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Review

Clinical outcomes of pterygoid implants: Systematic review and meta-analysis

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A B S T R A C T

The aim of this systematic literature review was to analyze clinical outcomes of pterygoid implant for the treatment of patients with atrophic posterior maxillae and to provide clinical recommendations for this dental implant technique. An extensive search of electronic databases (PubMed/Medline, Science Direct, Lilacs, Embase, and Cochrane Library) was conducted, for articles published between January 1995 and January 2018, to identify literature presenting clinical outcomes of pterygoid implants in the treatment of patients with atrophic posterior maxillae. The systematic review was performed in accordance with PRISMA/PICO statement guidelines, and the risk of bias was assessed (Australian National Health and Medical Research Council scale). The relative risk of implant failure was analyzed within a 95% confidence interval (95% CI). After screening 331 abstracts from the electronic databases, 36 full-text articles were accessed for eligibility, and a total of 6 studies were included in this systematic review (after applying the inclusion and exclusion criteria). All studies were retrospective in nature and were classified with a poor level of evidence. A total of 634 patients received 1.893 pterygoid implants, with a mean implant survival rate of 94.87%. The mean prevalence of implant failure was 0.056 with a 95% CI of 0.04–0.077. This study demonstrates that pterygoid implants can be successfully used in patients with atrophic posterior maxilla. However, the results should be interpreted with caution, given the presence of uncontrolled confounding factors in the included studies.

1. Introduction

Dental prosthetic rehabilitation based on osseointegrated implants is a well-established and highly predictable treatment modality (Papaspyridakos et al., 2013; Brånemark et al., 1969). However, the dental rehabilitation of patient with severe posterior maxillary atrophy using osseointegrated implants has been challenging due to lack of bone volume (pneumatization of the maxillary sinus), poor bone quality (type III and IV) and difficulty of surgical technique access (Goiato et al., 2014; Jaffin and Berman, 1991; Lekholm et al., 1985) A number of different treatment modalities have been proposed to solve these problems, i.e., tilted implants, shorter and/or wider implants and zygomatic implants (Jaffin and Berman, 1991; Lekholm et al., 1985; Curi et al., 2015). Bone graft procedures, such as maxillary sinus lifting and onlay/inlay grafts, have also been used to address insufficient bone volume in this region (Curi et al., 2015; Balshi et al., 2005). However, these procedures require adding surgical areas and increased numbers of treatment stages, with higher morbidity and longer treatment periods. Biomechanical factors may also influence the survival of implants placed in the posterior maxilla due to high occlusal forces in the molar region during mastication, which may also result in prosthetic complications including prosthesis fracture, screw fracture, and bone loss (Goiato et al., 2014; Jaffin and Berman, 1991). Under these mentioned considerations, the pterygomaxillary area has been considered for some authors as a region that does not present the ideal conditions for implant placement,

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given the large amount of poor bone quality and lack amount of cortical bone added to its anatomical and biomechanical technical features (Curi et al., 2015; Balshi et al., 2005).

Tuslane and Tessier (Tulasne et al., 1989) were the first to describe pterygoid implants, designed to be inserted and engaged in the dense cortical bone formed by the posterior wall of the maxillary tuberosity, horizontal process of the palatine bone, and pterygoid process of the sphenoid bone. Pterygoid implants are required to cross the maxillary tuberosity area and to reach the dense pterygomaxillary plate, providing anchorage in the posterior region of the maxilla without grafting procedures, also avoiding posterior prosthetic cantilevers (Tulasne et al., 1992). According to Tulasne (Tulasne et al., 1989), atrophic posterior maxillae preserve 80% of the original bone corridor, sufficient for inserting a 13–20-mm long implant. Previous studies have measured this bone corridor and suggested that the ideal pterygoid implant angulation should reach the pterygoid plate (Curi et al., 2015; Balshi et al., 2005; Tulasne et al., 1992; Rodrıguez et al., 2015; Yamakura et al., 1998; Lee et al., 2001). The mean of the anteroposterior angulation axis of the pterygoid implant varies, from 45 to 70°, relative to the Frankfurt plane, and the buccopalatal angulation axis varies from 10 to 15° (Curi et al., 2015; Balshi et al., 2005, 2013a, 2013b; Tulasne et al., 1992; Rodrıguez et al., 2015; Yamakura et al., 1998; Rodriguez et al., 2014; Graves, 1994; Penarrocha et al., 2009). Some anatomical and radiological studies have proposed that pterygoid implants should be at least 13 mm long to engage the dense cortical pterygoid plate (Rodrıguez et al., 2015; Yamakura et al., 1998; Lee et al., 2001; Rodriguez et al., 2014). Moreover, some studies have suggested that longer implants (13–20 mm) have better survival rates in this region (Curi et al., 2015; Balshi et al., 2005, 2013a; Rodrıguez et al., 2015).

There are few studies in the literature evaluating pterygoid implant survival rates in short and long term follow-up studies (Bidra and Huynh-Ba, 2011). Although a definition of pterygoid implants is provided in the glossary of Oral and Maxillofacial Implants (GOMI) (Bidra and Huynh-Ba, 2011; Laney, 2007), as an "implant placed through the maxillary tuberosity and into the pterygoid plate", several studies in the literature have incorrectly included implants inserted into the tuberosity or the pterygomaxillary region as pterygoid implants (Bidra and Huynh-Ba, 2011). Short implants placed only in the maxillary tuber, tilted implants inserted into the tuberosity or in the pterygomaxillary region, and implants shorter than 13 mm that are not inserted into the dense cortical pterygoid plate should not be considered pterygoid but rather pterygomaxillary implants (Curi et al., 2015; Rodrıguez et al., 2015; Lee et al., 2001; Bidra and Huynh-Ba, 2011). These considerations result in an even smaller number of studies correctly reporting pterygoid implants in the literature. This confusion in misclassifying pterygoid implants with pterygomaxillary or tuberosity implants should be deliberated and clarified. Since the last systematic review of the literature reported by Bidra (Bidra and Huynh-Ba, 2011), new clinical, anatomical and imaginological studies have been published contributing to a better knowledge of implant installation in the pterygomaxillary region, which makes it necessary to systematically revise this topic. Thus, the aim of this systematic review was to analyze pterygoid implant survival rates in patients with atrophic posterior maxilla.

2. Materials and methods

2.1. Focused questions

A systematic review of the literature was performed to answer the following clinical questions: "Are pterygoid implants predictable for the rehabilitation of patients with atrophic posterior maxillae?" and "What are the main factors influencing pterygoid implant failure in patients with atrophic posterior maxillae?"

2.2. Procedure

This systematic review was performed in accordance with the guidelines established in the PRISMA statement (Moher et al., 2010). All articles selected were based on the inclusion and exclusion criteria. Two independent researchers (RZA and ABC) performed a quality assessment of the studies in accordance with the fixed eligibility criteria. All disagreements were resolved via individual analyses of the articles. When there was no agreement between the 2 reviewers, a third reviewer (MMC) assessed the article, and made the decision accordingly. This systematic review was registered in the PROSPERO database, an international prospective register of systematic reviews (National Institute for Health Research, UK; pre-protocol Centre for Reviews and Dissemination [CRD], 42017065023).

2.3. Protocol and registration

2.3.1. Eligibility criteria

The studies were selected based in the PICO questions, as follows: "participants" = patients with atrophic posterior maxillae (Less than 08 mm bone height in premolar and molar region; Class IV, V and VI according to Cawood and Howel classification (Cawood and Howell, 1988)) rehabilitated with dental implants; "intervention" = dental implant placed in the pterygoid plate, specifically the cortical bone formed by the palatine bone and pterygoid process of the sphenoid bone (Curi et al., 2015; Tulasne et al., 1992; Graves, 1994; Penarrocha et al., 2009; Rodríguez et al., 2012; Valerón and Valerón, 2007); "comparisons" = dental implant placed in the posterior maxillary region, but not in the pterygoid bone; "outcomes" = dental implant survival rate, prosthesis survival rate, implant surgical technique, implant length, complications, and clinical recommendations for the use of this implant technique. The main question to be answered was as follows: what is the pterygoid implant survival rate for the treatment of patients with atrophic posterior maxilla?

The inclusion criteria were: English and Spanish language; studies in humans; studies reporting implants in the pterygoid, pterygomaxillary, or maxillary tuberosity regions; studies with at least 1 year of follow-up; clinical cases with a minimum of 10 patients; randomized controlled trials (RCTs) and prospective studies; retrospective and prospective studies. The following definition of pterygoid implant was considered: an implant inserted through the maxillary tuberosity, engaging with the dense cortical bone formed by the pyramidal process of the palatine bone and the pterygoid laminae of the sphenoid bone (Tulasne et al., 1989, 1992; Laney, 2007); implant length of minimum 13 mm and able to effectively reach the pterygoid plate (Curi et al., 2015; Rodrıguez et al., 2015; Yamakura et al., 1998; Rodriguez et al., 2014).

Exclusion criteria were as follows: duplicated studies; animal studies; cadaver studies; radiological or computed simulation studies; in vitro studies; morphometric studies; clinical studies on human patients with implants only in the tuberosity or pterygomaxillary regions, without engagement with the pterygoid bone; implants shorter than 13 mm; clinical cases with less than 10 patients; studies with less than 10 pterygoid implants; literature reviews; studies with missing data; studies not specifying engagement (of the implant apex) with pterygoid bone; studies with bone graft procedures.

2.4. Search strategy

An extensive search of electronic databases (PubMed/Medline, Science Direct, Embase, and Cochrane Library) was carried out for articles published between January 1995 and January 2018. A search in the Lilacs database was also conducted for relevant articles in Spanish. A detailed search strategy was applied using the following key words: "pterygoid implants," "pterygomaxillary implants," "pterygoid plate implants," and "tuberosity implants". There is a slight misunderstanding in the correct orthography in regard to the word pterygoid, and even when the keywords were written with an "I" (pterigoid), the results were the same. All studies were selected by title and abstract, according to the inclusion and exclusion criteria. In addition, a manual search of specific periodicals in the current year (until June 2018) was conducted, including: Clinical Implant Dentistry and Related Research; Clinical Oral Implants Research; International Journal of Oral and Maxillofacial Implants; International Journal of Oral and Maxillofacial Surgery; Journal of Oral and Maxillofacial Surgery; Journal of Periodontology; Journal of Prosthodontics; Journal of Craniofacial Surgery; Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology; and the Journal of Prosthetic Dentistry.

2.5. Reliability and quality assessment

All researchers conducted the execution of this systematic review. All studies selected were extensively and systematically analyzed, to identify possible biases in the surgical procedure, results, or conclusions. Quality assessment of the study methodologies was performed in accordance with the PRISMA statement guidelines. The quality of each study included in this review was assessed using the Australian National Health and Medical Research Council (NHMRC) scale (Lopes et al., 2015; National Health and Medical Research Council, 2000). The NHMRC is a handbook that presents and classifies level, relevance and quality of evidence appropriate for interventional studies (National Health and Medical Research Council, 2000). The NHMRC Evidence Hierarchy: designations of 'levels of evidence' according to type of research question can be visualized in Supplementary Table 1. The Body of Evidence matrix, which classifies studies based on Evidence base, Consistency, Clinical Impact, Generalisability, and Applicability, can be visualized in Supplementary Table 2. A risk quality and bias assessment was performed to eliminate studies not specifying, or with inconsistent data on, the length and/or engagement of implant in the pterygoid laminae of the sphenoid bone.

2.6. Data analysis

For each study included, the following data (related to survival outcomes) was recorded and analyzed: (1) first author, (2) year of publication, (3) study design, (4) number of patients, (5) number of implants in pterygoid region, (6) number of implants in the anterior maxilla, (7) length and diameter of implants, (8) implant surfaces, (9) patient age and sex, (10) implant prosthesis loading timing of prostheses installation, (11) type of oral prosthesis rehabilitation, (12) region or bone where implants were installed or engaged, (13) survival rate, (14) type of bone, (15) surgical or prostheses complications, (16) peri-implant marginal bone resorption, (17) type of edentulous arch, (18) follow-up period, and (19) study design.

2.7. Data synthesis

The studies included and excluded from the final selected articles were extensively compared. Data was recorded and summarized for qualitative and quantitative analyses, to enable comparisons between the selected studies. The survival rates of pterygoid implants were analyzed, as well as implant length and insertion angulation. Implant survival and prosthesis success were analyzed based on the criteria proposed by Albrektsson (Albrektsson et al., 1986). Failure and survival data, surgical and implant characteristics, and peri-implant bone loss were analyzed using tables and graphs. Pterygoid implant survival rates were calculated by Kaplan–Meier curves.

2.8. Statistical analysis

The quantitative data collected from the selected articles were tabulated. Failure prevalence analysis, with 95% confidence intervals (95% CI), and the contribution of each study was performed for meta-analytic calculation purposes. Comprehensive Meta-Analysis Software (CMA, NJ, USA) was used for the meta-analysis and graphing. Analysis of the homogeneity of the data was performed via a funnel chart. Quantitative data also enabled analysis of the failure period of the implants, facilitating a survival curve analysis. The forest plot method compared pterygoid implants with implants in other areas. Significant heterogeneity was assessed using the Cochrane χ^2 (Brånemark et al., 1969) test method and the I (Brånemark et al., 1969) index, when the p value was less than 0.1 and I (Brånemark et al., 1969) was less than 0.75, indicative of heterogeneity. In such cases, a random effects model was used (Al-Moraissi et al., 2016, 2017).

3. Results

3.1. General outcomes

The database search identified 331 studies (231 studies from PubMed, 67 studies from Science Direct, 18 studies from Embase, and 15 studies from the Cochrane Library). One additional record was identified through a hand search. Seven duplicates were removed and 325 studies were screened by title and abstract. A total of 36 full-text articles were selected based on titles and abstract reviews. Of these, 30 studies were excluded, as they did not meet all the eligibility criteria. Table 1 illustrates the main studies removed after application of the rigorous exclusion criteria, and their main reasons for removal (Balshi et al., 1995, 1999, 2005, 2013b; Aparício et al., 2010; Krekmanov, 2000; Park and Cho, 2010; Ridell et al., 2009; Rodríguez-Ciurana et al., 2008; Valeron and Velázquea, 1997; Venturelli, 1996; Vrielink et al., 2003). Other studies were removed for the following reasons: systematic review of the literature (Bidra and Huynh-Ba, 2011) (1 study); literature reviews (Ali et al., 2014; Candel et al., 2012; Haskel et al., 2010; Monteiro et al., 2015; Sorní et al., 2005) (5 studies); case reports (Anandakrishna and Rao, 2012; Peñarrocha et al., 2004; Sherry et al., 2010) (4 studies); anatomical and radiological studies (Rodrıguez et al., 2015; Rodriguez et al., 2014) (3 studies); anatomical cadaveric study (Lee et al., 2001) (1 study), implants in the posterior maxilla but not pterygoid (Bahat, 2010; Nocini et al., 2000; Rosén and Gynther, 2007; Peñarrocha et al., 2012) (4 studies) and are summarized in Table 2. The eligibility process and quality assessment resulted in 6 included studies (Fig. 1).

3.2. Quantitative and qualitative analysis

Author, level of evidence, number of patients, number of pterygoid implants, implant characteristics, survival rates, surgery complications, type of rehabilitation, peri-implant bone loss, and follow-up period of the 6 included studies are summarized in Table 2. All studies were retrospective case series (Curi et al., 2015; Balshi et al., 2013a; Graves, 1994; Penarrocha et al., 2009;

Table 1
Studies excluded on basis of full text and reason for exclusion in this systematic review (NR, not reported).

Study Year	Number of patients	Number of Pterygomaxillary implants	Implants Length (mm)	Main Exclusion Reason	Survival Rate (mean)	Follow up period (mean)
Balshi 2013	981	1068	7 - 18	Pterygomaxillary implants shorter than 13mm long Implant surgery technique not fully specified	NR	NR
Park 2010	7	7	11.5 - 15	All cases are of tuberosity implants and not pterygoid implants	100%	3.4 years
Aparício 2010	25	10	7 - 18	Lack of consistent data to be considered pterygoid implants Implant surgery technique and implants length not specified	NR	2-5 years
Ridell 2009	21	22	13 - 20	All cases of tuberosity implants	100%	1-12 years
Rodríguez 2008	NR	135	18 - 20	Repeated data in other study	NR	NR
Balshi 2005	82	164	10 - 18	Repeated data in other study Implants shorter than 13mm long and implant surgery technique not specified	96.3%	2.6 years
Vrielinck 2003	29	17	NR	Intrasinusal surgery technique described in the study is not compatible with pterygoid implants Less than ten pterygoid implants	71%	NR
Krekmanov 2000	22	9	NR	Inconsistent data to be considered pterygoid implants Less than ten pterygoid implants	NR	1.5 years
Balshi 1999	189	356	8.5 - 20	Part of the implants are shorter than 13mm long Inconsistent data to be considered pterygoid implants	88.2%	4.68 years
Valeron 1997	19	31	NR	Lack of data to be considered pterygoid implants (Technique and implant length not described) Repeated data in other study	93.5%	1.3 years
Venturelli 1996	29	29	10 - 20	Mixed data of tuberosity, pterygomaxillary implants and pterygoid implants	97.6%	3 years
Balshi 1995	44	51	10 - 15	Pterygomaxillary implants shorter than 13mm Repeated data in other study	86.3%	1 – 3 years

Table 2
Data summary of the remaining studies excluded from the review.

Author / Year	Main exclusion reason
Ali, 2014	Literature review for several techniques for implant rehabilitation for atrophic maxilla
Sorní, 2005	Literature review on implant insertion in anatomical buttresses of the upper jaw
Bidra, 2011	Systematic review of the literature for implants in the pterygoid region
Monteiro, 2015	Literature review on rehabilitation of posterior edentulous jaws
Haskel, 2010	Literature review in Spanish language
Candel, 2012	Literature review on pterygoid implants
Rosén, 2007	Patients treated without bone grafting and tilted implants
Peñarrocha, 2012	Implants placed in maxillary buttresses and pterygomaxillary area in syndromic patients
Bahat, 2000	Implants placed in the posterior maxilla, but not pterygoid implants
Nocini, 2000	Implants placed in the maxillary tuberosity
Peñarrocha, 2004	Case Report
Anandakrishna, 2012	Cases Report
Cuchi, 2017	Cases Report
Sherry, 2010	Case report
Uchida, 2017	Anatomical and radiological study
Rodriguez, 2016	Anatomical and radiological study
Lee, 2001	Anatomical cadaveric study on pterygoid implants
Rodriguez, 2014	Anatomical Cone Bean Computed Tomographic study

Rodríguez et al., 2012; Valerón and Valerón, 2007), ranging from 1994 to 2015, and 5 of the 6 studies were published after 2005. One study did not provide the total number or mean age of patients. The mean age of patients from the other 5 studies was 53.17 years. A total of 634 patients received 1.893 pterygoid implants, with a mean implant survival rate of 94.87% (Fig. 4). The follow-up period ranged from 12 to 132 months. Implant length varied from 13 to 20 mm. None of the studies reported significant clinical, surgical, or prosthetic complications. Curi et al. (2015) and Valerón and Valerón (2007) reported only a few cases of intra-operative bleeding, which stopped with insertion of the pterygoid implants. Five of the 6 studies (Curi et al., 2015; Graves, 1994; Penarrocha et al., 2009; Rodríguez et al., 2012; Valerón and Valerón, 2007) (except Balshi et al. (2013a)) had a mean healing

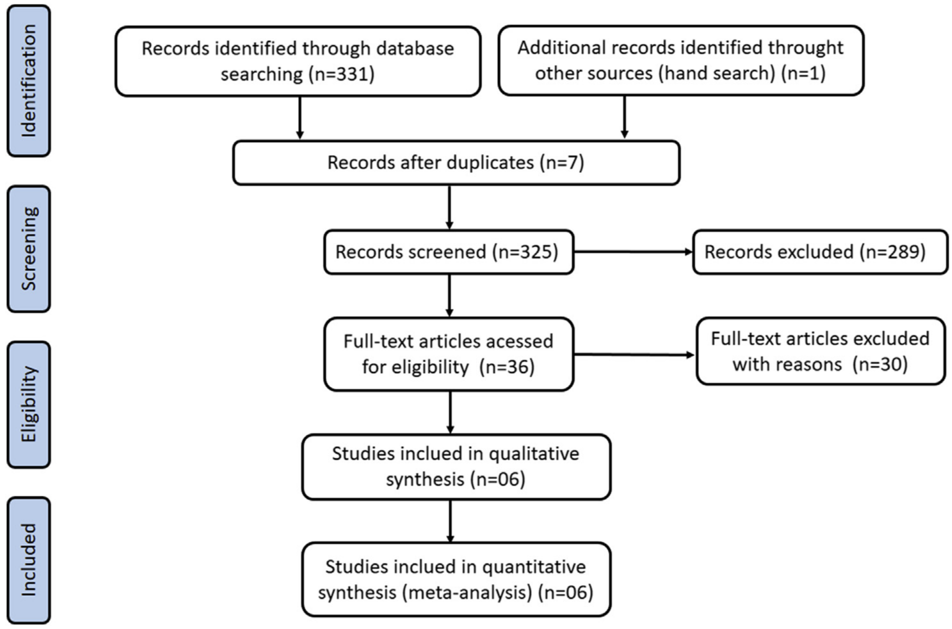

Fig. 1. Flowchart of the search strategy for the systematic review.

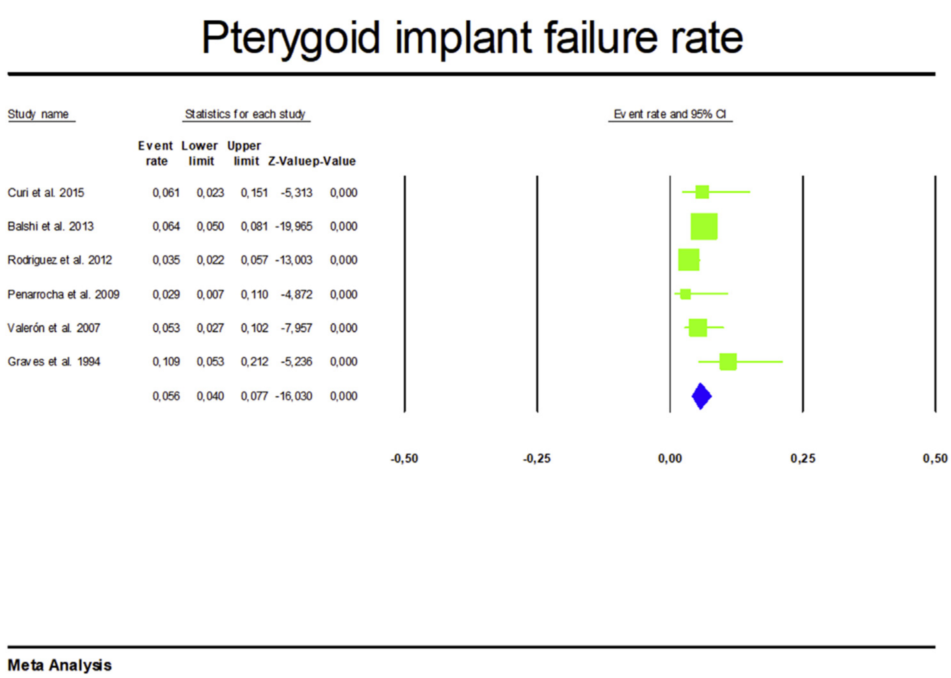

Fig. 2. Florest plot of pterygoid implant failure.

time of 4–6 months prior to implant loading. Two studies reported low peri-implant bone loss of the pterygoid implants. Curi et al. (2015) and Peñarrocha et al. (Penarrocha et al., 2009) reported a mean bone loss of 1.21 mm and 0.71 mm, respectively. All studies mentioned the importance of adequate implant length and proper implant angulation to engage the dense cortical bone of the pterygoid plate (Table 3).

3.3. Implant failure

An analysis comparing the number of pterygoid implants with the number of implants lost was performed across the 6 studies. The rate of implant loss varied among the studies. The lowest and highest implant failure rates were 2.9% and 10.9%. A possible explanation for this significant difference may be the different sample proportions and implant surface treatments between the studies. The study with the lowest survival rate (89.1%) was from Graves, published in 1995. At that time, most dental implants did not have surface treatment. The other 5 studies were published after 2007, and among those studies, the pterygoid implant survival rate was 96,24%. The mean prevalence of implant failure was 0.056 with a 95% CI of 0.040–0.077 (Fig. 2). Of a total of 1893 pterygoid implants, 97 implants were lost. Table 3 shows the life-table survival analysis showing the cumulative survival rate of pterygoid

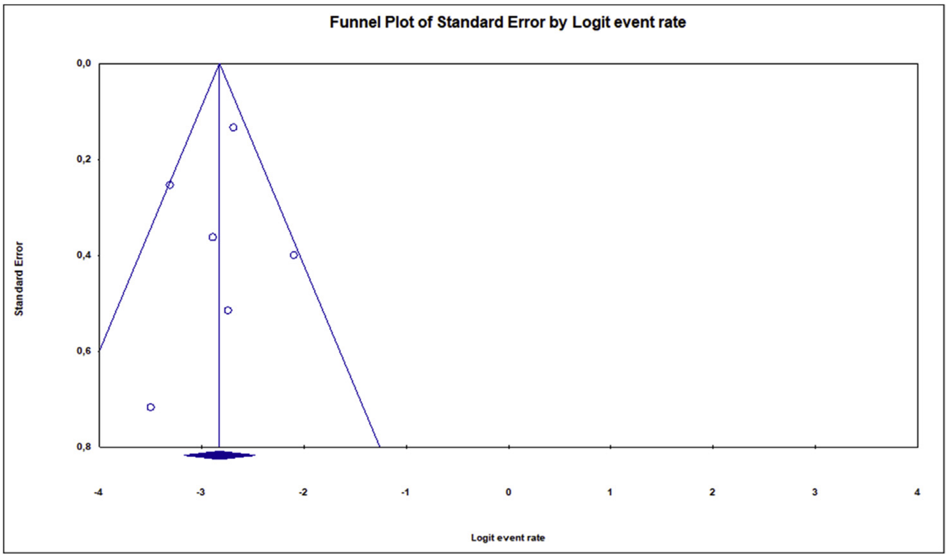

Fig. 3. Funnel plot of the risk of failure of pterygoid implants in the 6 included studies to evaluate potential publication bias.

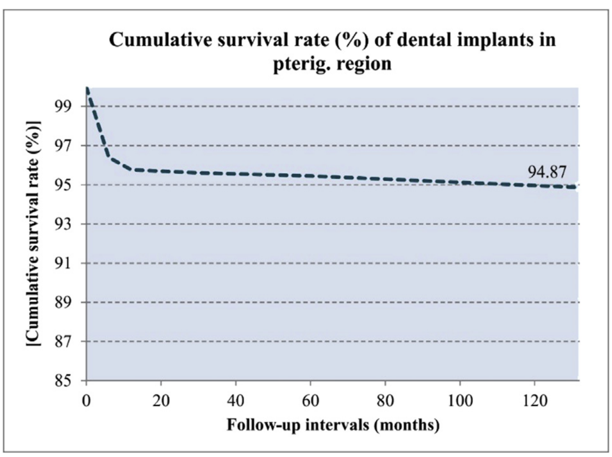

Fig. 4. Pterygoid implants survival rate for the 6 selected studies (follow-up 0–132 months).

implants across the 6 studies. Most implant failures occurred 6 months after implant surgery and before loading.

3.4. Bias analysis

The risk of bias was evaluated through a funnel plot standard error rate. Results showed that there was a distribution of the studies within the funnel, with an index of heterogeneity of I (Brånemark et al., 1969) of 43,237 ($p = 0.117$; Q-value: 8,809), indicative of low heterogeneity (Fig. 3). With regards to the total implant survival rate and moment of implant failure, 97 implants failed at the end of the follow-up period (132 months), with an overall survival rate of 94.87% (Table 4; Fig. 4). Related studies included those by Curi et al. (2015), Rodrigues et al (Rodríguez et al., 2012), Peñarrocha et al. (Penarrocha et al., 2009), Valerón and Valerón (2007), and Graves (1994). A study by Balshi et al. (2013a) was not clear; 10 failures occurred over a period of 1–9 years.

4. Discussion

The main finding of this systematic review based on the retrospective studies analyzed is that the pterygoid implants have a high survival rate in the dental rehabilitation of posterior atrophic maxilla. In general, all included studies reported that pterygoid implants can osseointegrate and remain functionally stable. The 10-year survival rate of pterygoid implants was high (94.85%) in the analyzed studies. The main finding of this systematic review based on the retrospective studies analyzed is that the pterygoid implants have a high survival rate in the dental rehabilitation of posterior atrophic maxilla. Most of the implant failures occurred 6 months after implant installation surgery and before implant loading. Once osseointegrated, pterygoid implants remained stable and functional after the first year. The null hypothesis was accepted: pterygoid implant are predictable for the rehabilitation of posterior atrophic maxilla. The survival rates evaluated are as high as conventional dental implant survival rates in other regions of the maxilla (Goiato et al., 2014; Lopes et al., 2015; Moraschini et al., 2015).

This systematic review covered the main journal databases in the field using a search strategy that had no time or language restrictions. This systematic review was registered in the Prospero database (CRD 42017065023) and followed the PRISMA statement (Moher et al., 2010). All included studies were classified for risk of bias according to the NHMRC scale (National Health and Medical Research Council, 2000). The validity of results of any given systematic review depends upon the quality and quantity of the included studies. In our revision, all included studies were retrospective and were classified with a low level of evidence (III-3 according to the NHMRC scale). No randomized controlled clinical trials were included. In cases where there is a lack of studies with a high level of evidence, prospective or retrospective studies may also serve to the review specific questions or objectives. Meta-analysis showed that the included studies were homogeneous, suggesting that the results are robust (Fig. 3). This systematic review shows there is still misunderstanding regarding the definitions and differences among pterygoid, pterygomaxillary, and tuberosity implants, as reported in a previous systematic review of the literature. The outcomes of this systematic review are in agreement with those of a previous systematic review (Bidra and Huynh-Ba, 2011); however, a smaller number of studies were included in the present systematic review, based on the current definition and inclusion criteria for pterygoid implants as described in the literature (Curi et al., 2015; Tulasne et al., 1992; Rodrıguez et al., 2015; Yamakura et al., 1998; Lee et al., 2001; Rodriguez et al., 2014; Balshi et al., 2013a, 2013b; Graves, 1994; Penarrocha

Table 3
Data summary of the six included studies analyzed in this systematic review (NR, not reported).

Study (Year)	NHMRC Level of Evidence	Number of Patients	Number of Pterygoid Implants	Pterygoid Implants Length (mm)	Implant Manufacturer	Survival Rate (%)	Surgical Complications	Antero-posterior Angulation	Osseointegration period	Periimplant Bone Loss (mean)	Follow up Period (mean)
Curi (2015)	III-3	56	66	18 - 20	Branemark MK III TiUnite	93.93	Slight venous intraoperative bleeding	15° - 60°	4 months	1.21mm	3 years
Balshi (2013)	III-3	NR	925	15 - 18	Branemark System – Nobel Biocare	94.16	NR	NR	NR	NR	NR
Rodriguez (2012)	III-3	392	454	13 - 18	Osseotite, 3i / Implant Innovations	96.5	Slight venous intraoperative bleeding	60° - 90°	4.2 months	NR	6 years
Penarrocha (2009)	III-3	45	68	16	Defcon Avantblast (Impladent, Senmenat) and ITI Straumann	97.05	None	NR	3 months	0.71mm	1 year
Valleron (2007)	III-3	92	152	NR	Branemark System – Nobel Biocare	94.6	Slight venous intraoperative bleeding	NR	6 months	NR	4 years
Graves (1994)	III-3	49	64	15 - 20	NR	89.1	NR	45°	6 months	NR	4 years

Table 4
Life-table survival analysis showing the cumulative survival rate of pterygoid implants for the six selected studies.

Follow-up intervals of the study, months	Nº, of implants in each interval (Pterygoid region)	Nº, of failures in each interval (Pterygoid region)	Survival rate within each interval (%)	Cumulative survival rate (%)
0-6	1893	68	96,4	96,4
6 a 12	1825	12	99,34	95,77
12 a 30	1813	3	99,83	95,61
24-60	1810	3	99,83	95,45
61-132	1807	11	99,39	94,87

et al., 2009; Bidra and Huynh-Ba, 2011; Laney, 2007; Rodríguez et al., 2012; Valerón and Valerón, 2007). The main reasons for a new systematic review were the need for standardization and adequate identification of studies that actually reported strictly pterygoid implants, and the inclusion of new studies with relevant casuistry after the first systematic preview was published. Only 3 of the 9 studies include for meta-analysis from the previous systematic review were included. The misclassified and duplicated studies removed after application of the inclusion and exclusion criteria are summarized in Table 1. The complete list of excluded studies is provided in Table 2 (Balshi et al., 1995, 1999, 2005, 2013b; Aparício et al., 2010; Krekmanov, 2000; Park and Cho, 2010; Ridell et al., 2009; Rodríguez-Ciurana et al., 2008; Valeron and Velázquea, 1997; Venturelli, 1996; Vrielink et al., 2003; Ali et al., 2014; Candel et al., 2012; Haskel et al., 2010; Monteiro et al., 2015; Sorní et al., 2005; Anandakrishna and Rao, 2012; Peñarrocha et al., 2004; Bahat, 2010; Nocini et al., 2000; Rosén and Gynther, 2007).

Study selection and data extraction from the included studies were challenging. After application of rigorous inclusion and exclusion criteria, especially in regard to the pterygoid implant definition and technique, a total of 6 studies were included. The main criteria for study exclusion were implants shorter than 13 mm and lack of information related to the implant surgical technique. Some studies (Aparício et al., 2010; Krekmanov, 2000; Venturelli, 1996) did not report pterygoid implant techniques, implant lengths, and/or whether the implants were engaged into the pterygoid plate. Vrielink et al. (2003) used a maxillary intrasinusal technique to engage the pterygoid bone, and cannot be considered pterygoid by definition. Balshi et al., 1995, 1999, 2005, 2013b used implants smaller than 13 mm, and some of their studies as well as one study by Valeron and Velázquez (Valeron and Velázquea, 1997) did not differentiate between pterygoid implants in subsequent publications, and it was not clear if they were using the same data or patient sample to achieve their results. Those studies could not be included due to the risk of duplicated data. The studies by

Park and Cho (2010) and Ridell et al. (2009) used what we considered to be maxillary tuberosity or pterygomaxillary implants, and were excluded. In the 6 included studies, there was lack of data, such as peri-implant bone loss, implant trademark, or number and type of anterior implants placed in the maxilla. No studies specified whether there were differences in their results related to patient age, gender, smoking status, or any other systemic condition associated with implant success or failure. All included studies had a minimum follow-up period of 1 year, and 3 of the 6 studies (Curi et al., 2015; Graves, 1994; Valerón and Valerón, 2007) had a minimum follow-up of 3 years. Measurements of bone loss were incomplete or not reported in most studies (Balshi et al., 2013a; Graves, 1994; Rodríguez et al., 2012; Valerón and Valerón, 2007).

Pterygoid implant surgical technique follows the same basic principles of conventional implant surgery. The pterygoid implant technique can be considered a simpler surgical approach, as it does not require a bone grafting procedure. This technique is associated with less overall morbidity, lower treatment costs, and shorter healing times. From a prosthetic point of view, dental rehabilitation with pterygoid implants has the advantage of eliminating long distal cantilevers, due to the emergence of pterygoid implants in the second molar region. Although cleaning of the pterygoid implants prostheses that emerge in the posterior region of the maxilla may be a concern for both patients and professionals, this factor was not reported in any of the included studies. Curi and Penarrocha also reported a high degree of satisfaction of patients related to the final prosthesis rehabilitation (Curi et al., 2015; Penarrocha et al., 2009). Excellent implant primary stability may also provide possibilities for immediate implant loading and prosthetic rehabilitation (Curi et al., 2015; Balshi et al., 2013b). Rodriguez et al. (Rodrıguez et al., 2015) analyzed 202 cone bean computed tomographic files of patients with atrophic maxilla, and found that bone density of the pterygoid plate area was three times higher compared to the tuberosity area. Bone density in the tuberosity area ranged from 285.8 to 329.1 DV units, and density in the pterygoid plate area varied from 602.9 to 661.2 DV units, with a 95% CI[10].

Some studies have established a minimum implant length of 13 mm for pterygoid implants (Rodrıguez et al., 2015; Yamakura et al., 1998; Lee et al., 2001; Rodriguez et al., 2014). Lee et al. (2001) reported an anatomical study of the pyramidal process of palatine bone in relation to implant placement in the posterior maxilla; they measured the height and anteroposterior and mediolateral distances of the pyramidal process. They found a mean height of 13.1 mm, anteroposterior distance of 6.5 mm, and mediolateral distance of 9.5 mm. Rodriguez et al. (2014) reported an anatomical study of the pterygomaxillary area with 100 cone-beam computed tomography; they found a mean bone corridor height of 22.5 mm. In this systematic review, implants were only considered pterygoid if they had minimum length of 13 mm. One study that did not mentioned the pterygoid implant length (Laney, 2007). Although these authors did not mentioned implant length, they described the complete technique for pterygoid implants, with implant apex engaged at the pterygoid plate. The pterygoid implant lengths of the included studies are listed in Table 2.

It is important to highlight that in all the included studies, no major complications were reported. Although it might be expected that the greater the bone reabsorption of the maxilla, the greater will be its complications or transoperative difficulties; however, none of the authors correlated or reported this association (Curi et al., 2015; Balshi et al., 2013a; Graves, 1994; Penarrocha et al., 2009; Rodríguez et al., 2012; Valerón and Valerón, 2007). Some authors reported their major complications, which are summarized in Table 5 (Curi et al., 2015; Penarrocha et al., 2009; Rodríguez et al., 2012; Valerón and Valerón, 2007). The Curi (Curi et al., 2015), Graves (1994) and Rodriguez (Rodríguez et al., 2012) studies pointed out that one of the major "complications" associated with this technique might be the learning curve and the anatomical knowledge of the area so that the proper pterygoid implant technique may be accomplished. There were no associations in regard to the amount of bone atrophy and difficulties related to the

Table 5
Complications reported in the included studies.

Author Year	Number of Patients and Pterygoid Implants	Complications	Implant failure and period	Follow up period
Curi 2015	56 / 66	Two cases of intraoperative bleeding that stopped after implant placement. No complications such as infection, edema ou wound dehiscense, discompfort or pain in the postoperative reevaluations. Speech or hygiene problems where not observed.	4 failures before 2nd surgery	3 years
Balshi 2013	- / 925	NR	NR	NR
Rodriguez 2012	392 / 454	**Intraoperative:** 4 cases of hemorrhage that stopped when the implants were seated **Postoperative**: 1 case of transiente hypoesthsia of the palatine nerv lasting 4 weeks, and one case of pterygomaxillary pain thaht needed the implant removed. **Prosthetic**: 1 patient thaht exhibited bruxism fractured 2 bilateral pterygoid implants and the maxillary anterior implant of the premolar region. Three fractured hybrid proshtesis due to patients with bruxism.	16 failures - 13 before 2nd surgery	6 years
Penarrocha 2009	45 / 68	None of the patients exhibited sinus complications, local mucositis, paresthesias, or neurologic postoperative problems.	2 failures before 2nd surgery	Mean 35.5 months (12-69)
Valleron 2007	92 / 152	Slight venous intraoperative bleeding in cases where the drilling extended a few millimeters in the retropterygoid area that subsided with implant placement. Slight trismus and discomfort in those patients easely solved with phisiotherapy and muscular relaxants.	8 failures - 6 before 2nd surgery	4 years (89.7+-30.7)
Graves 1994	49 / 64	NR	7 failures before 2nd surgery	4 years

insertion of the pterygoid implants. That could be explained to the fact that the bone corridor formed by the pyramidal process of the palatine bone and the lateral plate of the pterygoid process of the sphenoid bone does not undergo bone resorption like the maxillary alveolar bone, since it does not support teeth and does not have the influence of the masticatory forces or the periodontal ligament (Lee et al., 2001). Lee (Lee et al., 2001) and Rodriguez (Rodriguez et al., 2014), in their anatomical and radiological studies, consistently found stable and bulky bone in the pterygoid region. A larger amount of sinus pneumatization will be associated with a lesser bone availability in the maxillary tuberosity, and ultimately this will have a direct influence in the anteroposterior angulation axis to the implant insertion.

There was no consensus as to pterygoid implant angulation insertion among the studies analyzed in this review. The anteroposterior angulation axis varied from 45° to 75° in relation to the Frankfurt plane (Curi et al., 2015; Graves, 1994; Rodríguez et al., 2012). However, the buccopalatal angulation axis had a mean of 80° degrees, in relation to the Frankfurt plane in all studies. There was no significant difference in pterygoid implant survival rates among the included studies, when comparing implant angulation. All included studies reported high pterygoid implant success rates, and varied from 97.1% to 89.1%. The lowest pterygoid implant success rate was reported in 1994, and did not specify the type, manufacturer, or implant surface treatment (Graves, 1994). Potentially, if the implants had modern surface treatment, the results might have been better. All the other studies were published after 2007, with minimum survival rates was of 94.16% (Curi et al., 2015; Balshi et al., 2013a; Penarrocha et al., 2009; Rodríguez et al., 2012; Valerón and Valerón, 2007).

None of the included studies in this systematic review discussed the possible primary causes for pterygoid implant failure (Curi et al., 2015; Balshi et al., 2013a; Graves, 1994; Penarrocha et al., 2009; Rodríguez et al., 2012; Valerón and Valerón, 2007). A hypothesis for possible failure of pterygoid implants relates to incorrect execution of the surgical technique, as all studies were unanimous in affirming that there is a learning curve on the part of the surgeon. This also contributes to the fact that most implant failures occur during the implant healing period and prior to loading. The lack of surgical skills associated with lack of anatomical site knowledge by the surgeon may result in incorrect implant insertion and, consequently, a final positioning in bone type III and IV with poor primary implant stability. Pterygoid implant surgical technique has been associated with very few complications. The most common complication reported was intraoperative bleeding. Intraoperative bleeding is probably due to damage to pterygoid muscles during implantation or drilling through the pterygoid bone plate (Tulasne et al., 1992). All surgery complications reported in the included studies are shown in Table 2 (Curi et al., 2015; Balshi et al., 2013a; Graves, 1994; Penarrocha et al., 2009; Rodríguez et al., 2012; Valerón and Valerón, 2007). All the other data analyzed (age, gender, implant manufacturer, type of prosthesis, implant surface) did not influence the survival rates of pterygoid implants.

It is known that several factors contribute to peri-implant bone loss, such as soft tissue quantity and quality, implant surface, implant platform abutment interface, peri-implant microbiota, and stress distribution (Al-Nsour et al., 2012; Maeda et al., 2007; Santiago Junior et al., 2016). The quality of soft tissue commonly found in the tuberosity area (where pterygoid implants emerge) can be a positive factor when considering pterygoid implants for the rehabilitation of atrophic posterior maxillae. The soft tissue in this area is usually thick and keratinized. Curi (Curi et al., 2015) and Peñarrocha (Penarrocha et al., 2009) found mean peri-implant bone losses of 1.21 mm and 0.71 mm, respectively, in 3-year follow-up periods. Park (Park and Cho, 2010) and Venturelli (1996) explored implants in the tuberosity and pterygomaxillary regions, respectively; they reported optimal results for peri-implant bone loss in the tuberosity region. It was not possible to draw any conclusions or statistical data on this topic, as only 2 studies reported peri-implant bone loss during the follow-up period (Curi et al., 2015; Penarrocha et al., 2009). While these studies present good clinical results, they were all evaluated with panoramic radiographs, and even with good calibration and controlled clinical and radiographic evaluation, this can lead to imprecise interpretation of results. Further controlled studies with cone beam computed tomography evaluation are required to improve the level of knowledge on this topic.

5. Conclusion

The outcomes of the present systematic review should be interpreted with caution because of certain limitations. The lack of control over influencing factors limits our conclusions. In addition, no prospective studies were available for analysis and, therefore, the retrospective nature of the included studies should be considered when interpreting the outcomes of this review. Due to the retrospective nature of all studies included, based on the NHMCR classification, their level of evidence was considered poor and inconsistent, with restricted clinical impact. Within the limits of this meta-analysis, this study demonstrates comparable implant survival rates between pterygoid and conventional implants in other regions of the maxilla.

Ethical approval

No ethical approval was needed for this study.

Conflicts of interest

The authors declare no competing interests.

Patient consent

Patient consent was not required.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcms.2019.01.030.

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