Background: Platform switching for maintaining peri-implant bone levels has gained popularity among implant manufacturers over the last few years. However, the assumption that the inward shifting of the implant-abutment junction may preserve crestal bone was primarily based on serendipitous finding rather than scientific evidence. The objectives of the present study were to systematically review radiographic marginal bone-level changes and the survival of platform-switched implants compared to conventional platform-matched implants.

Methods: A literature search of electronic databases (MEDLINE, EMBASE, The Cochrane Oral Health Group’s Trials Register, The Cochrane Central Register of Controlled Trials, the U.K. National Research Register, the Australian New Zealand Clinical Trials Registry, the Database of Abstracts of Reviews of Effectiveness, and Conference Proceedings Citation Index) was performed up to March 15, 2010. Hand searches included several dental journals, and authors were contacted for missing information. Controlled trials that compared marginal bone-level changes around platform-switched dental implants with those restored with platform-matched prostheses were selected. The review and meta-analysis were done according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement. Data were analyzed using two meta-analytic statistical packages. Mean differences (MDs) were calculated for analyzing continuous data, and risk ratios (RRs) were used for dichotomous data with 95% confidence intervals (CIs).

Results: Ten studies with 1,239 implants were included. The marginal bone loss around platform-switched implants was significantly less than around platform-matched implants (MD: -0.37; 95% CI: -0.55 to -0.20; P < 0.0001). No statistically significant difference was detected for implant failures between the two groups (RR: 0.93; 95% CI: 0.34 to 2.95; P = 0.89). Subgroup analyses showed that an implant-abutment diameter difference ≥0.4 was associated with a more favorable bone response.

Conclusions: The review and meta-analysis show that platform switching may preserve interimplant bone height and soft tissue levels. The degree of marginal bone resorption is inversely related to the extent of the implant-abutment mismatch. Further long-term, well-conducted, randomized controlled studies are needed to confirm the validity of this concept. J Periodontol 2010;81:1350-1366.

KEY WORDS
Alveolar bone loss; dental implants; meta-analysis; review.

The peri-implant bone level has been used as one of the criteria to assess the success of dental implants.1-5 It is an important prerequisite for preserving the integrity of gingival margins and interdental papillae.7,8 Traditionally, a radiographic marginal bone loss of 1.5 mm during the first year followed by a radiographic marginal bone loss of ≤0.2 mm during each succeeding year is an important parameter for the assessment of implant success.2 The peri-implant bone remodeling occurs once the implant is exposed to the oral environment in a second surgical procedure or when the abutment is placed immediately after implant placement. The remodeling process involves marginal bone resorption that is affected by one or more of the following factors: 1) a traumatic surgical technique;9 2) excessive loading conditions;10 3) the location, shape, and size of the implant-abutment microgap and its microbial contamination;11-13 4) the biologic width and soft tissue considerations;14,15 5) a peri-implant inflammatory
infiltrate;\textsuperscript{16} 6) micromovements of the implant and prosthetic components;\textsuperscript{11,17} 7) repeated screwing and unscrewing;\textsuperscript{18} 8) the implant-neck geometry;\textsuperscript{19} and 9) the infectious process.\textsuperscript{20}

In the late 1980s, wide-diameter implants were commercially introduced. Initially, the implants were restored with standard-diameter abutments because of the lack of matching prosthetic components. Contrary to what was expected, post-loading radiographic evaluations showed no changes in the crestal bone levels around those implants. This serendipitous finding led to the introduction of the concept of platform switching, in which a smaller-diameter prosthetic component was connected to a larger-diameter implant platform to create an \( \sim 90^\circ \) step between the implant and abutment.\textsuperscript{21-23} Several clinical reports\textsuperscript{24-27} demonstrated more favorable soft and hard tissue responses using implants placed with platform switching compared to standard platform-matched implants. Consequently, an increasing number of implant systems incorporated platform switching into their designs as an innovative feature for preserving the peri-implant bone.

Although the concept of platform switching is a relatively new one in the implant market, implants were restored with mismatched prosthetic components for more than a decade. In fact, a long-term prospective study\textsuperscript{28} with a follow-up period of 11 to 14 years was recently published. The article\textsuperscript{28} did not include a control group but confirmed the advantageous features of platform-switched implants in preserving crestal bone levels. In addition, the use of platform-switched implants was suggested in anatomic sites where the recommended minimum distances between implants and adjacent units cannot be achieved.\textsuperscript{29} In a prospective study,\textsuperscript{30} 41 pairs of platform-switched implants were placed at \(< 3\) mm of interimplant distance. The radiographic evaluation showed that a platform-switched implant design can reduce the vertical and horizontal components of bone loss and may be used in atrophic sites.\textsuperscript{30}

However, the concept of platform switching was not fully understood, and several theories were suggested to explain this phenomenon. The biomechanical theory proposed that connecting the implant to a smaller-diameter abutment may limit bone resorption by shifting the stress-concentration zone away from the crestal bone–implant interface and directing the forces of occlusal loading along the axis of the implant.\textsuperscript{31} One theory\textsuperscript{23} assumed that shifting the implant-abutment connection may medialize the location of the biologic width and minimize the marginal bone resorption. This theory was based on previous studies\textsuperscript{32,33} that showed that placing the implant-abutment junction (IAJ) at or below the crestal bone level may cause vertical bone resorption to reestablish the biologic width. Another theory concerned the role of the inflammatory cell infiltrate at the IAJ. Ericsson et al.\textsuperscript{13} showed that the bone resorption at the IAJ was caused by an inflammatory cell infiltrate that formed a 1.5-mm semispherical zone around the IAJ. The presence of the peri-implant microbiota was suggested to influence the crestal bone resorption by maintaining the inflammatory cell infiltrate within the IAJ.\textsuperscript{16,34} However, the relationship between the composition of microorganisms at the IAJ and marginal bone resorption was recently questioned.\textsuperscript{35} Regardless of the nature of the peri-implant inflammatory infiltrate, the physical repositioning of the IAJ away from the external outer edge of the implant and neighboring bone may limit bone resorption by containing the inflammatory cell infiltrate within the angle formed at the interface away from the adjacent crestal bone.\textsuperscript{23}

In addition to the clinical studies,\textsuperscript{24-28,34} the concept of platform switching was extensively studied histologically and biomechanically. In histomorphometric studies in dogs,\textsuperscript{36,37} there was no significant difference in the marginal bone level around platform-switched and -matched implants after 28 days of healing. In contrast, other studies\textsuperscript{38-40} reported a significantly less bone loss around platform-switched implants after a loading period of 2 to 6 months. Moreover, the biomechanical advantages of internally connected, platform-switched implants were proposed because of the inward shifting of the stress concentration.\textsuperscript{31,41} Conversely, Canay and Akça\textsuperscript{42} and Schrotenboer et al.\textsuperscript{43} showed that the horizontal shifting of the implant-abutment connection did not significantly alter the stress generated at the marginal bone around the implants.

The choice to use a platform-switched or -matched implant design is currently not guided by evidence-based protocols and is mainly influenced by manufacturers’ recommendations. Hence, the aims of this systematic review and meta-analysis examine whether there is a difference in the marginal bone level changes around dental implants restored with either narrower or matched prostheses (platform-switched versus platform-matched prostheses) and evaluates the effect of platform-switching on implant survival.

**MATERIALS AND METHODS**

The current systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement\textsuperscript{44} and the Cochrane Collaboration recommendations.\textsuperscript{45} The four Population, Intervention, Comparison, and Outcome (PICO) elements\textsuperscript{46} were used to summarize the objectives and inclusion criteria into a well-defined formulated question: In patients
who receive implant treatment, does the use of platform-switched implants compared to platform-matched implants result in more favorable marginal bone level changes (primary outcome) and lower implant failure rate (secondary outcome)?

Selection Criteria
Eligible studies were included in the meta-analysis if they met the following criteria: 1) published in English; 2) human study population; 3) were randomized controlled trials (RCTs) or controlled clinical trials (CCTs) with two treatment groups, with one related to the use of platform-switched implants and the other related to the use of conventional platform-matched implants; 4) had ≥10 implants in the platform-switched group; and 5) had a mean follow-up period ≥12 months.

In the presence of duplicate publications, only the study with the most inclusive data was selected.

Search Sources and Strategy
A systematic electronic searching was performed in the following databases:

1. MEDLINE (1969 to March 15, 2010).
2. EMBASE (1980 to March 15, 2010).
3. The Cochrane Oral Health Group’s Trials Register (up to March 15, 2010).
4. The Cochrane Central Register of Controlled Trials (up to March 15, 2010).
5. U.K. National Research Register (up to March 15, 2010).
6. Australian New Zealand Clinical Trials Registry (up to March 15, 2010).
7. Database of Abstracts of Reviews of Effectiveness (up to March 15, 2010).
8. Conference Proceedings Citation Index (up to March 15, 2010).

The following search format was performed using Boolean operators: (“platform-switching” OR “platform-switched implant”) AND (“platform-matched implant” OR “non-platform switched implant”) AND (“immediate placement” OR “delayed placement”) AND (“immediate loading” OR “immediate restoration”) AND (“dental implant” OR “oral implant”) AND (“marginal bone level” OR “crestal bone level”) AND (“success rate” OR “survival rate”).


The bibliographies of all selected articles were further scanned for potentially relevant articles. In cases of missing or insufficient data, clarification was sought from corresponding authors.

Data Collection
A data-extraction form was developed and used by each author (MAA, HMI, and AHA) to collect the following study information: 1) title; 2) year of publication; 3) site and number of implants; 4) implant design and system; 5) implant length and diameter; 6) implant-placement protocol; 7) use of regenerative procedures; 8) time of placement of definitive crown; 9) difference between implant and abutment diameters in the platform-switched implant group; 10) marginal bone level changes; 11) implant survival rate of each treatment group; and 12) follow-up period.

Quality Assessment
The methodologic quality assessment was based on the Jadad quality scale (Appendix 1); the scale assigns a score ranging from 0 to 5 points, with a score of ≥3 indicating a higher study quality. In addition, the Cochrane scale for assessment of allocation was also used to evaluate the validity of the included studies (Appendix 2).

Data Synthesis
Meta-analyses were carried out using two statistical software programs. The first program was used to pool the data and produce the forest plots, whereas the second program was used to assess the publication bias. We planned to test the significance of treatment effects by using a fixed-effects model in the absence of a statistically significant heterogeneity and a random-effects model in the case of substantial heterogeneity among the trials. Heterogeneity was assessed using the χ²-based Q-statistic method and I² measurement. A significant heterogeneity was indicated by P<0.1 because of the moderate insensitivity of the Q statistic. The value of I² ranged from 0 to 100, with larger values (≥75%) suggesting high heterogeneity.

For continuous-data elements such as marginal bone changes, the mean difference (MD) and 95% confidence interval (CI) were calculated. For dichotomous data, such as the implant-failure rate, a risk ratio (RR) with the 95% CI was used to pool the results of each treatment group. The pooled effect was considered significant if P was <0.05. The possibility of publication

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§ RevMan software, version 5.0. The Nordic Cochrane Center, The Cochrane Collaboration, Copenhagen, Denmark.
|| Comprehensive Meta-Analysis software, version 2.2, Biostat, Englewood, NJ.
bias was visually detected using a funnel plot \(^5^1\) and quantitatively using the regression asymmetry test \(^3^2\) and the trim-and-fill method \(^5^3\). In addition, the sensitivity and subgroup analyses were planned to identify any potential causes of heterogeneity.

**RESULTS**

The initial electronic literature search identified 146 titles (Fig. 1). The hand search did not provide any additional studies. The review of the abstracts and key words resulted in 43 studies. After full-text evaluation, 26 studies were excluded because they failed to meet the inclusion criteria. The remaining 17 studies and one conference paper were further analyzed in depth for potential inclusion in the review. Eight studies were excluded from the review for the following reasons: four studies did not include a control group, \(^2^6\), \(^5^4\), \(^5^5\), \(^5^6\) two studies used a finite element model, \(^3^1\), \(^4^2\) one study had an observation period of 6 months, \(^2^4\) and one study was a duplicate \(^5^7\) of another published report. \(^5^8\) Thus, a total of 10 studies \(^2^5\), \(^2^7\), \(^3^4\), \(^5^8\)-\(^6^4\) that contained 1,239 implants in total were included in the systematic review and meta-analysis (Table 1).

**Description of Studies**

The selected 10 studies \(^2^5\), \(^2^7\), \(^3^4\), \(^5^8\)-\(^6^4\) were published between 2007 to 2010 and reported similar inclusion criteria, including the presence of sufficient alveolar bone height and width, the absence of signs of local infection, and adequate plaque control. The selected studies excluded patients with chronic systemic diseases, untreated periodontitis, or bruxism and heavy smokers (>10 cigarettes/day). Seven of the studies were randomized \(^2^5\), \(^3^4\), \(^5^8\)-\(^6^1\), \(^6^3\) and the remaining three studies \(^2^7\), \(^6^0\), \(^6^4\) were CCTs. The observation period ranged from 12 months \(^2^5\), \(^2^7\), \(^3^4\), \(^6^3\) to 60 months. \(^6^4\) Only two studies \(^5^8\), \(^6^0\) reported implant placement into fresh extraction sockets followed by immediate restoration/loading, where the other studies \(^2^5\), \(^2^7\), \(^3^4\), \(^5^9\), \(^6^1\)-\(^6^4\) followed the conventional placement protocol.

With regard to the surgical protocol, five studies \(^5^8\)-\(^6^1\), \(^6^3\) described the use of a pre- and postoperative antibiotic regimen, and all implants were placed in type II and III bone. \(^6^5\) Bone regenerative procedures were used in three studies: one study \(^5^8\) filled the socket voids with bovine bone matrix \(^3^4\) during implant placement into fresh extraction sockets, another study \(^5^9\) used sinus-lift augmentation, \(^6^6\) and the third study \(^6^3\) performed minor bone augmentation. The assessment of bone-level changes around test and control implants was based on digital radiographic measurements in all of the selected studies \(^2^5\), \(^2^7\), \(^3^4\), \(^5^8\)-\(^6^3\) but one. \(^6^4\) Measurements were usually limited to the vertical extent of marginal bone resorption in the study except for one study \(^3^4\) in which both the vertical and horizontal changes in marginal bone level were measured.

Canullo et al. \(^5^8\) performed an RCT to measure the amount of marginal bone loss and periodontal indices at 22 implants placed in maxillary fresh-extraction sites and restored with either platform-switched or matched prostheses. A significant radiographic difference in marginal bone levels was observed between the test and control groups after a mean follow-up period of 25 months. On the other hand, periodontal parameters (i.e., bleeding on probing, probing depth, and the modified plaque index) did not show any statistically significant difference between the two groups. In addition, no correlation was detected between the gingival biotype (thick or thin) and amount of marginal bone loss.

Canullo et al. \(^5^9\) assessed the marginal bone level around 80 implants. The implants were randomly assigned into four groups (three test and one control) based on the discrepancy between the diameters of the abutment and the implant platform. The use of 3.8-, 4.3-, 4.8-, and 5.5-mm diameter implants with 3.8-mm abutments resulted in a 0.25-mm (test group 1), 0.50-mm (test group 2), and 0.85-mm (test group 3) implant-abutment diameter difference, and a matched-implant-abutment diameter in the control group. After a follow-up period of 33 months, the mean marginal bone losses of 0.99 ± 0.42 mm for test group 1, 0.87 ± 0.43 mm for test group 2, 0.64 ± 0.32 mm for test group 3, and 1.48 ± 0.42 mm for the control group were reported. The findings suggested that the extent of the inward shifting was inversely proportional to the amount of marginal bone loss.

Cappiello et al. \(^2^7\) evaluated the marginal bone-level alterations of 73 implants with an extended platform of 4.8 mm and 55 implants with a matched platform of 4.0 mm. One implant failed in the control group. After 1 year of function, the radiographic examination showed that the marginal bone loss around the platform-switched implants ranged between 0.6 and 1.2 mm (mean: 0.95 ± 0.32 mm), whereas the marginal bone loss around the control implants ranged between 1.3 and 2.1 mm (mean: 1.67 ± 0.37 mm). The difference between the two groups was considered to be statistically significant.

Crespi et al. \(^6^0\) placed 30 platform-switched implants and 34 platform-matched implants. All implants were placed into fresh extraction sockets of incisors, canines, and premolars. Provisional crowns were immediately placed after surgery, and implants were followed up for a period of 2 years. A radiographic marginal bone resorption of 0.73 ± 0.52 mm
and $0.78 \pm 0.49$ mm were reported in the platform-switched and platform-matched groups, respectively. No statistically significant difference was shown between the two groups. In the authors’ view, the use of an atraumatic surgical protocol might have preserved the peri-implant bone levels and minimized the difference between the two groups.

Enkling et al.\textsuperscript{34} performed a split-mouth trial of 50 platform-switched and matched implants placed in the posterior mandible and followed up for 12 months. The radiographic examination included the measurement of the vertical and horizontal extents of marginal bone loss. The differences in both dimensions were not statistically significant. Microbiologic samples were collected at different time points after implant insertion. The authors suggested that the extent of microbial colonization had a greater impact on the amount of peri-implant bone loss than the platform design.

Hürzeler et al.\textsuperscript{25} evaluated the marginal bone-level changes of 22 wide-diameter implants, which were randomly connected to either platform-switched or non–platform-switched abutments. Baseline standardized digital radiography was taken at the time of placement of the definitive prosthesis and at 1-year after placement. The mean bone loss for the platform-switched implants was significantly less than those placed with traditional abutments ($P \leq 0.013$). The authors concluded that platform switching may reduce peri-implant bone loss but warned of the limitation
Table 1. Characteristics of Included Studies

<table>
<thead>
<tr>
<th>Study design</th>
<th>Canullo et al., 200958</th>
<th>Canullo et al., 201059</th>
<th>Cappiello et al., 200827</th>
<th>Crespi et al., 200960</th>
<th>Erkling et al., 200964</th>
<th>Hürlinger et al., 200725</th>
<th>Kielbassa et al., 200963</th>
<th>Prosper et al., 200961</th>
<th>Trammell et al., 200962</th>
<th>Vigolo and Givani, 200964</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implants (n)</td>
<td>22</td>
<td>61</td>
<td>128</td>
<td>64</td>
<td>50</td>
<td>22</td>
<td>32</td>
<td>360</td>
<td>25</td>
<td>182</td>
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<tr>
<td>PS</td>
<td>11</td>
<td>17 (test group 1); 13 (test group 2); 14 (test group 3)</td>
<td>73</td>
<td>30</td>
<td>25</td>
<td>14</td>
<td>199</td>
<td>180</td>
<td>13</td>
<td>97</td>
</tr>
<tr>
<td>PM</td>
<td>11</td>
<td>17</td>
<td>55</td>
<td>34</td>
<td>25</td>
<td>8</td>
<td>126</td>
<td>180</td>
<td>12</td>
<td>85</td>
</tr>
<tr>
<td>Implant system</td>
<td>*</td>
<td>*</td>
<td>46</td>
<td>Not clear</td>
<td>11</td>
<td>*</td>
<td>**</td>
<td>*</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Implant diameter (mm)</td>
<td>5.5</td>
<td>PS: 4.3, 4.8, 5.5; PM: 3.8</td>
<td>PS: 4.5, 5.5; PM: 3.8, 5.0</td>
<td>73</td>
<td>30</td>
<td>25</td>
<td>14</td>
<td>199</td>
<td>180</td>
<td>13</td>
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<tr>
<td>Implant length (mm)</td>
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<td>PS: 14.0; PM: 13.0</td>
<td>Not clear</td>
<td>0.25, 0.35</td>
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<td>0.45</td>
<td>0.25</td>
<td>0.5, 0.7</td>
<td>0.45</td>
<td>Not clear</td>
</tr>
<tr>
<td>Implant location</td>
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<td>Mandible</td>
<td>Maxilla, mandible</td>
<td>Maxilla, mandible</td>
<td>13.0</td>
<td>8.5</td>
<td>0.7</td>
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<td>Allocation concealment</td>
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<td>Grade A</td>
<td>Grade D</td>
<td>Grade D</td>
<td>Grade B</td>
<td>Grade B</td>
<td>Grade A</td>
<td>Grade B</td>
<td>Grade B</td>
<td>Grade D</td>
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<td>Jadad score</td>
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<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0</td>
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<tr>
<td>Survival rate (%)</td>
<td>PS</td>
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<td>100</td>
<td>98.3</td>
<td>100</td>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>97.6</td>
<td>100</td>
<td>98.3</td>
</tr>
</tbody>
</table>

PS = platform-switching; PM = platform-matched.

Global, Sweden-Marina, Padova, Italy.

Ankylos Plus, Dentsply Friadent, Mannheim, Germany.

NobelReplace, Nobel Biocare, Gothenburg, Sweden.

Osseotite, 3i Implant Innovations, Palm Beach Gardens, FL.

NobelActive, Nobel Biocare.

WINSIX, Winsix, London, U.K.
in interpreting the results because of the small number of implants included in their analyses.

Kielbassa et al.\textsuperscript{63} reported on the marginal bone loss around immediately restored implants using an implant with a built-in platform-switch and a standard control one. A total of 325 implants were placed in 12 centers following a similar protocol. At 12 months, three implants failed in the control group versus seven implants that failed in the test group. No significant difference in crestal bone levels was observed between the two implant designs ($P = 0.729$). Additionally, all implants showed a favorable soft tissue response with a significantly higher papilla score after the first year of function.

Prosper et al.\textsuperscript{61} reported a multicenter RCT of 360 platform-switched and control implants that were placed using three different placement methods: submerged, non-submerged, and submerged with reduced abutment. Patients were followed up for 24 months. Two of the platform-matched implants failed as a result of overloading. A masked radiographic evaluation was carried out by one calibrated examiner, and a statistically significant difference in the crestal bone changes was found between the two groups. In addition, there was no significant difference in the modified sulcus bleeding index, plaque index, and implant-stability quotient between platform-switched and matched implants during the period of the study.

Trammell et al.\textsuperscript{62} conducted an RCT in which 25 dental implants were placed in the mandible to evaluate the marginal bone loss around platform-switched and platform-matched implants. Each patient acted as his or her own control. The randomization was achieved by scratching a randomization card, and the intraexaminer reliability was tested. None of the implants failed after a follow-up period of 2 years. The platform-switched implants showed significantly less crestal bone loss compared to conventional implants ($0.99 \pm 0.53$ mm versus $1.19 \pm 0.58$ mm). In contrast, there was no difference in the radiographic surrogate measure of biologic width in both groups.

Vigolo and Givani\textsuperscript{64} evaluated 182 single wide-diameter implants placed in posterior sites. Of these, 97 implants were restored with prosthetic components that were 0.8 mm narrower in diameter than the implant platform, and 85 implants were restored with prosthetic components of the same diameter. The implants were evaluated for 5 years after the placement of abutments, and radiographic changes were measured using a $\times$6 magnifying lens. There was a statistically significant difference in the marginal bone loss between the test and control groups at 1 year. However, the marginal bone levels did not show any significant changes at 2, 3, 4, and 5 years of function.

**Methodologic Quality**

The overall quality of the included studies was considered satisfactory. The Jadad score ranged from 0 to 4 because seven studies\textsuperscript{25,34,58-61,63} were RCTs. The randomization was performed by the use of sealed opaque envelopes,\textsuperscript{61} a randomization card,\textsuperscript{62} and a predefined randomization table.\textsuperscript{58,59,63} Although it may not always be possible to mask the examiner to the design of the implant–abutment connection, one study\textsuperscript{58} was described as a double-masked RCT. In addition, the allocation concealment was not properly described or was not used in all studies\textsuperscript{25,27,34,60-64} but two.\textsuperscript{58,59}

**Meta-Analyses**

**Primary outcome.** The range of the marginal bone loss in test and control groups was 0.055 to 0.99 mm and 0.19 to 1.67 mm, respectively. A statistically significant reduction in peri-implant bone loss was reported around the platform-switched implants in seven studies,\textsuperscript{25,27,58,59,61,62,64} whereas three studies\textsuperscript{34,60,63} failed to show any significant difference between the two groups. In one study,\textsuperscript{59} the differences among the three test groups and the control group were regarded as three separate comparisons, and each one was included in the meta-analysis as a study unit. Thus, the 10 selected studies\textsuperscript{25,27,34,58-64} were treated as 12 study units throughout the analyses. When the marginal bone-level changes were measured at different follow-up intervals in one study, the data recorded at the longest follow-up interval was included in the overall analysis. The random-effects model was applied as the heterogeneity among studies was significant. The meta-analysis of all included studies\textsuperscript{25,27,34,58-64} showed a significant bone loss in the platform-switched implant group with an MD of $-0.37$ mm (95% CI: $-0.55$ to $-0.20$; $P < 0.0001$; Fig. 2). The $\chi^2$ of heterogeneity was 126.79 ($P < 0.0001$; $I^2 = 91\%$).

**Secondary outcome.** All included studies\textsuperscript{25,27,34,58-64} showed no significant difference in the implant-failure rate between the two platform designs. The only reported failed implants were eight platform-switched implants\textsuperscript{27,63} and six control implants,\textsuperscript{61,63} whereas the remaining implants in either group were well integrated. Based on a fixed-effects model, there was no significant difference in implant failure (RR: 0.93; 95% CI: 0.34 to 2.59; $P = 0.89$; Fig. 3). No within-study ($\chi^2 = 2.30; P = 0.32$) or between-study heterogeneity ($I^2 = 13\%$) was observed.

**Subgroup analyses.** The possible sources of heterogeneity were assessed by subgroup analyses on the primary outcome (Table 2). The multiple comparisons included: the study design (RCT versus CCT), sample size ($\geq60$ implants versus $<60$ implants), time of implant placement (immediate versus delayed),
difference between the implant platform-abutment diameter (≥0.4 mm versus <0.4 mm), and follow-up period (12 months versus >12 months).

In general, the subgroup analyses showed that the platform-switched implants offered more bone preservation than the traditional implants. However, the difference was not always significant. The subgroup analyses of the RCTs\textsuperscript{25,34,58,61-63} showed a significant difference with less bone-level changes in the platform-switched implant group (MD: −0.38; 95% CI: −0.63 to −0.13; \(P = 0.003\); Fig. 4). Likewise, the three CCTs\textsuperscript{27,60,64} in this review demonstrated a similar estimate of the treatment effect with a significant difference between the two platform designs in favor of the platform-switching implant design (MD: −0.37; 95% CI: −0.71 to −0.03; \(P = 0.03\); Fig. 5).

The subgroup analyses of the five studies\textsuperscript{27,60,61,63,64} that had sample sizes of ≥60 implants showed a borderline significant difference (MD: −0.23; 95% CI: −0.47 to 0.00; \(P = 0.05\); Fig. 6). On the other hand, the difference was statistically significant when only studies\textsuperscript{25,34,58,62} with a smaller sample size (<60 implants) were included in the analysis (MD: −0.50; 95% CI: −0.78 to −0.22; \(P = 0.0005\); Fig. 7). Limiting the analysis to the studies\textsuperscript{25,27,34,59,61-64} that placed the implants in healed sites revealed a significant difference in favor of platform switching (MD: −0.35; 95% CI: −0.54 to −0.17; \(P = 0.0001\); Fig. 8).

With regard to the degree of implant-abutment diameter mismatch, the subgroup analyses demonstrated a significant difference when a diameter difference ≥0.4 mm was used\textsuperscript{25,27,34,59,61,62,64} (MD: −0.50; 95% CI: −0.72 to −0.29; \(P < 0.0001\); Fig. 9). However, the difference was not significant among the studies\textsuperscript{34,59,60,63} that used an implant/abutment diameter mismatch <0.4 mm (MD: −0.10; 95% CI: −0.35 to 0.15; \(P = 0.43\); Fig. 10). The subgroup analyses of the studies\textsuperscript{25,27,34,60,61,63,64} with a >12-month follow-up period showed significantly less peri-implant bone resorption around platform-switched implants (MD: −0.48; 95% CI: −0.70 to −0.26; \(P < 0.0001\); Fig. 11). However, the difference was marginally significant among the 12-month follow-up studies\textsuperscript{25,27,34,60,61,63,64} (MD: −0.19; 95% CI: −0.39 to 0.01; \(P = 0.06\); Fig. 12).

**Publication bias.** The funnel plot showed a slight asymmetry (Fig. 13A). However, the regression asymmetry test did not suggest a publication bias (\(P = 0.54\)). The trim-and-fill method\textsuperscript{53} indicated one missing study, and the adjusted overall effect size was not substantially different from the original estimate. A slight publication bias may have been present, suggesting that the missing study was more likely to favor the standard platform-matching system (Fig. 13B). Moreover, a series of analyses for publication bias was also conducted for the selected subgroups. The Egger regression method\textsuperscript{52} did not suggest any possible publication bias, and the difference between the original estimate and the adjusted effect size according to the trim-and-effect procedure remained non-significant for all subgroups of studies (Appendix 3).

**DISCUSSION**

This systematic review and meta-analysis used the recent guidelines of PRISMA\textsuperscript{44} and the Cochrane Collaboration methods\textsuperscript{45} to evaluate the best available evidence for the use of platform switching as a design feature to limit peri-implant bone loss around implants. A meta-analysis of 1,239 implants was conducted to examine the radiographic marginal bone-level

---

**Figure 2.**

Comparison: platform switching versus platform matching. Outcome: marginal bone level changes. TG = test group; df = degrees of freedom; IV = inverse variance.
changes and implant-failure rate. The results of the analysis showed that platform-switched implants experienced less marginal bone loss than implants restored with matching prostheses. However, the implant-failure rate did not seem to be affected by platform switching.

The subgroup analyses was conducted to explore the sources of heterogeneity because the test of heterogeneity had a low power, and a non-significant result may not be reliable to identify heterogeneity. The subgroup analyses examined the influence of the study design, sample size, implant-placement method, degree of discrepancy between implant and abutment diameters, and the length of the observation period on the overall effect size. A substantially more stable peri-implant bone level around platform-switched implants was observed in studies that followed the conventional placement protocol and had a smaller number of implants (<60 implants) with a >0.4-mm difference between implant and abutment diameters on one side. This indicated that the changes in marginal bone levels were more favorable with increasing the extent of mismatch between implants and abutments. Indeed, the positive effect of increasing the degree of mismatch between the implant platform and abutment diameter was previously demonstrated. Increasing the physical distance between the IAJ and the marginal alveolar bone may further place the inflammatory infiltrate and its resorptive effects away from the marginal bone. However, long-term studies with larger sample sizes may still be needed to validate such a conclusion.

The principle of platform-switching was previously reviewed. Both reviews provided a summary of the current human, animal, and biomechanical studies on the advantages and potential applications of platform switching. The authors concluded that platform-switching may preserve the crestal bone level and maintain the soft tissue level in the esthetic zone. However, the radiographic marginal bone level is a surrogate measurement for the esthetic outcome. Hence, the enhanced preservation of peri-implant bone around a platform-switched implant may not
necessarily improve esthetics. Further research that clearly evaluates esthetic outcomes with larger sample sizes and longer follow-up periods are recommended to validate the esthetic advantages of platform switching. The present systematic review was different from the previous reviews\textsuperscript{67,68} in several aspects. First, the present review was carried out systematically following PRISMA guidelines\textsuperscript{44} and using a well-focused PICO question. Second, only human studies with a control group were selected. Third, the existing literature was quantitatively assessed by performing a meta-analysis and subgroup analyses to provide a better understanding of the role of platform-switching in the maintenance of crestal bone levels compared to the role of standard platform-matched implants.

This systematic and meta-analytic review had several limitations. First, the search was limited to
Figure 7.
Comparison: platform switching versus platform matching. Outcome: marginal bone level changes (sample size <60). TG = test group; df = degrees of freedom; IV = inverse variance.

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Platform Switching Mean</th>
<th>Platform Matching Mean</th>
<th>Mean Difference IV, Random, 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canullo et al.</td>
<td>0.3 0.16 11</td>
<td>1.10 0.35 11</td>
<td>-0.89 (-1.12 to -0.66)</td>
</tr>
<tr>
<td>Canullo et al.</td>
<td>0.99 0.42 17</td>
<td>1.49 0.54 17</td>
<td>-0.50 (-0.83 to -0.17)</td>
</tr>
<tr>
<td>Canullo et al.</td>
<td>0.62 0.36 13</td>
<td>1.49 0.54 17</td>
<td>-0.67 (-0.99 to -0.35)</td>
</tr>
<tr>
<td>Canullo et al.</td>
<td>0.56 0.31 14</td>
<td>1.49 0.54 17</td>
<td>-0.93 (-1.23 to -0.63)</td>
</tr>
<tr>
<td>Enkling et al.</td>
<td>0.56 0.44 25</td>
<td>0.61 0.57 25</td>
<td>-0.05 (-0.33 to 0.23)</td>
</tr>
<tr>
<td>Hürzeler et al.</td>
<td>0.12 0.4 14</td>
<td>0.29 0.34 8</td>
<td>-0.17 (-0.49 to 0.15)</td>
</tr>
<tr>
<td>Trammell et al.</td>
<td>0.99 0.53 13</td>
<td>1.19 0.58 12</td>
<td>-0.20 (-0.64 to 0.24)</td>
</tr>
</tbody>
</table>

Total (95% CI) 107
Heterogeneity: $t^2 = 0.12; 
\chi^2 = 35.31, df = 6 (P < 0.00001); I^2 = 83%.
Test for overall effect: Z = 3.46 (P = 0.0005)

Figure 8.
Comparison: Platform switching versus platform matching. Outcome: marginal bone level changes (delayed implant placement). TG = test group; df = degrees of freedom; IV = inverse variance.

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Platform Switching Mean</th>
<th>Platform Matching Mean</th>
<th>Mean Difference IV, Random, 95% CI</th>
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</tr>
<tr>
<td>Canullo et al.</td>
<td>0.82 0.36 13</td>
<td>1.49 0.54 17</td>
<td>-0.67 (-0.99 to -0.35)</td>
</tr>
<tr>
<td>Canullo et al.</td>
<td>0.56 0.31 14</td>
<td>1.49 0.54 17</td>
<td>-0.93 (-1.23 to -0.63)</td>
</tr>
<tr>
<td>Cappiello et al.</td>
<td>0.95 0.32 73</td>
<td>1.67 0.37 55</td>
<td>-0.72 (-0.84 to -0.60)</td>
</tr>
<tr>
<td>Enkling et al.</td>
<td>0.56 0.44 25</td>
<td>0.61 0.57 25</td>
<td>-0.05 (-0.33 to 0.23)</td>
</tr>
<tr>
<td>Hürzeler et al.</td>
<td>0.12 0.4 14</td>
<td>0.29 0.34 8</td>
<td>-0.17 (-0.49 to 0.15)</td>
</tr>
<tr>
<td>Kielbassa et al.</td>
<td>0.8 1.17 156</td>
<td>0.63 1.18 85</td>
<td>0.17 (-0.14 to 0.48)</td>
</tr>
<tr>
<td>Prosper et al.</td>
<td>0.055 0.234 180</td>
<td>0.193 0.474 180</td>
<td>-0.14 (-0.22 to -0.06)</td>
</tr>
<tr>
<td>Trammell et al.</td>
<td>0.99 0.53 13</td>
<td>1.19 0.58 12</td>
<td>-0.20 (-0.64 to 0.24)</td>
</tr>
<tr>
<td>Viglio and Givani</td>
<td>0.6 0.2 97</td>
<td>0.9 0.3 85</td>
<td>-0.30 (-0.38 to -0.22)</td>
</tr>
</tbody>
</table>

Total (95% CI) 591
Heterogeneity: $t^2 = 0.07; 
\chi^2 = 97.82, df = 9 (P < 0.00001); I^2 = 91%.
Test for overall effect: Z = 3.83 (P = 0.0001)

Figure 9.
Comparison: Platform switching versus platform matching. Outcome: marginal bone level changes (implant-abutment diameter difference ≥0.4). TG = test group; df = degrees of freedom; IV = inverse variance.

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Platform Switching Mean</th>
<th>Platform Matching Mean</th>
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<td>Canullo et al.</td>
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</tr>
<tr>
<td>Canullo et al.</td>
<td>0.82 0.36 13</td>
<td>1.49 0.54 17</td>
<td>-0.67 (-0.99 to -0.35)</td>
</tr>
<tr>
<td>Canullo et al.</td>
<td>0.56 0.31 14</td>
<td>1.49 0.54 17</td>
<td>-0.93 (-1.23 to -0.63)</td>
</tr>
<tr>
<td>Cappiello et al.</td>
<td>0.95 0.32 73</td>
<td>1.67 0.37 55</td>
<td>-0.72 (-0.84 to -0.60)</td>
</tr>
<tr>
<td>Hürzeler et al.</td>
<td>0.12 0.4 14</td>
<td>0.29 0.34 8</td>
<td>-0.17 (-0.49 to 0.15)</td>
</tr>
<tr>
<td>Prosper et al.</td>
<td>0.055 0.234 180</td>
<td>0.193 0.474 180</td>
<td>-0.14 (-0.22 to -0.06)</td>
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<tr>
<td>Trammell et al.</td>
<td>0.99 0.53 13</td>
<td>1.19 0.58 12</td>
<td>-0.20 (-0.64 to 0.24)</td>
</tr>
<tr>
<td>Viglio and Givani</td>
<td>0.6 0.2 97</td>
<td>0.9 0.3 85</td>
<td>-0.30 (-0.38 to -0.22)</td>
</tr>
</tbody>
</table>

Total (95% CI) 415
Heterogeneity: $t^2 = 0.08; 
\chi^2 = 106.92, df = 7 (P < 0.00001); I^2 = 93%.
Test for overall effect: Z = 4.60 (P < 0.00001)
English-language publications, which may have introduced a publication bias and excluded other relevant articles. However, such an exclusion may not considerably change the overall estimate of treatment effects.\textsuperscript{69} Second, an inherent limitation in each selected study was the use of conventional radiographs, which allowed for the detection of bone loss at the mesial and distal peri-implant sides but did not evaluate the buccal and lingual bone levels. Third, the bone levels were generally assessed in one dimension, which is the vertical distance from the most coronal aspect of the implant shoulder to
the first bone–implant contact. It is important to measure the horizontal and vertical marginal bone changes around implants because the distance between the IAJ with its associated inflammatory cell infiltrate (0.75 mm above and below the IAJ) and the crestal bone level can influence both the horizontal and vertical extension of bone resorption. Only one study measured the marginal bone level changes in both the vertical and horizontal dimensions and concluded that platform switching may not have a significant influence on maintaining vertical and horizontal marginal bone levels. Fourth, the implants included in the review may not have been placed at a standardized distance from the alveolar crest, which may have added to the heterogeneity of the studies. The placement of the IAJ above the crest may result in less bone loss than placing it below the crest because bone resorption increases to establish the biologic width. Fifth, the inclusion of non-randomized CCTs in the analysis may have introduced a bias. However, it was postulated that CCTs can complement the evidence provided by RCTs, particularly when RCTs are not of a high quality. In addition, the subgroup analyses presented RCTs and CCTs separately and showed that CCTs did not overestimate or underestimate the treatment effect.

Nonetheless, the quality of the included studies appeared to be moderately acceptable as assessed by Jadad quality scoring and the Cochrane scale for the assessment of allocation concealment. The obvious heterogeneity between studies was accounted for by using a more conservative random-effects model and performing subgroup analyses to detect the factors that may affect the outcome. Furthermore, the possibility of a publication bias was thoroughly investigated, and an overestimation of the overall mean effect size was excluded. A publication bias is one of the drawbacks of a meta-analysis and its absence substantially validated the conclusions of this review. Nonetheless, the limitations of the publication-bias analyses need to be considered.

CONCLUSIONS
In this systematic review and meta-analysis, the controversial evidence on the use of platform switching to maintain bone levels around implants is summarized. Within the limitation of the available data, the results reveal that the inward shift of IAJ platform switching can be considered a desirable morphologic feature that may prevent the horizontal saucerization and preserve the vertical crestal bone levels. An additional improvement in the marginal bone levels around dental implants may also be obtained with a greater degree of shifting.

Additional properly designed, large RCTs are needed before establishing the long-term predictability of platform switching in preserving the horizontal and vertical marginal bone levels or modifying the minimum distances between platform-switched implants and adjacent teeth or implants.

ACKNOWLEDGMENT
The authors report no conflicts of interest related to this review.

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5. Buser D, Weber HP, Lang NP. Tissue integration of non-submerged implants. 1-year results of a prospective


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Appendix 1.

Jadad-Score Calculation

<table>
<thead>
<tr>
<th>Item</th>
<th>Jadad Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>The study was described as randomized</td>
<td>+1</td>
</tr>
<tr>
<td>The method for random allocation was appropriate</td>
<td>+1</td>
</tr>
<tr>
<td>The study was described as double masked</td>
<td>+1</td>
</tr>
<tr>
<td>The method for double masking was appropriate</td>
<td>+1</td>
</tr>
<tr>
<td>The method used to generate the sequence of randomization was inappropriate</td>
<td>-1</td>
</tr>
<tr>
<td>The method of masking was inappropriate</td>
<td>-1</td>
</tr>
<tr>
<td>The number and reasons for withdrawals/dropouts were reported</td>
<td>+1</td>
</tr>
</tbody>
</table>

Appendix 2.

Cochrane Assessment of Allocation Concealment

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Adequate: the randomization sequence was hidden from the examiners (e.g., the use of central randomization by a third party, sequentially numbered opaque envelopes, computer generated with allocations kept in a locked unreadable file)</td>
</tr>
<tr>
<td>B</td>
<td>Unclear: the method of allocation concealment was not described</td>
</tr>
<tr>
<td>C</td>
<td>Inadequate: allocation was not adequately concealed (e.g., the use of the day of admission, date of birth, and hospital record number)</td>
</tr>
<tr>
<td>D</td>
<td>Not used</td>
</tr>
</tbody>
</table>

Appendix 3.

Tests for Publication Bias

| MBLC = marginal bone-level change; DP = delayed placement. * In one report, each of the three test groups was considered a separate study unit. † Three studies reported data at two different time points (12 and >12 months) and, hence, were included in both analyses. |

<table>
<thead>
<tr>
<th>MBLC</th>
<th>Original Meta-Analysis</th>
<th>Trim-and-Fill Analysis</th>
<th>Egger Regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MD (95% CI)</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall sample</td>
<td>−0.37 (−0.55 to −0.20)</td>
<td>&lt;0.0001</td>
<td>−0.32 (−0.15 to −0.50)</td>
</tr>
<tr>
<td>Study design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCT</td>
<td>−0.38 (−0.63 to −0.13)</td>
<td>0.003</td>
<td>−0.14 (−0.41 to 0.13)</td>
</tr>
<tr>
<td>CCT</td>
<td>−0.37 (−0.71 to −0.03)</td>
<td>0.03</td>
<td>−0.37 (−0.71 to −0.03)</td>
</tr>
<tr>
<td>Sample size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N ≥60</td>
<td>−0.23 (−0.47 to 0.00)</td>
<td>0.08</td>
<td>−0.23 (−0.47 to 0.00)</td>
</tr>
<tr>
<td>N &lt;60</td>
<td>−0.50 (−0.78 to −0.22)</td>
<td>0.0005</td>
<td>−0.50 (−0.78 to −0.22)</td>
</tr>
<tr>
<td>Implant-placement protocol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP</td>
<td>−0.35 (−0.54 to −0.17)</td>
<td>0.0001</td>
<td>−0.29 (−0.47 to −0.11)</td>
</tr>
<tr>
<td>Implant–abutment diameter difference (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥0.4</td>
<td>−0.50 (−0.72 to −0.29)</td>
<td>&lt;0.0001</td>
<td>−0.35 (−0.56 to −0.13)</td>
</tr>
<tr>
<td>&lt;0.4</td>
<td>−0.10 (−0.35 to 0.15)</td>
<td>0.43</td>
<td>−0.10 (−0.35 to 0.15)</td>
</tr>
<tr>
<td>Follow-up period (months) †</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;12</td>
<td>−0.48 (−0.70 to −0.26)</td>
<td>&lt;0.0001</td>
<td>−0.33 (−0.55 to −0.12)</td>
</tr>
<tr>
<td>= 12</td>
<td>−0.19 (−0.39 to 0.01)</td>
<td>0.06</td>
<td>−0.19 (−0.39 to 0.01)</td>
</tr>
</tbody>
</table>