dentures because of the higher load on the posterior teeth, which are wide teeth. The mesial cantilever has lower stress in the peri-implant bone and may be a small lever in the absence of the mandibular premolar, which is a narrow tooth. A study found that the highest stress is located in the alveolar bone crest of the implant closest to the cantilever. The cantilever’s length and stress distribution are more uniform in the bone around the implant with the mesial cantilever than with the distal cantilever.

Biomechanical success and failure of implant supported fixed dental prostheses

The implant number is a critical factor when considering the biomechanical response of an implant-supported FDP, as it may have an influence on the masticatory stress transmitted to the bone tissue.[39] The mechanical response to prosthetic treatment is influenced by a large number of implants.[40] In the most difficult clinical situations, placing an implant to replace one tooth is controversial and requires careful consideration.[41]

The use of two or three implants for these extracted teeth is determined by the masticatory stress and available bone.[42] The placement of a single implant per missing tooth appears to be a clinically effective option for reducing certain risk factors, including overload.[43] When three implants are used, less load is predicted to be transferred to the bone–implant interface. The use of three implants in the treatment of a three-unit edentulous area may be limited by a lack of mesio-distal space and insufficient bone support. Two implants supported by a bridge can be used to overcome this limitation.[43] However, it has been found that the load direction in an implant-supported FDP can affect the stress concentration. By comparing two or three implants with different load distributions, the biomechanical behavior of abutments, prosthetic screws, and dental implants has not yet been explored.[42]

The prosthetic components are constantly exposed to a combination of horizontal, vertical, and oblique stresses during chewing. Axial forces on the implant are compressive in nature; however, horizontal or oblique resultant forces can increase lateral displacement and, as a result, cause the formation of torsional forces and lever points, which can lead to failure in the prosthesis structure and at the bone–implant interface if they are excessive. Regardless of the load state, a 3-unit FDP can withstand a load of 500–600 N in the posterior region. However, there is still a scarcity of literature for a three-unit implant-supported FDP.[42]

Porcelain fracture, screw loosening, screw fracture, and loss of retention are the most commonly reported biomechanical complications. Despite the fact that these values are now often used, they have never been linked to screw or cement retention.[23]

The main radiographic findings to examine when evaluating the success or failure of an implant are changes in the marginal bone level and osseointegration.[44] Despite the limitations of 2-D images, conventional dental radiography is currently the most favored clinical approach for determining the long-term success of an implant. At this time, there is no doubt in the dental literature that the loss of marginal bones is associated with the implant retention mechanism. Nowadays, there is no consensus on the best retention technique for implant-supported fixed restorations.

The biomechanics of the various retention systems may also have an impact on marginal bone loss, with some studies claiming that cement-retained prostheses distribute stress better. Because different restorative materials might transfer occlusal loads laterally to the implant instead of axially, access to the screw hole may also contribute to marginal bone loss. Furthermore, cement may be more effective at filling gaps, absorbing the strain of deformation caused by a mismatch between the abutment and implant in the implant abutment-prosthesis structure, and assisting in even distribution.[45]

Strain gauge

Strain gauge analysis is a microstrain measurement method that permits electrical resistance, or strain gauges. Strain gauges work on the idea that when certain materials are subjected to a force, their electrical resistivity changes. Varying materials have different resistivities, which can be reliably measured using a Wheatstone's bridge circuit at the location where the strain gauge is mounted.[46] This method has been developed for evaluating implant-supported prostheses in vitro, in vivo, and under static and dynamic loads.

When force is applied, the specimen's size and shape are likely to change. These changes are referred to as "deformation," At the point of contact, strain is described as either normal strain or shear strain. Normal strain is a measure of the deformation caused by changes in the length of line sections. When a material receives a tensile force (P), the ratio of the elongation to the original length is called the tensile strain, which is expressed by equation 1 and shown in Figure 10, where ε is the strain, L is the original length, and ΔL is the elongation.[47]

$\varepsilon = \Delta L/L$ ------ Equation 1

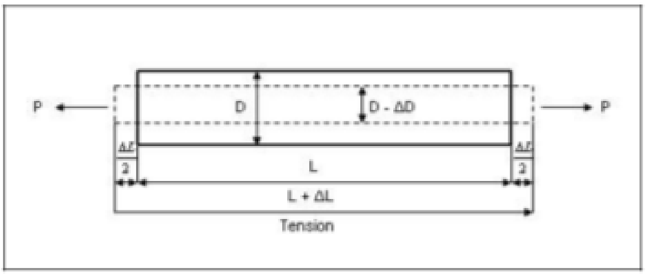

Figure 11 When the material receives a tensile force (P), tensile strain is the ratio of the elongation to the original length.

Strain gauges detect strains on the surface of interest and measure the gauge resistance before and after the structure is loaded. The change in resistance can be calculated using equation 2, where ΔRg is the change in resistance, Fg is the gauge factor, Rg is the initial gauge resistance, and εm is the strain that is measured by the strain gauge. The most widely used strain gauge circuit is the "Wheatstone Bridge."

ΔRg = (Fg)(Rg)(εm) ------ Equation 2[47]

The Wheatstone bridges

The Wheatstone bridge circuit consists of four arms. Each arm includes a resistance (i.e., resistances R1, R2, R3, and R4). An excitation voltage Vex (typically 2 to 10 volts) is applied across junction A-C, and the resulting potential across junctions B-D (voltage ΔE) is measured by a voltmeter. If all the resistances are equal (i.e., R1 = R2 = R3 = R4), ΔE is zero and the bridge is said to be balanced.[47]

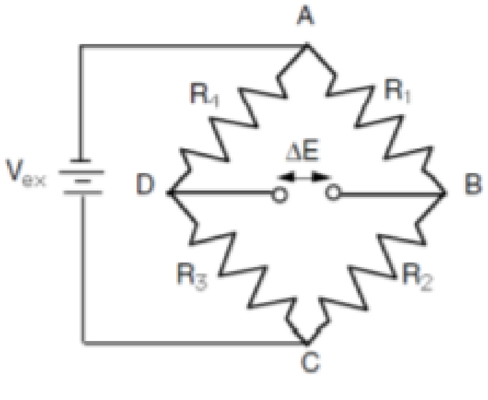

Figure 12 Diagram of a Wheatstone Bridge

If a strain is expressed, the strain gauge resistance changes, causing the bridge to become unbalanced.

The gauge factors

Strain gauge manufacturers indicate standard calibration measurements for each lot of strain gauge that they produce. One of these constants is the gauge factor. The gauge factor permits the user to convert the change in gauge resistance to the corresponding strain level. The strain is calculated using equation 3.

$\varepsilon m = 1/Fg\ [\Delta Rg/Rg]$ ------ Equation 3[47]

CHAPTER 3
RESEARCH METHODOLOGY

Materials and methods

1. 3D printed models (V3, Formlab) 4 models
2. Static surgical guide 1 template
3. IS-III active dummy implant size 4x10 mm. and 5x10 mm. (neobiotech, Seoul, South Korea) 8 dummy implants
4. Engaging type IS cement abutment size 4.5x5.5 mm. cuff 1 mm. (Neobiotech, Seoul, South Korea) 2 abutment
5. Angled abutment 15° with engaging size 5.2x7 mm. cuff 2 mm. (Neobiotech, Seoul, South Korea) 1 abutment
6. Non-engaging type IS cement abutment size 4.5x5.5 mm. cuff 1 mm. (Neobiotech, Seoul, South Korea) 1 abutment
7. Non-engaging type IS cement abutment size 5.2x5.5 mm. cuff 1 mm. (Neobiotech, Seoul, South Korea) 2 abutments
8. SCRP type IS cement abutment size 4.5x5.5 mm. cuff 1mm (Neobiotech, Seoul, South Korea) 1 abutment
9. SCRP type IS cement abutment size 5.2x5.5 mm. cuff 1 mm. (Neobiotech, Seoul, South Korea) 1 abutment
10. Cercon HT A1, A2 (Dentsply Sirona, Bensheim, Germany) 2 disks
11. Polytetrafluoroethylene tape (Teplon)
12. Kerr Silane Primer (Kerr, Orange, CA, USA) 1 bottom
13. OptiBond Solo Plus (Kerr, Orange, CA, USA) 1 bottom
14. NX3 refill automix dual syringe opaque (Kerr, Orange, CA, USA) 1 set
15. Filtek Supreme Z350 XT (3M ESPE, St. Paul, MN, USA) 1 syringe
16. Stainless steel plate 1 piece
17. Waterproof abrasive paper DCC 600 (TOA paint Co., Thailand)
18. Strain gauge (Kyowa Electronic Instruments Co., Tokyo, Japan) 32 pieces

19. Cyanoacrylate-based cement (Strain Gage Cement CC—33 A-Kyowa Electronic Instruments Co., Tokyo, Japan). 1 piece
20. Universal testing machine (EZ test; Shimadzu corporation, Kyoto, Japan)

Figure 13 *3D* printed models (V3, Formlab)

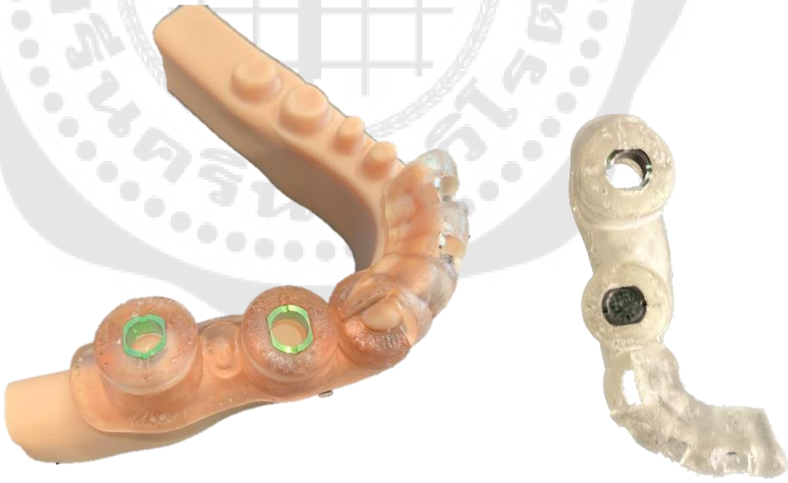

Figure 14 Static surgical guide

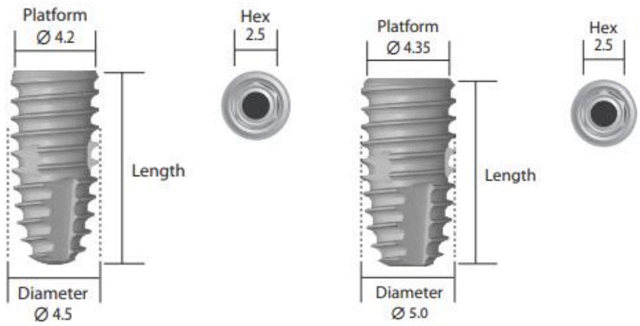

Figure 15 Dummy IS-III active implant size 4x10 mm. and 5x10 mm.

(neobiotech, Seoul, South Korea)

Catalog Neobiotech implant system 2017

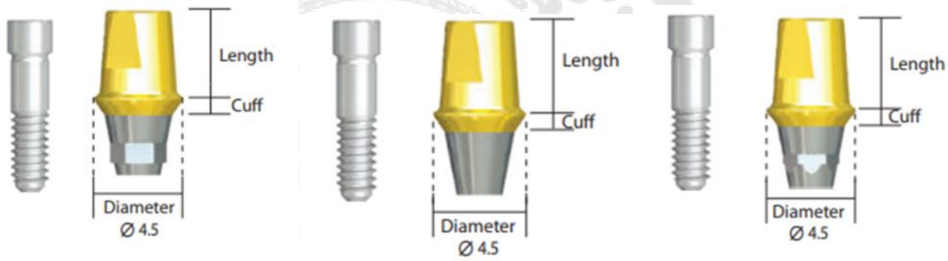

Figure 16 Engaging, non-engaging, SCRP type IS cement abutment

(Neobiotech, Seoul, South Korea)

Catalog Neobiotech implant system 2017

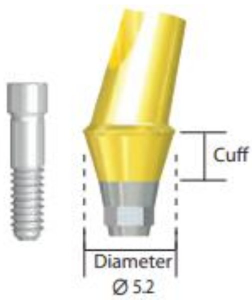

Figure 17 IS Angled abutment 15° (Neobiotech, Seoul, South Korea)

Catalog Neobiotech implant system 2017

Figure 18 Cercon HT disk *(Dentsply Sirona, Bensheim, Germany)*

Figure 19 Kerr Silane Primer (Kerr, Orange, CA, USA)

Figure 20 OptiBond Solo Plus (Kerr, Orange, CA, USA)

Figure 21 NX3 refill automix dual syringe opaque (Kerr, Orange, CA, USA)

Figure 22 Stainless steel plate

Figure 23 Strain gauge (Kyowa Electronic Instruments Co., Tokyo, Japan) and Cyanoacrylate-based cement (Strain Gage Cement CC—33 A-Kyowa Electronic Instruments Co., Tokyo, Japan).

Figure 24 Universal testing machine

(EZ test; Shimadzu corporation, Kyoto Japan)

3.1 Sample size

The sample size for this study was determined by Dogus SM et al. (2011) and has been used as a reference in the calculation of sample size for similar studies. A power analysis was performed with a G*Power 3.1.9.4 program. The effect size was 0.7293805 at 95% power; therefore, the minimum sample size for the study was 40. As a result, 10 were used for each group.

A total of 8 dummy implants and 16 stock abutments (ISIII, Neobiotech, Seoul, South Korea) with various connections will be used in tooth area 45 and 47 and separated into 4 models as shown in table 1

Table 1 Experimental group

Group (Model no.)	Area 45 Implant (D 4.0 mm L 10 mm) Abutment (D 4.5 H 5.5 GH 1 mm)	Area 47 Implant (D 5.0 mm L 10 mm) Abutment (D 5.2 H 5.5 GH 1 mm) Except group 1, which uses angled abutment 15° (D 5.2 H 7 GH 2 mm)
1	Engaging	Engaging (Angled abutment)
2	Non-engaging	Non-engaging
3	SCRP	SCRP
4	Engaging	Non-engaging

3.2 Model preparation and implant placement

The STL file of the lower arch was designed to be a Kennedy Class II unilateral distal extension of edentulous area at 44-48. The resin models were printed by a 3D printer (V3, Formlab), which had a Young's modulus of 2.2 GPa, approximating estimates for trabecular bone (2.2 GPa). Preparation at 34, 35, 36, and 37 in all models (Groups 1-4) for fabrication of the monolithic zirconia crown for bilateral load. The model was x-rayed by CBCT (Whitefox, A company of ACTEON Group, Italy) and model scanner (3shape D900L; 3shape A/S, Copenhagen, Denmark). The Dicom and STL file of the model were imported into implant planning software (Implant Studio 3 shape). Groups 1-4 at the 45-area implant (4.0*10 mm, ISIII, Neobiotech, Seoul, South Korea) were aligned perpendicular to the occlusal plane, while at the 47-area, implant (5.0*10 mm, ISIII, Neobiotech, Seoul, South Korea) were 15 degrees inclined to the lingual side. A static surgical guide was designed and printed. Then, the dummy implants were drilled following Neobiotech protocol, and both dummy implants were placed via a static surgical guide.

Figure 25 The model was x-rayed by CBCT

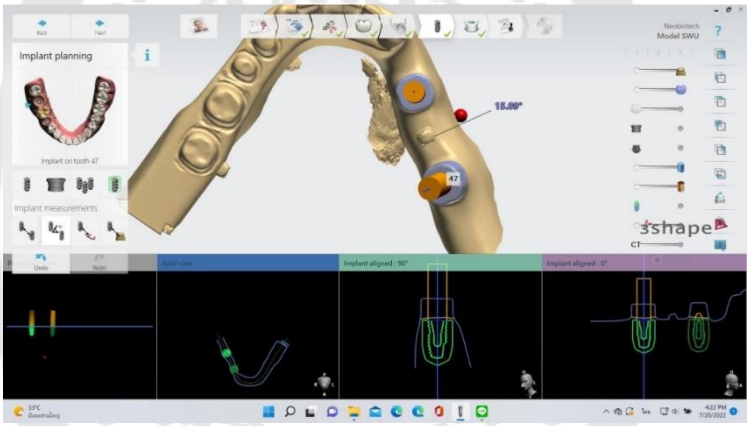

Figure 26 Dicom and STL file of the model were imported to implant planning software (Implant Studio, 3 shape).

Figure 27 The dummy implants were placed via a static surgical guide, drilled following Neobiotech protocol.

3.3 Abutment connection and implant supported 4-units bridge fabrication

Stock abutments were connected to any implants in each model following the planning in Table 1. Torque 30 NCm will be applied to each abutment twice. Polytetrafluoroethylene tape (Teplon) was filled at abutment screw access. Prepared zirconia crown on teeth no.34-37, 4-unit zirconia bridges on teeth no. 44-47 and both stock abutments in group 2-4 were scanned to design crowns and implant supported 4-unit bridges with open screw access (Screw and cement-retained restoration), and in group 1 they were scanned to design crowns and implant supported 4-unit bridges without screw access (Cement-retained restoration) by model scanner and Dental System (3shape, Netherlands). Monolithic zirconia crown and bridge (Cercon HT, Dentsply Sirona, Bensheim, Germany) were milled as designed by Sainamtip Dental Laboratory (Samut Prakan, Thailand) and taken periapical film for verification of the completed seating of the implant-abutment connection in all models.

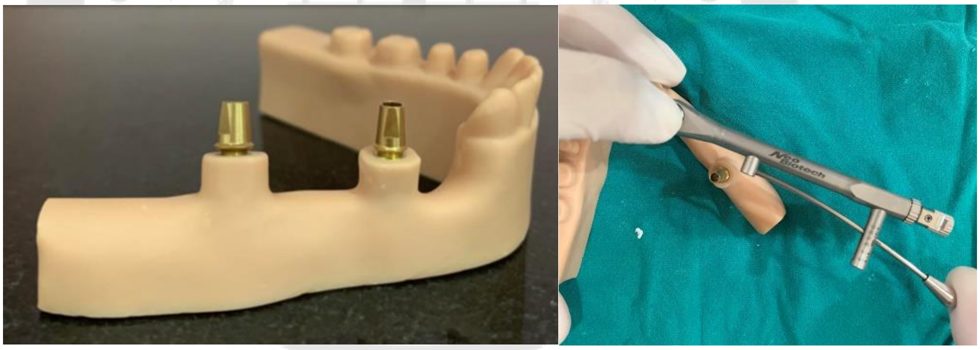

Figure 28 Stock abutments were connected to any implants and torqued to 30 NCm

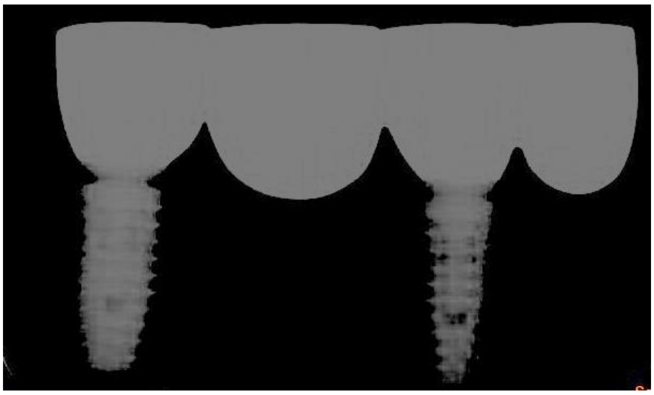

Figure 29 X-ray check seating of the implant-abutment connection

3.4 Stain gauges preparation

32 strain gauges (KFGS-03-120-C1, Strain Gages, Kyowa Electronic Instruments Co., Tokyo, Japan), 8 strain gauges were bonded 2 mm away from the peripheral implant surface with a cyanoacrylate-based cement (Strain Gage Cement CC—33 A-Kyowa Electronic Instruments Co., Tokyo, Japan) to the mesial, distal, buccal, and lingual regions at the implant-abutment interface area of each 3D printed model.

The strain gauge in each model, measured by the surrounding bone around the implant in a 360-degree circle, was set and divided into four sections by making a 90-degree angle. Then a marker line was made to fix the strain gauge by fixing a strain gauge onto the markers on the line so that the middle of the strain gauge is fixed to the marker line and the upper part of the strain gauge is fixed to the margin of the bone.

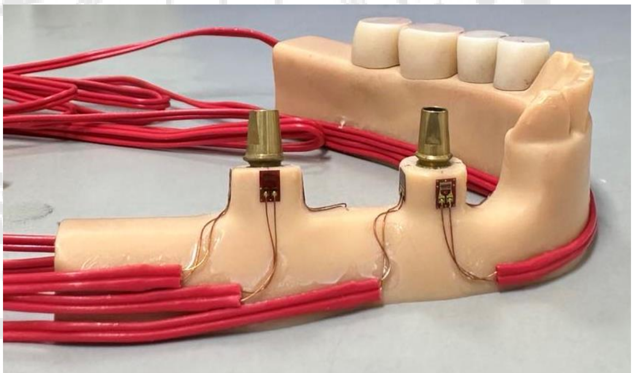

Figure 30 Location of stain gauge on dental implant

3.5 Cementation of crowns and bridges

Following the manufacturer's instructions, the restoration in all groups is particle-abrading the intaglio surfaces of the zirconia crowns and zirconia bridges with 50-μm silica particles coated with Al_2O_3 (sandblast) for 10 seconds at a pressure of 2 bar and a distance of 10 mm form laboratory Then, A silane primer (Kerr, Orange, CA, USA) was applied to the intaglio surface of zirconia crowns and zirconia bridges for 60 seconds. To be luted after air drying. Finally, zirconia crowns were chemically bonded to the abutments (34-37) with resin cement (Kerr, Orange, CA, USA) and the excess cement will be carefully removed from the margin. Light cure all surfaces for 20 seconds each. In all groups An Optibond Solo Plus (Kerr, Orange, CA, USA) was applied to the abutment implants for 15 seconds using a light brushing motion. Air-thin the adhesive for 3 seconds. Light cure for 20 seconds. Zirconia bridges were chemically bonded to the abutment implants (45,47) with NX3 refill automix dual syringe opaque resin cement (Kerr, Orange, CA, USA) and the excess cement will be carefully removed from the margin. Light-cure all surfaces for 20 seconds each. Groups 2-4 are torqued to 30 Ncm, and the access screw hole will be covered with composite resin to enhance the restoration's aesthetic and function.

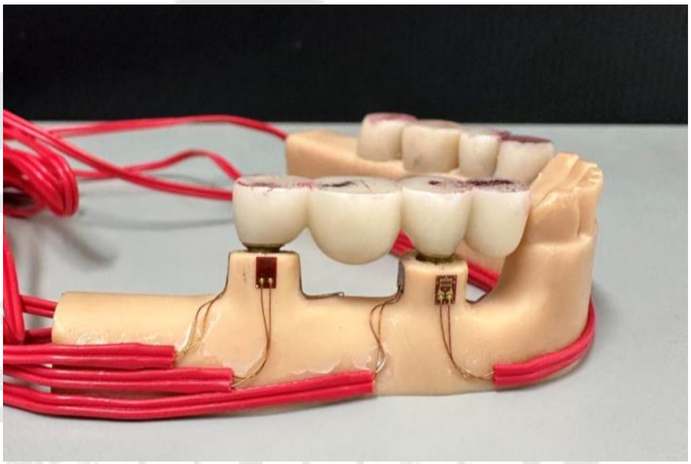

Figure 31 The model after cementation of crowns and bridges

3.6 Measurements

Strain gauges (KFGS-03-120-C1, Strain Gages, Kyowa Electronic Instruments Co., Tokyo, Japan) were connected to a data acquisition system (EDX-10 Series, Compact Recording System, Kyowa Electronic Instruments Co., Tokyo, Japan), which delivered the signal to a reading board (EDX-10 Series, Compact Recording System, Kyowa Electronic Instruments Co., Tokyo, Japan) on a desktop computer (Notebook). The strain gauge inputs were evaluated using National Instruments' LabVIEW FDS, version 5.1 for Windows. A channel on the data acquisition board was assigned to each strain gauge. All strain gauge values were set to 0 before connection.

A static axial load (compressive load) of 300 N simulated masticatory force (42, 48, 49) was applied at a crosshead speed of 0.05 mm/sec for 15 seconds using the universal testing machine. A bilateral loading was applied on the first premolar, second premolar, first molar, and second molar on each side with a wide stainless-steel plate and was calibrated by OccluSense by Bausch (GmbH & Co. KG, Koln, Germany). Each loading condition was repeated nine times. Before each loading, all strain gauge were set to zero. Data were collected for strain values by each strain gauge. Each strain gauge was used to determine the strain, which were calculated using an equation.

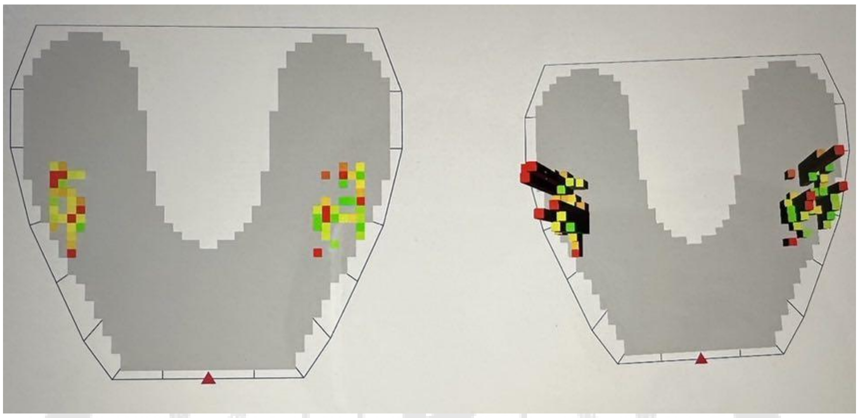

Figure 32 The bilateral loading was calibrated by OccluSense by Bausch (GmbH & Co. KG, Koln, Germany)

Figure 33 3D printing model and wide stainless-steel plate

3.7 Statistical analysis

The analysis of the results of this study was conducted using the statistical software SPSS version 27.0 (SPSS, Inc., Chicago, IL, USA). The confidence level for the statistical hypothesis test was set at 95%. In this study, there were three independent factors: the different types of abutment connections, the effect of position and surface on microstrain around two non-parallel implant-supported bridges. Test the normal distribution of data in each sample corner with the skewness/std.error ratio test[50] with the Z test statistics and verify the sphericity prerequisite of the repeated variability analysis with the Mauchly's Test if there is a breach of the agreement, use the Greenhouse-Geisser solution or use the results of the analysis with MANOVA without this pre-agreement.

Analyze the effects of abutment connection, position and surface differences (4x2x4) using Three-way repeated ANOVA variability analysis, with surface as a body factor in the sample unit (within-subject factor). If significant influences are found, the differences between groups are determined by pairwise comparisons and controlled by the Bonferroni method.

CHAPTER 4
RESULT

The study evaluated the microstrain around two non-parallel implant-supported bridges in the posterior region with different types of abutment connections and different positions of abutments to meet the following goals: Compare microstrain with different types of abutment connections and microstrain with different positions of the abutment.

4.1 Microstrains test (Different types of abutment connections)

The study was conducted to evaluate the microstrain around two non-parallel implant-supported bridges in the posterior region with different types of abutment connections (engaging, non-engaging, and SCRP) and different positions of abutments (areas 45 and 47) for implant-supported bridges with a vertical static load using a strain gauge. The mean, standard deviations, and statistical significance of the microstrain of the tested groups are summarized in Table 2 and Figure 33. The data were statistically analyzed using SPSS version 27. The data followed the ANOVA assumptions: 1) normally distributed, 2) homogeneity of variance, and 3) independent of each other. All data in groups and positions have a normal distribution and homogeneity of variance.

Three-way repeated ANOVA results for microstrain show statistically significant differences between groups (p = 0.000, F = 1445.708), and a pairwise comparison was performed to compare the tests of group and position.

Table 2 The mean values and standard deviations of the microstrain around two non-parallel implant-supported bridges in the posterior region in four groups

Microstrains Group	N (Repeated)	Mean microstrains	Standard deviation
1 Control (hex, angle abutment)	10	-25.239*	0.593
2 non-hex, non- hex	10	-52.975*	0.593
3 scrp, scrp	10	-14.505*	0.593
4 hex, non- hex	10	+0.418*	0.593

* Indicated the mean difference is significant at the 0.05 level, - = compression, + = tensile, hex = engaging, non-hex = non-engaging

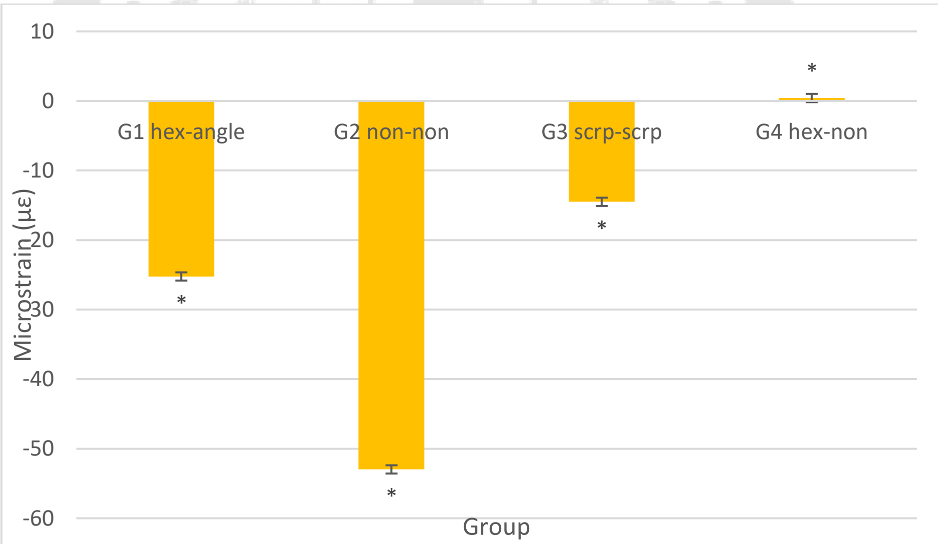

Figure 34 Bar chart representing means and standard deviations of microstrains of each tested group, and * indicates the mean difference is significant at the 0.05 level.

As shown in Table 2 and figure 34, comparing the mean of the microstrain around two non-parallel implant-supported bridges, group 2 (non-engaging, non-engaging) showed the highest compressive microstrains (-52.975), followed by control group 1 (engaging, angled abutment) (-25.239), and group 3 (SCRP-SCRP) had the lowest compressive microstrains (-14.505), while only group 4 (engaging, non-engaging) had tensile microstrains (0.418). Microstrains in groups 3 and 4 were significantly lower than those in the control group (α=.5)

4.2 Microstrains test (Different position of implant)

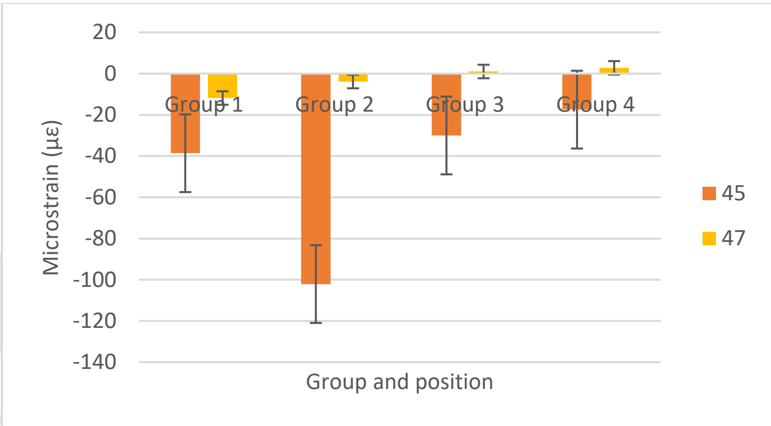

Figure 35 Bar chart representing means and standard deviations of microstrains around two non-parallel implant-supported bridges in 2 positions in each group

Table 3 The mean values and standard deviations of the microstrain around two non-parallel implant-supported bridges in the posterior region in 2 positions in all group

Microstrains Position	N (Repeated)	Mean microstrains	Standard deviation
45	10	-47.06*	0.419
47	10	+0.91*	0.419
* Indicated the mean difference is significant at the 0.05 level			

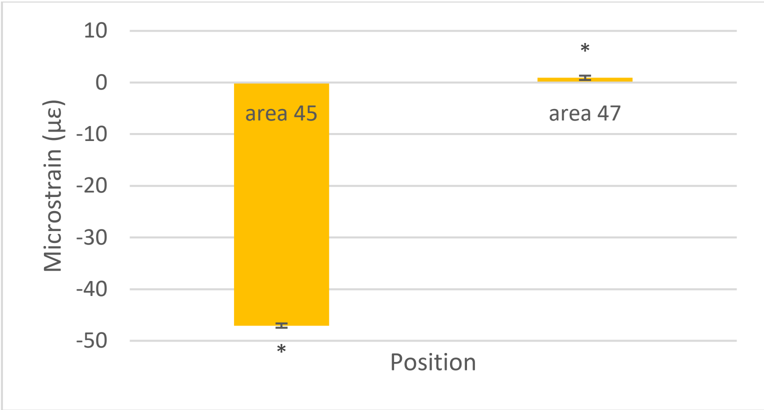

Figure 36 Bar chart representing means and standard deviations of microstrains around two non-parallel implant-supported bridges in each position in all groups, and * indicates the mean difference is significant at the 0.05 level.

As shown in Table 3 and figure 36, comparing the mean of the microstrain around two non-parallel implant-supported bridges in two positions, Area 45 showed compressive microstrains (-47.06) and Area 47 had tensile microstrains (+0.91). Microstrains in area 45 were significantly higher than in area 47 (α=.5)

4.3 Microstrains test (Different surface of implant)

Table 4 The mean values and standard deviations of the microstrain around two non-parallel implant-supported bridges in the posterior region on each surface in all group at implant 45

Group	N	Mesial 45	Distal 45	Buccal 45	Lingual 45	Mesial 47	Distal 47	Buccal 47	Lingual 47
1	10	-146.30 (1.405)	+38.5 (1.333)	-97.46 (1.843)	+50.75 (2.152)	+47.63 (1.405)	-29.11 (1.333)	-51.28 (1.843)	-14.64 (2.152)
2	10	-333.87 (1.405)	+18.64 (1.333)	-121.42 (1.843)	+28.20 (2.152)	-36.01 (1.405)	+13.46 (1.333)	-19.029 (1.843)	+26.24 (2.152)
3	10	-37.70 (1.405)	-25.34 (1.333)	-38.43 (1.843)	-18.62 (2.152)	+6.35 (1.405)	+2.72 (1.333)	-21.93 (1.843)	+16.92 (2.152)

4	10	-16.18 (1.405)	-78.91 (1.333)	+51.07 (1.843)	-25.89 (2.152)	+7.85 (1.405)	+35.97 (1.333)	+0.461 (1.843)	+28.96 (2.152)

*1= hex-angled, 2= non-non, 3= SCRP-SCRP, 4=Hex-non

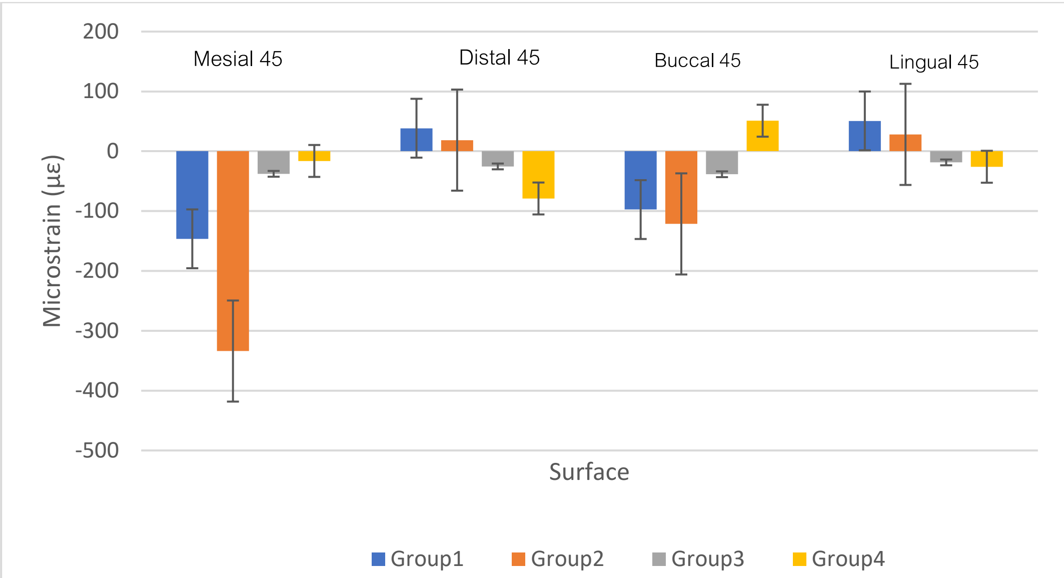

Figure 37 Bar chart representing means and standard deviations of microstrains around two non-parallel implant-supported bridges of each surface at implant 45

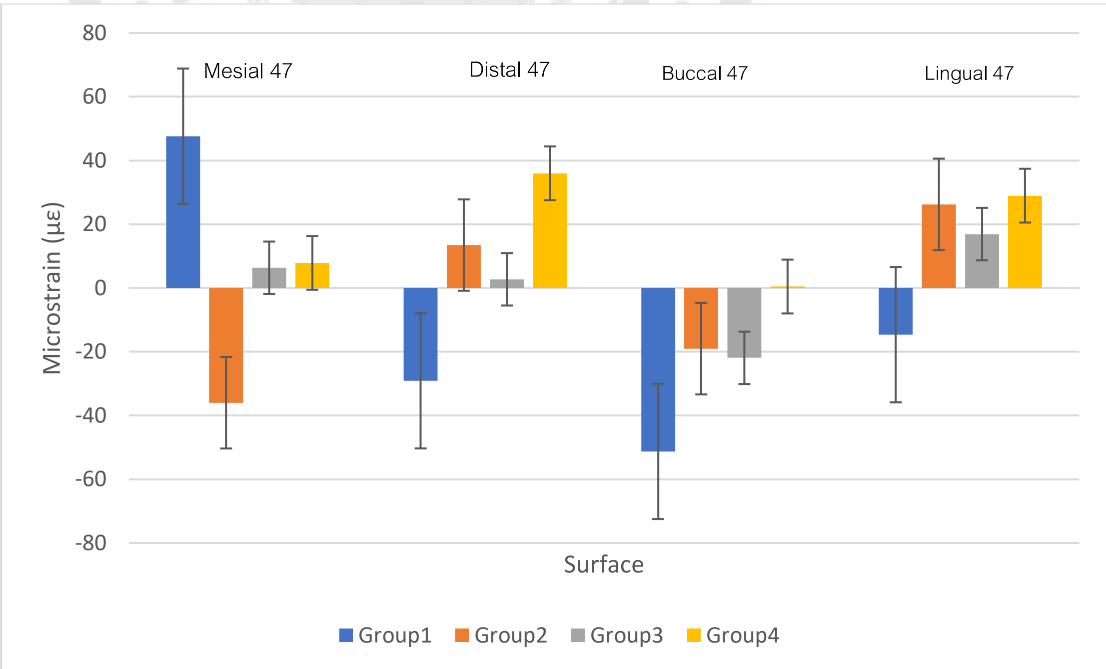

Figure 38 Bar chart representing means and standard deviations of microstrains around two non-parallel implant-supported bridges of each surface at implant 47

As shown in Table 4 and Figure 37-38, comparing the mean of the microstrain around two non-parallel implant-supported bridges on each surface in all groups, the highest compressive microstrains were recorded on the mesial surface of implant 45 in group 2 (non-engaging-non-engaging) (-333.866), and the highest tensile microstrains were recorded on the buccal surface of implant 45 in group 4 (engaging-non-engaging) (+51.07), and on the lingual surface of implant 45 in the control group (engaging-angled abutment) (+50.75).

CHAPTER 5
DISCUSSION

Strains at bone around implant-supported bridge

Strains around dental implants and bone are one of the factors that indicate the long-term success of implant-supported bridges. Strains over the threshold values may lead to porcelain chipping, abutment screw loosening, abutment screw fracture, peri-implant bone loss, dental implant fracture, and loss of osseointegration[51, 52]. This study was conducted to evaluate the microstrain around two non-parallel implant-supported bridges in the posterior region with different types of abutment connections and different positions of abutments. The null hypothesis was rejected; the type and position of the abutments have significantly affected microstrain at the implant-bone interface of two non-parallel implant-supported bridges in the posterior region.

This study showed a relationship between the abutment connection and stress around the bone; both non-engaging abutments caused the most microstrains on the bone. Both SCRP abutments caused the least compressive microstrains on the bone. It is challenging to restore an implant-supported bridge with both engaging abutments because it requires careful planning, enough bone to allow accurate parallel insertion of the dental implants, and a passive fit with the prosthesis. If two implants are not parallel, both SCRP abutments are recommended. Because SCRP abutments had both engaging and non-engaging parts that functioned: reposition, retrievability, and providing spaces to compensate for nonparallel implants, when two implants make an angle of no more than 20 degrees. SCRP abutment has the advantages of both screw- and cement-retained implant prostheses that achieve passive fit and retrievability and can cement extraoral or intraoral cases by case.[12] Moreover, the result of this study showed that SCRP abutments gave the lowest compressive microstrains on the bone.

The study found that the microstrains were highest on the mesial surface of implant 45 in group 2 (non-engaging, non-engaging). It may be that the non-engaging abutment does not have an engaging part that increases the contact area at the implant-abutment interface to reduce strain and stress on the abutment screw. These results may increase micromovement, which results in an increased chance of screw loosening[6]. One possible reason is that there are areas of high stress at the implant necks that could be transferred through the implant surface and into the alveolar bone. This demands another FEA investigation. The result was similar to the study of Savignano (2021)[6] that analyzed the stress distribution using FEA on mandibular screw-retained FDP. When using different combinations of engaging abutments and non-engaging abutments, various stress distributions for the screws were found. Higher stress was found in the closest area of the abutment, close to the screw neck, for non-engaging abutments. Two areas of high stress have been found for engaging abutments: the lower part of the screws, near the screw threads, and near the screw neck. Since the non-engaging abutment screws had more equally distributed stress throughout the screw rather than concentrated around the screw neck, it is expected that this different distribution of stress may have an impact on the failure mechanism. And found the highest stress distribution on the cancellous and cortical bones in both non-engaging abutments. Both engaging abutments have the best stress distribution and are recommended if all implants are parallel for restoration and have a passive fit; if implants are not parallel, the alternative is to use a combination of an engaging abutment and a non-engaging abutment. And the result was similar to that of the study by Dogus (2011)[14], which investigated the fatigue response of the effects of internally connected engaging component position in screw-retained fixed cantilevered prostheses and found that both non-engaging components had a lower number of cycles to fracture and a lower amount of axial force at fracture. Meaning lower force and lower cycles are required for early failure when compared with an engaging abutment in a screw-retained fixed cantilevered FDP, which provides a mechanical advantage, but both implants should be parallel; if both implants are non-parallel, use an engaging abutment in the implant farthest from the cantilever when designing a screw-retained cantilever FDP for increased resistance to fracture of the abutment screw. But in contrast, Linkevicius T (2019)[13] found engaging and non-engaging abutments had the same conical connection to engage the implant. A conical connection is a contact plane between the implant and abutment. The hex in the engaging abutment and implant are not physically in contact. So, load transfer is the same for engaging and non-engaging abutments because loads are transferred to the implant with a conical connection. Moreover, in this study, group 4 (engaging, non-engaging) had the lowest microstrain and tensile microstrain. But dental implants and bone prefer compressive stress to tensile stress. Because the implant-bone interface is typically maintained by compressive loads. This contact is typically disturbed by tensile and shear forces. Shear force might damage the implant and the bone(53). From this study, it was found that different abutment connections influenced the stress distribution. This might be because engaging abutments increase the contact area between the implant and abutment, which puts less strain and stress on the abutment screw. There is less contact area between the implant and the SCRP abutment than with the engaging abutment, but the microstrain value is lower than in the control group. This may be due to other factors, such as the position of the strain gauge in each model and the load distribution on the crown in each model. So, in this study, we suggest using both SCRP abutments in two non-parallel implant-supported bridges when two implants make an angle no more than 20 degrees, followed by a combination of engaging and non-engaging.

But allowing a certain amount of space between the dental implants and getting a passive fit can also be done by using a mix of engaging and non-engaging abutments, or both non-engaging combinations. A similar previous study of Vygandas Rutkunas et al. (2022)(54), which evaluated the fit of a 2-implant-supported screw-retained zirconia framework with 3 different combinations of abutment connections, both engaging, engaging and non-engaging, and both non-engaging found that both non-engaging 2-implant-supported zirconia frameworks tolerated the vertical and horizontal misfit levels better, followed by combinations of engaging and non-engaging. Both engaging frameworks are less recommended for 2-implant-supported FDPs because they are more sensitive to small distortions that occur during the prosthetic workflow. With increased levels of misfit, stress levels increase in the prosthesis and peri-implant bone(55, 56).

In the control group, the implant 47 that used angled abutments should have greater microstrains than the straight abutment at the implant 45. According to the study of John Cavallaro et al. (2011)[16], a study reported increased stress on implants if angled abutments are used; however, these increases were within physiological limits. But, in this study, straight abutments were found to have a higher microstrain because the implant at 45 had a diameter of 4.0 mm, which was smaller than the implant at 47, which had a diameter of 5.0 mm, and the implant at 45 had an anterior and posterior cantilever to the implant. Even with 15°-tilted implants and an angled abutment, the microstrain of implant at 47 was less in this study. This agrees with R. Eazhil et al. (2016)[57], and Matsushita et al. (1990)[58], who found that the use of narrower-diameter implants resulted in an overall increase in stress and strain magnitude around the implant. This may be due to the smaller surface area and dimension of these implants, which exert more force per square millimeter of bone enveloping than larger-diameter implants[59]. The result was similar to the study by Hyeonjog Lee et al. (2020)[60], which found implant diameter has an effect on the stress distribution on the implant complex; when implant diameter is decreased, stress concentration is increased. When the diameter is increased by 1 mm, the stress level is reduced by about 15%. Following this study, it's possible that the diameter has a greater impact on microstrain distribution than the implant angulation, which is 15 degrees inclined.

In this study, in all groups, microstrains around the peri-implant bone at implant 45 were greater than at implant 47. In addition to the smaller diameter, there are cantilevers at the front and back of the implant, but the implant 47 had only the front cantilever. Many previous studies found that as the cantilever length increased, the stress concentration around the implants increased[61-63]. So a short cantilever length is recommended because it is the main factor in reducing stress on the cortical bone.[63] According to studies by White et al. (1994)[64] on the effects of cantilever length on load transfer to the mandible, for all cantilever lengths, the greatest stresses were found at the ridge crest on the distal surface of the distal implant, and as cantilever lengths increased, the maximal stress on the implants also increased. Similar to the study of

Suya Moura Mendes Alencar et al. (2017)[65], they found that distal cantilevers generate more stress in the peri-implant bone, and the stress is more heterogeneously distributed in the bone around the implant than mesial cantilevers. So the use of cantilevers (especially distal cantilevers) should be avoided in cases where it is not possible to place one implant for each missing tooth, which could increase the risk of treatment failure[66].

The strains on two non-parallel implant-supported bridges were tested under static axial loading conditions of 300 N, which is considered to be the average functional occlusal force in the posterior teeth region[67, 68]. In this study of the implant-supported bridge, bilateral loading was applied on the occlusal surfaces of the left and right posterior teeth (34–37, 44–47) so that the load was transferred simultaneously and evenly to the crown and bridge in the posterior teeth. It has been reported that the physiological loading zone is in the 1000–3000 microstrain range, whereas a microfracture may occur at the bone-implant interface for ranges over 4000, leading to implant failure[48]. According to Frost (2004)[69], bone responses to tension can be divided into four windows: acute disuse, adaptation, mild overload, and pathologic overload. The acute disuse window has tensions below 50 micrometers, resulting in bone loss. The adaptation window has tensions between 50 micrometers and 1,500 micrometers, resulting in a balance between resorption and formation. The mild overload window has tensions between 1,500 and 4,000 micrometers, resulting in an increase in modeling process. And the pathologic overload window has tensions above 4,000 micrometers, which indicate bone resorption. In this study, these ranges were taken as a guide to estimate the effect of loading on different abutment connections of implant-supported bridges.

When the microstrain distribution on the FDP component is higher than the yield strength of the material, plastic deformation of the component can occur, leading to screw loosening. Additionally, high stress concentrations can lead to deformation and wear between components[6]. However, in this study, all groups had compressive and tensile microstrians within the physiological zone (1000–3000 microstrain)[48]. Because this study used bilateral static axial loading of 300 N, which is the average functional occlusal force, the load was transferred simultaneously and evenly to the crown and bridge, abutment connection, implant, and bone. It may make the microstrain value less than the physiological zone.

Suedam et al. (2009)[70] we cannot just add up the deformation seen in the area around each implant and think that it is the total deformation. This is because each part of the system (the prosthesis, the abutment, the implant, or the bone) can be found in a variety of adaptability and load conditions. This means that we need to evaluate the results both quantitatively and qualitatively based on the statistical tests. This allows us to see the biomechanical behavior of the entire system, not just the strain gauges and the peri-implant regions separately.

This study was modeled as an implant-supported bridge with 4-units in the posterior teeth because that is the most common area for missing teeth. But most of the treatment was a single unit or bridge three units, but in this study, it was modeled as a 4-unit implant-supported bridge because a strain gauge can be attached around implants 45 and 47 to study the microstrains on the bone around the implant. A control group is used as an engaging and angled abutment and designed as a cement-retained implant-supported bridge because it is an option available to overcome when two implants are more non-pararell. It corrects the angle of the implant that is inclined to straighten the abutment and then fabricates a bridge for easy insertability and passivity. In future studies, we suggest comparing validity with finite element analysis that can study the microstrain distribution on various implant designs, abutment screws, implants, and bones. This will be a guideline for clinical selection and will reduce research costs compared to laboratory research.

Limitation

The limitation of this study was that it did not simulate all clinical situations and oral environments. However, we tried to stimulate the compressive force as a static load on the stimulated trabecular bone, which has a Young's modulus of 2.2 GPa.

Conclusions

Within the limitations of this in vitro study, it can be concluded that different types of abutment connections (engaging, non-engaging, and SCRP) and different positions of abutment (areas 45, 47) for two non-parallel implant-supported bridges of four units have different microstrain effects on the bone around the implant. as following;

(1) Both SCRP abutments for two non-parallel implant-supported bridges of four units had the lowest compressive microstrain distribution on bone, followed by the control group that had combinations of both engaging abutments.

(2) Both non-engaging abutments for two non-parallel implant-supported bridges of four units had the highest microstrain distribution on bone.

(3) Both SCRP abutments are alternatives to use in two non-parallel implant-supported bridges of four units when two implants make an angle no more than 20 degrees.

(4) If two implants make an angle greater than 20 degrees, combinations of engaging and non-engaging abutments are alternatives to use in two non-parallel implant-supported bridges.

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APPENDIX

Appendix

Table 5 Mean microstrains values of different abutment-connection types for implant supported bridges in four Group

Group	Time	Mesial 45	Distal 45	Buccal 45	Lingual 45	Mesial 47	Distal 47	Buccal 47	Lingual 47
1	1	-159.17	48.07	-94.06	32.48	64.54	-43.13	-54.42	-1.96
	2	-149.34	43.92	-98.31	45.62	48.25	-29.76	-48.67	-18.46
	3	-146.9	44.16	-94.49	51.39	46.79	-20.34	-40.66	-17.42
	4	-151.99	34.59	-115.05	61.62	55.69	-32.99	-68.52	1.95
	5	-140.72	39.71	-90.89	51.55	46.1	-24.67	-43.86	-20.78
	6	-140.39	37.07	-87.63	49.27	42.96	-28.16	-42.78	-25.57
	7	-145.43	36.87	-94.14	51.57	44.7	-28.68	-49.15	-19.5
	8	-144.95	34.52	-92.85	45.98	39.94	-28.97	-48.02	-24.5
	9	-142.07	36	-98.63	57.52	46.2	-24.52	-50.48	-12.67
	10	-141.99	30.09	-108.52	60.46	41.15	-29.91	-66.27	-7.48
2	1	-327.35	24.11	-127.86	34.66	-31.65	12.99	-26.49	33.71
	2	-334.72	21.18	-126.14	34.99	-33.28	14.45	-22.52	34.4
	3	-340.74	19.26	-128.17	32.51	-36.27	14.67	-24.5	34.76
	4	-330.42	18.45	-124.76	33.02	-33.3	12.9	-22.15	34.25
	5	-332.21	15.23	-115.21	21.74	-40.07	13.55	-10.72	11.34
	6	-334.4	9.97	-113.49	14.28	-40.67	6.07	-15.06	5.3
	7	-344.37	20.69	-123.53	29.47	-38.97	12.96	-23.67	32.19
	8	-331.7	21.62	-117.18	28.73	-33.98	16.71	-13.03	25.69
	9	-328.72	18.41	-115.96	25.9	-34.5	15.03	-13.49	24.34
	10	-334.03	17.43	-121.92	26.68	-37.4	15.23	-18.66	26.4
3	1	-41.95	-25.93	-35.68	-21.76	3.59	-6.96	-26.63	11.18
	2	-36.32	-23.14	-40.27	-17.33	6.06	3.99	-21.52	18.57
	3	-40.68	-27.55	-44.17	-18.11	4.82	-0.82	-29.52	19.48
	4	-35.35	-27.54	-40.99	-17.42	8.7	0.09	-25.17	20.36
	5	-36.4	-23.59	-40.44	-14.79	8.19	5.92	-22.29	20.58
	6	-39.98	-31.8	-37.83	-23.5	1.42	2.42	-20.86	11.1

Table 5 (Continued)

3	7	-40.17	-27.26	-38.09	-25.05	0.99	0.56	-20.95	9.53
	8	-35.07	-21.33	-30.79	-18.16	10.77	5.71	-12.71	15.3
	9	-37.67	-25.06	-39.64	-16.24	8.46	6.3	-21.71	19.98
	10	-33.38	-20.23	-36.37	-13.87	10.47	9.99	-17.95	23.08
4	1	-15.54	-73.79	54.33	-25.19	11.69	38.3	-0.46	31.93
	2	-17.54	-78.26	46.05	-22.97	8.64	34.23	-6.24	35.37
	3	-18.05	-80.67	51.7	-27.26	6.32	33.65	-1.68	30.25
	4	-17.2	-80.97	48.69	-28.07	4.95	34.87	-0.28	28.75
	5	-17.67	-84.52	48.46	-28.36	3.97	34.63	0.26	23.29
	6	-14.26	-76.18	52.87	-24.78	10.51	40.46	4.7	30.95
	7	-15.4	-75.39	52.03	-23.47	11.91	35.39	-1.44	33.47
	8	-14.05	-77.9	53.35	-23.02	8.89	39.67	4.5	29.3
	9	-17.23	-81.74	52.48	-28.65	4.24	32.43	2.75	20.57
	10	-14.89	-79.68	50.76	-27.12	7.41	36.23	2.5	25.68

*1= Hex-angled, 2= Non-non, 3= SCRP-SCRP, 4=Hex-non

Table 6 Test the normal distribution of data in each group and position with the skewness/std.error ratio test

	Group	Skewness	Std. Error	$Z_{skewness}$
Mesial	1	0.003	0.512	0.006
	2	-0.001	0.512	-0.002
	3	0.012	0.512	0.002
	4	0.063	0.512	0.123
Distal	1	-0.011	0.512	-0.021
	2	-0.251	0.512	-0.490
	3	0.063	0.512	0.120
	4	-0.002	0.512	-0.004
Buccal	1	0.000	0.512	0.000
	2	0.001	0.512	0.002

	3	0.168	0.512	0.328
	4	-0.010	0.512	-0.020
Lingual	1	-0.020	0.512	-0.039
	2	-1.345	0.512	-2.623
	3	0.034	0.512	0.066
	4	0.029	0.512	0.057

	Position	Skewness	Std. Error	$Z_{skewness}$
Mesial	45	-0.726	0.374	-1.941
	47	-0.014	0.374	-0.037
Distal	45	-0.411	0.374	-1.099
	47	-0.339	0.374	-0.906
Buccal	45	0.554	0.374	1.481
	47	-0.575	0.374	-1.537
Lingual	45	0.223	0.374	0.596
	47	-0.888	0.374	-2.374

For medium-sized samples (50 < n < 300), reject the null hypothesis at absolute z-value over 3.29, which corresponds with an alpha level of 0.05, and conclude the distribution of the sample is non-normal[50].

Group and position are used to test the normal distribution of data in each sample corner with the skewness/std.error ratio test with the Z test statistics.

$$Z_{skewness} = \text{Skewness/std.error}$$

$Z_{skewness}$ of all data in Group and Position< 3.29; For medium-sized samples[50] (50 < n < 300), z-value over all < 3.29, which corresponds with an alpha level of 0.05, and conclude the distribution of the sample is normal.

Table 7 Mauchly's Test of Sphericity[a]

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
surface	.124	147.433	5	.000	.531	.594	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Position + Gr + Position * Gr

Within Subjects Design: surface

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 8 Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
surface	Sphericity Assumed	274769.887	3	91589.962	3063.662	.000
	Greenhouse-Geisser	274769.887	1.593	172432.183	3063.662	.000
	Huynh-Feldt	274769.887	1.782	154173.130	3063.662	.000
	Lower-bound	274769.887	1.000	274769.887	3063.662	.000
surface * Position	Sphericity Assumed	230910.821	3	76970.274	2574.637	.000
	Greenhouse-Geisser	230910.821	1.593	144908.372	2574.637	.000
	Huynh-Feldt	230910.821	1.782	129563.848	2574.637	.000
	Lower-bound	230910.821	1.000	230910.821	2574.637	.000
surface * Gr	Sphericity Assumed	450391.329	9	50043.481	1673.942	.000
	Greenhouse-Geisser	450391.329	4.780	94214.546	1673.942	.000
	Huynh-Feldt	450391.329	5.347	84238.053	1673.942	.000
	Lower-bound	450391.329	3.000	150130.443	1673.942	.000
surface * Position * Gr	Sphericity Assumed	373850.516	9	41538.946	1389.468	.000
	Greenhouse-Geisser	373850.516	4.780	78203.451	1389.468	.000
	Huynh-Feldt	373850.516	5.347	69922.393	1389.468	.000
	Lower-bound	373850.516	3.000	124616.839	1389.468	.000
Error(surface)	Sphericity Assumed	6457.445	216	29.896		
	Greenhouse-Geisser	6457.445	114.732	56.283		
	Huynh-Feldt	6457.445	128.320	50.323		
	Lower-bound	6457.445	72.000	89.687		

Table 9 Three-way repeated ANOVA analysis of microstrain values in all groups

Estimates				
Measure: MEASURE_1				
กลุ่ม	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Hex-angle	-25.239	.593	-26.420	-24.057
non-non	-52.975	.593	-54.157	-51.793
scrp-scrp	-14.505	.593	-15.686	-13.323
hex-non	.418	.593	-0.763	1.600

Table 10 Pairwise Comparisons of microstrain between groups (different types of abutments)

Pairwise Comparisons						
Measure: MEASURE_1						
(I) กลุ่ม	(J) กลุ่ม	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Hex-angle	non-non	27.736*	0.838	.000	25.462	30.011
	scrp-scrp	-10.734*	0.838	.000	-13.008	-8.459
	hex-non	-25.657*	0.838	.000	-27.931	-23.382
non-non	Hex-angle	-27.736*	0.838	.000	-30.011	-25.462
	scrp-scrp	-38.470*	0.838	.000	-40.745	-36.196
	hex-non	-53.393*	0.838	.000	-55.668	-51.119

scrp-scrp	Hex-angle	10.734*	0.838	.000	8.459	13.008
	non-non	38.470*	0.838	.000	36.196	40.745
	hex-non	-14.923*	0.838	.000	-17.197	-12.649
hex-non	Hex-angle	25.657*	0.838	.000	23.382	27.931
	non-non	53.393*	0.838	.000	51.119	55.668
	scrp-scrp	14.923*	0.838	.000	12.649	17.197
Based on estimated marginal means						
*. The mean difference is significant at the .05 level.						
b. Adjustment for multiple comparisons: Bonferroni.						

Table 11 Three-way repeated ANOVA analysis of microstrain values in 2 positions

Estimates				
Measure: MEASURE_1				
Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
45	-47.060	.419	-47.896	-46.224
47	.910	.419	.074	1.746

Table 12 Pairwise Comparisons of microstrain between positions (area 45 and 47)

Pairwise Comparisons						
Measure: MEASURE_1						
(I) Position	(J) Position	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
45	47	-47.970*	.593	.000	-49.152	-46.788
47	45	47.970*	.593	.000	46.788	49.152

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

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