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Original article

Factors associated with the risk of fracture of mandibular overdentures on one or two implants: Findings from a 5-year follow-up

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Abstract

Purpose: This was a prospective study conducted alongside a randomized controlled trial (RCT) that evaluated the incidence of fractures and associated risk factors in single-implant overdentures (1-IOD) compared with two-implant overdentures (2-IOD).

Methods: The participants received either a mandibular 1-IOD or 2-IOD (attachments: Straumann® retentive anchor and elliptical titanium matrix with gold insert; implants: 4.1 mm diameter, Straumann® Standard Plus SLActive® Regular Neck), within the context of a randomized clinical trial. The primary outcome of interest was the incidence of IOD fractures at 5-year follow-up. Prosthetic factors, such as area and cervico-incisal height in the attachment region, and volume at the inter-canine region, were measured. Patient-related factors including age, sex, handgrip strength, manual dexterity, bite force, and chewing performance were assessed. Data analysis included descriptive statistics, bivariate tests, Kaplan-Meier plots, and linear discriminant analysis with $\log_{10}$ transformation for variable normalization.

Results: A total of 47 patients were recruited, and 34 (n = 34, 1-IOD = 16, 2-IOD = 18; mean-age: 63.9 ± 8.6 years; 79.4% women) completed the 5-year follow-up. There were no differences in the incidence of fractures between the 1-IOD and 2-IOD groups ($P < 0.05$). Fractures were more frequent in younger patients, and reduced cervico-incisal IOD height was significantly associated with fractures ($P = 0.040$). Linear discriminant analysis predicted fractures with 84.4% accuracy and identified cervico-incisal height and age as key predictors.

Conclusions: There were no significant differences in the incidence of overdenture fractures between groups. Reduced cervico-incisal denture height in the attachment region of ball-retained IODs was associated with mandibular IOD fractures. Further studies with larger cohorts are recommended to identify additional risk factors for mandibular IODs.

Keywords: Implant overdentures, Single-implant mandibular overdenture, Two-implant mandibular overdenture, Edentulous jaw, Removable prosthodontics

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1. Introduction

Denture fractures may occur due to various types of stress on the acrylic resin of the denture base associated with repeated intraoral masticatory forces that lead to fatigue. Alternatively, extraoral high-impact forces may occur when a denture is dropped[1]. Fractures due to functional loading are frequently associated with stress concentration in areas such as a large frenum notch, poorly designed dentures with thin or under-extended flanges, poorly fitting dentures, lack of adequate relief, inadequate occlusal relationship, or previously repaired dentures[1–3]. There is also an inherent risk of fractures due to accidental denture dropping. It is common among the elderly where in the impaired manual dexterity and visual acuity

WHAT IS ALREADY KNOWN ABOUT THE TOPIC?

» *Prior clinical studies have indicated that overdenture fractures are one of the most common complications encountered in both 1- and 2-IOD therapies. However, potential risk factors for overdenture fractures remain unclear.*

WHAT THIS STUDY ADDS?

» *This study confirmed that the absence of sufficient resin thickness in the IODs in the region of the implants was the main predictor of a higher risk of fracture in 1- or 2-IODs.*

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limit their ability to properly handle small objects with precision and agility[3].

Prosthesis fractures are one of the most common complications in patients rehabilitated with implant-retained overdentures (IODs)[2–5]. Evidence suggests that the incidence of IOD fractures is between 15% and 21%[3], and the increased fracture risk may be due to insufficient bulk acrylic resin in the region of the retentive attachments[6]. An increased risk of fracture may be more frequently associated with single-implant overdentures (1-IODs) compared to two-implant overdentures (2-IODs) without metal framework reinforcement[7]. Although these factors leading to IOD fractures have been explored in prospective and retrospective observational studies, few studies have investigated the cause-and-effect relationship between patient-related and prosthesis-related factors and the incidence of IOD fractures.

This study aimed to identify the incidence and risk factors of mandibular overdenture fractures using longitudinal data from a randomized clinical trial comparing outcomes of overdentures retained by one or two implants. The null hypothesis stated there would be no relationship between patient- or prosthesis-related factors and the incidence of mandibular overdenture fractures, regardless of whether one or two implants were retained.

2. Materials and Methods

2.1. Design, setting, and sample

The study was designed as a prospective cohort to investigate the incidence of mandibular overdenture fractures and associated risk factors. It was conducted in conjunction with a parallel two-group randomized clinical trial that compared the primary outcomes of mandibular IOD treatment using one or two implants, including patient-reported outcomes, implant-related outcomes, and prosthodontic complications. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. This study adhered to the Declaration of Helsinki ethical principles for medical research involving human subjects, and was approved by the local research ethics committee (CAAE: 56675822.7.0000.5083; CAAE: 65525322.4.0000.5083). The data was collected at the Federal University of Goias, Brazil from May 2017 to June 2023. Previous reports on this patient cohort have compared 1-IOD and 2-IOD regarding short-term surgical symptoms[8], treatment burdens[9], functional outcomes, patient satisfaction, and impacts on oral health-related quality of life[10], as well as the incidence of prosthodontic complications[6].

2.2. Participants

Participants were edentulous individuals seeking prosthodontic treatment and those who consented to receive implant therapy to stabilize mandibular dentures. Additional inclusion criteria included a minimum bone height in the anterior mandible to insert an implant with a length of at least 8 mm with no general or local contraindications for implant surgery.

2.3. Sample size, randomization, study group allocation

A total of 48 participants were initially selected as the sample size for the randomized clinical trial[10]. All eligible participants were fully edentulous and received a new pair of complete dentures fabricated according to a standard clinical protocol. This included a preliminary impression with an irreversible hydrocolloid, a final impression with zinc oxide eugenol paste, interocclusal registration in centric relation and articulator assembly, arrangement of teeth in bilateral balanced occlusion, a trial visit, delivery of the denture, and post-insertion visits for adjustments. After continuous use of the dentures for at least 3 months, participants were invited for baseline data collection and randomly assigned to one of two treatment groups: the 1-IOD or 2-IOD group. Block randomization with sex stratification was performed. The randomization sequence was generated and the allocation was concealed in opaque envelopes and maintained securely by another research collaborator who was not involved in the clinical treatments. The envelopes were opened only after a signed consent form was received prior to implant intervention. Clinicians who treated the patients were blinded to the allocation sequence.

2.4. Intervention

Conventional complete removable dentures were fabricated with heat-polymerized polymethylmethacrylate (PMMA) resin, set in bilateral balanced occlusion, delivered, and allowed an adaptation period before the implant intervention.

In a single-stage surgical procedure, tissue level Straumann® Standard Plus SLActive® Regular Neck implants (Straumann 033.561S/652S/563S) were inserted in the midline of the mandible or the lateral incisor-canine area bilaterally for the participants randomized to the 1-IOD group or 2-IOD group, respectively. Mandibular dentures were adjusted to fit and allow for uneventful healing following surgery. After a 3-week healing period, a retentive titanium anchor abutment (Straumann 048.439) was connected to the implants at 35 N.cm, and a corresponding titanium elliptical matrix (Straumann 048.456) with gold inserts was incorporated into the mandibular denture using a chairside procedure with self-curing acrylic resin for a conversion into an overdenture[10].

One experienced implant dentist performed all implant placements, whereas another experienced prosthetic dentist fabricated all prostheses following a standardized protocol. All the laboratory procedures were performed by the same technician.

Participants were followed up, and endpoints were assessed at baseline (before implant insertion) and at the 6-month, 1-, 3-, and 5-year follow-up visits after overdenture delivery. However, in the case of unexpected events, patients could request a clinical visit during the follow-up period, when the intercurrences were assessed and registered, and patients' complaints were properly managed.

2.5. Outcome and independent variables

The primary outcome measure was occurrence of IOD fractures. A clinically confirmed fracture was defined as the complete separation of the denture parts. Data analysis excluded maxillary denture fractures and other minor fracture types, such as acrylic teeth or minor denture flange fractures.

Three distinct methods, selected based on specific criteria, were used to repair the overdenture fractures. Direct relining or repair with self-curing acrylic resin was applied when quick and less complex adjustments were required, and the prosthesis was in good general condition without major structural changes. This method involves applying acrylic resin directly to the prosthesis, followed by

finishing and adjusting chairside. Indirect relining was used when the prosthesis presented with significant wear or required edge correction owing to a fracture or unsatisfactory fit. In this case, the prosthesis serves as a mold and may require molding of the edge for adequate sealing. After molding, the prosthesis was sent to the laboratory for inclusion and pressing with a thermopolymerized acrylic resin, and adjustments were made before installation. Finally, overdenture replacement was performed when the prosthesis was too damaged, making effective repair with direct or indirect relining impossible. Thus, a new prosthesis had to be fabricated.

Risk factors evaluated for IOD fracture comprised the following:

1. Prosthesis-related factors: The cross-sectional dimensions of the overdenture at the attachment sites, total volume of the overdenture base in the intercanine area, and vertical (cervico-incisal) height in the attachment region
2. The patient-related factors included age, sex, handgrip strength and dexterity, bite force, chewing performance, and duration of overdenture use.

Descriptions and measurement methods for the selected risk factors explored in this study are described in detail in the following sections.

The dimensions of the overdentures were analyzed using the Shining DS-EX Scanner (Talmax, Curitiba, Brazil) at the 5-year visit, regardless of previous fractures or repairs. The scanning method involves positioning the object centrally in a device, which performs rotational movements to capture the entire surface and produce an STL file. These files were then processed using Meshmixer 3.5 software (Autodesk, San Rafael, USA). Three measurements were taken: cross-sectional area at the attachment level (mm^2), cervico-incisal height in the attachment housing region (mm), and overall denture base volume in the inter-canine region (cm^3) (**Fig. 1**).

Handgrip strength was measured using a manual dynamometer (Crown Manual Dynamometer 50-100 KgF, iTest, São Paulo, Brazil). For the handgrip strength test using a dynamometer, the participants stood with their elbow bent at 90 °, forearm in a neutral position, and the wrist extended slightly. The dynamometer was held in the hands and squeezed as hard as possible without moving the arms. Three peak force measurements were performed on the right and left hands, and the highest value among the three measurements was considered for the analysis. Furthermore, the participant's dominant side (right- or left-handed) was recorded to determine which hand the prosthesis was being pressed during handling to assess fracture risk.

Manual dexterity was assessed using the Functional Dexterity Test (FDT), validated by Aaron and Jansen[11]. The test used a board with 16 holes and wooden pins. Participants had to remove the pin, rotate it by 180°, and reinsert it, avoiding penalties for touching the board, supination movements, or dropping the pin. The test measured dexterity while performing tripod pinching movements with the index, middle, and thumb fingers to evaluate speed and accuracy. The dominant hand (right or left) of the patient was also recorded.

The bite force was measured using the maximum voluntary bite force (MBF) in Newtons with a digital gnathodynamometer (DMD Kratos, Kratos Equipamentos Industriais Ltd., Brazil). For the oral function tests, the participants were positioned comfortably in a dental chair and instructed about the test procedure. The participants were placed in the sagittal plane perpendicular to the ground and their heads rested on a dental chair. MBF was recorded bilaterally in the first molar and anterior midline region. The participants bitten as hard as possible on a force gauge using a contralateral stabilizing device of identical thickness to prevent denture dislodgement. The peak force from three consecutive recordings on each side was recorded and the mean MBF was calculated.

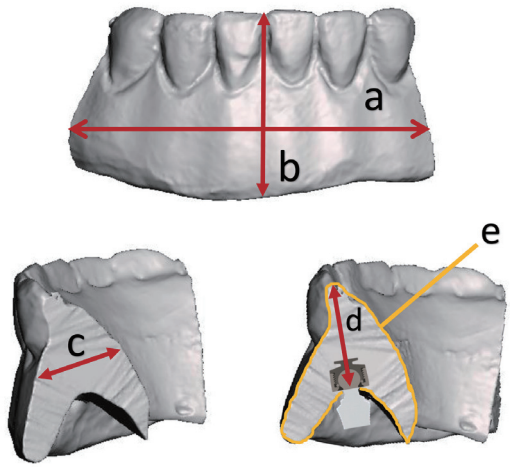

Fig. 1. Denture base volume in the inter-canine region (cm^3), (a) width, (b) height and (c) depth; Cervico-incisal height and cross-sectional area in the attachment housing region, (d) cervical-incisal height (mm) and (e) cross-sectional area (mm^2).

Chewing function (CF) was assessed with the mixing ability test using a two-color chewing gum (Vivident Fruitswing Karpuz/Asai Üzümü, Perfetti van Melle, Turkey) over 20 chewing cycles. The chewed specimens were collected, rinsed, stored in transparent plastic bags, and flattened to a thickness of 1 mm. Both sides of the flattened specimens were scanned at 300 dpi using an HP Photosmart scanner (C4780). Images were analyzed using ViewGum© software (dHAL Software, Greece, www.dhal.com) to obtain the variance of hue (VoH), a measure of color mixing. A lower VoH value indicates better chewing function[12].

Data collection was standardized, with the chewing performance assessed at baseline, 6-month, 1-year, and 5-year intervals. The dimensions of prosthesis-related factors, including handgrip strength, manual dexterity, and bite force, were assessed exclusively at the 5-year follow-up, following observation of the incidence of fractures among participants.

2.6. Data analysis

Descriptive statistics were performed using frequency analysis for nominal variables and mean values ± standard deviations (SD) or median (IQR) for numerical variables. Outcome measures were expressed as the 5-year incidence of overdenture fractures (incidence rate) and person-time incidence rates (incidence density rate) due to multiple fracture events within the same individual. Based on the occurrence of overdenture fractures, the patients were divided into two groups: those with a fracture(s) (F-Group) and those without a fracture (NF-Group).

The normality of the data for the F and NF groups was assessed using the Shapiro-Wilk test. Bivariate tests were performed to compare the F and NF groups using the chi-square test, independent *t*-test, and Mann-Whitney *U* test. The Benjamini-Hochberg (BH) procedure was used to control the False Discovery Rate (FDR) in multiple hypothesis testing. Correlations between the numerical variables were tested using Pearson's correlation coefficients. A Kaplan-Meier plot was constructed to show the probability of fracture over time, and the log-rank test was used to identify differences between the different clinical groups (sex, age, and IOD groups).

Linear discriminant analysis was used to build a predictive model that best discriminated between the F and NF groups. Oral function parameters (MBF and CF), manual dexterity, and prosthesis-related factors were used as independent quantitative predictors. Box's M test was used to test the homogeneity of variances between the variables. The variation in the inflation factor was calculated to exclude collinearity, which was confirmed by a value below 10. Two discriminant models were presented: Model 1 included all predictors and Model 2 included the most relevant predictors obtained by stepwise selection. A structure matrix was constructed using the canonical correlation coefficients for each predictor, which reflected the strength of the association between the independent predictors and the dependent variable (F and NF groups). Standardized discriminant coefficients were used to construct a linear discriminant function for the final model, ranking each variable's contribution to the discrimination between the groups. The significance of the models (Wilks' lambda) and their predictive powers (canonical correlation, R2) were calculated. Subsequently, the discriminant scores were used to calculate the percentage of correct classifications of the predicted group membership compared with the actual groups of the study sample. IBM SPSS Statistics software (version 24.0, Armonk, NY, USA) was used for data analysis, and statistical significance was set at $P < 0.05$.

3. Results

No implant failure occurred after loading or overdenture use. The initial sample of 47 participants in the original randomized clinical trial included 74.5% females, a mean age of 64.1 (± 9.5), and 10 were first-time users of a mandibular denture.

Eighteen patients (38.3%) had an overdenture fracture: 10 in the 1-IOD group and 8 in the 2-IOD group, as reported previously[6]. For this follow-up study, 34 patients were assessed for data collection, comprising 27 (79.4%) females, aged 45 to 82 years (mean: 63.9 ± 8.6) at the time of overdenture treatment. A total of 13 patients were excluded from the analysis: one due to death and 12 due to loss to follow-up or failure to attend a follow-up visit. The follow-up time ranged from 5.0 to 6.9 years (mean: 5.5 ± 0.4), considering the time from overdenture delivery and the follow-up visit. With respect to the number of implants for overdenture retention, 47.1% had a single midline implant and 52.9% had two implants. The complete patient flowchart is detailed in **Figure 2**. Due to the high attrition rate (27.7%) and consequent risk of bias (dropout bias), the baseline characteristics of the retained and dropout participants were compared to assess whether dropouts occurred at different rates between those who were lost to follow-up and those who remained, potentially skewing the results. No significant differences were observed in attrition rates among the IOD groups ($P > 0.299$), nor in relation to sex ($P = 0.158$) or age ($P = 0.203$). **Table 1** presents the summary values of the variables assessed in this study, categorized by the treatment group. The results indicated no differences in patient-related and prosthodontic-related factors between the 1-IOD and 2-IOD groups ($P > 0.05$). The patient- and prosthodontic-related variables associated with the occurrence of overdenture fractures is shown in **Table 2**.

Participants were categorized into those who had experienced a fracture of the mandibular overdenture (n=16) and those who did not (n=18). None of the patient-related factors were significant ($P > 0.05$). Regarding prosthodontic-related factors, nearly 75% of the F-group had a cervico-incisal height below 12 mm, whereas 60% of the NF-group had a height above 13 mm. Cervico-incisal height was significantly reduced in patients with fractures ($P = 0.040$), indicating that reduced cervico-incisal height may be associated with a higher likelihood of overdenture fracture. However, the FDR procedure revealed that the p-value was less than the corresponding threshold of clinical significance ($P = 0.012$), indicating a false positive risk for statistical inference.

The Kaplan-Meier plot in **Figure 3** illustrates the probability of fracture over time up to the 5-year follow-up. The steeper slope in the first two years suggests a higher risk of fracture during the initial period of overdenture use. The mean survival time was 4.1 years (95% CI = 3.3– 5.0 years). No differences in survival time were found with respect to sex ($P = 0.100$), age ($P = 0.611$), groups, or IOD group ($P = 0.887$).

Subsequently, linear discriminant analysis was performed to predict the categories of the dependent variable (overdenture fracture) with proper discriminant functions. A log10 transformation was performed to normalize the variables (handgrip strength, maximum anterior bite force, manual dexterity, and intercanine volume) when applicable, assuming that the variables followed a normal distribution curve.

Table 3 presents a pooled within-group correlation matrix (**Table 3**), which averages the separate covariance matrices for all groups before computing the correlations. **Table 4** outlines the parameters of the linear discriminant function models used to predict the fracture outcomes. Model 1, including all variables, demonstrated a canonical correlation of 0.657 and correctly classified 84.4% of cases overall, with 75.0% accuracy in predicting fractures and 84.4% accuracy in predicting non-fractures. The strongest predictors in this model were the cervico-incisal height (discriminant coefficient = 0.406) and patient age (discriminant coefficient = 0.382). Model 2, which employed a stepwise selection process, showed a lower canonical correlation (0.435) and reduced overall classification accuracy of 69.7%. However, cervico-incisal height (discriminant coefficient = 0.758) and patient age (discriminant coefficient = 0.637) were significant predictors. Box's test indicated that the assumption of homogeneity of the covariance matrices ($P < 0.05$) was met in both models ($P = 0.465$ for Model 1 and $P = 0.337$ for Model 2). The significance of the models, as determined by Wilks' Lambda, approached statistical significance in Model 1 ($P = 0.065$) and reached significance in Model 2 ($P = 0.032$), suggesting that the variables included in Model 2 were more robust predictors of fracture outcomes.

4. Discussion

The findings of this follow-up study suggest that overdenture fractures are not associated with specific patient-related risk factors. In contrast, overdentures with a thin acrylic resin bulk around the at-

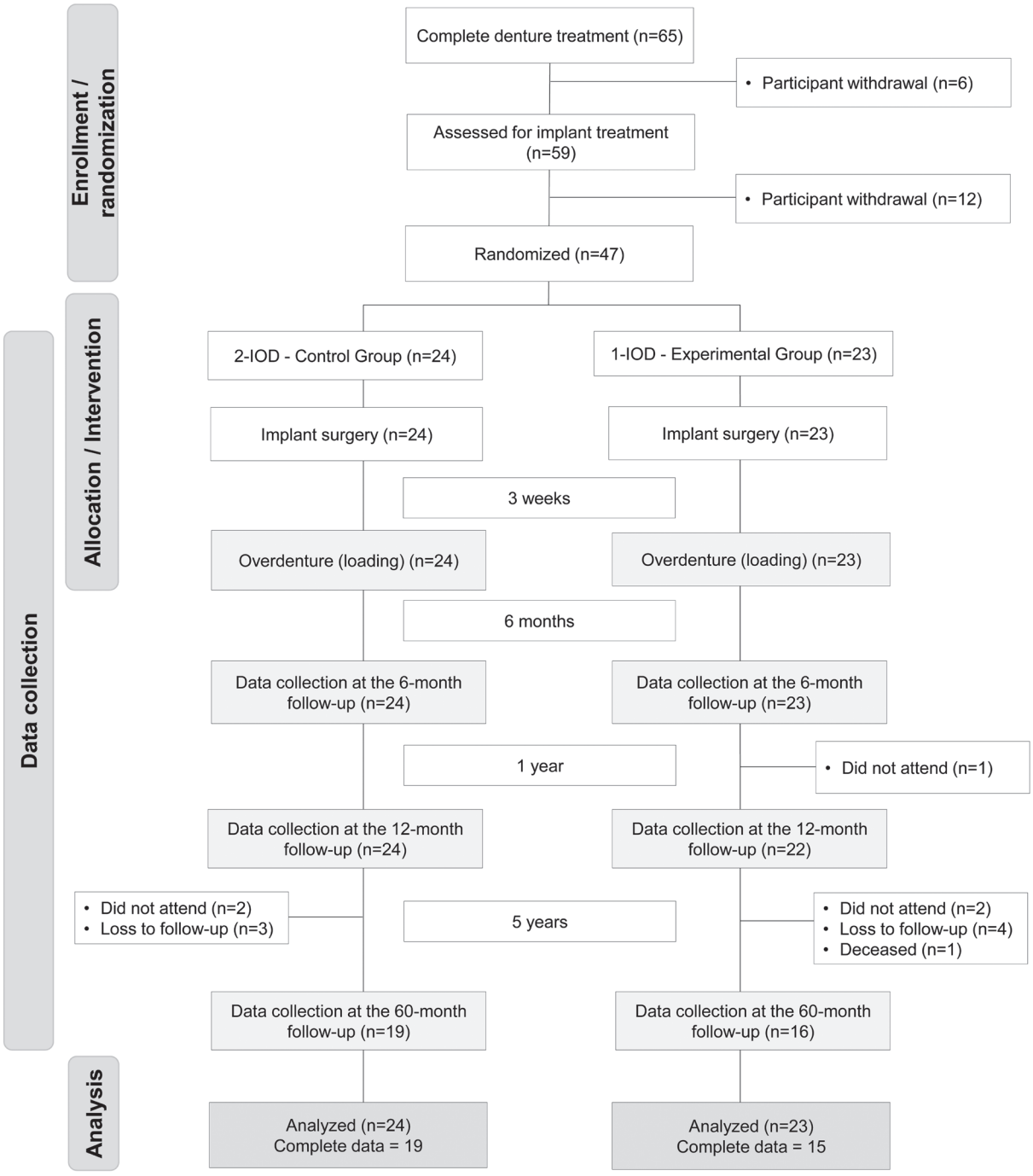

Fig. 2. Patient flowchart

tachment may increase the risk of fracture regardless of the number of implants retaining the overdenture. Therefore, several potential risk factors explored in this study may not predict the likelihood of fracture. These include functional patient-related factors such as improper handling or exaggerated manual forces, poor dexterity, and harder bite or chewing forces. Specific characteristics of the overdenture structure and mechanical stress it is subjected to are important factors associated with a higher fracture risk under certain conditions. The reasons for denture fracture include both external and intraoral causes. External causes are most often related to dentures falling from the patient's hand onto a hard surface. These events are not typically considered actual prosthodontic-related complications, but rather improper handling.

In contrast, overdenture fracture within the mouth during function may be due to the combination of high-stress concentrations and reduced thickness of the overdenture base in the created relief space where the attachments were incorporated. Although bite force was not a significant predictor of fracture, several studies have demonstrated a substantial increase in the maximum bite force of

Table 1. Summary values of the assessed patient-related and prosthodontic-related variables, according to the study treatment groups: 1-IOD (n=16); 2-IOD (n=18)

Variables			Treatment groups		All patients	*P*-value
			1-IOD	2-IOD		
Patient-related factors	Maximum Bite Force (N)	Left	131.7 (81.1)	128.6 (56.1)	130.1 (68.0)	0.899 [a]
		Right	144.6 (71.7)	162.8 (62.3)	154.2 (66.5)	0.435 [a]
		Anterior	82.6 (52.9)	75.1 (31.7)	78.7 (42.5)	0.670 [b]
	Hand grip strength (KgF)	Left	26.4 (9.7)	27.1 (9.2)	26.8 (9.3)	0.845 [b]
		Right	26.4 (10.2)	26.6 (6.8)	26.5 (8.5)	0.606 [b]
	Dexterity	Left	81.2 (30.6)	69.4 (18.2)	75.1 (25.3)	0.345 [b]
		Right	68.2 (26.9)	59.8 (16.1)	63.9 (22.1)	0.488 [b]
	Chewing performance (VoH)		0.39 (0.12)	0.42 (0.13)	0.40 (0.12)	0.439 [a]
Prosthodontic-related factors	Cross-sectional area (mm^2)		117.0 (21.8)	121.3 (19.2)	119.4 (20.2)	0.552 [a]
	Volume (cm^3)		34.4 (5.4)	36.4 (8.5)	35.5 (7.2)	0.682 [b]
	Cervico-incisal height (mm)		12.6 (2.0)	12.6 (1.9)	12.6 (1.9)	0.999 [a]

[a] Independent *t*-test; [b] Mann-Whitney test

Table 2. Summary values of the assessed patient-related and prosthodontic-related variables, according to the case classification regarding the occurrence of overdenture fracture

Variables			Fracture		All patients	*P*-value
			Yes (n=16)	No (n=18)		
Patient-related factors	Sex	Female	15 (55.6)	12 (44.4)	16 (47.1)	0.090 [a]
		Male	1 (14.3)	6 (85.7)		
	Age (years)		61.3 (9.7)	66.2 (6.9)	64.0 (8.8)	0.090 [b]
	Maximum Bite Force (N)	Posterior	143.7 (64.1)	140.8 (65.5)	142.1 (63.9)	0.897 [b]
		Anterior	79.2 (37.2)	78.2 (47.8)	78.7 (7.3)	0.621 [c]
	Mean handgrip strength (KgF)		25.4 (6.1)	27.8 (10.5)	26.3 (1.5)	0.790 [c]
	Manual dexterity		66.4 (16.1)	72.4 (25.2)	69.5 (21.2)	0.422 [b]
	Chewing performance (VoH)		0.39 (0.12)	0.41 (0.13)	0.40 (0.12)	0.757 [b]
Prosthodontic-related factors	Number of implants	1-IOD	7 (43.8)	9 (56.3)	16 (47.1)	0.716 [c]
		2-IOD	9 (50.0)	9 (50.0)		
	Cross-sectional area (mm^2)		115.3 (20.5)	123.2 (19.8)	119.4 (20.2)	0.266 [b]
	Volume (cm^3)		35.4 (7.8)	35.5 (6.8)	35.5 (7.2)	0.790 [d]
	Cervico-incisal height (mm)		11.9 (2.0)	13.2 (1.7)	12.6 (2.0)	0.040 [b]

[a] Fisher's Exact test; [b] Independent t-test; [c] Chi-square test; [d] Mann-Whitney test.

patients rehabilitated with an overdenture compared to their baseline using conventional dentures[13–16]. Therefore, implant-retained overdentures, especially around the attachment area, appear to be more susceptible to crack propagation in the acrylic framework[17], which, under continued cyclic stress, can result in complete fracture over time. These factors, combined with other clinical factors, such as lack of balanced occlusion, high occlusal forces, poor retention and stability causing overdenture movement, prolonged use, and poor

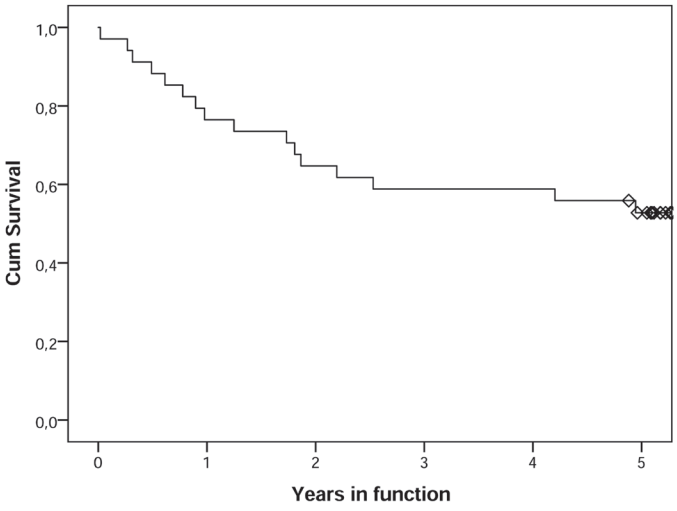

Fig. 3. Kaplan-Meier plot illustrating the cumulative incidence of fracture over time

fit due to residual ridge resorption and frenular attachment relief, among others[18,19], may directly influence the observed fractures and may be more relevant than the overall bite force.

Midline complete denture fracture after substantial clinical use represents a flexural fatigue failure resulting from cyclic deformation. Any factor that increases the deformation of the base may change the stress distribution and predispose the denture to fracture[20]. Therefore, it was hypothesized that a single midline mandibular overdenture is more prone to fracture[3], and that there is an increased risk of insufficient space to accommodate the body of the overdenture attachment height[21]. Moreover, in midline single-implant overdentures, the implant-abutment region may act as a fulcrum for overdenture rotation during function, and rotational movements are not limited to a single axis when occlusal forces are applied, as in 2-IOD, thereby increasing the risk of fracture in this area[3]. Nevertheless, clinical studies indicate that the incidence of overdenture fractures retained by one or two implants is similar and should be considered a common risk for all types of overdenture designs[2,22].

This study included factors that were not explored in similar studies on single- and two-implant overdentures[2,3]. The prospective nature of the investigation and the inclusion of potential risk factors related to patients and prosthetics are the strengths of this study. Additionally, although the use of 3D scanning to quantify prosthesis geometry may be considered a methodological strength, the prostheses analyzed in this study, as in previous studies were fabricated using conventional methods. Future studies using digital techniques to fabricate dentures may facilitate the control and assessment of prosthesis geometry, including acrylic resin bulk, space for artificial teeth, and the incorporation of retentive insert housing for attachments.

This study suggests that the thin denture base in the attachment due to a small cervico-incisal height, especially when the artificial teeth were placed on the buccal slope of the ridge, was the main factor in the F-group. This could also be associated with younger patients who are expected to have fewer resorbed ridges and less space for denture materials[23]. Although the hypothesis regarding reduced ridge resorption in younger individuals is plausible, it requires further support from specifically designed studies addressing this topic. Moreover, the identification of reduced cervico-incisal height as a fracture predictor depends on the threshold value for clinical inference. According to the data from this study, a height below 12 mm may be associated with an increased risk and could justify modifying the overdenture design, tooth arrangement, or metal reinforcement to improve the resistance to fracture.

A previous study reported a high prevalence of denture fractures resulting from tooth debonding, probably due to lesser ridge lap surface areas available for bonding, polymerization of acrylic resin, or wax remaining between the surface of artificial teeth and denture base acrylic resin[18] In addition to the small dimensions of the cervico-incisal area, there is also an attachment incorporated into the overdenture, which reduces the total volume of the acrylic resin in this area and reduces the overdenture resistance due to the intraoral pick-up technique using auto-polymerizing PMMA resin.

Our study documented manual dexterity did not significantly predict the risk of overdenture fracture. However, this finding does not eliminate the clinical importance of conditions that affect manual dexterity, especially in older patients or those with neurodegenerative diseases where motor decline compromises the safe handling of objects such as removable prostheses[24]. Accidental dropping of the prosthesis during activities such as cleaning and insertion was one of the most common causes of fractures, as observed in other studies[25,26]. This risk may be exacerbated by decreased visual acuity and sensorimotor impairment, which affect the ability to handle the prosthesis accurately and agilely, particularly in systems with complex retention mechanisms[24,27,28]. Although our participants did not include patients diagnosed with neurodegenerative diseases, these pathologies may have played a relevant role in fracture risk. Future investigations should explore specific interventions to reduce fracture risk in patients with motor and cognitive limitations while also improving the durability and functionality of prostheses, specifically among the geriatric age groups.

Despite its contribution, the study has limitations. As this was a prospective study, the time of fracture occurrence varied across patients, and data collection on the independent variables occurred five years after overdenture use. Therefore, overdentures may be submitted for relining, replacement, or repair of the fracture site, which can alter the contour of the overdenture and thus differ from the measurements at the time of the fracture and data collection. Another problem is the lack of standardization of laboratory procedures, as different techniques and defects in the denture during processing may also predispose the denture to fracture. In this study, fractured prostheses were repaired in the laboratory using either direct repair with a self-curing acrylic resin or a denture base with heat-cured processing, depending on the clinical aspect of the defect. Notably, this study has an exploratory character, serving as a secondary outcome to the previous RCT. This was prompted by the clinical observation of a high fracture incidence among patients in the long-term.

Analysis of longitudinal changes in oral function and other physical parameters would provide a valuable opportunity to investigate the functional changes associated with prosthetic fractures. However, the risk factors were assessed at the 5-year follow-up, and overdenture fractures may have occurred at any point during the

Table 3. Pooled within-groups correlation matrix

	Age	MBF – Posterior	MBF – Anterior	Chewing performance	Handgrip strength	Manual dexterity	Cross-sectional area	Cervico-incisal height
MBF – Posterior	-0.227							
MBF – Anterior	-0.231	0.602						
Chewing performance	0.314	-0.277	-0.085					
Handgrip strength	-0.514	0.611	0.631	-0.259				
Manual dexterity	0.306	-0.225	-0.060	0.200	-0.254			
Cross-sectional area	0.074	0.284	0.160	-0.082	0.239	0.058		
Cervico-incisal height	-0.006	-0.098	0.154	0.003	0.282	0.044	0.539	
Intercanine volume	0.111	0.257	0.004	-0.059	0.279	0.129	0.824	0.389

Table 4. Parameters of the linear discriminant function models

			Structure matrix	
Predictors		**Normalization**	**Model 1**	**Model 2 (Discriminant Coefficient*)**
Cervico-incisal height			0.406	0.758 (0.771)
Patient's age (years)			0.382	0.637 (0.652)
Cross-section dimension			0.191	
Handgrip strength		Log10	0.172	
Chewing performance			0.101	
MBF – Anterior		Log10	-0.074	
Manual dexterity		Log10	0.060	
MBF – Posterior			0.046	
Intercanine volume		Log10	-0.029	
Box's test			$P = 0.465$	$P = 0.337$
Significance of the model (Wilks' Lambda)			0.568; $P = 0.065$	0.795; $P = 0.032$
Canonical correlation			0.657	0.435
% of cases correctly classified	Overall		84.4%	69.7%
	Fracture		75.0%	62.5%
	No fracture		84.4%	76.5%

Model 1: All variables together, Model 2: Stepwise selection of variables (entry: $P < 0.05$; removal: $P > 0.10$, performed automatically by SPSS). * Standardized canonical discriminant function coefficient.

follow-up period. Therefore, exposure was not consistently evaluated throughout the study, and confounding factors could have been more challenging to control, increasing the risk of bias. This discrepancy limits the causal inference, particularly for prosthodontic dimensions that may have been altered by repair or relining, as stated previously. Additionally, participants' conditions may change throughout the follow-up period, which can limit the accuracy and reliability of the observed associations. For example, it was not feasible to assess functional status at the time of IOD fracture occurrence or to correlate trends in fracture risk with functional deterioration, if present, as a possible contributing factor. Future studies should incorporate this investigation into a more robust design.

Loss to follow-up is a significant challenge in medium- and long-term longitudinal studies. Approximately 30% of the participants in this study did not complete the 5-year assessment, which limits the sample size and introduces the potential for bias. Data were missing for various reasons, including difficulties in contacting participants, missed scheduled visits, loss to follow-up, and death. However, the losses were balanced between the 1-IOD and 2-IOD groups, which reduced the likelihood of systematic statistical bias due to incomplete data. This balance allowed us to conclude that the two treatment groups were comparable in terms of fracture occurrence.

Overdenture fractures pose a challenge to clinicians and remain a significant problem as reflected by the rising costs of prosthetic repair. The decision to exclude metal reinforcement in overdentures in this study was made to minimize intervention costs, considering that more than half of the participants did not experience fractures during the study and would not benefit from this approach. The findings of de Paula *et al.*[3] suggested that metal reinforcement is a more suitable repair strategy for recurrent fractures than universal prevention. Therefore, caution should be exercised in patients, including regular follow-up visits for the assessment of appropriate occlusal relationships and maintenance of adequate mucosal and implant support. Furthermore, studies on the use of metal reinforcement are needed to assess the comparative cost-effectiveness of this approach in reducing the incidence of fractures in the long term despite increased laboratory costs. Nevertheless, denture reinforcement materials may effectively enhance the strength and durability of dentures, prevent fractures, and improve longevity, particularly in the intercanine regions where stress is concentrated. Common

types of reinforcement include fiber reinforcement (e.g., glass fiber, carbon fiber, and aramid fiber), polyetheretherketone (PEEK), metal reinforcement (e.g., metal wires and meshes), and nanomaterials, and clinicians should decide on the most appropriate materials based on costs, preferences, and aesthetics. However, regardless of the reinforcement material used, regular cleaning and checkups are essential for denture longevity[29].

Although future studies exploring the effects of these protective measures may be needed to provide sound clinical guidelines for the prevention of overdenture fractures, clinicians and technicians may consider specific measures to modify the overdenture design and laboratory protocols during the treatment planning phase to enhance the resistance of overdentures to fractures. Therefore, specific and actionable recommendations for clinicians are available in literature. First, the selection of low-profile attachments, such as Locator systems, should be prioritized because they are designed to provide stability and retention for dentures while minimizing the space required between the denture and implant[30,31]. Second, there is a positive relationship between the acrylic resin thickness and fracture strength[32–34], and the thinnest acrylic resin areas, which are around the overdenture attachments, are assumed to be responsible for the higher fracture risk, owing to the biomechanical stresses focused on these areas[32,35]. Moreover, the selection of artificial teeth with lower cusps reduces the leverage effect of biting forces, prevents excessive stress on the denture base, and minimizes the risk of fracture. A well-balanced occlusion with reduced cuspal inclines and proper interocclusal space distributes forces more evenly, preventing localized stress concentrations that can lead to denture base failure[36].

Reinforcement may be necessary by overcontouring the overdenture in the attachment area, which might help minimize fractures in certain areas, such as the flange[34]. However, because fractures usually occur after repeated flexion of the denture base under small repetitive loads, which result in the development of microscopic cracks in areas of biomechanical stress concentration[34,37,38], a properly contoured denture with appropriate thickness and support is crucial for preventing fractures. This means that proper fitting of the overdenture to the supporting mucosa and distribution of occlusal forces are crucial for preventing fractures. Therefore, regular maintenance and adjustment of the overdenture, including replacement of worn parts and relining, are essential for avoiding fractures and ensuring proper function. Moreover, in cases of extremely limited vertical space, surgical interventions, such as alveoloplasty, may be necessary to improve space availability and create sufficient room for overdenture retention parts[39].

5. Conclusions

Based on the study findings, no significant differences were observed in the incidence of overdenture fractures between the groups (1-IOD and 2-IOD). A reduced cervico-incisal denture height in the attachment region of ball-retained IODs was a significant predictor of mandibular IOD fractures. However, these findings should be interpreted with caution, as there is a risk of false-positive inferences due to multiple testing and the potential for confounding factors that were not accounted for in this observational study. Further research with larger cohorts, experimental designs, and a broader inclusion of variables influencing the fracture rate are recommended to identify additional risk factors for unreinforced mandibular IODs.

Conflict of interest statement

The authors declare no conflicts of interest.

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