

# Does the implant-abutment interface interfere on marginal bone loss? A systematic review and meta-analysis

Enéias Carpejani ROSA<sup>(a)</sup>   
Tatiana Miranda DELIBERADOR<sup>(a)</sup>   
Tuanny Carvalho de Lima do  
NASCIMENTO<sup>(a)</sup>   
Cibele Cândida de Almeida  
KINTOPP<sup>(a)</sup>   
Juliana Shaia Rocha ORSI<sup>(a)</sup>   
Letícia Maíra WAMBIER<sup>(a)</sup>   
Sharukh Soli KHAJOTIA<sup>(b)</sup>   
Fernando Luis ESTEBAN FLOREZ<sup>(b)</sup>   
Carmen Lucia Mueller STORRER<sup>(a)</sup> 

<sup>(a)</sup>Universidade Positivo, School of Health Sciences, Graduate Program in Dentistry, Curitiba, PR, Brazil.

<sup>(b)</sup>The University of Oklahoma Health Sciences Center, Division of Dental Biomaterials, Department of Restorative Sciences, Oklahoma City, Oklahoma, USA.

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**Corresponding Author:**  
Carmen Lucia Muller Storrer  
E-mail: carmen.storrer@up.edu.br;  
carmen.storrer@gmail.com

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**Abstract:** The objective of this systematic review was to compare the conical internal connection (IC) with the external hexagonal connection (EH) on the occurrence of marginal bone loss ( $\Delta$ MBL). Different databases were used to carry out the selection of the elected studies. The studies were judged according to the risk of bias as “high”, “low” and “unclear” risk. For the meta-analysis we included only studies that could extract the data of  $\Delta$ MBL, survival rate (SR) and probing depth (PD). No statistically significant differences were found for  $\Delta$ MBL data at one, three- and five-year survival rates between implant connections ( $p < 0.05$ ), however statistically significant differences were found for PD between EH and IC implants (1-year follow-up)  $-0.53$  [95%CI  $-0.82$  to  $-0.24$ ,  $p = 0.0004$ ]. This present systematic review demonstrated that there are no significant differences between IC and EH implants for both  $\Delta$ MBL and SR at 1, 3 e 5 years after functional loading, although better PD values were observed for implants pertaining to the IC connections. Considering the high heterogeneity, more well-delineated, randomized clinical trials should be conducted.

**Keywords:** Dental Implants; Dental Implant-Abutment Design; Systematic Review.

## Introduction

Great scientific evidence (*in vitro*, *in vivo* and clinical trials) has demonstrated that modern oral rehabilitation techniques, based on the use of endosseous dental implants, have recently allowed for the attainment of highly osseointegrated restorations displaying remarkable initial esthetic and mechanical properties.<sup>1-5</sup> Numerous studies, however, have shown that these types of rehabilitations are typically associated with significant bone loss over the course of their service lives. Because of that, marginal bone loss has been considered one of the most important criteria to define the clinical success of dental implants.

According to a consensus reached at the International Congress of Oral Implantology (ICOI), a successful dental implant may display at radiographic assessment, physiological bone losses (i.e., saucerization) smaller than 2.0 mm after the installation of the prosthesis<sup>6</sup> (within the first year) and additional 0.2 mm for each subsequent year of activity.<sup>7,8</sup> Even though saucerization may adversely impact the position of the



gingival margin and consequently the expected esthetic results, saucerization has been shown to be necessary for the re-establishment of the biological space surrounding dental implants.<sup>9,10</sup> Thus, the localization of the implant-pillar interface (micron-sized gap) is of fundamental relevance for the success of dental implants because it has been previously demonstrated to act as a contributing factor for the occurrence of peri-implant-related marginal bone loss.<sup>10,11,12</sup>

The implant developed by Brånemark displayed an external hexagon (EH, height = 0.7 mm). Such design should work as a locking system to prevent unwanted rotation and to facilitate the surgical placement of implants.<sup>13</sup> This implant design, however, favors the concentration of high amount of force over the screw and leads to micromovement generation, that combined, typically results in the subsequent critical failure of the implants due to mechanical and biological reasons.<sup>14,15</sup> To solve this problem, new connection designs were developed, that resulted in a classification division between tapered and non-tapered and internal and external abutments.<sup>16</sup>

The internal tapered connection (IC) provides a juxtaposition (by attrition) and superior mechanical stability that eliminates unwanted rotation and pillar loosening.<sup>17</sup> In addition, the tapered interface decreases the distance between the pillar and the implant body that results superior seals and decreased risk of infiltration. These factors combined, have been shown to hinder tissue inflammation (both soft and hard), periimplantitis and marginal bone loss.<sup>18,19,20</sup> Even though image assessments have significantly improved over the last few years, and tomographic analyses provide very precise  $\Delta$ MBL results, periapical radiographies, standardized by the parallelism method, continues to be the most commonly used technique to measure the time-dependent evolution in  $\Delta$ MBL.<sup>21,22,23</sup>

A few clinical studies investigating  $\Delta$ MBL in EH and IC implants, using radiographic analysis, have found that after 1 year of follow-up, EH implants displayed the lowest levels of  $\Delta$ MBL.<sup>24,25</sup> Other studies, however, have contradicted these results by reporting data suggesting that higher  $\Delta$ MBL levels were found for EH implants when compared to IC implants (1<sup>26</sup>

and 3<sup>27</sup> years of follow-up). The lack of consensus regarding the impact of connection design on  $\Delta$ MBL is demonstrated further in the literature by studies that have reported that no statistical differences in  $\Delta$ MBL could be found for both EH and IC dental implants (2<sup>28</sup> and 5<sup>29</sup> years of follow-up). Thereby, and taking into consideration the observation of strongly contradictory results, it was decided to perform a systematic review and meta-analysis of follow-up clinical studies (1 year or more) investigating the impact of implant connection designs (either IC or EH) on  $\Delta$ MBL.

## Methodology

The present study was conducted according to the Preferred Reporting Items for Systematic Review and Meta-analysis Protocols (PRISMA-P)<sup>30</sup> and it was performed at the Universidade Positivo, UP, Curitiba, Paraná, Brazil from June to September of 2018. The research protocol utilized was then registered at the International Prospective Register of Systematic Review (PROSPERO) under the protocol number CRD42018090991.

## Research strategy

The research strategy was based on the PICOS acronym where (P) stands for the population investigated (edentulous patients with dental implants), (I) stands for the types of intervention (Morse taper internal connection), (C) stands for intervention comparison (external connection), (R) stands for the results assessed [primary outcome: marginal bone loss ( $\Delta$ MBL); secondary outcome: probing depth and implant survival rates] and (S) stands for study design (randomized clinical trials). The strategy was also based on the utilization of Mesh terms to allow for further standardization of the search.

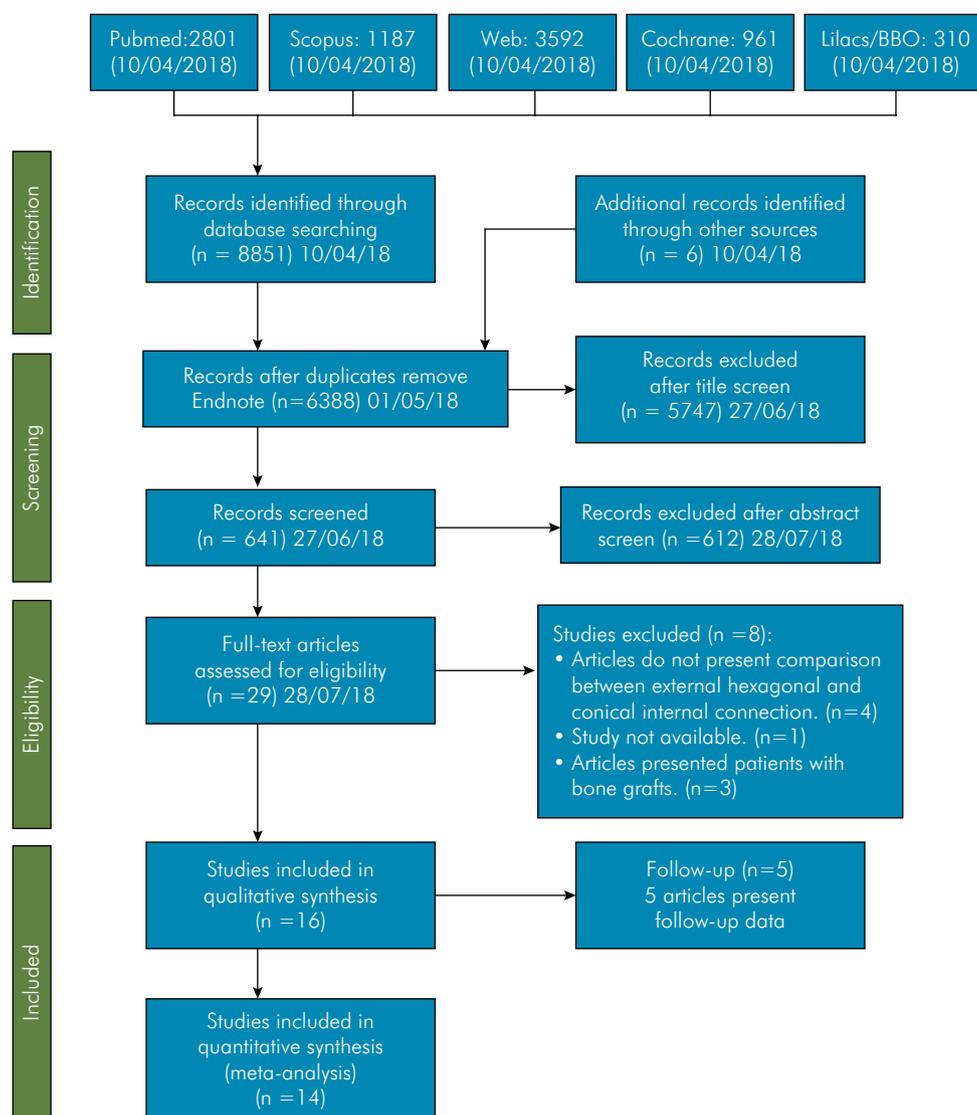
## Data bases

PubMed/MEDLINE, Scopus, Cochrane Library, Web of Science, Biblioteca Brasileira em Odontologia (BBO) and Centro Latino-Americano e do Caribe de Informação em Ciências da Saúde (LILACS) were searched (Figure 1). Table 1 illustrates both the

Mesh- and free-terms used during the execution of the present study. Other data bases such as the System for Information on Gray Literature (SIGLE), *Periódicos de bancos de dados e teses da CAPES* and ProQuest Dissertations and Theses Full Text were also used to strengthen the power of the search strategy. References from primary literature were manually checked for other relevant publications in PubMed, where no restrictions regarding language or data were considered. Finally, repositories containing results from on-going clinical studies such as Clinical Trials ([www.clinicaltrials.gov](http://www.clinicaltrials.gov)), Rebec ([www.ensaiosclinicos.gov.br](http://www.ensaiosclinicos.gov.br)), Current Clinical Trials ([\[www.controlled-trials.com\]\(http://www.controlled-trials.com\)\) and The International Clinical Trials Registry Platform \(<http://www.who.int/ictrp/en/>\) were also searched regarding PICOS of the present systematic review.](http://www.controlled-</a></p>
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### Inclusion and exclusion criteria

Follow-up (at least 1 year) randomized clinical trials (RCT) that investigated the impact of implant-pillar connection designs (either EH or IC) on the evolution of peri-implant  $\Delta$ MBL in edentulous patients (male and female) subjected to implant-based oral rehabilitation techniques in maxilla or mandibula with any type of functional loading (either immediate, premature



**Figure 1.** Present study's flow diagram.

**Table 1.** Systematic review search strategy.

Scopus= 1187 (10/04/2018)	
#1 (TITLE-ABS-KEY (mandible) OR TITLE-ABS-KEY (maxilla) OR TITLE-ABS-KEY ("jaw edentulous") OR TITLE-ABS-KEY ("maxillary bone?") OR TITLE-ABS-KEY ("mandible bone?") OR TITLE-ABS-KEY ("mandibular bone?") OR TITLE-ABS-KEY ("Maxillary implant?"))	#2 (TITLE-ABS-KEY ("dental implant?") AND TITLE-ABS-KEY ("dental implant abutment design") OR TITLE-ABS-KEY ("dental abutment?") OR TITLE-ABS-KEY ("Cone Morse") OR TITLE-ABS-KEY ("short dental implants") OR TITLE-ABS-KEY ("Morse taper") OR TITLE-ABS-KEY ("internal connection") OR TITLE-ABS-KEY ("external connection") OR TITLE-ABS-KEY ("implant abutment connection") OR TITLE-ABS-KEY ("implant abutment connection"))
#1 AND #2 AND #3	
Web of Science-3592 (10/04/2018)	
#1	#2
TS=(Mandible) OR TS=(Maxilla) OR TS=("jaw edentulous") OR TS=("maxillary bone?") OR TS=("mandible bone?") OR TS=("mandibular bone\$") OR TS=("maxillary implant\$")	TS=("dental implant?") OR TS=("dental implant abutment design") OR TS=("dental abutment\$") OR TS=("Cone Morse") OR TS=("short dental implants") OR TS=("Morse taper") OR TS=("internal connection") OR TS=("external connection") OR TS=("implant abutment connection") OR TS=("implant abutment interface")
#1 AND #2	
Lilacs and BBO= 310 (10/04/2018)	
#1 (MH: mandible OR MH:maxilla OR "jaw edentulous" OR "maxillary bones" OR "mandible bones" OR "mandibular bones" OR "maxillary implants" OR "arcada edêntulas" OR "osso maxilar" OR "ossos da mandíbula" OR "osso mandibular" OR "implantes maxilares" OR "arcada edêntula" OR "hueso maxilar" OR "huesos del mandíbula" OR "hueso del mandibular")	#2 (MH:"dental implants" OR MH: "dental implant abutment design" OR MH: "dental abutments" OR "Cone Morse" OR "short dental implants" OR "morse taper" OR "dental implant" OR "internal connection" OR "external connection" OR "implant abutment connection" OR "implant abutment interface" OR "implantes dentários" OR "implante dental curto" OR "implante dental" OR "projeto do implante dentário pivô" OR "dente suporte" OR "conexão interna" OR "conexão externa" OR "interface implante pilar" OR "conexão implante pilar" OR "implantes dentales" OR "implantes dentales cortos" OR "pilares dentales" OR "diseño de implante dental pilar" OR "implante pilar dental con interfase" OR "implante pilar dental con conexión" OR "conexión interna" OR "conexión externa")
#1 AND #2 AND #3	
Cochrane Library = 961 (10/04/2018)	
#4 MeSH descriptor: [Mandible] explode all trees #3 MeSH descriptor: [Maxilla] explode all trees mandible:ti,ab,kw or maxilla:ti,ab,kw or "jaw edentulous":ti,ab,kw or "maxillary bones":ti,ab,kw or #1 "mandible bones":ti,ab,kw (Word variations have been searched) #2 mandibular next bones:ti,ab,kw or maxillary next implants:ti,ab,kw (Word variations have been searched) #5 #4 or #3 or #1 or #2	MeSH descriptor: [Dental Implants] explode all trees. MeSH descriptor: [Dental Implant-Abutment Design] explode all trees MeSH descriptor: [Dental Abutments] explode all trees dental next implant:ti,ab,kw or "dental implant abutment design":ti,ab,kw or dental next abutments:ti,ab,kw or "cone morse":ti,ab,kw or "short dental implants":ti,ab,kw (Word variations have been searched) "morse taper":ti,ab,kw or "internal connection":ti,ab,kw or "external connection":ti,ab,kw or "implant abutment connection":ti,ab,kw or "implant abutment interface":ti,ab,kw (Word variations have been searched) #6 or #7 or #8 or #9 or #10
#5 AND #11	

or delayed) and prosthetic rehabilitations. Pilot, retrospective, *in vitro* (laboratorial and animal models) or clinical studies comprised of patients with selected risk factors (*i.e.*, diabetes, bruxism, pregnancy, chemo- and radiotherapy) or that had been subjected to bone grafts were excluded from the present study.

### Selection of publications and data collection process

The ENDNOTE® software (Philadelphia, USA) was used to select all the manuscripts included in the present study. After initial selection, the compiled

library was checked for duplicates and manuscripts were further triaged based on a dynamic and focused reading of abstracts that took into consideration the inclusion and exclusion criteria previously described. This process was performed independently by two trained and calibrated examiners, authors, reviewers (ECR and TL). Eventual discrepancies between them were solved by a third independent, trained and calibrated examiner (CMS). A data collection chart was used to standardize the extraction of data that was used for the manufacturing of two results tables (Tables 2 and 3).

**Table 2.** Summary of the studies selected for this systematic review for purposes of MBL comparison between External Hexagon (EH) and Conical Internal Connection (ICC). (n = 16)

Journal/Author/Year	Study Design	No. of subjects (total and per group)	No. of implants (total and per group)	Gender % male	Subjects age (range and mean ± SD)	%Mandible implants	%Maxillary implant	Type of prosthetic rehabilitation	Loading protocol	Follow-up period	No. of implants lost per group.
Eur J Oral Implantol Amhart et al./ 2012 <sup>22</sup>	Parallel	1yr /Total: 117 ICC <sup>v</sup> :64 EH <sup>f</sup> :53 3yr/Total: 89 ICC <sup>v</sup> : 45 EH <sup>f</sup> : 41	Total: 199 ICC <sup>v</sup> : 117 EH <sup>f</sup> : 82	Male: 50.4%	ICC <sup>v</sup> : N.R yrs (49.5±13.1) EH <sup>f</sup> : N.R yrs (49.9±13.6)	ICC <sup>v</sup> : 70.94% EH <sup>f</sup> : 65.85%	ICC <sup>v</sup> : 34(29.06%) EH <sup>f</sup> : 28(34.15%)	Total rehab. ICC <sup>v</sup> : 5 EH <sup>f</sup> : 0 Partial rehab. ICC <sup>v</sup> : 41 EH <sup>f</sup> : 39 Unitary rehab. ICC <sup>v</sup> : 71 EH <sup>f</sup> : 43	Immediate load	1 yr 3 yrs	1yr ICC <sup>v</sup> : 4 EH <sup>f</sup> : 3 3yrs ICC <sup>v</sup> : 4 EH <sup>f</sup> : 3
Clin Implant Dent Relat Res Astrand et al./ 2004 <sup>44</sup>	Split-mouth	Total: 28 ICC <sup>v</sup> : NR EH <sup>f</sup> : NR	Total: 150 ICC <sup>v</sup> : 77 EH <sup>f</sup> : 73	Male: 53.6%	36-76yrs (61.70±N.R)	N.R	ICC <sup>v</sup> : 51.3% EH <sup>f</sup> : 48.7%	Partial rehab. 100%	Late load	1 yr 3 yrs	1yr ICC <sup>v</sup> : 1 EH <sup>f</sup> : 2 3 yrs CC <sup>s</sup> : 2 EH <sup>f</sup> : 2
Implant Dent Bilhan et al./ 2010	Parallel	Total: 26 ICC <sup>m</sup> : N.R EH <sup>o</sup> : N.R ICC <sup>s</sup> : N.R	Total: 107 ICC <sup>m</sup> : 42 EH <sup>o</sup> : 36 ICC <sup>s</sup> : 29	Male: 34.6%	N.R yrs (50.82±N.R)	ICC <sup>m</sup> :N.R EH <sup>o</sup> : N.R ICC <sup>s</sup> : N.R	ICC <sup>m</sup> :N.R EH <sup>o</sup> : N.R ICC <sup>s</sup> : N.R	Partial rehab. 100%	Late load Immediate load	2 yrs	ICC <sup>m</sup> : 0 EH <sup>o</sup> : 0 ICC <sup>s</sup> : 0
Clin Implant Dent Relat Res Cehrelli et al./ 2010	Parallel	Total: 22 ICC <sup>w</sup> : 12 EH <sup>o</sup> : 10	Total 44 ICC <sup>w</sup> : 24 EH <sup>o</sup> : 20	Male: 21.4%	N.R yrs (63.50±N.R)	ICC <sup>w</sup> : 50% EH <sup>o</sup> : 50%	NR	Overdenture 100%	Early load	5 yrs	ICC <sup>w</sup> : 0 EH <sup>o</sup> : 0
Int J Periodontics Restorative Dent Cooper et al./ 2016	Parallel	Total: 36 ICC <sup>i</sup> : 18 EH <sup>o</sup> : 18	Total : 93 ICC <sup>i</sup> : 47 EH <sup>o</sup> : 46	Male: 36.1%	N.R yrs (53.0±N.R)	ICC <sup>i</sup> : 29.2% EH <sup>o</sup> : 22.9%	ICC <sup>i</sup> : 16.7% EH <sup>o</sup> : 20.8%	Unitary rehab. 100%	Late load	3 yrs	ICC <sup>i</sup> : 2 EH <sup>o</sup> : 2
Int J Oral Maxillofac Implants Crespi et al./ 2009	Parallel	Total: 45 ICC <sup>r</sup> : N.R EH <sup>o</sup> : N.R	Total 64 ICC <sup>r</sup> : 30 EH <sup>o</sup> : 34	Male: 40.0%	25-67yrs (48.73±N.R)	ICC <sup>r</sup> : 12 EH <sup>o</sup> : 12	ICC <sup>r</sup> : 18 EH <sup>o</sup> : 22	Unitary rehab. 100% ICC <sup>r</sup> : 30 EH <sup>o</sup> : 34	Immediate loading after tooth extraction.	1 yr 2 yrs	ICC <sup>r</sup> : 0 EH <sup>o</sup> : 0
Eur J Oral Implantol Esposito et al./2016	Parallel	Total: 120 ICC <sup>b</sup> : 60 EH <sup>b</sup> : 60	Total: 203 ICC <sup>b</sup> : 107 EH <sup>b</sup> : 96	Male: 39.2%	ICC <sup>b</sup> : 20-79yrs (54±13.4) EH <sup>b</sup> : 25-74yrs (50.4±13.8)	ICC <sup>b</sup> : 67(62.6%) EH <sup>b</sup> : 58(60.4%)	ICC <sup>b</sup> : 40(37.4%) EH <sup>b</sup> : 38(39.6%)	Partial rehab. ICC <sup>b</sup> : 31(51.7%) EH <sup>b</sup> : 30(50.0%) Unitary rehab. ICC <sup>b</sup> : 26(43.3%) EH <sup>b</sup> : 30(50.0%) Overdenture. ICC <sup>b</sup> : 2(2.3%) EH <sup>b</sup> : 0	Late load Early load Immediate load	1 yr 5 yrs	1yr ICC <sup>b</sup> : 2 EH <sup>b</sup> : 1 ICC <sup>b</sup> : 3 EH <sup>b</sup> : 1
Clin Implant Dent Relat Res Kaminaka et al./ 2015	Parallel	Total: N.R	Total: 23 ICC <sup>v</sup> : 12 EH <sup>x</sup> : 11	Male: 31.25%	ICC <sup>v</sup> : 28-85yrs (53.8±N.R) EH <sup>x</sup> : 37-77yrs (63±N.R)	ICC <sup>v</sup> : N.R EH <sup>x</sup> : N.R	ICC <sup>v</sup> : N.R EH <sup>x</sup> : N.R	Unitary rehab. 100%	Late load	1 yr	ICC <sup>v</sup> : 0 EH <sup>x</sup> : 0

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Continuation	Parallel	Total: 40 ICC <sup>φ</sup> : 20 Br <sup>φ</sup> : 20	Total: 40 ICC <sup>φ</sup> : 20 EH <sup>φ</sup> : 20	Male: 37%	Total: N.R yrs (52.2±N.R)	ICC <sup>φ</sup> : 11(55%) EH <sup>φ</sup> : 9 (45%)	ICC <sup>φ</sup> : 9(45%) EH <sup>φ</sup> : 11(55%)	Unitary rehab. 100%	Late load	1 yr	ICC <sup>φ</sup> : 0 EH <sup>φ</sup> : 0
J Periodontol Koo et al./ 2012	Parallel	Total: 40 ICC <sup>φ</sup> : 20 Br <sup>φ</sup> : 20	Total: 40 ICC <sup>φ</sup> : 20 EH <sup>φ</sup> : 20	Male: 37%	Total: N.R yrs (52.2±N.R)	ICC <sup>φ</sup> : 11(55%) EH <sup>φ</sup> : 9 (45%)	ICC <sup>φ</sup> : 9(45%) EH <sup>φ</sup> : 11(55%)	Unitary rehab. 100%	Late load	1 yr	ICC <sup>φ</sup> : 0 EH <sup>φ</sup> : 0
J Clin Periodontol Meijer et al./ 2009 <sup>2,4,5</sup>	Parallel	Total: 60 ICC <sup>φ</sup> : 30 EH <sup>φ</sup> : 30	Total: 120 ICC <sup>φ</sup> : 60 EH <sup>φ</sup> : 60	Male: 70%	ICC <sup>φ</sup> : 38-74yrs (52.8±N.R) EH <sup>φ</sup> : 35-79yrs (56.6±N.R)	ICC <sup>φ</sup> : 50% EH <sup>φ</sup> : 50%	N.R	Overdenture 100%	Late load	1 yr 3 yrs 5 yrs 10 yrs	1 yr ICC <sup>φ</sup> : 0 EH <sup>φ</sup> : 1 3yrs ICC <sup>φ</sup> : 0 EH <sup>φ</sup> : 1 5yrs ICC <sup>φ</sup> : 0 EH <sup>φ</sup> : 1 10yrs ICC <sup>φ</sup> : 0 EH <sup>φ</sup> : 1
Braz Dent J Melo et al./ 2017	Parallel	Total: 20 ICC <sup>φ</sup> : 9 EH <sup>φ</sup> : 11	Total: 40 ICC <sup>φ</sup> : 18 EH <sup>φ</sup> : 22	Male: 20%	Total: 42-75yrs (58.35±9.12)	ICC <sup>φ</sup> : 45% EH <sup>φ</sup> : 55%	N.R	Overdenture 100%	Immediate loading	1 yr	ICC <sup>φ</sup> : 1 EH <sup>φ</sup> : 0
Clin Oral Implants Res Moberg et al./ 2001	Parallel	Total: 40 ICC <sup>φ</sup> : 20 EH <sup>φ</sup> : 20	Total: 208 ICC <sup>φ</sup> : 106 EH <sup>φ</sup> : 102	Male: 50%	ICC <sup>φ</sup> : 40.2-77.2yrs (64.0±6.8) EH <sup>φ</sup> : 44.2- 75.2yrs (62.6±7.0)	ICC <sup>φ</sup> : 51% EH <sup>φ</sup> : 49%	N.R	Total rehab. 100%	Late load	3 yrs	ICC <sup>φ</sup> : 1 EH <sup>φ</sup> : 2
Clin Oral Implants Res Penarrocha-Diago et al./ 2013	Parallel	Total: 15 ICC <sup>φ</sup> : N.R EH <sup>φ</sup> : N.R	Total: 120 ICC <sup>φ</sup> : 64 EH <sup>φ</sup> : 56	N.R	N.R yrs	N.R	N.R	Total rehab. Overdenture N.R	Late load	1 yr	ICC <sup>φ</sup> : 1 EH <sup>φ</sup> : 1
Clin Implant Dent Relat Res Pessoa et al./ 2016	Split- mouth	Total: 12 ICC <sup>φ</sup> : NR EH <sup>φ</sup> : NR	Total: 24 ICC <sup>φ</sup> : 12 EH <sup>φ</sup> : 12	Male: 25%	Total: 48-75yrs (68.08±10.36)	ICC <sup>φ</sup> : 50% EH <sup>φ</sup> : 50%	N.R	Total rehab. 100%	Immediate loading.	1 yr	ICC <sup>φ</sup> : 0 EH <sup>φ</sup> : 0
Eur J Oral Implantol Pozzi et al./ 2014	Split- mouth	Total: 34 ICC <sup>φ</sup> : 34 EH <sup>φ</sup> : 34	Total: 88 ICC <sup>φ</sup> : 44 EH <sup>φ</sup> : 44	Male: 44.1%	Total: 39-59 yrs (52.2±5.3)	ICC <sup>φ</sup> : 50% EH <sup>φ</sup> : 50%	N.R	Unitary rehab. ICC <sup>φ</sup> : 44 EH <sup>φ</sup> : 44	Late load	1 yr 3 yrs	ICC <sup>φ</sup> : 0 EH <sup>φ</sup> : 0
Clin Oral Implants Res Ravald et al./ 2013 <sup>4,3</sup>	Parallel	1 yr Total: 66 ICC <sup>φ</sup> : 33 EH <sup>φ</sup> : 43 12 yrs Total: 46 ICC <sup>φ</sup> : 25 EH <sup>φ</sup> : 21	Total: 362 ICC <sup>φ</sup> : 184 EH <sup>φ</sup> : 187	Male: 41.3%	ICC <sup>φ</sup> : 51-88yrs (73.1±N.R) EH <sup>φ</sup> : 66-88yrs (75.7±N.R)	ICC <sup>φ</sup> : 85(46.5%) EH <sup>φ</sup> : 80(42.8%)	ICC <sup>φ</sup> : 99(53.8%) EH <sup>φ</sup> : 107(57.2%)	Total rehab. 100%	Late load	1 yr 12 yrs	1 yr ICC <sup>φ</sup> : 1 EH <sup>φ</sup> : 8 12yrs ICC <sup>φ</sup> : 8 EH <sup>φ</sup> : 10

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**Table 3.** Summary of the studies selected for this systematic review for purposes of  $\Delta$ MBL comparison between External Hexagon (EH) and Conical Internal Connection (ICC). (n = 16)

Journal/Author/Year	Marginal Bone Level (MBL) (Mean $\pm$ SD)	Marginal Bone Loss ( $\Delta$ MBL) (Mean $\pm$ SD)	Mean probing depth (PD) (mean $\pm$ SD)	n (%) Survive rate absolute
Clin Implant Dent Relat Res Astrand et al./ 2004 <sup>44</sup>	Baseline = Loading = Implant placement ICC <sup>o</sup> : (-0.60 $\pm$ 0.83) EH <sup>o</sup> : (-1.01 $\pm$ 1.02) 1yr ICC <sup>o</sup> : (-1.48 $\pm$ 1.26) EH <sup>o</sup> : (-1.66 $\pm$ 1.04) 3yrs ICC <sup>o</sup> : (-1.41 $\pm$ 1.54) EH <sup>o</sup> : (-1.18 $\pm$ 0.91)	Baseline-1yr p: N.R ICC <sup>o</sup> : (-0.95 $\pm$ 1.37) EH <sup>o</sup> : (-0.64 $\pm$ 0.97) Baseline-3yr p=0.0035 ICC <sup>o</sup> : (-0.89 $\pm$ 1.65) EH <sup>o</sup> : (-0.16 $\pm$ 1.06) 1yr-3yr p= No significant ICC <sup>o</sup> : (-0.06 $\pm$ 1.32) EH <sup>o</sup> : (0.39 $\pm$ 0.82)	N.R	1yr ICC <sup>o</sup> : 113 (96.6%) EH <sup>o</sup> : 79 (96.3%) 3yrs ICC <sup>o</sup> : 80 (95.7%) EH <sup>o</sup> : 63 (96.3%)
Eur J Oral Implantol Arnhart et al./ 2012 <sup>32</sup>	Baseline = loading ICC <sup>o</sup> : (1.4 $\pm$ 0.33) EH <sup>o</sup> : (1.8 $\pm$ 0.11) 1yr ICC <sup>o</sup> : (1.6 $\pm$ 0.30) EH <sup>o</sup> : (2.0 $\pm$ 0.23) 3yrs ICC <sup>o</sup> : (1.3 $\pm$ 0.27) EH <sup>o</sup> : (1.8 $\pm$ 0.13)	Baseline- 1yr not significance ICC <sup>o</sup> : (-0.2 $\pm$ 0.16) EH <sup>o</sup> : (-0.2 $\pm$ 0.09) Baseline-3yrs not significance ICC <sup>o</sup> : (0.2 $\pm$ 0.25) EH <sup>o</sup> : (0.1 $\pm$ 0.09) 1yr-3yrs ICC <sup>o</sup> : (0.29 $\pm$ 0.19) EH <sup>o</sup> : (0.28 $\pm$ 0.08)	N.R	1yr ICC <sup>o</sup> : 76 (98.7%) EH <sup>o</sup> : 71 (97.3%) 3yrs ICC <sup>o</sup> : 75 (97.3%) EH <sup>o</sup> : 71 (97.3%)
Implant Dent Bilhan et al./ 2010	Baseline = Implant placement = Loading ICC <sup>o</sup> : N.R Implant placement ICC <sup>o</sup> : N.R EH <sup>o</sup> : N.R Baseline = Prosthesis delivery = Loading ICC <sup>o</sup> : N.R EH <sup>o</sup> : N.R	Baseline-2yr ICC <sup>o</sup> : (0.66 $\pm$ 0.1mm) p<0.05 EH <sup>o</sup> : (1.1 $\pm$ 0.1mm) p<0.05 ICC <sup>o</sup> : (0.8 $\pm$ 0.1mm) p>0.05	N.R	2yrs ICC <sup>o</sup> : 42 (100%) EH <sup>o</sup> : 36 (100%) ICC <sup>o</sup> : 29 (100%)
Clin Implant Dent Relat Res Cehreli et al./ 2010	Implant placement N.R Baseline = Prosthesis delivery = Loading N.R 5yrs N.R	Baseline-5yrs p=0.002 ICC <sup>o</sup> : (0.73 $\pm$ 0.06) EH <sup>o</sup> : (1.21 $\pm$ 0.1)	N.R	5yrs ICC <sup>o</sup> : 24 (100%) EH <sup>o</sup> : 20 (100%)
Int J Periodontics Restorative Dent Cooper et al./ 2016	Baseline = Implant Placement N.R loading N.R 1yr N.R 3yrs N.R	Baseline-loading ICC <sup>o</sup> : (0.53 $\pm$ 0.43) EH <sup>o</sup> : (1.11 $\pm$ 0.91) Baseline-1yr ICC <sup>o</sup> : (-0.48 $\pm$ 0.55) EH <sup>o</sup> : (-0.68 $\pm$ 1.2) Baseline-3yr ICC <sup>o</sup> : (-0.25 $\pm$ 0.60) EH <sup>o</sup> : (-0.50 $\pm$ 0.93)	N.R	3yrs ICC <sup>o</sup> : 45 (95.7%) EH <sup>o</sup> : 44 (95.6%)

Continue

Continuation	Baseline= Implant placement= Loading	Tooth-Baseline	1yr
Int J Oral Maxillofac Implants Crespi et al./ 2009	N.R 1yr N.R 2yrs N.R	p<0.001 ICC <sup>a</sup> : (0.98±0.34) EH <sup>b</sup> : (0.99±0.38) Baseline-1yr p<0.001 ICC <sup>a</sup> : (0.78±0.49) EH <sup>b</sup> : (0.82±0.40) Baseline-2Yrs p<0.001 ICC <sup>a</sup> : (0.73±0.52) EH <sup>b</sup> : (0.78±0.45)	ICC <sup>a</sup> : 30 (100%) EH <sup>b</sup> : 34 (100%) 2yrs ICC <sup>a</sup> : 30 (100%) EH <sup>b</sup> : 34 (100%)
Eur J Oral Implantol Esposito et al./2016	Baseline= Implant Placement ICC <sup>b</sup> (0.10±0.24) EH <sup>b</sup> (0.21±0.45) loading ICC <sup>b</sup> (0.65±0.73) EH <sup>b</sup> (0.79±0.62) 1yr ICC <sup>b</sup> (1.03±0.87) EH <sup>b</sup> (1.23±0.93) 5yrs ICC <sup>b</sup> (1.28±1.11) EH <sup>b</sup> (1.36±1.04)	Baseline-loading p<0.001 ICC <sup>b</sup> (0.56±0.67) EH <sup>b</sup> (0.58±0.66) Baseline-1yr p<0.001 ICC <sup>b</sup> (0.94±0.84) EH <sup>b</sup> (1.00±1.03) Baseline-5yr p<0.001 ICC <sup>b</sup> (1.21±1.09) EH <sup>b</sup> (1.13±1.24)	1yr ICC <sup>b</sup> : 105 (98.13%) EH <sup>b</sup> : 95 (98.9%) 5yr ICC <sup>b</sup> : 104 (97.2%) EH <sup>b</sup> : 95 (98.9%)
Clin Implant Dent Relat Res Kaminaka et al./ 2015	Implant placement N.R Baseline=Prosthesis delivery= Loading ICC <sup>a</sup> : (0.04±0.84) EH <sup>a</sup> : (0.08±0.33) 1yr ICC <sup>a</sup> : (0.25±0.87) EH <sup>a</sup> : (1.94±0.87)	Baseline-1yr ICC <sup>a</sup> : (0.21±0.28) EH <sup>a</sup> : (1.85±0.90)	1yr ICC <sup>a</sup> : 11 (100%) EH <sup>a</sup> : 11 (100%)
J Periodontol Koo et al./ 2012	Baseline= Implant placement ICC <sup>b</sup> : (0.24±0.30) EH <sup>b</sup> : (0.25±0.38) Prosthesis delivery=Loading ICC <sup>b</sup> : (0.31±0.36) EH <sup>b</sup> : (0.85±0.40) 1yr ICC <sup>b</sup> : (0.24±0.29) EH <sup>b</sup> : (1.14±0.54)	Baseline-Loading ICC <sup>b</sup> : (0.08±0.30) EH <sup>b</sup> : (0.61±0.37) Baseline-1yr ICC <sup>b</sup> : (0.00±0.28) EH <sup>b</sup> : (0.90±0.53) Loading-1yr ICC <sup>b</sup> : (-0.07±0.21) EH <sup>b</sup> : (0.29±0.35)	1yr ICC <sup>b</sup> : 20 (100%) EH <sup>b</sup> : 20 (100%)

Continue

Continuation	Implant placement				Baseline=Prosthesis delivery=Loading				Baseline-1yr not significance				Baseline p<0.001			
	Implant	MED	Q <sub>25</sub>	Q <sub>75</sub>	LI	LS	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>
J Clin Periodontol Meijer et al./ 2009 (42,45)	N.R				N.R				ICC <sup>α</sup> : (0.3±0.6) EH <sup>α</sup> : (0.2±0.7)				1yr ICC <sup>α</sup> : 60 (100%) EH <sup>α</sup> : 59 (98.3%)			
	N.R				N.R				Baseline-2yrs not significance ICC <sup>α</sup> : (0.5±0.7) EH <sup>α</sup> : (0.6±1.1)				3yrs ICC <sup>α</sup> : 60 (100%) EH <sup>α</sup> : 59 (98.3%)			
	1yr				N.R				Baseline-3yrs not significance ICC <sup>α</sup> : (0.5±0.8) EH <sup>α</sup> : (0.4±0.9)				5yrs ICC <sup>α</sup> : 60 (100%) EH <sup>α</sup> : 59 98.3%			
	2yrs				N.R				Baseline-5yrs not significance ICC <sup>α</sup> : (0.9±0.9) EH <sup>α</sup> : (0.7±0.8)				10yrs ICC <sup>α</sup> : 60 (100%) EH <sup>α</sup> : 59 (98%)			
	3yrs				N.R				Baseline-10yrs significant ICC <sup>α</sup> : (1.3±1.1) EH <sup>α</sup> : (0.7±0.5)							
	N.R				N.R											
	5yrs				N.R											
	N.R				N.R											
	10yrs				N.R											
	N.R				N.R											
Braz Dent J Melo et al./ 2017	Baseline=Implantplacement=Loading				Baseline-1yr p=0.032				N.R				1yr ICC <sup>α</sup> : 17 (94.4%) EH <sup>α</sup> : 22 (100%)			
	Implant	MED	Q <sub>25</sub>	Q <sub>75</sub>	LI	LS	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>
	0.12	-0.27	0.55	-2.59	1.83											
	-0.34	-1.48	0.79	-1.78	1.90											
Clin Oral Implants Res Moberg et al./ 2001	N.R				N.R				N.R				3yrs ICC <sup>α</sup> : 103 (96.8%) EH <sup>α</sup> : 100 (97.9%)			
	Implant	MED	Q <sub>25</sub>	Q <sub>75</sub>	LI	LS	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>
	-0.73	-1.42	1.81	-2.14	2.54											
	-1.28	-1.98	-0.31	-2.63	1.68											
Clin Oral Implants Res Penarrocha-Diago et al./ 2013	Implant placement				Baseline-1yr				N.R				1yr ICC <sup>α</sup> : 63 (98.6%) EH <sup>α</sup> : 55 (98.6%)			
	N.R				ICC <sup>α</sup> : (0.12±0.17) EH <sup>α</sup> : (0.38±0.51)				N.R							
	Baseline=Prosthesis delivery=Loading				N.R				N.R							
Clin Implant Dent Relat Res Pessoa et al./ 2016	Baseline=Implant placement= loading				Baseline-1yrs p< 0.001				1 yr p=0.12				1yr ICC <sup>α</sup> : 12 (100%) EH <sup>α</sup> : 12 (100%)			
	Implant	MED	Q <sub>25</sub>	Q <sub>75</sub>	LI	LS	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>	ICC <sup>α</sup>	EH <sup>α</sup>
	-0.54	-0.34														
	-0.56	-0.30														

Continue

Continuation

Baseline-loading  
 p=0.000  
 ICC<sup>y</sup>: (0.37±0.23)  
 EH<sup>x</sup>: (0.95±0.56)  
 Baseline-1yr  
 p<0.061  
 ICC<sup>y</sup>: (0.51±0.34)  
 EH<sup>x</sup>: (1.10±0.52)  
 Loading-1yr p>0.776  
 ICC<sup>y</sup>: (0.14±0.20)  
 EH<sup>x</sup>: (0.16±0.19)  
 Baseline-3yr  
 p=0.000  
 ICC<sup>y</sup>: (0.67±0.39)  
 EH<sup>x</sup>: (1.24±0.47)  
 Loading-3yr  
 p=0.832  
 ICC<sup>y</sup>: (0.28±0.39)  
 EH<sup>x</sup>: (0.30±0.57)

Baseline=Implant placement  
 ICC<sup>y</sup>: (0.16±0.28)  
 EH<sup>x</sup>: (0.05±0.30)  
 Prosthesis delivery=loading  
 ICC<sup>y</sup>: (0.54±0.28)  
 EH<sup>x</sup>: (0.99±0.38)  
 1yr  
 ICC<sup>y</sup>: (0.68±0.34)  
 EH<sup>x</sup>: (1.15±0.34)  
 3yr  
 ICC<sup>y</sup>: (0.83±0.27)  
 EH<sup>x</sup>: (1.29±0.42)

Eur J Oral Implantol  
 Pozzi et al./ 2014

N.R

1yr  
 ICC<sup>y</sup>: 44 (100%)  
 EH<sup>x</sup>: 44 (100%)  
 3 yrs  
 ICC<sup>y</sup>: 44 (100%)  
 EH<sup>x</sup>: 44 (100%)

	12yrs Frequency%		
	1-3 mm	4-5 mm	≥ 6 mm
Maxilla	ICC <sup>m</sup>		
Baseline-1yr			
p: N.R			
ICC <sup>m</sup> : (-0.22±0.14)	Maxillary 49	32	19
EH <sup>o</sup> : (-0.03±0.0)	Mandible 66	23	11
Baseline-1yr	EH <sup>o</sup>		
p: N.R			
ICC <sup>m</sup> : (-0.31±0.16)	Maxillary 47	50	3
EH <sup>o</sup> : (-0.31±0.09)	Mandible 70	26	4
Baseline-12yrs	p-values: ICC <sup>m</sup> maxillary vs. EH <sup>o</sup>		
p: N.R	maxillary= 0.475.		
ICC <sup>m</sup> : (-0.67±1.18)	ICC <sup>m</sup> mandible vs. EH <sup>o</sup> mandible =		
EH <sup>o</sup> : (-0.42±0.81)	0.467.		
Implant placement	N.R		
Baseline=Prosthesis delivery=Loading	N.R		
1yr	N.R		
5yrs	N.R		
12yrs	N.R		
Clin Oral Implants Res	N.R		
Ravald et al./ 2013 (43)	N.R		
1yr	ICC <sup>m</sup> : 183 (99.5%)		
EH <sup>o</sup> : 179 (95.7%)	EH <sup>o</sup> : 177 (94.7%)		
12 yrs	ICC <sup>m</sup> : 176 (95.5%)		
EH <sup>o</sup> : 177 (94.7%)	EH <sup>o</sup> : 177 (94.7%)		

N.R: Not reported; ICC: Internal conical connection; EH: Exagon EA22;E24;external; Yr: Year; Yrs: Years; No: Number. <sup>o</sup>Neodent<sup>o</sup>/Titanax; <sup>o</sup>UNITITE<sup>o</sup>, SIN – Sistema de Implante, São Paulo, Brazil; <sup>o</sup>Nobel Active, NA Internal; Nobel Biocare AB; <sup>o</sup>Nobel Speed Groovy, NA External; Nobel Biocare AB; <sup>o</sup>Oneplant, Warantec, Seoul, Korea; <sup>o</sup>Astra Tech AB, Molndal, Sweden; <sup>o</sup>Branemark<sup>o</sup> - Nobel Biocare AB, Göteborg, Sweden; <sup>o</sup>TI implant system (Straumann<sup>o</sup> -Institute Straumann AG,Basel, Switzerland). <sup>o</sup>Inhex<sup>o</sup>, Mozo-Grau, S.L.V., Spain; <sup>o</sup>Osseous<sup>o</sup>, Mozo-Grau, S.L.V., Spain.

## Individual studies-associated bias

The quality assessment of randomized clinical trials selected were conducted in an independent and individual manner by three trained and calibrated reviewers (ECR, CMS and TL) that used the Cochrane Collaboration RoB 2.0 tool to evaluate the risk of bias in randomized studies.<sup>31</sup> Such tool is comprised of seven criteria including a) random sequence generation, b) allocation concealment, c) selective reporting, d) other source of bias, e) blinding (participants and personnel) and f) incomplete outcome data, where in randomization and allocation (items a and b, respectively) were considered key-domains.

Manuscripts included in the present research were then classified as being associated with either “low” (green and positive), “high” (red and negative) or “unclear” (yellow and question mark) risk of bias according to Cochrane’s Handbook for Systematic Reviews of Interventions (V 5.1.0, publicly available at <http://handbook.cochrane.org>). The classification described was based on allocation concealment and random sequence generation (key-domains). Studies classified as “low risk of bias” described and presented both key domains, studies classified as “high risk of bias” described but didn’t present either one or both of the key domains and, studies classified as “unclear risk of bias” didn’t describe and present one or both key-domains.

## Results

Data of the studies classified as “low risk of bias” or “unclear risk of bias” were meta-analyzed using the Review Manager software (V. 5.3, Cochrane Collaboration, The Nordic Cochrane Center, Copenhagen, Denmark). A total of 8,851 studies were found by the research strategy described. After the removal of duplicated studies, the total number of manuscripts included was reduced to 6,382 studies. Six additional studies<sup>26,29,32,33,34,35</sup> extracted from other data bases were added to that number to result in a total of 6,388 studies. After the dynamic reading of titles and abstracts, the total number of studies was further reduced to 641 and 29, respectively. Full-texts of manuscripts were obtained to evaluate the studies according to the inclusion and exclusion

criteria of the present study. Eight studies were excluded, wherein, four studies<sup>36,37,38,39</sup> were not comparing between EH and IC, one study was not open access<sup>40</sup> and three other studies described patients that received bone grafts as part of their oral rehabilitation treatments.<sup>23,25,41</sup> From the remaining 21 studies, five<sup>32,42,43,44,45</sup> were longitudinal with distinct follow-up periods, and therefore, displayed overlap of data-sets and patient-related information. These manuscripts were referenced in tables 2 and 3 of the present study. Thus, data from only 16 studies<sup>26,27,28,29,33,34,35,46,47,48,49,50,51,52,53,54</sup> were included for the meta-analysis portion of the study.

The results shown in Table 2 were alphabetically sorted in terms of authors’ last names to facilitate the distribution and visualization of data. Parallel studies (n = 13)<sup>26,28,33,34,35,46,48,49,50,51,52,54</sup> have prevailed in the present systematic review of the literature. Only 3 studies<sup>27,47,53</sup> were associated with a split-mouth experimental design. The total number of participants in the studies selected ranged between 12 and 206. The total number of patients considered in the present study was 841. Only one study<sup>34</sup> did not include the total number of patients treated with either EH or IC. The total number of dental implants placed considered in the present study was 1885. The number of implants placed per group ranged from 12 (both EH<sup>53</sup> and IC) up to 184/187 (IC/EH, respectively).<sup>54</sup>

Considering the age and gender of participants, the percentage of men ranged from 21.4 to 70%, and the mean age reported also varied amongst the studies selected, ranging from 48.73 to 74.4 years of age. In regards to implant placement localization (either superior or inferior arches), nine studies<sup>28,29,33,34,35,46,48,50,54</sup> had implants placed in both of the arches, six studies<sup>26,27,49,51,52,53</sup> placed implants only in the mandibular bone and one study<sup>47</sup> described implants being place only in the maxilla. Another important variable investigated was the type of prosthetic implant-supported rehabilitation. Two studies<sup>47,48</sup> described the utilization of fixed partial prosthesis, five studies<sup>27,28,34,35,50</sup> described fixed single-units, three studies<sup>52,53,54</sup> described overdentures, three studies<sup>29,33,46</sup> described implant-supported total fixed rehabilitation and finally, three

studies<sup>29,33,46</sup> described a combination of techniques. In regard to the functional loading of the implants placed, the studies reported immediate ( $n = 3$ )<sup>26,46,53</sup>, premature ( $n = 1$ )<sup>49</sup> and delayed ( $n = 9$ )<sup>27,33,34,35,47,50,51,52,54</sup>. Other three studies<sup>28,29,48</sup> described a combination of loading techniques.

In regards to follow-up periods after implant placement, the following information could be extracted: five studies<sup>26,33,34,50,53</sup> assessed their patients one year after functional loading, one study<sup>48</sup> assessed their patients two years and one study<sup>48</sup> assessed their patients at one and two years after implants placement. Other two studies<sup>35,52</sup> reported data for 3 years of follow-up and three studies<sup>27,46,47</sup> reported data collected at 1 and 3 years after placement, two studies<sup>29, 49</sup> reported data after 5 years of placement and only one study<sup>51</sup> reported data for 1 ½ and 10 years. Finally, only one study<sup>54</sup> reported follow-up data from 1 and 12 years. Data regarding lost implants per groups have demonstrated that seven studies<sup>28,34,48,49,50, 53,54</sup> have reported no losses. The remaining studies<sup>29,33,35,46,47,51,52,54</sup> reported a total of 22 and 24 implants for IC and EH, respectively.

Table 3 shows the results from the radiographic assessment of  $\Delta$ MBL in each follow-up period. The functional loading baseline determination was also observed to vary depending on the studies. Five studies<sup>27,29,35,50,52</sup> considered the placement of implant (without functional loading), other five studies<sup>26,28,46,48,53</sup> considered implants with immediate functional loading and six studies<sup>33,34,47,49,51,54</sup> considered the moment of prosthesis as their baseline. In 9 studies<sup>26,28,33,35,48,49,51,52,54</sup>  $\Delta$ MBL data was not recorded. In regards to  $\Delta$ MBL, higher mean values were detected for EH at one year ( $1.85 \pm 0.9$  mm),<sup>34</sup> three years ( $0.5 \pm 0.93$  mm)<sup>35</sup> and five years ( $1.21 \pm 0.1$  mm)<sup>49</sup> of follow-up. The highest values of  $\Delta$ MBL observed for IC at one, three and five years of follow-up were  $0.95 \pm 1.37$  mm,  $0.89 \pm 1.65$  mm and  $1.21 \pm 1.09$  mm, respectively.

In regards to probing depth (PD) only two manuscripts<sup>51,53</sup> have provided sufficient data for the meta-analysis. One study<sup>51</sup> has demonstrated that the highest PD values for EH and IC, within one year, were  $3.1 \pm 0.6$  mm and  $2.5 \pm 0.5$  mm, respectively. Seven studies<sup>27,28,34,48,49,50,51,52,53</sup> have reported 100% of

implant survival rates after one-year for both types of implant-pillar connections (EH and IC). Two studies have demonstrated the lowest one-year survival rates for EH (97.7%)<sup>54</sup> and IC (94.4%)<sup>26</sup> amongst all manuscripts. For 3-year survival rates, the lowest values observed were 95.6%<sup>35</sup> and 95.7%<sup>35,46</sup> for EH and IC, respectively. Finally, the lowest values of 5-year survival rates were found for EH (98.3%)<sup>51</sup> and IC (97.2%)<sup>29</sup> implants.

### Assessment of bias risk

The assessment of bias risk associated with the manuscripts selected is shown in Figure 2. The random sequence generation and allocation concealment were determined as key-domains in the present study. Ten studies<sup>28,33,47,48,49,50,51,52,53,54</sup> did not report the methodology used during the processes of randomization and/or allocation of implants, and therefore, were classified as “unclear risk of bias”. Two studies<sup>26,34</sup> did not perform the randomization and the allocation concealment of implants, and therefore, were classified as “high risk of bias”. Finally, four studies<sup>27,29,35,46</sup> have adequately reported the methodologies for the randomization and/or allocation of implants, and therefore, were classified as “low risk of bias”.

### Meta-analysis

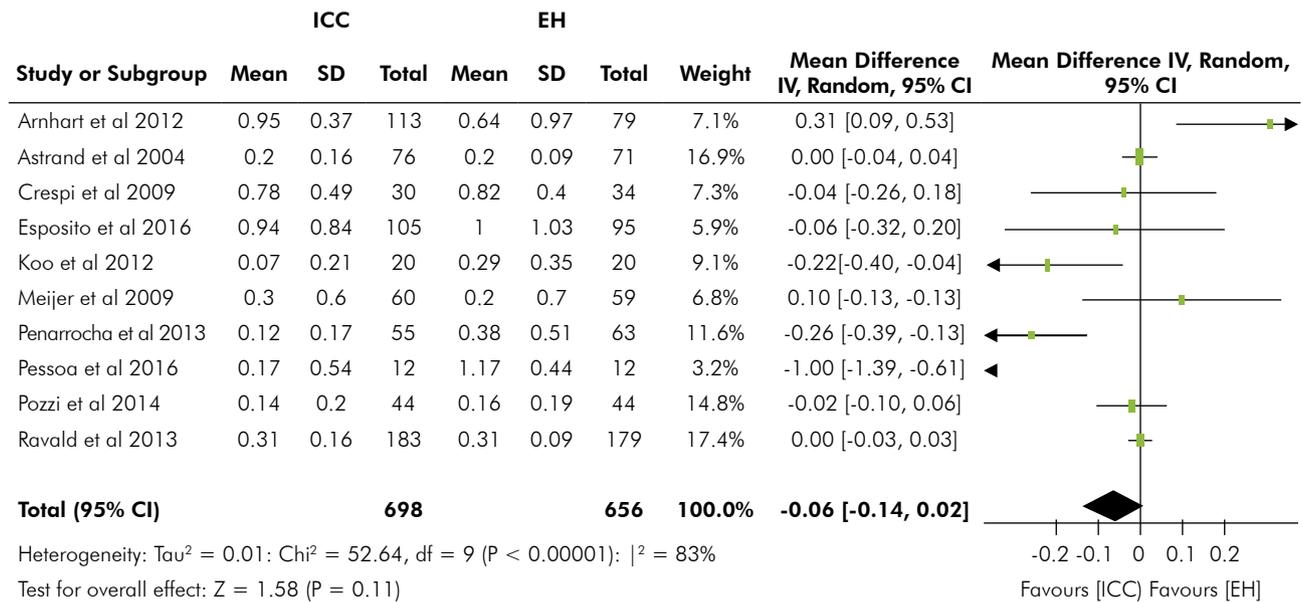
The meta-analysis was performed using the results extracted from studies classified either as a “low” or “unclear” risk of bias, which included complete follow-up outcomes for  $\Delta$ MBL and survival rates (1, 3 and 5 years), and PD values (one year).

### Marginal bone loss ( $\Delta$ MBL)

The first  $\Delta$ MBL analysis included 10 studies<sup>27,28,29,33,46,47,50,51,53,54</sup> with one year of follow-up. The difference between median values (MD) was -0.06 with a 95% confidence interval from - 0.14 to 0.02 ( $p=0.11$ ). As denoted in Figure 3, the analyzed data set was heterogeneous ( $\text{Tau}^2 = 0.01$  e  $\text{Chi}^2 = 52.64$ ,  $p < 0.00001$ ;  $I^2 = 83\%$ ). The analysis of data sensitivity could not indicate which study has skewed the results. Statistical significant differences among the groups was not found, thereby demonstrating that there is no significant  $\Delta$ MBL differences between EH and IC after one year of prosthetic functional loading.

Author/Year	Adequate sequence generation?	Allocation concealment?	Incomplete outcome data addressed?	Free of selective outcome reporting?
Arnhart et al./ 2012 <sup>46</sup>	+	+	+	+
Astrand et al./ 2004 <sup>47</sup>	+	?	+	+
Bilhan et al./ 2010 <sup>48</sup>	?	?	+	+
Cehreli et al./ 2010 <sup>49</sup>	?	+	-	+
Cooper et al./ 2016 <sup>35</sup>	+	+	+	+
Crespi et al./ 2009 <sup>28</sup>	?	?	+	+
Esposito et al./2016 <sup>29</sup>	+	+	+	+
Kaminaka et al./2015 <sup>34</sup>	-	-	+	+
Koo et al./ 2012 <sup>50</sup>	?	?	+	+
Meijer et al./ 2009 <sup>51</sup>	?	+	+	+
Melo et al./ 2017 <sup>26</sup>	-	-	+	+
Moberg et al./ 2001 <sup>52</sup>	?	?	+	?
Penarrocha-Diago et al./ 2013 <sup>33</sup>	+	?	+	+
Pessoa et al./ 2016 <sup>53</sup>	+	?	+	+
Pozzi et al./ 2014 <sup>27</sup>	+	+	+	+
Ravald et al./ 2013 <sup>54</sup>	+	?	+	+

**Figure 2.** Summary of the risk of bias assessment according to the Cochrane Collaboration tool.



**Figure 3.** Marginal bone loss after 1 year.

Five 3-year follow-up studies<sup>27,35,46,47,51</sup> were included for the ΔMBL analysis. According to the results obtained, the differences of MD values was 0.08 with 95% confidence interval from -0.10 to 0.27 (p = 0.38). As denoted in Figure 4, the analyzed data set was heterogeneous (Tau<sup>2</sup> = 0.03 e Chi<sup>2</sup> = 12.80, p=0.01; I<sup>2</sup> = 69 %). The analysis of data sensitivity was not able to discriminate which study skewed the results and no statistical differences were observed between EH and IC for ΔMBL at 3 years of follow-up.

Insert Figure 4

The analysis of ΔMBL, three studies<sup>29,49,51</sup> of 5 years of follow-up were included in the present study, wherein the differences among MD values was -0.08 with confidence interval of 95% from -0.59 to 0.42 (p = 0.74). As denoted in Figure 5, the analyzed data was found to be heterogeneous (Tau<sup>2</sup>= 0.18 e Chi<sup>2</sup> = 28.91 p<0.00001; I<sup>2</sup> = 93 %). These results lead to a sensitivity analysis and the removal of 1 study.<sup>49</sup>

After that procedure, the remaining studies became homogenous, but no significant statistical differences were observed.

### Implant survival rates

The assessment of implant survival rates included 10 studies<sup>27,28,29,33,46,47,50,51, 53,54</sup> with one year of follow-up. The relative risk (RR) was 1.01 with confidence interval of 95% varying from 1.00 to 1.03 (p = 0.18). As denoted in Figure 6, the data set analyzed did not result in heterogeneity (Tau<sup>2</sup>= 0.00 e Chi<sup>2</sup>= 4.93, p=0.84; I<sup>2</sup>=0%). Statistical significant differences were not found between implants pertaining to both EH and IC. An additional survival rate analysis included 5 studies<sup>27,35,46,47,51</sup> with 3 years of follow-up. The RR was 0.99 with confidence interval of 95% varying from 0.96 and 1.03 (p = 0.63). As denoted in Figure 7, the data set was found to be heterogeneous (Tau<sup>2</sup>= 0.00 e Chi<sup>2</sup> =

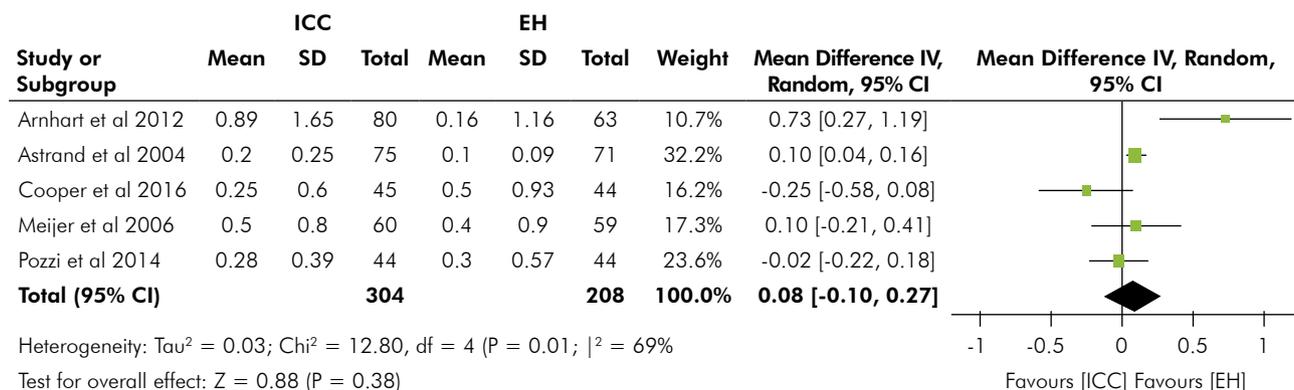


Figure 4. Marginal bone loss after 3 years.

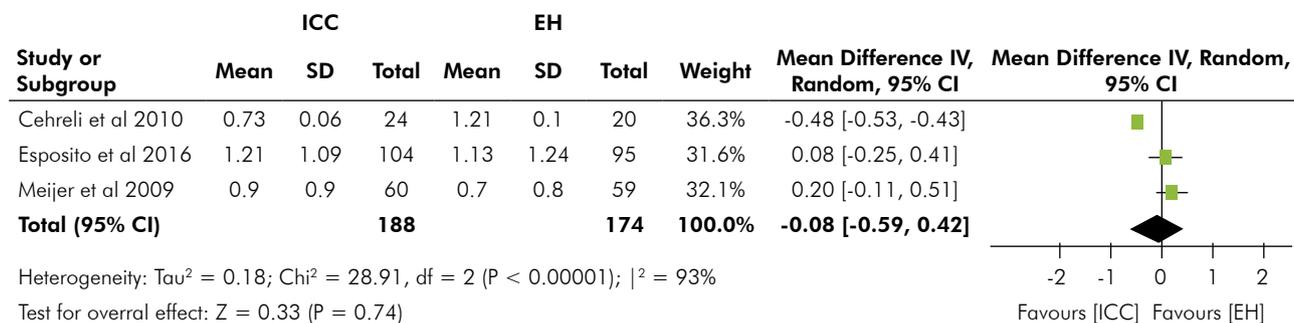


Figure 5. Marginal bone loss after 5 years.

8.25,  $p = 0.08$ ;  $I^2 = 52\%$ ). The sensitivity analysis led to the removal of one manuscript, which resulted in the attainment of zero heterogeneity of data. No statistical significant differences were observed for implants of EH or IC in 3-year follow-up studies.

Finally, three studies<sup>29,49,51</sup> with 5 years of follow-up were included in the analysis of implant survival rates. The RR was 0.99 with confidence interval of 95% varying from 0.98 to 1.02 ( $p = 0.62$ ). The data set was not heterogeneous ( $\text{Tau}^2 = 0.00$  e  $\text{Chi}^2 = 0.19$ ,  $p = 0.91$ ;  $I^2 = 0\%$ ), as shown in Figure 8 and no statistical

differences were observed between the survival rates of implants of EH or IC.

### Probing Depth (PD)

The analysis of PD included 2 studies<sup>51,53</sup> with 1 year of follow-up. The difference of median values was -0.53 with confidence interval of 95% from -0.82 to 0.24 ( $p = 0.0004$ ). The data was not heterogeneous ( $\text{Tau}^2 = 0.02$  e  $\text{Chi}^2 = 1.28$   $p = 0.26$ ;  $I^2 = 22\%$ ), as can be observed in Figure 9. Significant statistical differences were observed between EH and IC, wherein better

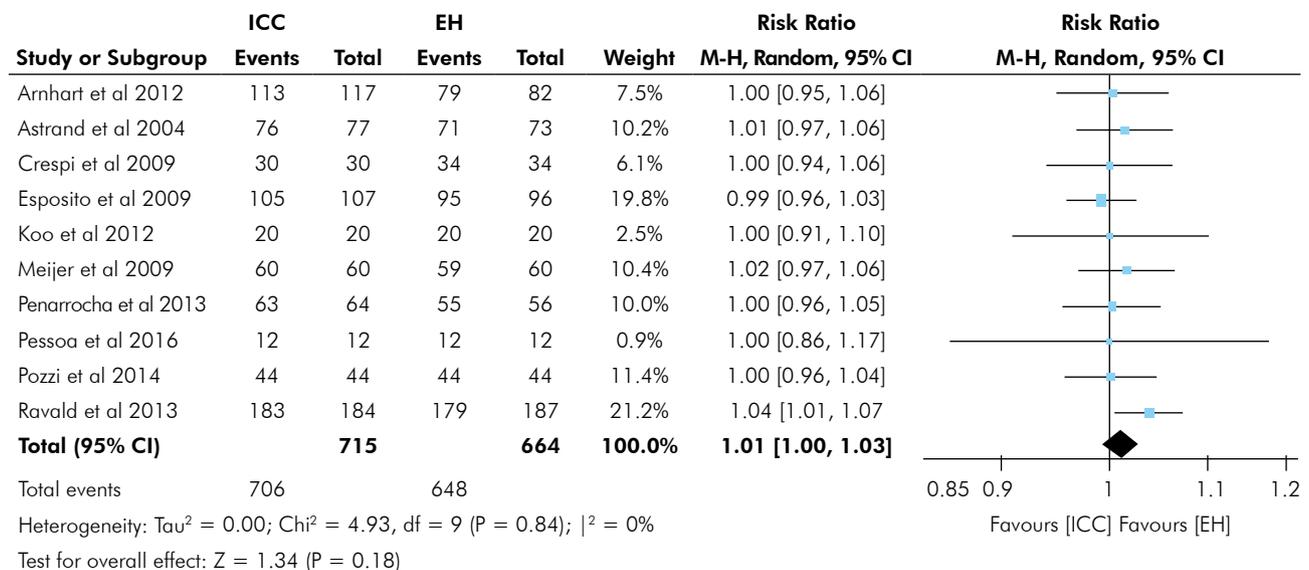


Figure 6. Implant survival rates after 1 year.

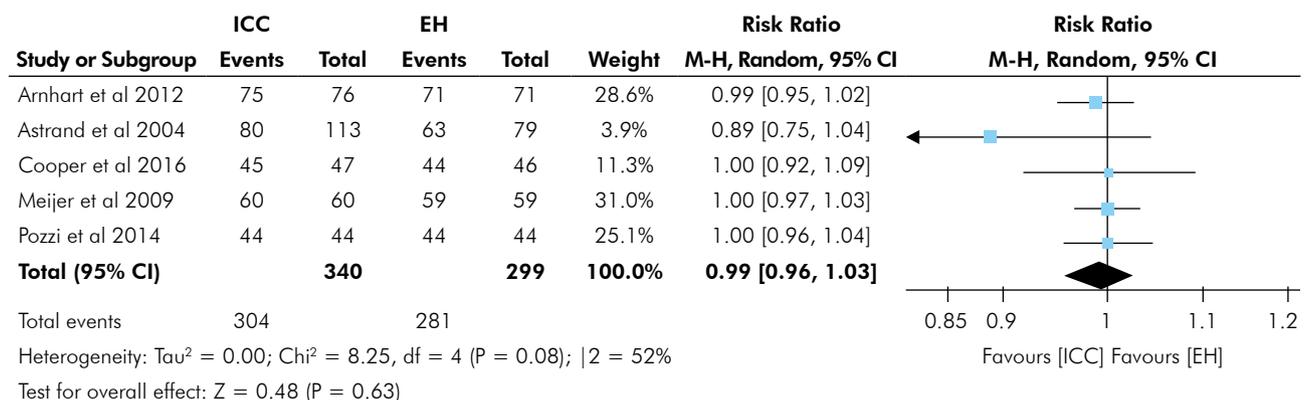
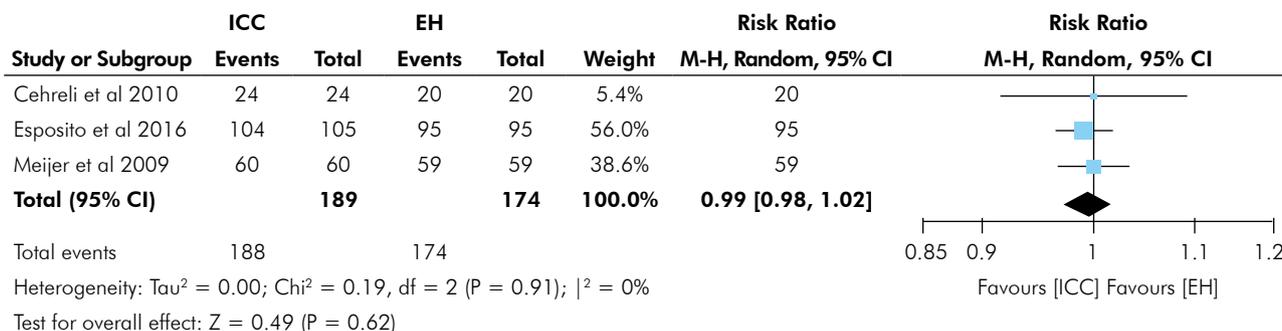
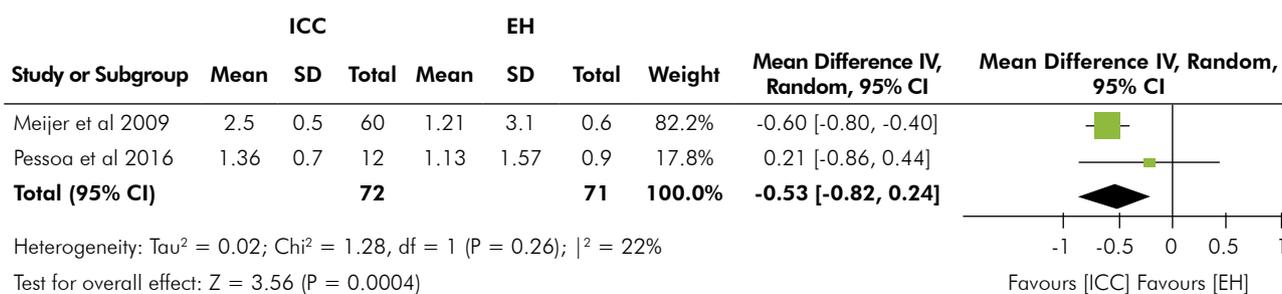


Figure 7. Implant survival rates after 3 years.



**Figure 8.** Implant survival rates after 5 years.



**Figure 9.** Probing depth after 1 year.

PD values were observed for implants pertaining to the IC group.

## Discussion

The present systematic review of the literature had the primary objective to identify which implant-pillar connection provides with the lowest ΔMBL values after the installation of the prosthesis and the beginning of implants functional loading.

The question regarding which type of implant-pillar connection is better regarding peri-implant marginal bone loss is justifiable because 35% of the worldwide population is edentulous, and dental implants are considered the only type of oral rehabilitation strategy capable of restoring the masticatory function, deglutition and speech, and is capable of maintaining bone level while displaying superior levels of prosthesis stability and remarkable social and psychological well-being.<sup>1,55</sup> Initially, implants with EH connections were considered the first option amongst clinicians. However, with the evolution

of materials and implant designs, IC became the most common type of implants used due to their superior biological and biomechanical properties.<sup>16</sup> It has been previously shown that the superior biomechanical results reported for IC implants are associated with more adequate distribution of masticatory forces in the longitudinal-axis of the pillar-implant-bone complex which results in enhanced biological properties due to a better separation between the micro-sized gap and bone that respects the requirements for a healthy biological space.<sup>56</sup>

The results of the present systematic review at one-year ΔMBL have demonstrated that no significant statistical differences were observed among the groups. However, the results from the meta-analysis has detected high heterogeneity levels among the studies investigated. Such behavior could not be explained by the sensitivity analysis probably because of the different types of prosthetic rehabilitation techniques, different placement locations and functional loading baselines.<sup>29</sup> Other factors that might have contributed for the observation of such results are related to

implant design, surface treatment and presence or absence of short platforms.<sup>33,46,50</sup>

The heterogeneity observed during the meta-analysis of 3-year follow-up studies in regard to  $\Delta$ MBL values, can be partially explained by the diversity of functional loading protocols, types of prosthetic rehabilitations, implant design and surface treatments. Even with such heterogeneity of results, no statistical significant differences were observed for  $\Delta$ MBL between EH and IC implants. The findings of the present study have been corroborated by previous studies published by Ganeles et al.<sup>57</sup> and Esposito et al.<sup>58</sup> The  $\Delta$ MBL values after 5 years of follow-up reported in the study published by Cehreli et al.<sup>49</sup> have rendered the meta-analysis data of the present study as heterogeneous. This trend could have happened because of the premature functional loading of overdenture prosthetic restorations. When these results were removed from the present meta-analysis, the results became homogenous.

High levels of heterogeneity were also observed for studies with 3 years of follow-up. The sensitivity analysis indicated that data extracted from the manuscript published by Astrand et al.<sup>47</sup> was the sole responsible for such a trend. These results could be explained by the location restriction imposed by the assessment of that particular manuscript, that only investigated dental implants placed in the maxillary bone (less dense and more trabecular in nature). It well-known that lack of bone density can adversely impact the obtained results because of the rise of tensile forces at peri-implant locations that may lead to significant  $\Delta$ MBL.<sup>59</sup>

For the 1 and 5-year survival rates (homogenous data sets for both time-periods), no statistical differences could be detected between EH and IC. The assessment of PD values indicated that IC implants were associated with better values (statistically significant differences). However, the results were only associated with a mild heterogeneity that might be explained by the small number of studies analyzed ( $n = 2$ ).<sup>51,53</sup> Two systematic review studies<sup>60,61</sup> recently published have reported findings for EH and IC that do not corroborate the results of the present study. Nonetheless, the present study had a more robust

and broader search strategy and covered studies without any language restrictions for follow-up assessments of 1, 3 and 5 years after the prosthetic loading of implants. The manuscripts investigated in the present systematic review study were used to compare the results between implants of EH or IC connections, where studies that utilized bone grafts as part of their treatment plans were excluded from the present analysis.

Marginal bone loss can be influenced by other factors than implant-pillar connection, including other technical differences such as implant design,<sup>62</sup> reduced platform,<sup>41,63,64</sup> micron-sized gap position<sup>18,65</sup> and surface treatment.<sup>66,67,68,69</sup> These factors combined, may have directly influenced the  $\Delta$ MBL<sup>16</sup> and the heterogeneity of the results of the present systematic review of the literature. According to the retrospective study recently published by Galindo-Moreno et al.,<sup>62</sup> the microstructure or the design of the implant adversely impacted the  $\Delta$ MBL in peri-implant areas, possibly due to the generation of unbalanced tensile forces in the long-axis of the implant fixture. Some clinical studies included in the present systematic review have compared implants of distinct connections, similar microstructures and identical surface treatments,<sup>29,46,50,53</sup> which might have decreased the heterogeneity associated with the studies investigated. Nonetheless, the majority of the studies included described the use of implants of different designs and surface treatments. These types of surface treatment may positively influence the osseointegration of dental implants, may upregulate the adhesion and proliferation of osteoblastic cells and may even increase the surface area available for attachment.<sup>66,67,68,69</sup>

Another important point that must be considered is the presence of reduced implant platforms. These might have generated some of the differences detected among the manuscripts investigated in the present study. Some of these studies have correlated low  $\Delta$ MBL values with the presence of reduced implant platforms.<sup>41,63,64,70,71</sup> From all the studies investigated, only 3 studies<sup>33,46,50</sup> have compared EH and IC implants with reduced platforms, while other studies<sup>27,28,49</sup> have IC implants with or without reduced platforms, thus increasing the difficulty

levels associated with interpretation of results. Bacterial penetration and biofilm formation at the micro-sized gap is another relevant point that may adversely influence the results between different types of implant connections. The position of the micron-sized gap at the implant-pillar connection has been recognized to generate  $\Delta$ MBL and intense bone remodeling, through a saucerization process, due to its close proximity to the cortical bone.<sup>18,65,72,73</sup>

The types of prosthetic rehabilitation strategies described (fixed partial or total, single unit and overdenture) in the clinical trials selected is another relevant topic that must be underscored, because each type of technique results in unique masticatory dynamics and particular hygiene procedures.<sup>74,75</sup> Moreover, a large variability of functional loading protocols were described in the manuscripts selected. These factors combined, might have impacted the ability of the authors to significant statistical differences among the types of implants analyzed and functional loading baselines (immediate, premature or delayed).<sup>75,8</sup>

The experimental methodology utilized by the majority of the studies selected was based on the assessment of periapical radiographies. It is well-known that in order to correctly perform these types of measurements, it is necessary to calibrate and standardize the evaluators prior to the execution of the study.<sup>21,22</sup> Significant limitations of radiographic assessments are associated with the flattening of 3-dimensional structures into a 2-dimensional plane. Three-dimensional computer tomography (CT-scan)<sup>21</sup> has been shown to provide with high-resolution and high-quality digital images that allow for the precise assessment of marginal bone levels at all peri-implant areas.<sup>23</sup> Therefore CT-scans are currently considered as

the preferred type of digital image assessment for dental implants.

Despite these promising characteristics, several studies have demonstrated that CT-scans and intraoral radiographies are associated with comparable levels of precision during the determination of mesial and distal bone heights. The lack of standardization in regards to the type of  $\Delta$ MBL image assessment (either radiographic or tomographic) is considered one the limitations detected by the present systematic review, once distinct types of techniques were utilized including the parallel technique (n = 7),<sup>29,33,35,46,48,53,54</sup> custom parallel technique (n = 6),<sup>26,27,28,47,50,51</sup> panoramic X-ray (n = 2)<sup>48,49</sup> and only one study<sup>34</sup> used tomographic assessment. These findings further demonstrate the lack of standardization observed in the literature regarding the assessment of  $\Delta$ MBL in peri-implant areas. These results can be partially used to explain the high heterogeneity levels observed among the groups investigated.

Finally, in its vast majority, the investigated studies did not report their findings according to the CONSORT statement. Only three studies<sup>27,29,46</sup> have followed this declaration in their reports, which suggest the needed for randomized clinical trials that are better designed and conducted.

## Conclusions

This present systematic review demonstrated that there are no significant differences between IC and EH implants for both  $\Delta$ MBL and SR at 1, 3 e 5 years after functional loading, although better PD values were observed for implants pertaining to the IC connections. Considering the high heterogeneity, more well-delineated, randomized clinical trials should be conducted.

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