Average rate of ridge resorption in denture treatment: A Systematic Review

Nguyen Quan Pham, Tomoya Gonda, Yoshinobu Maeda, Kazunori Ikebe

Abstract

Purpose: To clarify the rate of posterior residual ridge resorption (PRRR) in different denture treatments and the factors that can affect PRRR. Study selection: A bibliographical electronic search was conducted on MeSH, Web of Science, and Ovid databases. Hand searching was also conducted. Longitudinal studies recording the average rate of PRRR in the mandible were included. The effect size was calculated based on the mean rate of PRRR with standard deviation and group size. The random-effects analysis was used to perform meta-analyses across qualified studies. Results: A total of 2245 eligible studies were collected from the MeSH, Web of Science, and Ovid databases and hand searching. In the end, 19 studies met the inclusion criteria and were extracted. The average rate of PRRR in different mandibular denture treatments was assessed in this systematic review. The mean combined effect size was -1.05 ± 0.5 (95% confidence interval [CI]: -3.18–1.08) between four-implant overdentures and two-implant overdentures. Body mass index, number of dentures used, denture wearing habit, impression technique, artificial tooth material, and peri-implant bone resorption showed no significant effect on the rate of PRRR. Gender, denture material, and relining frequency showed a significant effect on the rate of PRRR. Conclusions: This review summarized different average rates of PRRR in mandibular denture treatments. Meta-analyses have reported that four-implant overdenture treatments can lower the rate of PRRR compared to two-implant overdenture treatments. However, there was no significant difference in the treatment effect between the complete denture and two-implant overdenture treatments.

Keywords: Bone resorption, Complete denture, Removable partial denture, Dental implants, Meta-analysis

1. Introduction

Posterior residual ridge resorption (PRRR) is an inevitable consequence of tooth loss and long-term denture wearing. PRRR has been described as a "major oral disease entity", which is a chronic, progressive, irreversible, disabling disease, probably of multifactorial origin [1]. Severe PRRR in the mandible may lead to worsening of stability, retention, and support of a complete denture (CD) [1,2]. Implant overdenture (IOD) can improve function and comfort for patients and eliminate many problems with CDs [3]. However, this treatment option also results in continued bone resorption in the posterior region because of free overdenture rotation during function [4-7]. Other treatment options for edentulous or partially edentulous mandibles were a removable partial denture (RPD), a tooth-supported overdenture (TSO), and an implant-supported overdenture (ISO).

Nevertheless, most studies have focused only on peri-implant bone resorption. Few studies have focused on PRRR, and there is little information about the average rate of PRRR for different denture treatments. Furthermore, there have been no systematic reviews about the effect of denture treatment on PRRR and the factors that influence PRRR. Therefore, the aim of this systematic review was to collect and analyze all the available evidence to clarify the average rate of PRRR for different denture treatments, the effect of denture treatment on PRRR, and the factors that can affect PRRR. The research question was: “In the edentulous mandible, what is the average rate of PRRR for different denture treatments?”

2. Materials and Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [8,9].

2.1. Criteria for considering studies for this review

A population, intervention, and outcome (PIO) framework was used to guide the inclusion and exclusion of studies. Patients with partially or completely edentulous mandibular arches (population) were included. Mandibular denture treatments included RPD, CD, TSO, ISO, and IOD (Intervention). All studies were required to provide quantitative measurements of radiographic evidence that could be converted to an average rate of PRRR per year (Outcome). Studies were included in the meta-analysis if they met the following criteria: 1) including two different groups of denture treatments (CD vs. 2-IOD, 2-IOD vs. 4-IOD, or ISO vs. IOD, etc.); and 2) had a mean follow-up period of ≥12 months.

2.2. Search methods for identification of studies

A bibliographical electronic search was carried out on the MeSH, Web of Science, and Ovid databases, selecting all articles dealing with PRRR, from 1950 to 2019 (Appendices 1–3). The keywords used in the search include...
engines are listed in Table 1. A manual search limited to articles published between January 2000 and December 2019 was also performed. Table 1 summarizes peer-reviewed dental journals.

2.3. Data collection and analysis

2.3.1. Selection of studies
A parallel, double-blind screening procedure of all titles and abstracts retrieved by electronic and manual searches was carried out by two review authors. The inclusion and exclusion criteria are shown in Table 1. The screening process used to identify eligible studies is summarized in Figure 1. The selection of articles was based on title and abstract evaluations. Some articles were excluded after full-text reading due to a lack of relevance.

2.3.2. Data extraction and management
A data-extraction form was created to collect the following information: (1) title; (2) year of publication; (3) study design; (4) number of years of follow-up; (5) patient ages; (6) number of patients; (7) sex; (8) initial mandibular height; (9) number of years of edentulosity; (10) prosthesis type; (11) attachment type; (12) occlusion; (13) denture wearing habit; (14) relining frequency; (15) evaluation method of PRRR; (16) radiography; (17) average rate of PRRR per year, and (18) other factors affecting PRRR rate. A sensitivity analysis was performed at the level of data extraction.

2.3.3. Assessment of risk of bias in included studies
The quality of the studies was assessed using the risk of bias assessment tool outlined in the Cochrane Handbook for Systematic Reviews of Interventions (version 5.3.0). This tool comprises selection bias (random sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome data), attrition bias (incomplete outcome data), and reporting bias (selective reporting).

2.3.4. Types of outcomes
The primary outcome was the average rate of PRRR per year (unit: mm/year). This rate was calculated using a linear vertical resorption measurement (by panoramic or cephalometric radiography) [10,11] or posterior area index (PAI) [6,12,13].

Other information about patients and treatment outcomes and their association with the rate of PRRR was also extracted. The data were reported qualitatively because of the heterogeneity of the information provided.

2.3.5. Data synthesis and meta-analyses
Data were synthesized qualitatively based on the categories of outcomes established by the data extraction. The effect size was calculated based on the average rate of PRRR (with standard deviation, or SD) and group size. Analyses from the included studies were pooled to estimate the effect size, expressed as weighted mean differences and 95% confidence intervals (CIs). For studies with more than one eligible experimental group and only one control group, each experimental group was included as a separate comparison, and the sample size of the control group was divided evenly among the comparisons to avoid duplicate counting of participants.

2.3.6. Assessment of heterogeneity and publication bias
Heterogeneity across studies was characterized using Cochran-Q and I² statistical tests. Subgroup analyses and meta-regression analyses were performed to examine the cause of heterogeneity if the number of studies was large. Potential publication bias for the primary outcome variable was explored by funnel plots and a statistical test for heterogeneity if the number of studies was large (at least 30 studies).

2.3.7. Statistical analysis
A random-effects analysis was used to perform meta-analyses regardless of whether there was heterogeneity or not, even when the number of included studies was small. Statistical analyses were conducted using Excel workbooks and the user manual, which are licensed under Creative Commons Attribution–Non-Commercial–No Derivative License [14]. These tools were created by the Erasmus Research Institute of Management. The null hypothesis of this study was that all denture treatments had the same treatment effect on PRRR.

3. Result

3.1. Study selection
Figure 1 illustrates the flow diagram of the search results. The electronic search identified a total of 2240 citations, and the manual search identified 3 citations. After duplicates were removed (1766 papers), 441 papers were excluded after title and abstract screening. Next, the full texts of the remaining 36 articles were reviewed, and an additional 17 articles were excluded. Reasons for exclusion are presented in Appendices 4 and 5. Finally, 19 studies were eligible (Table 2).

3.2. Study characteristics
All 19 studies were non-randomized controlled trials (Table 2). The follow-up period ranged from 1 to 11 years (mean 6.5 ± 3.6 years), including 1-year follow-up [10,15,16], 5-year follow-up [6,11,12,17-19], 7-year follow-up [12,20], and more than 10-year follow-up [4,5,7,21-24]. The sources of funding were only reported in four studies [7,13,20,21]. Only seven studies mentioned bilateral balanced occlusion as the occlusal scheme [5,10,12,13,17,19,24]. For IOD treatment, a bar attachment was used in 11 studies [4,5,6,12,13,17,19,21,23,25], and a ball attachment was used in three studies [17,21,23]. For the radiographic method to identify the average rate of PRRR, PAI was used in 10 studies [4-7,12,13,17,20,23,25], and vertical linear resorption was used in nine studies [10,11,15,16,18,19,21,22,24]. Among studies using the vertical linear resorption measurement, cephalometric radiographs were used in six studies [11,15,18,19,22,24], panoramic radiographs were used in two studies [10,21], and panoramic computed tomography was used in one study [16]. The initial height ranged from 11.5 to 42.8 mm [4,5,9-13,15,17,19,20,22,23]. The number of years of edentulosity ranged from 2.2 to 23 years [4-7,12,13,17,20,22,24]. Only four studies mentioned the number of dentures worn (until the start of research), which ranged from 1.1 to 2.5 dentures [6,12,13,17]. Only two studies recorded the relining frequency, which ranged from 0 to 2 in 5 years [12,13]. The characteristics of the studies are presented in Table 2.

3.3. Quantitative analyses

3.3.1. Average rate of PRRR for different treatments
Among the 19 included studies, the mean rate of PRRR in patients using a CD was 0.5 ± 0.7 mm/year (range 0.01–2.4 mm/year) during a mean follow-up time of 5.8 ± 3.9 years (range 1–10 years) [5-7,10,11,15,16,18,22,24]. The average rate of PRRR in patients using a 2-IOD was 0.19 ± 0.15 mm/year (range 0.01–0.49 mm/year) during a follow-up time of 7.7 ± 3.3 years (range 1–11 years) [4-7,12,17,20,21,23,25]. The average rate of PRRR in patients using a 4-IOD was 0.08 ± 0.07 mm/year (range 0.01–0.15 mm/year) during a follow-up time of 8.3 ± 2.9 years (range 5–10 years) [4,5,17]. The average rate of PRRR in patients using a TSO was 0.13 ± 0.14 mm/year during a 5-year follow-up period [19]. In patients using an RPD, the average rate of PRRR was 0.03 ± 0.06 mm/year for an ISO and 0.21 ± 0.12 mm/year for an IOD during a 5-year follow-up period [17]. Figure 2 shows that PRRR followed a linear increase over time.

3.3.2. Results of meta-analysis and effects of interventions
Only six studies included two different groups of denture treatments: CD vs. 2-IOD (2 studies), 2-IOD vs. 4-IOD (2 studies), CD vs. 2-IOD vs. 4-IOD (1 study), and ISO vs. IOD (1 study) [4-7,13,17]. However, only five analyses were pooled to estimate the effect size and 95% CI [4-7,13]. With 2-IOD as the control group, two comparisons were made between 4-IOD and 2-IOD, and between CD and 2-IOD. Given that two experimental groups were examined in the study by Tymstra et al. [7], the
Table 1. Systematic search strategy.

<table>
<thead>
<tr>
<th>Focus question</th>
<th>What is the average rate of posterior residual ridge resorption in different prosthesis types?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>Population: #1—(edentulous patient OR partial edentulous) AND (mandib*)</td>
</tr>
<tr>
<td>Intervention</td>
<td>Intervention: #2—implant OR overdenture OR denture OR implant overdenture OR partial denture OR tooth-supported denture OR implant-supported overdenture</td>
</tr>
<tr>
<td>Search strategy</td>
<td>Outcome: #3—posterior residual ridge resorption OR residual ridge resorption OR ridge resorption OR ridge resorption rate OR average ridge resorption OR ridge preserving OR ridge preservation OR posterior area index</td>
</tr>
<tr>
<td>Search combination</td>
<td>#1 AND (#2 OR #3)</td>
</tr>
</tbody>
</table>

Database search
- Electronic search: MeSH, Web of Science, and Ovid databases, selecting all articles from 1950 to 2019

Selection criteria
- Inclusion criteria: Human clinical studies, full-text articles written in English, designed as longitudinal studies, recorded average rate of PRRR
- Exclusion criteria: Only abstract available, related to abnormal conditions as systematic diseases, maxillofacial abnormality; mentioned reported only ridge preservation, ridge apposition or improving bone density through the remodeling process in posterior region; related to only peri-implant bone resorption

Fig. 1. Flowchart of the search strategy, according to the PRISMA guidelines.
Table 2. Studies included in the present systematic review.

<table>
<thead>
<tr>
<th>No.</th>
<th>Author</th>
<th>Year</th>
<th>Groups</th>
<th>Treatment</th>
<th>Patients (Male/Female)</th>
<th>Mean age</th>
<th>Ridge resorption rate/year</th>
<th>No. of years of follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Babu BD et al.</td>
<td>2017</td>
<td>Experiment 1, Experiment 2</td>
<td>All CDs:† Soft liner</td>
<td>14 (7/7), 14 (7/7)</td>
<td>54</td>
<td>0.8 ± 0.08 mm/year</td>
<td>1 year</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Heat cured acrylic resin</td>
<td></td>
<td>55</td>
<td>1.6 ± 0.1 mm/year</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Badr AMI et al.</td>
<td>2017</td>
<td>Experiment 1, Experiment 2, Experiment 3</td>
<td>All IODs:‡ resilient bar, semi-resilient rigid bar</td>
<td>6 (6/0), 6 (6/0), 6 (6/0)</td>
<td>66</td>
<td>0.49 ± 0.12 mm/year, 0.39 ± 0.13 mm/year, 0.36 ± 0.16 mm/year</td>
<td>1 year</td>
</tr>
<tr>
<td>3</td>
<td>Carlsson G et al.</td>
<td>1967</td>
<td>Experiment 1, Experiment 2</td>
<td>All CDs: Immediate vs conventional</td>
<td>14 (5/9), 16 (9/7)</td>
<td>NMA</td>
<td>2.1 ± 2.6 mm/year, 2.4 ± 2.3 mm/year</td>
<td>5 years</td>
</tr>
<tr>
<td>4</td>
<td>de Jong MH et al.</td>
<td>2010</td>
<td>Experiment 1, Experiment 2, Experiment 3</td>
<td>2-IOD, 4-IOD</td>
<td>23 (5/18), 18 (6/12), 16 (16/0)</td>
<td>76.5</td>
<td>0.14 ± 0.1 mm/year, 0.07 ± 0.09 mm/year, 0.03 ± 0.06 mm/year</td>
<td>10 years</td>
</tr>
<tr>
<td>5</td>
<td>Ely$yad MA et al.</td>
<td>2011</td>
<td>Experiment 1, Experiment 2</td>
<td>2-IOD, ISO§</td>
<td>16 (18/0), 10 (7/3)</td>
<td>49.0</td>
<td>0.35 ± 0.09 mm/year</td>
<td>5 years</td>
</tr>
<tr>
<td>6</td>
<td>Ely$yad MA et al.</td>
<td>2017</td>
<td>Experiment 1, Experiment 2</td>
<td>All 2-IODs Bar + clip, Bar + resilient liner</td>
<td>9 (9/0), 9 (9/0)</td>
<td>NM</td>
<td>0.11 ± 0.08 mm/year, 0.2 ± 0.26 mm/year</td>
<td>7 years</td>
</tr>
<tr>
<td>7</td>
<td>Jacob R et al.</td>
<td>1992</td>
<td>Experiment 1, Experiment 2, Experiment 3</td>
<td>2-IODs, 4-6 fixed prosthesis, CDs</td>
<td>30 (9/21), 25 (6/19), 85 (16/69)</td>
<td>53</td>
<td>0.14 ± 0.14 mm/year, 0.04 ± 0.06 mm/year, 0.1 ± 0.19 mm/year</td>
<td>10 years</td>
</tr>
<tr>
<td>8</td>
<td>Kordatzis K et al.</td>
<td>2003</td>
<td>Experiment 1, Experiment 2</td>
<td>2-IODs, CDs</td>
<td>39 (13/26), 34 (16/18)</td>
<td>54.2</td>
<td>0.14 ± 0.44 mm/year</td>
<td>5 years</td>
</tr>
<tr>
<td>9</td>
<td>Kovačić I et al.</td>
<td>2010</td>
<td>One group</td>
<td>CDs</td>
<td>31 (13/18)</td>
<td>52.5</td>
<td>0.22 ± 0.2 mm/year</td>
<td>5 years</td>
</tr>
<tr>
<td>10</td>
<td>Kovačić I et al.</td>
<td>2003</td>
<td>One group</td>
<td>CDs with 3 period of edentulousness</td>
<td>50 (19/31)</td>
<td>53</td>
<td>Less than 1 year, 0.73 mm/year, 1 – 10 years, 0.49 mm/year, More than 10 years, 0.19 mm/year</td>
<td>1 year</td>
</tr>
<tr>
<td>11</td>
<td>Kremer U et al.</td>
<td>2016</td>
<td>One group</td>
<td>IOD with different sites</td>
<td>60 (15/45)</td>
<td>54</td>
<td>0.06 ± 0.13 mm/year at chewing site, 0.17 ± 0.17 mm/year at distal edge</td>
<td>11 years</td>
</tr>
<tr>
<td>12</td>
<td>Mercier P et al.</td>
<td>2002</td>
<td>Experiment 1, Experiment 2</td>
<td>Porcelain, Acrylic resin</td>
<td>69 (16/53), 40 (10/30)</td>
<td>66</td>
<td>0.17 ± 0.18 mm/year, 0.17 ± 0.19 mm/year</td>
<td>10 years</td>
</tr>
<tr>
<td>13</td>
<td>Mosnegutu A et al.</td>
<td>2015</td>
<td>One group</td>
<td>IOD: before and after treatment</td>
<td>82</td>
<td>NM</td>
<td>0.05 ± 0.1 mm/year</td>
<td>1 0  .  5 years</td>
</tr>
<tr>
<td>14</td>
<td>Tripathi A et al.</td>
<td>2019</td>
<td>Experiment 1, Experiment 2</td>
<td>Selective impression Mucostatic impression</td>
<td>18 (18/0), 18 (18/0)</td>
<td>76.5</td>
<td>0.21 mm/year, 0.3 mm/year</td>
<td>1 year</td>
</tr>
<tr>
<td>15</td>
<td>Tuncay OC et al.</td>
<td>1984</td>
<td>One group</td>
<td>CD</td>
<td>37 (17/20), 61 (28/33)</td>
<td>49.0</td>
<td>0.11 ± 0.22 mm/year</td>
<td>10 years</td>
</tr>
<tr>
<td>16</td>
<td>Tymstra N et al.</td>
<td>2011</td>
<td>Experiment 1, Experiment 2, Experiment 3</td>
<td>2 IOD, 4 IOD</td>
<td>16 (3/13), 14 (4/10), 15 (5/12)</td>
<td>58.0</td>
<td>0.01 ± 0.01 mm/year, 0.01 ± 0.01 mm/year, 0.01 ± 0.01 mm/year</td>
<td>10 years</td>
</tr>
<tr>
<td>17</td>
<td>Üçtaşli S et al.</td>
<td>1997</td>
<td>One group</td>
<td>TS0#: before/after treatment</td>
<td>10 (7/3)</td>
<td>NM</td>
<td>0.13 ± 0.14 mm/year</td>
<td>5 years</td>
</tr>
<tr>
<td>18</td>
<td>Wright PS et al.</td>
<td>2002</td>
<td>Experiment 1, Experiment 2</td>
<td>2 IOD, 5-6 fixed prosthesis</td>
<td>21 (1/20), 23 (3/16)</td>
<td>53</td>
<td>0.1 ± 0.14 mm/year, 0.1 ± 0.13 mm/year</td>
<td>7 years</td>
</tr>
</tbody>
</table>

†CD: Complete denture; ‡IOD: Implant overdenture; §RPD: Removable partial denture; ¶ISO: Implant supported overdenture; #TSO: Tooth-supported overdenture; ΔNM: Not mentioned.
sample size of the control group was divided to avoid duplicate counting of the participants.

3.3.2.1. Comparison between 4-IOD and 2-IOD

A meta-analysis of the average rate of PRRR was performed in three studies [4,5,13]. In total, 83 patients participated in two groups: 4-IOD (42 patients) and 2-IOD (41 patients). A forest plot of the meta-analysis is illustrated in Figure 3A. The combined effect size was $-1.05 \pm 0.5$ (95% CI: $-3.18$–1.08), with $p = 0.02$, heterogeneity $I^2 = 68.32\%$, and $\tau = 0.28$. 4-IOD treatment led to a lower rate of PRRR compared with 2-IOD treatment.

3.3.2.2. Comparison between CD and 2-IOD

A meta-analysis of the average rate of PRRR was performed in three studies [5–7]. In total, 211 patients participated in two groups: CD (134 patients) and 2-IOD (77 patients). A forest plot of the meta-analysis is illustrated in Figure 3B. The combined effect size was $-0.01 \pm 0.22$ (95% CI: $-0.93$–0.82) with $p = 0.49$, heterogeneity $I^2 = 50.82\%$, and $\tau = 0.28$. There was no significant difference in the treatment effect between the CD and 2-IOD groups.

Subgroup and meta-regression analyses were not performed because of the small number of studies (3 studies for each analysis). Potential publication bias was also not performed because of the small number of studies (only five studies).

3.3.2.3. Comparison between ISO vs. IOD

In partially edentulous mandibles, ISO was associated with a reduced rate of PRRR compared with IOD ($0.03 \pm 0.06$ mm/year and $0.21 \pm 0.12$ mm/year, respectively) [17].

3.3.2.4. Risk of bias assessment

Most of the included studies had a high risk of bias, selection bias in particular because all of the included studies were non-randomized controlled trials, and the method of concealment was not described. The method of blinding participants and personnel was double blinding in two studies [4,13], and three other studies showed a high risk of performance bias. For detection bias, self-report outcomes were not examined in all studies. Since the average rate of PRRR was evaluated by two examiners (blinded), this bias was judged as low risk in all studies. A low drop-out bias was judged as a low risk in all studies. Since the average rate of PRRR was evaluated by two examiners (blinded), this bias was judged as low risk in all studies. A low drop-out bias was judged as a low risk in all studies. Since the average rate of PRRR was evaluated by two examiners (blinded), this bias was judged as low risk in all studies. A low drop-out bias was judged as a low risk in all studies. Since the average rate of PRRR was evaluated by two examiners (blinded), this bias was judged as low risk in all studies.

3.3.3. Confounding factors for PRRR

Other factors influencing PRRR were also summarized, including patient characteristics and prosthetic-related characteristics (Table 2).
Fig. 2. Changes in posterior residual ridge resorption over time (expected linear increase over time).

<table>
<thead>
<tr>
<th>Author(s) &amp; year</th>
<th>4-IOD</th>
<th>2-IOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>de Jong MH 2010</td>
<td>18</td>
<td>23</td>
</tr>
<tr>
<td>Elsyad MA 2017</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Tymstra N 2011 (2)</td>
<td>14</td>
<td>8</td>
</tr>
</tbody>
</table>

**Combined Effect Size**

\[-1.05 \pm 0.5\]  
\[(\text{-3.18} - \text{1.08})\]

Heterogeneity: \(I^2 = 68.32\%\); \(\tau = 0.64\)
Test for overall effect: \(Z = -2.13\); \(p=0.017\)

A. A comparison between 4-IOD and 2-IOD.

<table>
<thead>
<tr>
<th>Author(s) &amp; year</th>
<th>CD</th>
<th>2-IOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jacob R 1992</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td>Kordatzis K 2003</td>
<td>34</td>
<td>39</td>
</tr>
<tr>
<td>Tymstra N 2011 (1)</td>
<td>15</td>
<td>8</td>
</tr>
</tbody>
</table>

**Combined Effect Size**

\[-0.01 \pm 0.22\]  
\[(\text{-0.93} - \text{0.92})\]

Heterogeneity: \(I^2 = 59.82\%\); \(\tau = 0.28\)
Test for overall effect: \(Z = -0.04\); \(p=0.485\)

B. A comparison between CD and 2-IOD.

Fig. 3. Forest plot based on meta-analysis evaluating rate of PRRR for different denture treatments.
3.3.3.1 Patients’ characteristics

3.3.3.1.1 Age
Age failed to show a significant effect on PRRR in three studies [4,6,7], but other studies showed that age was significantly correlated with changes in the posterior area [13,20].

3.3.3.1.2 Sex
Sex failed to show a significant effect on PRRR [4,18,21,22,24], but female sex was a risk factor for greater resorption [6,7,20]. A male patient was likely to lose 7.5% less bone (0.9 mm in 5 years) than a female patient [6].

3.3.3.1.3 Body mass index
BMI had no significant influence on the rate of PRRR [15,18].

3.3.3.1.4 Years of edentulousness
Most studies showed that this factor failed to significantly affect PRRR [4,6,15,18,24]. However, two studies found that PRRR was significantly affected by the number of years of edentulousness [20,22].

3.3.3.1.5 Initial mandibular height
This factor failed to show a significant effect on PRRR in three studies [4,6,22]. Conversely, initial mandibular height was correlated with PRRR in four studies [12,13,16,20].

3.3.3.2 Prosthetic related characteristics

3.3.3.2.1 Number of dentures used.
This factor failed to show a relationship with the rate of PRRR [6,12,13].

3.3.3.2.2 Denture wearing habit
No significant difference was found between patients who had been wearing dentures by day or night and those who had been wearing dentures only by day [18,24].

3.3.3.2.3 Impression technique
No significant differences in the rate of PRRR were found between the two techniques (mucostatic impression and selective pressure impression) [16].

3.3.3.2.4 Denture material
The use of a soft denture liner significantly reduced the rate of PRRR compared with the use of a denture without a denture liner (0.8 ± 0.1 mm/year and 1.6 ± 0.1 mm/year, respectively) [10].

3.3.3.2.5 Artificial tooth material
Tooth material did not play a significant role in PRRR [22].

3.3.3.2.6 Attachment type
The type and shape of the bar-clip connection did not significantly affect the rate of PRRR over a 1-year follow-up period [21,25]. Nevertheless, a resilient liner for bar attachments was associated with greater PRRR.
compared with clip attachments [12].

3.3.3.2.7. Relining frequency
This factor was associated with the rate of PRRR [12,17]. For each instance of relining, a 3.9% reduction in PRRR was noted.

3.3.3.2.8. Peri-implant bone resorption
No correlation was found between PRRR and peri-implant marginal bone loss in 2-IODs using a bar attachment [4].

4. Discussion

4.1. Summary of main results
This systematic review assessed different average rates of PRRR for different mandibular denture treatments. Meta-analyses showed that the 4-IOD treatment led to a lower rate of PRRR compared with the 2-IOD treatment. Conversely, there was no significant difference in the treatment effect between the CD and 2-IOD treatments. All included studies reported that BMI, number of dentures used, denture wearing habit, impression technique, artificial tooth material, and peri-implant bone resorption showed no significant effect on the rate of PRRR; and sex, denture material, and relining frequency significantly affected the rate of PRRR.

4.2. Overall completeness and applicability of evidence
The literature comparing the rate of PRRR between different denture treatments was scarce (only six studies). Between the 4-IOD and 2-IOD treatments, it was calculated that a combined effect size of 1.05, which can be said that “If one’s getting this treatment, the average patient will score 1.05 standard deviations above patients who do not get the treatment,” which makes it difficult to explain the clinical relevance to patients and clinicians when using the effect size. In a meta-analysis, the solution is to convert the effect size to numbers-needed-to-be-treated (NNT) according to the method proposed by Kraemer et al. [26]. The NNT indicates the number of patients that must be treated in order to generate one additional positive outcome. Between the 4-IOD and 2-IOD treatments, the combined effect size of 1.05 was equivalent to an NNT of 1.85. This indicates the number of patients who have to be treated (1.85 or about 2 patients) to generate one additional positive outcome (one patient with less PRRR on average). It can be inferred that to reduce 1 case with PRRR, 2 patients needed to be treated with 4-IOD. The effect size and SD of individual studies and the combined effect size mostly deviated to the left side, which indicates that the 4-IOD treatment was preferable to the 2-IOD treatment (Fig. 3A).

Conversely, the rate of PRRR was not associated with whether the subject was using a 2-IOD or a CD [5]. The NNT for this comparison was 166.67, with a combined effect size of 0.01. Two studies showed a left deviation in the effect size (favoring CD) [5,7], while one study showed a deviation in the opposite direction (favoring 2-IOD) [7]. Nevertheless, the SD bars covered the zero vertical line, which indicates that the intervention was not effective (Fig. 3B). Both forest plots showed that there were no outliers.

4.3. Quality of the evidence
Given that no randomized clinical trials investigating PRRR were found, all the included studies were non-randomized clinical trials, and only 6/19 studies included a control group. Comparisons of the treatment effects also varied widely, including denture type, denture material, attachment type, and artificial tooth material. Furthermore, different clinicians evaluated PRRR with different radiographic methods (PAI or linear vertical resorption) and different radiography modalities (panoramic and cephalometric), resulting in further heterogeneity between the studies. Both radiographic methods comprised approximately equal percentages (52.63% for PAI and 47.37% for vertical linear resorption). However, the points of measurement were unstandardized in the linear vertical resorption method (3 to 5 points), and the type of radiography (cephalometric, panoramic, or computed tomography) also differed in various studies. Conversely, PAI seemed to be more common and standard in determining the rate of PRRR (10/19 studies), and all studies included in the meta-analysis used this method. Although the PAI method could not assess specific changes in height at measurement points as illustrated in the linear vertical resorption method, it can be inferred that measurement of average bone resorption along the ridge in the PAI method was more crucial and significant for clinical decisions, such as denture relining.

Due to the heterogeneity of the studies, only five studies were eligible for the meta-analysis. These studies showed a high risk of selection bias and attrition bias because only non-randomized clinical trials were found. Moreover, studies with a low risk of performance bias and attrition bias accounted for 40% (2 out of 5) of all studies. This is because the treatment options depended on specific clinical situations and patient satisfaction, and a high drop-out rate was recorded as a result of the long-term follow-up (1–11 years). Nevertheless, all studies registered a low risk of detection and reporting bias, with clear assessments of outcomes and confounding factors, which was the main objective of this systematic review.

Finally, because English was the only language chosen, there was also the possibility of language bias. Therefore, other languages (German or Japanese, ...) should be included in the systematic review to create an objective overview of this problem.

4.4. Limitations and implications for research and practice
This review provides further information about changes in the posterior region of the mandible with different denture treatments, especially in three common denture types: CDs, 2-IODs, and 4-IODs. Although the meta-analyses showed that the 4-IOD treatment could lower the rate of PRRR compared with the 2-IOD treatment and that the treatment effect was almost the same between the 2-IOD and CD treatments, the number of included studies was still small, and the study design showed a high risk of bias. This constitutes a major limitation of this review. Nevertheless, our results provide an overview of the radiographic techniques used for calculating the rate of PRRR with their pros and cons as well as the factors affecting the rate of PRRR. This will also help clinicians to choose an appropriate method to investigate PRRR and to consider factors associated with PRRR during clinical practice and research.

5. Conclusion
This review assessed the average rates of PRRR for different mandibular denture treatments. Meta-analyses revealed that the 4-IOD treatment could lower the rate of PRRR compared with the 2-IOD treatment. However, there was no significant difference in the rate of treatment effect between the CD and 2-IOD treatments. BMI, number of dentures used, denture wearing habit, impression technique, artificial tooth material, and peri-implant bone resorption exerted no significant effect on the rate of PRRR. Sex, denture material, and relining frequency significantly affected the rate of PRRR.

Conflict of Interest
Pham Nguyen Quan, Tomoya Gonda, Yoshinobu Maeda, and Kazunori Ikebe declare that they have no competing interests.

Author contributions
PNQ and TG contributed to conception, design, data acquisition and interpretation, performed all statistical analyses, drafted the manuscript, and critically revised the manuscript. YM and KI contributed to conception, participated in the design and coordination, helped to draft the manuscript, and critically revised the manuscript. All authors gave their final approval to the manuscript and agree to be accountable for all aspects of work.
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