The Interrelation between Cortical Bone Thickness and Primary and Secondary Dental Implant Stability: a Systematic Review

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ABSTRACT

Objectives: Dental implants have emerged as a reliable and long-lasting solution for missing teeth, offering advantages over traditional prosthetic options. The aim of this systematic review was to thoroughly explore the correlation between cortical bone thickness of the jaws and bone-level dental implant primary and secondary stability.
Material and Methods: A comprehensive literature search was conducted in MEDLINE (PubMed), ClinicalKey and the Cochrane Library from 1 January, 2019 to 21 June, 2024. This review focused on patients undergoing dental implant placement with varying cortical bone thicknesses and implant stability levels. Quality and risk-of-bias assessment evaluated by Cochrane risk of bias tool.
Results: Out of 160 screened articles, 28 were reviewed in full, and 6 met the inclusion criteria, involving 209 patients and 418 implants. Implant stability quotient (ISQ) values showed no significant correlations during baseline and secondary assessments ($P > 0.05$). Correlations were noted between implant stability, bone density, alveolar ridge width, and implant size ($P < 0.01$). ISQ and insertion torque value (ITV) were strongly correlated at insertion ($P < 0.001$) but not at follow-ups ($P = 0.059$ at 2 months, $P = 0.817$ at 6 months, $P = 0.029$ at 12 months). ISQ values increased over time ($P < 0.001$). Implants in native bone showed higher ISQ values at baseline ($P = 0.011$), 8 weeks ($P = 0.013$), and 12 weeks ($P < 0.001$). Regions with thicker cortical bone demonstrated superior primary stability.
Conclusions: Thicker cortical bone enhances primary implant stability, as indicated by higher insertion torque and implant stability quotient values.

Keywords: cortical bone; dental implantation; immediate dental implant loading; osseointegration.

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INTRODUCTION

The utilization of dental implants for oral rehabilitation has gained increasing importance in recent times due to its potential to replace missing teeth, thereby restoring aesthetic appeal and masticatory function in patients [1]. This dental procedure has emerged as an effective solution for individuals who have lost their teeth due to aging, injury, or disease. The use of dental implants involves the surgical placement of artificial tooth roots into the jawbone, which serves as anchors for the replacement teeth [2]. Dental implant therapy has proven to be a reliable, predictable, and long-lasting solution for patients with missing teeth, offering numerous benefits over traditional prosthetic options. Moreover, dental implants have become a widely accepted and preferred treatment modality among patients seeking dental rehabilitation [1-3]. The success rate of such implants ranges between 90 to 95% over a follow-up period of 10 years [4]. In order to be considered fully osseointegrated, endosseous implants must meet a set of well-established criteria that indicate their efficacy and reliability [5].

The level of stability of an implant at the time of surgery is an extremely important factor in determining when the prosthetic can be loaded. This stability is primarily achieved through the interlocking between the implant and the surrounding bone so called, primary implant stability (PIS) [6]. On the other hand, secondary implant stability (SIS) relies on the regeneration and remodelling of the bone after the implant has been placed [7]. Various factors, including the quality and quantity of the bone, insertion torque value (ITV) the surgical technique used, and the size and surface characteristics of the implant, all play a significant role in achieving stability. Therefore, it is crucial to take these factors into consideration in order to achieve the best possible outcomes for implant procedures [8-10].

The aim of this systematic review was to thoroughly explore the correlation between cortical bone thickness of the jaws and bone-level dental implant primary and secondary stability.

MATERIAL AND METHODS

Protocol registration

A systematic review was performed according to the Preferred Reporting Item for Systematic Review Analysis and Meta-Analysis (PRISMA) guidelines [11].

The study was registered in the International Prospective Register of Systematic Reviews (PROSPERO). Prospero registration number: CRD42024541288. The protocol can be accessed at: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42024541288

Focus question

The following focus questions were framed according to the problem, intervention, comparison, and outcome (PICO) process (Table 1): Does cortical bone thickness affect the primary and secondary implants' stability? Is this relationship consistent over time as indicated by ITV and implant stability quotient (ISQ) values at different intervals?

Participants/population

Patients who have undergo implantation in cortical bone.

Types of publication

The studies included were peer-reviewed studies involving humans and published in English language published during the last five years (from 1 January,

Table 1. PICO guidelines

Population (P)	Patients undergoing dental implant placement with varying cortical bone thicknesses and implant stability levels.
Intervention (I)	Measurement of implant stability at different time points (primary implant stability at the time of insertion and secondary implant stability at follow-up intervals)
Comparison (C)	The correlation between primary stability metrics such as insertion torque value and ISQ and secondary stability metrics as ISQ values at 2, 6, and 12 months follow-ups, along with comparisons between implants with different insertion torques
Outcome (O)	Assessing the influence of cortical bone thickness on primary and secondary implant stability and determining the correlation between thicker cortical bone and higher implant stability over time.
Focus questions	Does cortical bone thickness affect the primary and secondary implant stability? Is this relationship consistent over time as indicated by insertion torque value and implant stability quotient values at different intervals?

ISQ = implant stability quotient.

2019 to 21 June, 2024): randomized controlled trials, cohort studies (prospective or retrospective cohort), cross-sectional studies, clinical trials.

Types of studies

The review included series trials, availability of at least one experimental and/or a control group, clinical studies evaluating the implant stability depending on cortical bone thickness in the maxilla and/or mandible. In addition, preoperative/postoperative measurements and follow-up were included.

Information sources

The information source was the databases of MEDLINE (PubMed), ClinicalKey (Elsevier) and the Cochrane Library. Reference lists of selected articles were manually searched for additional relevant publications. Grey literature, letters, editorials, doctoral dissertations, abstract case series, case reports, studies, reviews, unpublished literature were not included in the search strategy of this systematic review.

Search strategy

Publications were searched from January 1, 2019, until June 21, 2024, based on Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [11]
The heading keywords and MeSH terms, or combinations of them and their related terms (synonyms and hyponyms) that were used in the search strategy were: “Cortical bone thickness”, “Implant stability”, “Bone level”, “Immediate implant” and “Osseointegration”. The boolean operator “OR” was used to search for each PICO element concept, including MeSH or Emtree terms, as well as their related entry terms or synonyms. On the other hand, “AND” was utilized when searching for the concepts of the three PICO framework elements, namely population, intervention, and outcome.

Selection criteria

Clinical studies assessing the cortical bone thickness and implant stability immediately after placement and after osseointegration. There were no constraints regarding the number of patients treated and the protocol of application of the implants. The selection criteria, which is also known as inclusion and exclusion criteria, used in the study are based on PICO criteria.

Inclusion and exclusion criteria for the study selection

Inclusion criteria

- Studies on humans.
- Studies with an outcome correlation between cortical bone thickness and implant stability
- Cohort (prospective studies or retrospective studies) studies and randomized controlled trials.
- Only recent studies not older than five years.
- Studies in English language.

Exclusion criteria

- Studies not conforming the inclusion criteria.
- Experts’ opinion.
- Cadaver and animal studies, *in vivo* and *in vitro* studies.
- Reviews and meta-analysis.
- Case reports.
- Unclear description of the procedure.

Selection of studies

The titles of the identified reports underwent independent screening by two reviewers (H.J. and Z.P.) in accordance with the predefined inclusion criteria. Subsequently, additional reviewer (D.R.) conducted meticulous checks to identify and rectify any potential typographical errors. Upon review of the summary, a determination was made indicating the relevance of the study to the search topic, prompting a comprehensive full-text analysis for the selected articles. Any disparities were diligently addressed through deliberation with the senior investigator (D.R.). Furthermore, reviewer consistency was verified using Cohen’s kappa coefficient (κ) values to ensure the requisite inter-rater reliability for both abstract and title, based on a representative 10% sample of the publications.

Quality assessment

During the evaluation process, the potential for bias was analysed at the outcome level using the Cochrane Collaboration’s tool for assessing the risk of bias [12].
Five key quality criteria were considered:
1. Random sequence generation.
2. Allocation concealment.
3. Blinding of participants and personnel.
4. Incomplete outcome data.
5. Selective reporting.

Each study was categorized as having low, moderate, or high risk based on the assessment of these criteria [12].

A study was considered to have low risk if all criteria were positive or if only one variable was unclear or absent. Moderate risk was assigned if two variables were unclear and/or absent, and high risk was determined if more than two variables were absent.

Statistical analysis

Initially, a comprehensive literature review and meta-analysis that included both qualitative and quantitative components were conducted. However, due to the significant diversity of the data, it was determined that a quantitative analysis could not be performed via meta-analysis. The level of P-value was set considered statistically significant at $P < 0.05$.
As a result, the systematic review was limited to a descriptive analysis of the information retrieved, without a quantitative evaluation. Nonetheless, the review was still able to identify and analyse significant data for statistical purposes.
Statistical information was presented as the mean and standard deviation (mean [SD]), which provided a clear and concise method of expressing the results.

RESULTS
Study selection

The results were retrieved and selected for full-text screening. The search provided 392 articles (Figure 1). After filtrating according to the inclusion criteria and duplicates removed (232 articles removed), 160 articles were included in the title and abstract screening. In total, 28 articles were selected for full-text screened according to the inclusion criteria. Six studies were included in the literature review which accomplished the inclusion criteria.
Cohen's kappa coefficient (κ) values were computed at each stage of screening. The title yielded a κ of 0.5, signifying moderate agreement; the abstract showed a κ of 0.84, indicating almost perfect agreement; and the full-text review resulted in a κ of 1.00, signifying perfect agreement.

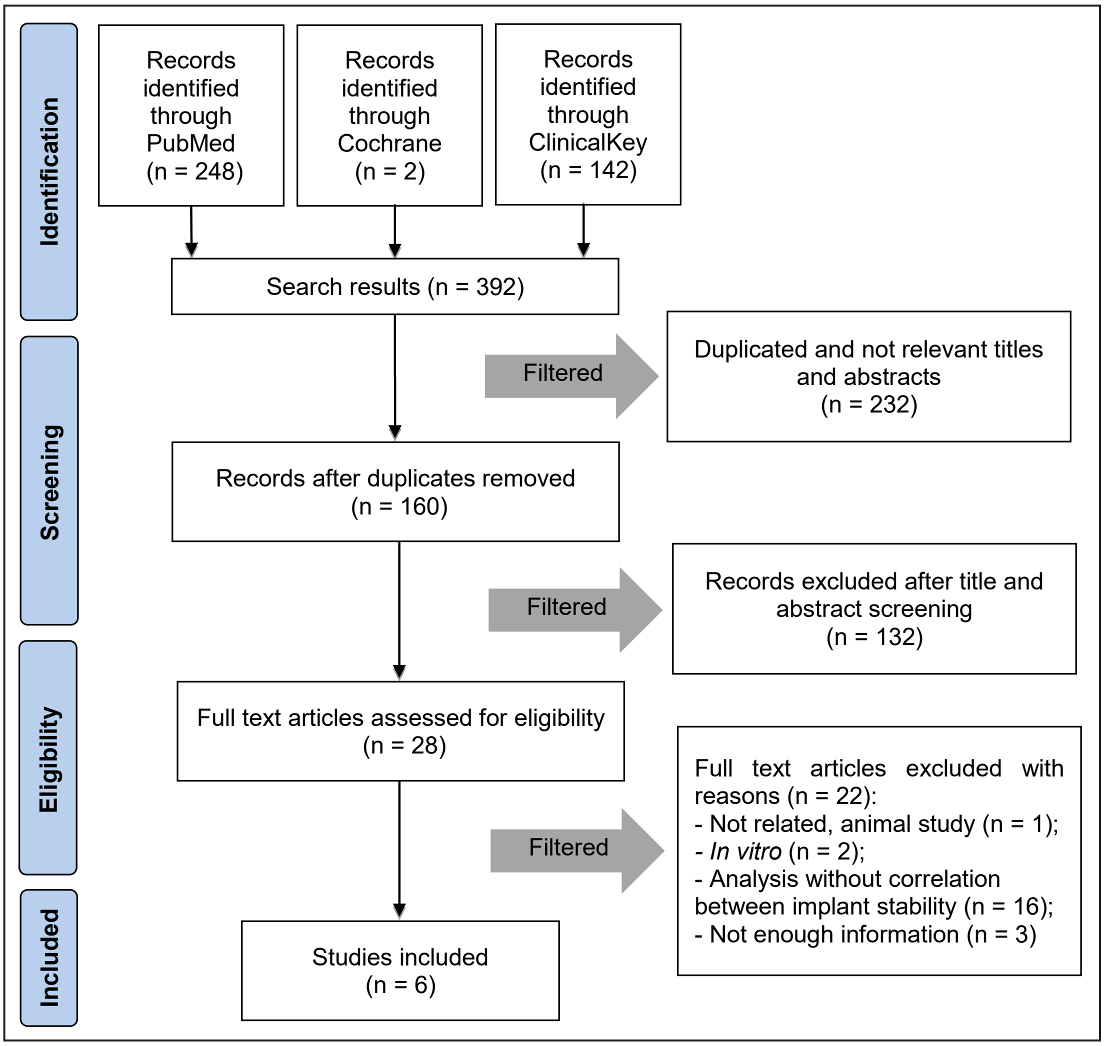

Figure 1. PRISMA flow chart of the selection of the articles.

Exclusion of studies

After full-text review, 22 articles were excluded: one article was not related and conducted on animals [13], two articles were *in vitro* studies [14,15], sixteen articles due to analysis without the correlation between implant stability [16-31] and three articles provided not enough information [32-34].

Study characteristics

This systematic review includes six articles: prospective study [35], observational clinical study [36], randomized controlled trial [37], clinical study [38], prospective cohort studies [39-40] (Table 2).

Risk of bias in individual studies

Out of the six articles included, three studies [35-37] exhibited a low risk, whereas the remaining three [38-40] were associated with a moderate risk (Figure 2 and 3).

Clinical characteristics

A total of 263 patients were potential participants of which 418 implants were placed (Table 2). The imaging modality employed for evaluating the PIS and SIS was cone-beam computed tomography (CBCT) [35-38]. Alternative diagnostic methodologies have been utilized to gauge ISQ of dental implants, including resonance frequency analysis (RFA) [39] and the integration diagnostics to determine the ISQ using Osstell™ device (Osstell AB; Gothenburg, Sweden) [40].
In this systematic review, six articles employed different implant materials. One study [35] utilized the Straumann® system (Straumann AG, Basel, Switzerland), while another [36] used the BEGO Implant system (BEGO GmbH & Co. KG; Bremen, Germany). The NobelActive® implant (Nobel Biocare AB; Gothenburg, Sweden) was employed in study [37], and AB Dental Implants (AB Dental Devices Ltd.; Ashdod, Israel) were used in study [38]. The Zimmer TSV implant (Zimmer Biomet Dental;

Table 2. Description of studies included in the review

Study	Year of publication	Study	Follow-up (months)	Method	Patients (n)	Implants (n)	Implant system	Implant length/ diameter (mm)	Insertion torque value (Ncm)
Feng et al. [35]	2023	Prospective study	3	CBCT	22	65	Straumann® Bone Level Implant System (Straumann AG; Basel, Switzerland)	NR	31.44 (SD 6.54)
de Elío Oliveros [36]	2020	Observational clinical study	Direct	CBCT	48	160	BEGO Implant (GmbH & Co. KG; Bremen, Germany)	NR	≤ 30 to > 50
Daher et al. [37]	2021	Randomized controlled trial	3 to 3.5, 12	OPG, CBCT	18	120	NobelActive® (Nobel Biocare AB; Gothenburg, Sweden)	Length: 10, 11.5, 13, 15. Diameter: 3.5, 4.3	< 10 to > 70
Ivanova et al. [38]	2021	Clinical study	4	CBCT	90	90	AB Dental Implants (AB Dental Devices Ltd; Ashdod, Israel)	Length: ≤ 6.0, (> 6 to < 10) or ≥ 10. Diameter: ≤ 3.0 to < 3.75, ≥ 3.75 to < 5 or ≥ 5	NR
Vallecillo et al. [39]	2021	Prospective cross-sectional study	2, 3	RFA	31	60	Zimmer TSV (Zimmer Biomet Dental; Palm Beach Gardens, Florida, USA)	Length: 10. Diameter: 3.7 or 4.1	40
Cassetta et al. [40]	2022	Prospective cross-sectional study	2, 6, 12	Osstell™ device (Osstell AB; Gothenburg, Sweden)	142	268	DIO Implant (DIO Corporation; Busan, South Korea)	Length: 10, 12 or 14. Diameter: 3.8, 4.1, 4.5, 5.0 or 5.3	> 50

N = number; NR = not reported; CBCT = cone-beam computed tomography; OPG = orthopantomogram; RFA = resonance frequency analysis.

	D1	D2	D3	D4	D5	Overall
Feng et al. [35]	+	+	+	+	+	+
de Elío Oliveros [36]	-	+	+	+	+	+
Daher et al. [37]	+	+	+	+	+	+
Ivanova et al. [38]	+	+	+	+	-	-
Vallecillo et al. [39]	+	+	+	+	-	-
Cassetta et al. [40]	+	-	-	+	+	-

Figure 2. Assessing the risk of bias of included publications in this study.
+ = low; - = some concerns; D1 = bias arising from randomizing process; D2 = bias due to deviation from intended intervention; D3 = bias due to missing outcome data; D4 = bias of measurement of the outcome; D5 = bias in selection of the reported result.

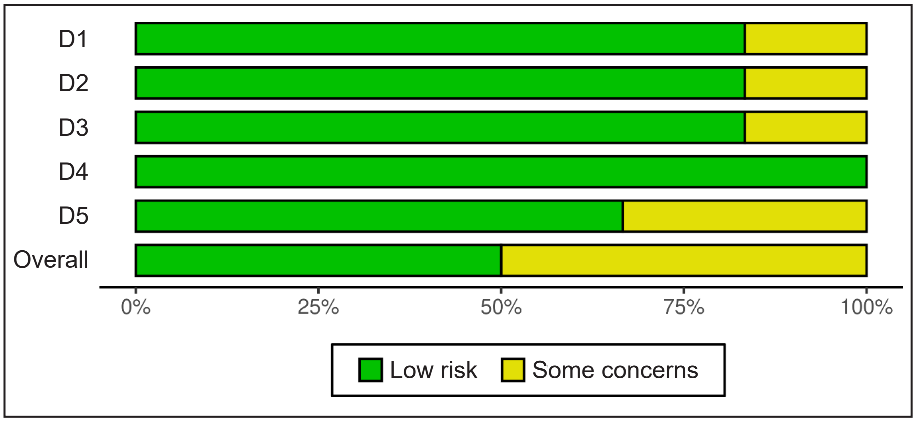

Figure 3. Assessment of risk of bias summary.
D1 = bias arising from randomizing process; D2 = bias due to deviation from intended intervention; D3 = bias due to missing outcome data; D4 = bias of measurement of the outcome; D5 = bias in selection of the reported result.

Palm Beach Gardens, Florida, USA) was implemented in study [39], and finally, the DIO Implant system (DIO Corporation; Busan, South Korea) was utilized in study [40].

Clinical assessment

In a study conducted by Feng et al. [35], the correlation between cortical bone thickness and implant stability was examined. The study focused on primary stability, which is influenced by bone-to-implant contact (CBIC) and bone microstructure evaluated through CBCT. A total of 22 patients with 65 implants were involved in the study (Table 2). ITVs and ISQ values were used to assess primary stability, measured immediately after implant placement and three months postoperatively. The results showed that ITV was significantly linked to the surface area of CBIC ($P = 0.006$), bone volume fraction, and bone surface fraction (BS/BV) ($P = 0.025$), but no significant correlations were found with ISQ values during baseline and secondary assessments ($P > 0.05$) (Table 3). The study concluded that preoperative CBCT assessments could potentially predict ITV, thus aiding in the anticipation of ISQ, although ISQ values were not effectively predicted by these measurements.

de Elio Oliveros et al. [36], evaluated the connection between alveolar bone density, as measured by Hounsfield Units (HUs) through CBCT and PIS was examined in 48 patients with 160 implants (Table 2). PIS, which is essential for successful implant integration, was evaluated using both the ISQ from resonance frequency analysis and ITV. The study revealed that ISQ values had a significant correlation with the alveolar ridge width in the coronal ($P < 0.05$), middle ($P < 0.01$), and apical ($P < 0.01$) thirds of the bone (Table 3). ISQs were also higher with larger-diameter implants ($P < 0.01$). Moreover, a strong correlation ($P < 0.001$) was observed between ISQ and ITV. These findings suggest that preoperative CBCT measurements of bone density can help anticipate the primary stability of dental implants and thus contribute to treatment planning.

A split-mouth randomized controlled trial conducted by Daher et al. [37] investigated the factors affecting

Table 3. Primary and secondary implant stability

Study	Follow-up (months)	Patients	Implants	Method	Primary implant stability	P-value	Secondary implant stability	P-value	Implant system
		N	N	CBCT	Mean (SD)		Mean (SD)		
Feng et al. [35]	3	22	65	CBCT	73.34 (SD 7.39)	0.006	80.32 (SD 4.58)	0.351	Straumann® Bone Level Implant System (Straumann AG; Basel, Switzerland)
de Elío Oliveros [36]	Direct	48	160	CBCT	NR	0.001	NR	NR	BEGO Implant (GmbH & Co. KG; Bremen, Germany)
Daher et al. [37]	3 to 3.5, 12	18	120	OPG, CBCT	62.6 (SD 7.7)	< 0.001	68.6 (SD 4.2)	< 0.001	NobelActive® (Nobel Biocare AB; Gothenburg, Sweden)
Ivanova et al. [38]	4	90	90	CBCT	Narrow implant: 67.75 Strandard impalnt: 66.78 Wide implants: 71.21	< 0.001	Narrow implants: 73.83 Standard implants: 75.25 Wide implants: 74.93	< 0.001	AB Dental Implants (AB Dental Devices Ltd; Ashdod, Israel)
Vallecillo et al. [39]	2, 3	31	60	RFA	Native bone: 75.4 (SD 12.8) Regenerative bone: 67.17 (SD 11.47)	0.011	Native bone: 75.33 (SD 6.82) Regenerative bone: 66.1 (SD 9.93)	< 0.001	Zimmer TSV (Zimmer Biomet Dental; Palm Beach Gardens, Florida, USA)
Cassetta et al. [40]	2, 6, 12	142	268	Osstell™ device (Osstell AB; Gothenburg, Sweden)	Group A (T0): 75.04 Group B (T0): 72.59	< 0.001	Group A (T1): 78.53; Group B (T1): 76.14 Group A (T2): 81.66; Group B (T2): 80.1 Group A (T3): 80.86; Group B (T3): 80.75	0.059	DIO Implant (DIO Corporation; Busan, South Korea)

N = number; NR = not reported; SD = standard deviation.

ISQ in the posterior maxilla using NobelActive® (Nobel Biocare AB; Gothenburg, Sweden) a variable-thread tapered implants. A total of 26 patients were enrolled in the study; however, ISQ recordings were obtained for only 18 patients due to logistic problems during the trial and the treatment of the first 8 patients. The enrolled patients received each 3 to 4 implants in maxillary premolar-molar sextants, resulting in a total of 120 implants placed: 60 implants immediately loaded and 60 inserted according to the delayed loading protocol (Table 2). The study compared immediate loading of provisional prostheses to conventional loading on the contralateral side. PIS was assessed by measuring ITVs and ISQ in four directions. SIS was measured by ISQ at definitive prosthesis delivery (3 to 3.5 months postoperatively) and 12 months after definitive loading. The results indicated that there were no significant differences in ISQ values between the two loading protocols at any point in time ($P > 0.05$), implying that immediate loading did not affect implant stability (Table 3). ISQs increased over time in both loading protocols, with P-values indicating statistical significance ($P < 0.001$) at each time interval assessed.

In a recent study by Ivanova et al. [38], the link between PIS and SIS, bone density, and the percentage of vital bone formation was investigated in 90 patients who underwent a socket preservation procedure followed by dental implant placement (Table 2). The results indicate that primary stability was positively correlated with bone density (P < 0.001) and the percentage of new bone formation (P < 0.001) (Table 3). Similarly, there was a significant association between SIS and these parameters (P < 0.001 for bone density and P < 0.001 for new bone formation). To evaluate the internal bone structure, histomorphometric analysis was conducted during surgical re-entry, and CBCT scans were used to assess bone density pre-operatively. This detailed examination suggests a strong interrelation between cortical bone density, bone formation, and implant stability, supporting the idea that both primary implant stability and secondary implant stability after osseointegration are influenced significantly by these factors.

Vallecillo et al. [39] conducted a prospective cohort study comparing implant stability in regenerated versus non-regenerated bone and assessing the impact of bone quality on implant stability outcomes. The study involved 31 patients and 60 implants with 30 in native bone and 30 in regenerated bone using xenograft bovine bone (Zimmer Biomet; Warsaw, Indiana, USA) and a resorbable collagen membrane (Zimmer Biomet) (Table 2). RFA was used to measure the ISQ at baseline, 8 weeks, and 12 weeks post-implant placement. The results showed statistically significant differences in ISQ values between implants placed in regenerated and native bone at all measured time points, with native bone consistently showing higher ISQ values at baseline (P = 0.011), at 8 weeks (P = 0.013), and at 12 weeks (P < 0.001 (Table 3). The study demonstrated that while implants in regenerated bone showed adequate stability for prosthetic loading, those in native bone achieved higher stability values, suggesting that bone quality influences primary stability but not SIS.

A prospective parallel cohort study conducted by Cassetta et al. [40] investigated the correlation between cortical bone thickness, ITV and ISQ. The study involved 142 subjects who received a total of 268 dental implants (Table 2). ITV and ISQ values were recorded to assess primary stability at implant insertion, while secondary stability was evaluated at 2, 6, and 12 months post-implantation. The results showed a strong correlation between ITV and ISQ at implant insertion (T0) with a Pearson correlation coefficient of 0.494 and a P-value of < 0.001, indicating that the mechanical force used during implant insertion plays a crucial role in initial implant stability. However, there was no significant correlation between ITV and ISQ at the 2-month (T1) follow-up (Pearson correlation coefficient of 0.172, P = 0.059), 6-month (T2) follow-up (Pearson correlation coefficient of -0.021, P = 0.817), and 12-month (T3) follow-up (Pearson correlation coefficient of 0.199, P = 0.029), suggesting that high ITV does not guarantee better long-term stability measured by ISQ. The study concluded that while initial mechanical stability is important, it should not be solely relied upon to predict long-term osseointegration success.

DISCUSSION

The aim was to analyse the correlation between cortical bone thickness and implant stability, with a focus on primary mechanical implant stability and secondary stability after implant osseointegration. A total of six articles were selected based on predefined eligibility criteria. However, the analysis revealed significant methodological differences between studies and heterogenic results. Nevertheless, the qualitative assessment revealed a positive association between greater cortical bone thickness and higher PIS at the time of implant insertion. Furthermore, the findings emphasized that while high ITV which reflect initial mechanical stability are highly correlated with primary stability and that they cannot reliably predict secondary stability outcomes over time. This review highlights the intricacy of predicting long-term implant success from initial stability metrics, underscoring the need for comprehensive preoperative assessments of bone quality.

In a study by Wang et al. [41], examined the relationship between cortical bone thickness, bone density measured in HU using CBCT and the primary stability of dental implants. The results revealed that cortical bone thickness, and implant length, both positively correlated with ITVs and ISQ values. The findings suggest that increased cortical bone thickness contributes significantly to both initial mechanical stability and measured stability over time SIS, as demonstrated by the correlation between cortical bone thickness and ITVs (P < 0.001) and ISQ values (P < 0.001). The study also found significant correlations between the voxel values obtained from CBCT scans and ITVs (P < 0.001), but the correlation with ISQ values varied depending on implant dimensions. Other studies have shown statistical analysis that revealed significant correlations in the association between gender and cortical thickness variations across different mandibular regions, with P ≤ 0.05 considered statistically significant for all comparisons [42-43].

According to a research conducted by do Vale Souza et al. [44], there is a correlation between ITV and ISQ values. The study demonstrated a positive correlation between ITV and initial ISQ values measured on the day of implant placement, suggesting that higher insertion torque leads to greater primary stability. However, this study argued weakly against the findings of previous studies. It revealed that after six months, no significant correlation was observed between ITV and ISQ values, indicating that insertion torque is not a reliable predictor of secondary stability following osseointegration.

Limitations

Although the study's approach is comprehensive, it is important to acknowledge several limitations. The relatively small sample size limits the statistical significance of the findings and their generalizability to a larger population. Additionally, the participants were from a single geographic region, which may not reflect the variation in bone density values [41], other factors affecting the bone health [45] and quality [46]. Moreover, RFA accuracy can be influenced by operator technique and the specific device used, potentially affecting the reliability of the results [47]. Furthermore, the majority of the included studies' follow-up period was relatively short. Finally, a large heterogeneity in this study was observed, whereas different implant systems, types, insertion torque and surface textures were used among participants, which can significantly affect osseointegration and stability, potentially introducing additional variability in the results.

CONCLUSIONS

The findings indicate that implants situated in regions with thicker cortical bone exhibited superior primary stability, as indicated by their higher insertion torque value and implant stability quotient values. Additionally, there may be a possibility of significant correlation between the secondary implant stability quotient and cortical bone thickness, which indicates the need for additional research in this area.

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The authors report no conflicts of interest related to this study.

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