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REVIEW ARTICLE

Clinical performance of single implant prostheses restored using titanium base abutments: A systematic review and meta-analysis

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Abstract

Purpose: The aim of this review was to evaluate the survival rates of restorations utilizing titanium base abutments (TBA) for restoring single-unit implant prostheses.

Materials and Methods: This review was conducted following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. The focus question was: In patients who require the restoration of a single dental implant utilizing a titanium base abutment, what are the determining factors and outcomes relating to implant prosthesis prognosis and survival? A comprehensive search of databases (PubMed, EMBASE, and Cochrane Library) was conducted on 16 April 2023 and updated on 5 May 2023. Randomized clinical trials (RCT), retrospective studies and prospective studies, reporting on the use of TBA for single implant prostheses, were reviewed. A Cochrane collaboration risk of bias assessment analysis was performed for randomized clinical studies, and the Newcastle–Ottawa Scale tool was applied for non-randomized studies. A meta-analysis was performed on clinical trials reporting on survival rates of both TBA and other abutments. Other clinical studies, reporting on TBA only, were included for descriptive statistics.

Results: The search provided 1159 titles after duplicates were removed. Six RCTs were included to perform a meta-analysis and compare the survival of the TBA to other abutments [OR 0.74; 95% CI: 0.21–2.63, heterogeneity; I^2 0%; $p = .99$]. Twenty-three prospective and retrospective studies fulfilled the criteria and were included in the meta-analysis after 12 months of function. A total of 857 single implant-supported prostheses fabricated with a TBA were included. TBA abutments have an estimate 98.6% survival rate after 1 year in function (95% CI: 97.9%–99.4%). The mean follow-up period was 31.2 ± 16.9 months.

Conclusions: Single implant prosthesis restored with titanium base abutments showed favourable short-term survival rates.

KEYWORDS
customized abutment, dental abutment, single dental implant, titanium abutment, titanium base abutment, zirconia abutment

1 | INTRODUCTION

Single fixed implant-supported prostheses, also referred to as implant-supported single crowns (iSC), have predictable clinical outcomes with high survival and success rates, and are a reliable option to replace the single missing tooth (Alqutaibi et al., 2021; Buser et al., 1997; Jung et al., 2012; Sailer, Zembic, et al., 2009). Advancements in technology and dental materials have resulted in different fabrication options for the single implant prosthesis (Joda, Ferrari, Gallucci, et al., 2017; Kapos & Evans, 2014; Karoussis et al., 2004). A dental implant-abutment fabricated utilizing a porcelain fused to metal reconstruction, has been the 'standard' to which newer techniques are compared (Alqutaibi et al., 2021; Lemos et al., 2019; Rammelsberg et al., 2020; Schmitt & Zarb, 1993; Schwarz et al., 2012). Clinicians have sought alternative techniques to abutment fabrication in attempts to reduce labour and material costs (Joda & Brägger, 2015).

Industrialized processes in the fabrication of a dental prostheses have led implant manufacturing companies to develop componentry which can be integrated into the complete digital dentistry workflow (Al-Thobity, 2022). The evolution of computer-aided design (CAD) and computer-assisted manufacturing (CAM; CAD/CAM) have enabled clinicians to access a wider variety of dental materials (Joda, Ferrari, & Brägger, 2017; Kapos et al., 2009; Mühlemann et al., 2020). CAD/CAM manufacturing facilitated the creation of the titanium base abutment (TBA). These abutments are importantly unique and different to customizable abutments as it is associated with a digital library. The digital library is provided by the manufacturer and allows the prosthesis designer to have a genuine digital replica of the abutment.

Titanium base abutments, for single unit restorations, commonly have anti-rotation features in the connection area to the endosseous implant, as well as surface irregularities along the retentive attachment segment to enhance resistance form for crown fixation. These abutments have specific geometric shapes and are unique to each manufacturer (Al-Thobity, 2022). In general, the geometry of TBA has four components; a prefabricated implant-abutment connection; a flat abutment shoulder; a retentive attachment segment; and a transmucosal segment. The TBA is available in a variety of retentive attachment and transmucosal heights and contours, which are stored in a digital library with open STL files containing the required TBA geometries. Once TBA is selected and the full crown or intermediate coping is designed using a (CAD) software, the resulting STL file of the restoration is sent for milling. The fitting surface of the milled restoration to the TBA should require very little adjustment and has an intimate fit prior to cementation. The restoration can then be contoured and finalized prior to being adhesively cemented to the TBA extra-orally.

The TBA offers several advantages for implant prostheses which include avoiding direct contact of zirconia in the connection area to the titanium implant (Sailer, Philipp, et al., 2009); a low metal profile, the emergence profile and improving mucosal colour (Carrillo de Albornoz et al., 2014; Jung et al., 2012); preventing the abutment–implant interface from damage or oxidative change during technical fabrication (Joda, Ferrari, Gallucci, et al., 2017); cementation of the restoration extra-orally and use as screw-retained implant prostheses (de Holanda Cavalcanti Pereira et al., 2022; Joda, Ferrari, & Brägger, 2017); and a lower cost of fabrication (Joda, Ferrari, Gallucci, et al., 2017).

Alternative names of such prefabricated abutments found in the literature include: Ti-base abutments; titanium-bonding bases; titanium insert; cementing cap; hybrid abutments (Al-Thobity, 2022). Furthermore, individual implant companies create confusion by referring to TBA with proprietary names. There is a lack of consistent terminology, and no suitable term has been published in the Glossary of Prosthodontic Terms. Moving forwards, a universal definition is required to enable historical information to be compared to newer strategies. Figure 1 categorizes the TBA abutment as a stock abutment with an integrated digital library. A single implant prosthesis fabricated with a TBA can be fabricated with one or two additional layers and is either screw- or cement-retained. The primary aim of this systematic review was to analyse the survival rates, and biological, technical and aesthetic outcomes of TBAs, when restoring a single implant prosthesis.

2 | MATERIALS AND METHODS

This systematic review is based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA) checklist structure (Moher et al., 2010).

A protocol was developed aiming to answer the focused question 'In patients who require the restoration of a single dental implant utilising a titanium base abutment, what are the determining factors and outcomes relating to implant prosthesis prognosis, survival?'

This question considered the following population, intervention, comparison and outcome (PICO) criteria:

- Population: Partially edentulous patients with at least one implant in the maxilla and/or mandible needing restoration.
- Intervention: Titanium dental implants restored with a TBA for a single-implant prosthesis.
- Comparison: Titanium dental implants restored with customized abutments incorporating any abutment material and design including cast to abutments; altered stock abutments; and

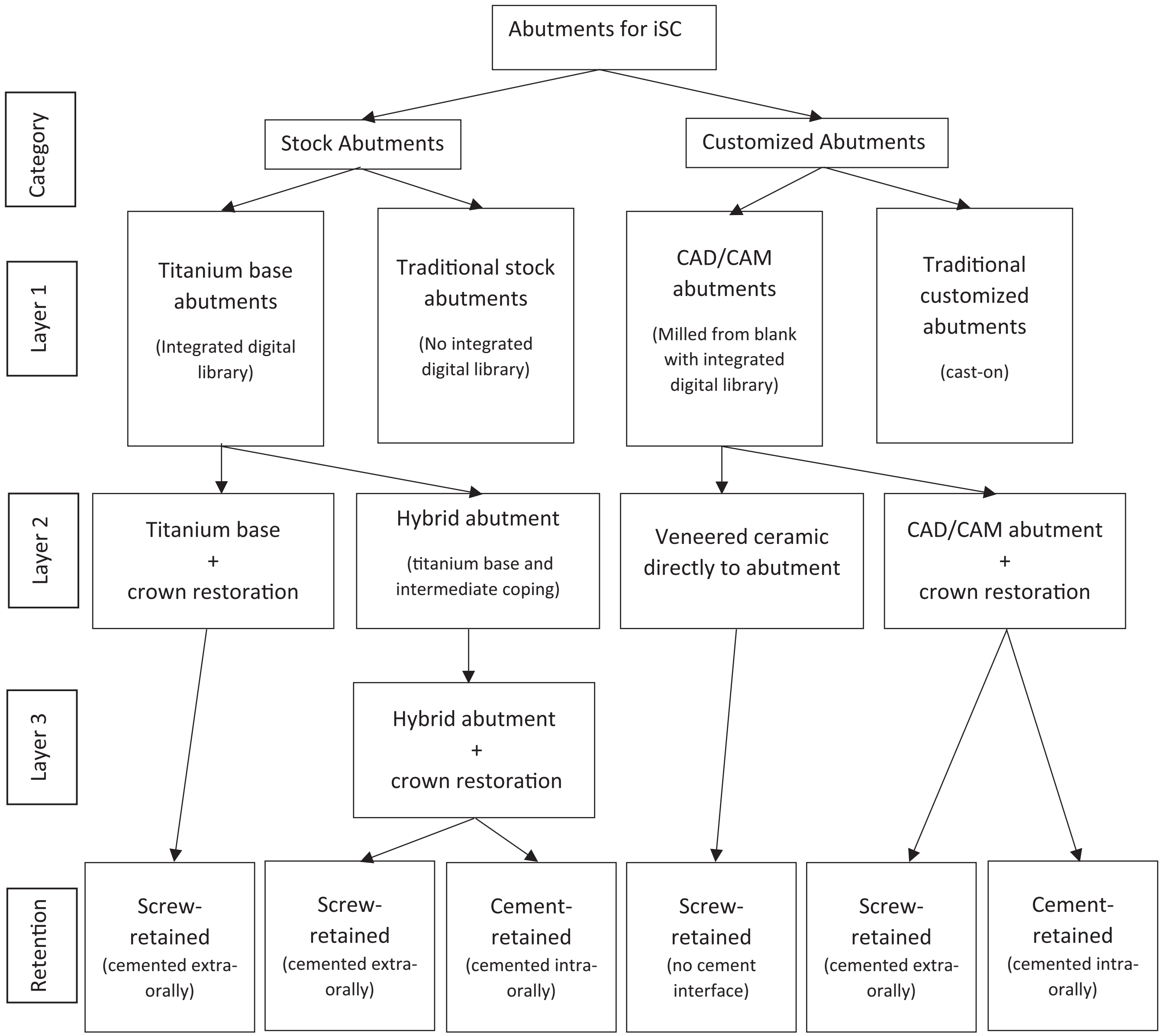

FIGURE 1 Flow diagram describing the layers to iSC. Other traditional stock and customized abutments historically used for screw-retained or cement-retained single implant crown restorations that are not stored in digital libraries are not further displayed.

customized CAD/CAM abutments fabricated from titanium, chrome-cobalt, or zirconia.

- Outcomes: survival rates, and technical complications, biological complications and aesthetic outcomes.

2.1 | Search strategy for identification of studies

Evaluation criteria were defined in accordance with the PICO criteria. A systematic electronic literature search from PubMed, EMBASE and Cochrane Library databases was performed. The complete search strategy aimed to identify all types of publications in English from 01 January 2000 up to 16 April 2023 and included the terms detailed in Table 1. The search was completed by JC and CE. Population-based search terms including dental implant, oral implant, endosseous implant, jaw, partially edentulous and single missing tooth. Considering the intervention that was performed the following terms were used; implant restoration or prosthesis; titanium abutment; Ti-base; Variobase®; universal abutment; implant hybrid restoration; two-piece abutment; titanium insert; titanium cementing abutment; hybrid zirconia abutment. The comparison group was searched using the terms—customized abutment, zirconia abutment, cast to abutment, gold abutment, CAD/CAM anatomical abutment. The outcomes searched were implant prognosis, implant survival, implant success, prosthetic complications, prosthetic survival, prosthetic success, patient satisfaction, clinical satisfaction, biological complications, aesthetics, technical complications and treatment time.

A free electronic search was updated on 5 May 2023 by WD of '(implant OR implants OR dental OR oral) AND (variobase OR ti-base

TABLE 1 Systematic search strategy.

Focus question: In patients who require the restoration of a dental implant utilizing a titanium base abutment, what are the determining factors and outcomes relating to implant and prosthesis prognosis, survival	
Search strategy	
Population	1. Dental implant OR oral implant OR endosseous implant 2. Jaw OR partially edentulous OR partial edentulous OR single missing tooth
Intervention or exposure	3. Implant restoration OR implant prosthesis 4. Titanium abutment OR Titanium base OR Ti Base OR Variobase® OR universal abutment OR implant hybrid restoration OR two-piece abutment OR titanium insert OR titanium cementing abutment OR hybrid zirconia abutment
Comparison	5. Customized abutment OR zirconia abutment OR cast-to abutment OR gold abutment OR CAD/CAM OR anatomical abutment OR UCLA abutment OR abutment
Outcome	6. Implant prognosis OR implant survival OR implant success OR prosthetic complications OR prosthetic survival OR prosthetic success 7. Patient satisfaction OR clinical satisfaction OR biological complications OR biological outcomes OR aesthetics OR technical complications OR treatment time
Search combination	1 OR 2 OR 3 OR 4 AND 5 AND (6 OR 7)
Database search	
Language	English
Electronic	PubMed, EMBASE and Cochrane Central Register of Controlled Trials (CENTRAL)
Selection criteria	
Inclusion criteria	1. Clinical studies on adults only (18+) 2. Published between 2000 and 2023 3. Studies at all levels of evidence, except expert opinion 4. Incorporate the use of a titanium base abutment 5. If there are multiple publications on the same patient cohort, only the publication with the longest follow-up time was included. 6. Sufficient reporting on the detailed clinical outcomes (survival) of TBA
Exclusion criteria	1. Not meeting all inclusion criteria 2. Studies in languages other than English 3. Studies with multiple units 4. Studies with mean follow-up time <1 year 5. Absence of clear methodology indicating type of abutment 6. Studies reporting on ceramic or subperiosteal implants 7. Poor reporting on drop-outs and number of patients at follow-up

OR titanium base abutment OR bonding base OR hybrid abutment OR titanium base) AND (Clinical OR RCT OR prospective OR outcome)'. The search results were exported and organized utilizing specialized bibliographic software, where any duplicate articles were removed (EndNote X9, Version 3.3, Wintertree Software Inc). Two independent observers independently scanned the abstracts and later, the preselected full-text articles. For studies meeting the inclusion criteria, full-text manuscripts were obtained and evaluated further. All studies meeting the inclusion criteria were subject to further data extraction. Data were extracted using structured data extraction forms. Any disagreement was discussed, and an additional review author, WD, was consulted when necessary. Outcome parameters, descriptive summaries of the relevant study characteristics and influence parameters (study design, number of patients, number of single inserted dental implants) of the respective included studies were extracted. The primary outcome was the survival rate of TBA and secondary outcomes were biological outcomes, prosthetic complications and aesthetic clinical outcomes.

2.2 | Eligibility criteria

2.2.1 | Study types

Clinical studies on dental implants restored with a single-implant prosthesis under functional loading, including at least 10 treated patients and published in English journals were evaluated. The studies must have had subjects over the age of 18, published between 2000 and 2023, evaluating a TBA with a superstructure manufactured using a digital implant-abutment library and CAD/CAM techniques. If there were multiple publications on the same patient cohort, only the publication with the longest follow-up time was included.

The following study designs were included:

- Prospective: randomized-controlled; non-randomized controlled; and cohort studies
- Retrospective: controlled; case–control; and single cohort.

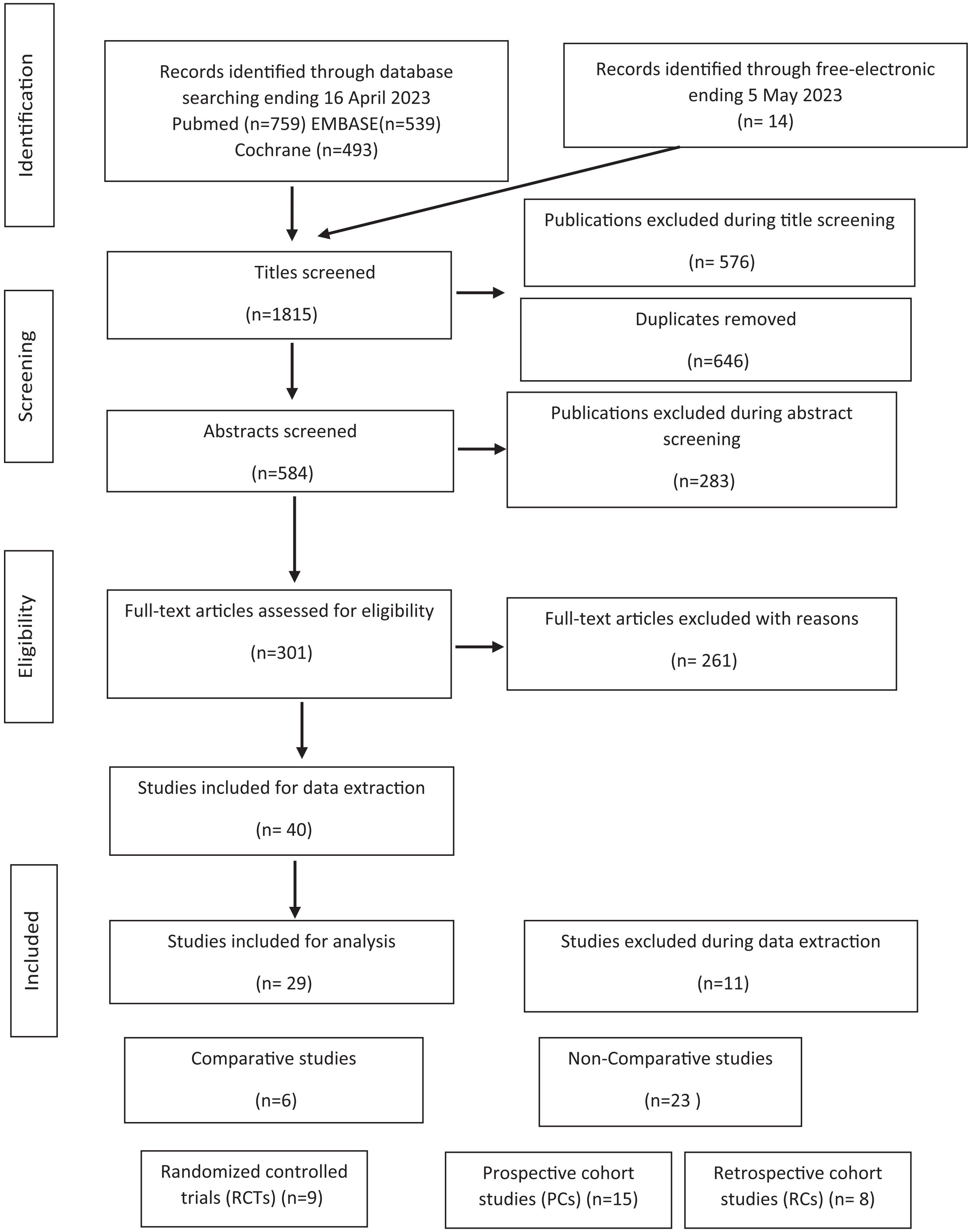

FIGURE 2 PRISMA flow diagram.

TABLE 2 Included papers.

	Number	Studies
Randomized controlled studies (RCTs)	6	Mühlemann et al. (2020) Erhan Çömlekoğlu et al. (2018) Mangano and Veronesi (2018) Vazouras et al. (2022) Rathe et al. (2022) Wolfart et al. (2021)
Prospective cohort studies	15	Linkevicius et al. (2018) Gierthmuehlen et al. (2020) Bodereau et al. (2020) Krawiec et al. (2021) Joda, Ferrari, & Brägger (2017) Strauss et al. (2022) Finelle et al. (2021) Trimpou et al. (2022) Lilet et al. (2022) Derksen & Wismeijer (2022) Linkevicius et al. (2022) Naumann et al. (2023) Joda et al. (2018) Salem et al. (2022) Strasding et al. (2023)
Retrospective cohort studies	8	Chen and Pan (2019) Diéguez-Pereira et al. (2020) Lerner et al. (2020) Menchini-Fabris et al. (2020) Guncu et al. (2022) De Angelis et al. (2020) Iglhaut et al. (2021) Gehrke et al. (2023)
Total	29	

TABLE 3 Excluded papers at data extraction.

Study	Reason for exclusion
Meijndert et al. (2021)	Full methodology of abutment design not reported
Rathe et al. (2021)	Same patient pool to a more recent study as Rathe et al. (2022)
Asgeirsson et al. (2019)/Stucki et al. (2021), Thoma et al. (2017)	Same patient pool to a more recent study Strauss et al. (2022)
Saponaro et al. (2023)	Single unit prostheses results not separated from multiple unit prostheses
Mangano et al. (2019)	Same patient pool to a more recent study Lerner et al. (2020)
Joda and Brägger (2015)	Same patient pool to a more recent study Joda, Ferrari, & Brägger (2017)
Akin and Chapple (2022)	Full methodology of abutment design not reported
Rattanapanich et al. (2019)	Abutment utilized does not have a digital library
Kunavisarut et al. (2022)	Follow-up period not sufficient
Derksen et al. (2021)	Same patient pool to a more recent study Derksen and Wismeijer (2022)

2.2.2 | Exclusion criteria

The following studies were excluded: (1) not meeting all inclusion criteria; (2) studies in languages other than English; (3) studies with multiple units; (4) studies with mean follow-up time less than 12 months; (5) absence of clear methodology indicating type of abutment; (6) studies reporting on ceramic or subperiosteal implants; (7) poor reporting on dropouts and number of patients at follow-up.

2.3 | Data analyses

Two reviewers (JC and CE) independently extracted the data of the included articles. The authors were calibrated prior to the data extraction to ensure consistency within the process. When an article was published as an RCT but did not directly compare TBA to other abutments, it was categorized as a prospective study. The study characteristics as author, year, study setting, study design, mean follow-up time, total number of included patients at baseline and at

TABLE 4 Descriptive characteristics of randomized clinical trials.

Study	Number of patients (baseline)	No TBA follow-up (baseline)/control customisable abutment (baseline)	Abutment location	Follow-up (months)	Intervention and control abutment types
Mühlemann et al. (2020)	74 (76)	38 (39)/36 (37)	Posterior maxilla and mandibular	12	TBA with zirconia suprastructure (t) compared to gold cast-to PFM (c)
Erhan Çömlekoğlu et al. (2018)	16 (16)	16 (16)/16 (16)	Anterior maxilla	24	Immediate finalized placement (t) of abutments and dis/reconnections (c)
Mangano and Veronesi (2018)	50 (50)	25 (25)/25 (25)	Posterior maxilla and mandible	12	Digital procedure TBA (t) vs. analogue procedure PFM (c)
Vazouras et al. (2022)	25 (25)	25(25) TBA/25 (25) titanium/25 (25) pink anodized	Anterior maxilla	12	Crossover design; grey titanium abutment; pink anodized titanium abutment; TBA with zirconia crown
Rathe et al. (2022)	22 (24)	22 (24)/22 (24)	All locations	60	Compared TBA (t) to one piece CAD/CAM titanium abutments (c)
Wolfart et al. (2021)	39 (41)	27 (28)/26 (28)	Posterior maxilla and mandible	24	Screw retained TBA compared to cement retained

Abbreviations: c control; PFM: porcelain fused to metal crowns; *t* test; TBA: titanium base abutments.

follow-up, number of patients dropped outs were recorded. The restoration design features extracted was either one piece cemented to a TBA or two pieces cemented to a TBA; material cemented to TBA; type of cement utilized; and TBA geometry.

2.4 | Outcome measures

Restoration survival was defined as a prosthesis with an abutment, and restorative crown or intermediate coping remaining in situ, for the entire observation period without replacement. Failure in this present systematic review was considered when the prosthesis was reported to be lost, removed and/or remade however, did not include reasons such as implant loss. Biological outcomes such as marginal bone level (MBL) loss, bleeding on probing and periodontal pocket depths (PPD) were recorded. Technical outcome of debonding was defined as loss of retention of the restorative material to the TBA. Chippings that were repairable and/or polishable, screw loosening and abutment fracture were considered as a technical complication and the data were extracted through descriptive measures. Aesthetic outcomes were recorded as PES and WES scores. Prosthetic loading was reported and classified according the ITI Treatment Guide Vol. 3 (Buser et al., 2019). The loading classification reported by the 4th ITI Consensus Conference was utilized for this review (Weber et al., 2009).

2.5 | Quality assessment of the included studies

JC and CE made the quality assessment of the included studies. The quality assessment for RCTs was performed with the Cochrane classification of assessing risk and non-randomized studies were performed with the Newcastle–Ottawa Scale (NOS). According to the NOS, studies with scores <5 were considered as low quality, 5–7 were considered as moderate quality and scores >7 were considered as high quality.

2.6 | Statistics

The included RCTs of similar design permitted a meta-analysis assessing the survival rate of a prosthesis restored with a TBA and comparing the TBA to other abutments. A meta-analysis was also used to compare survival rates and MBL loss of TBA to other abutments. In the present systematic review, survival rates were calculated by dividing the number of events (failed restorations) by the total number of restorations. For each study, event rates for the TBA were calculated by dividing the total number of events by the total number of TBA exposed after 1 year in function. Titanium base abutments were also compared to other abutments by calculating the number of events and dividing it by the total number of abutments exposed presented as odds ratios. For each outcome, the DerSimonian–Laird random effects models were used to constructed pooled estimates across studies. For the analysis of survival of TBA after 1 year of function, a correction factor of 0.5 was added in situations where the observed survival was 100%; that is, zero failures were observed. The handling of adding the correction factor of 0.5 was done according to the default settings of the OpenMetaAnalyst software as implemented as defaults in the metafor package (Wallace et al., 2012). The statistical heterogeneity among studies was assessed using the Q test based on a chi-square test (Cochran, 1954) and reported along with the I^2 index (Higgins et al., 2003), which represents the percentage of variation in the pooled estimate that was attributable to heterogeneity between the studies.

Marginal bone level loss was presented in millimetres: means ± standard deviations. Forest plots were created to illustrate the results of the meta-analysis across the different studies. Statistical significance was defined as p-value <.05.

3 | RESULTS

3.1 | Inclusion and exclusion of articles and data extraction

A flow diagram (Figure 2) reports the screening and selection of studies. The electronic search identified 1159 papers in total after all the duplicates were removed. Three hundred and one full-text articles obtained for screening and independently. A final 29 articles were found to qualify for inclusion in the review. The study designs of these articles were 15 prospective cohort studies (52%), eight retrospective (28%) and six RCT (21%; Table 2). The excluded articles at time of data extraction are tabulated in Table 3. Table 4 provides descriptive detail of the RCT studies and Table 5 outlines the details of all the 29 eligible studies. The mean and standard deviation of the follow-up period of 29 studies were 31.2 ± 16.9 months with the minimum being 12 months and maximum 72 months.

A total of 857 TBAs were assessed. Implants most commonly used per study were from the following manufacturers—Straumann (n = 11), Exacone (n = 2) and Camlog (n = 4). Other implant brand (n = 11) include; NucleOSS; Genesis; Biomet 3i; Biohorizons; Klockner; Nobel Biocare; Xive;Virtonex; Duocone; MIS; and Thommen Inciell. Stage C prosthetic loading of the implants was reported in 24 studies. The implant loading protocol reported varied from Stage 1 to 4: stage 1 (n = 4); stage 2 (n = 1); stage 3 (n = 3); stage 4 (n = 12) not reported (n = 10).

3.2 | Quality assessment of the included studies

The quality assessment and selected risk of bias for RCTs studies were classified according to the Cochrane classification of assessing risk of bias summarized in Figure 3. There were four studies which had a low risk of bias in all fields (Higgins et al., 2011). Two of the six studies had some concerns in one or two fields. The unweighted summary plot of RCTs is depicted in Figure 4.

Prospective and retrospective cohort studies were assessed utilizing the Newcastle–Ottawa Scale (NOS). Most of the studies were judged to have moderate methodological quality, NOS score 5, 6, 7 or 8 out of a total of 9 points. A maximum score of nine stars could be assigned to the investigations that conformed to the nine criteria as follows: (1) representativeness of exposed cohort, (2) selection of non-exposed cohort, (3) ascertainment of exposure, (4) demonstration of outcome of interest not present at the start of study, (5–6) comparability in use of abutment and endosseous implant, (7) assessment of outcome, (8) follow-up longer than 12 months and (9) adequacy of follow-up (Table 6).

3.3 | Survival rates

The odds ratio of a TBA compared to other abutments was 0.74 with the 95% confidence interval ranging from 0.21 to 2.63 and p-value .64. The I^2 heterogeneity was 0% and p-value = .99. The full description of the meta-analysis is tabulated in Table 7 and illustrated in a forest plot (Figure 5). The estimate survival rate of a TBA was 98.6% after 12 months of use; 95.0%CI: 97.9%–99.4%; heterogeneity I^2 = 0%, p = .99 (Figure 6 and Table 8).

3.4 | Biological outcomes

Radiographic data on MBL were reported in five of the six RCT studies. All studies utilized an intraoral radiograph to evaluate peri-implant MBLs. Data pooled from five studies found there was not a significant difference between the TBA and other customizable abutments (Mean difference: 0.095; 95% CI: −0.07 to 0.261; heterogeneity: p = .26, I^2 = 23.44%) (Figure 7 and Table 9). The customizable abutments included were gold cast-to, preformed titanium and zirconia abutments. Statistical analysis of the included studies did not display a significant difference in MBL change between different implant-abutment protocols. Other biological complications PDD and BOP were commonly reported; however, there was not enough consistency within the studies to allow for comparison (Table 10).

3.5 | Technical outcomes

The studies reviewed analysed a variety of TBA designs, the specifications of each are outlined in Table 11. The TBA varied in attachment height, width, material thickness, anti-rotation features, transmucosal heights and cement space. Seventeen studies utilized a zirconia; 14 studies utilized lithium disilicate; and single study utilized PEEK, resin-modified hybrid ceramic and titanium as the restorative material at the TBA. All of the studies utilized a resin cement to adhere the titanium base abutment to zirconia or lithium disilicate.

TABLE 5 Methodological characteristics of the studies included.

Study	Patients at follow up (patients at baseline)	Number of TBA	Follow-up (months)	Material cemented to TBA	Cement	Survival of restoration of TBA at 12 months	Survival of implant at 12 months (%)	Implant placement/loading protocol
(Erhan Çömlekoğlu et al., 2018)	16 (16)	8	24	Zirconia	Self-curing resin cement	7/8	100	4/C
Rathe et al. (2022)	24 (24)	24	60	Titanium	Dual cure resin cement	24/24	100	NR/C
(Strauss et al., 2022)	22 (24)	22	60	Zirconia	Dual cure resin cement	21/22	96	4/C
Iglhaut et al. (2021)	20 (20)	20	43.2	Zirconia	NR	20/20	100	NR/C
Linkevicius et al. (2018)	(54) 55	54	12	LDS	Resin cement	54/54	100	4C
Vazouras et al. (2022)	23 (25)	18	12	Zirconia	Dual cure resin cement	16/18	96	NR/C
Linkevicius et al. (2022)	29 (30)	29	12	Zirconia	NR	29/29	98	NR/NR
Linkevicius et al. (2022)	26 (30)	30	12	Zirconia	NR	26/26	100	NR/NR
Wolfart et al. (2021)	(40) 41	28	24	LDS	Self-curing resin cement	28/28	100	4C
Gierthmuehlen et al. (2020)	26 (27)	39	12	LDS	Self-curing resin cement	39/39	100	NR/C
Gierthmuehlen et al. (2020)		6		LDS	Self-curing resin cement	6/6	100	NR/C
Krawiec et al. (2021)	40 (40)	40	12	LDS	Self-curing resin cement	40/40	100	3B
Chen and Pan (2019)	32 (32)	32	72	Zirconia	NR	32/32	100	2C
Bodereau et al. (2020)	10 (10)	10	42	Zirconia	Self-adhesive resin cement	10/10	100	4C
Derksen and Wismeijer (2022)	30 (32)	45	36	Zirconia	Self-curing resin cement	44/45	96	4C
Mühlemann et al. (2020)	59 (60)	38	12	Zirconia	Self-curing resin cement	38/38	97	2C
Joda, Ferrari, & Brägger (2017)	44 (44)	50	36	LDS	Self-curing resin cement	50/50	100	NR/NR
Lerner et al. (2020)	90 (90)	106	36	Zirconia	Resin cement	101/105	99	NR/C
F. Mangano and Veronesi (2018)	50 (50)	25	12	Zirconia	NR	23/25	100	3C
Naumann et al. (2023)	10 (10)	10	36	LDS	Resin cement	9/10	100	NR/C
Naumann et al. (2023)	10 (10)	10	36	LDS	Resin cement	10/10	100	NR/C
Menchini-Fabris et al. (2020)	54 (54)	54	36	LDS	Self-adhesive resin cement	54/54	100	1C
Finelle et al. (2021)	17 (17)	17	24	LDS	Resin cement	19/19	100	4C
De Angelis et al. (2020)	19 (19)	19	36	LDS	Resin cement	19/19	100	4C

Implant brand (type)	Ti-base type	Bone level (BL) / tissue level (TL)	Transmucosal height	Attachment height	Connection	Prostheses with 1 cement layer (1) or 2 cement layers (2)
Camlog (conelog)	Conelog Ti Base	BL	2 mm	4.7 mm	Conical (7.5°)	1
Camlog (conelog)	Conelog Ti Base	BL	0.8 mm	4.7 mm	Conical (7.5°)	2
Straumann (bone level, 6x NC, 18x RC)	Medentika	BL	6 × 1 mm 18 × 0.8 mm	3.5 mm	Conical (15°)	1
Straumann (BLT)	Variobase	BL	1.5 mm	3.5 mm	Conical (7°)	1
MIS	Ti-Base	BL	0.5 mm	4.0 mm	Conical (12°)	1
Keystone (genesis)	NS	BL	<1 mm	NS	Conical connection (° NS)	2
NucleOSS (T6 standard bone level implant)	Titanium base	BL	0.7 mm	NS	Conical (First part 20°, 15°)	1
NucleOSS (T6 standard bone level implant)	Titanium base	BL	2.4 mm	NS	Conical (First part 20°, 15°)	1
Camlog screw-line promote plus	Camlog (flat ti-base	BL (0.4 mm machined)	0.3 mm	4.7 mm	Butt-joint	1
Nobel replace	Universal base tri-channel	BL (details NS)	1.5 mm	NS	Butt-joint	1
Xive S Plus	Dentsply Sirona ti-base	BL	NS	NS	Butt-joint	1
Thommen (Innicell®SPI Element MC)	Dentsply Sirona ti-base	BL	NS	NS	Butt-joint	1
Biomet 3i Certain R	Dentsply Sirona ti-base	BL	NS	NS	Butt-joint	2
BioHorizons (Tapered Internal Laser-Lok)	BioHorizons Ti Base Abutment	BL	1 mm	4 mm	45° internal hex	1
Straumann (tissue-level SP & TE)	Variobase RN	TL	NA	4 mm	Synocta, 45° external bevelled shoulder	1
Straumann (tissue-level SP)	Variobase RN	TL	NA	NS	Synocta 45° external bevelled shoulder	1
Straumann (tissue-level SP)	Variobase RN/WN	TL	NA	4,0–4.5 mm	Synocta 45° external bevelled shoulder	
Exacone	Ti-base on top of friction fit abutment	NA	NA	4.0 & 6.0 mm	Friction fit	2
Exacone	Ti-base on top of other friction fit abutment	NA	NA	4.0 & 6.0 mm	Friction fit	2
Camlog (conelog)	Conelog Ti Base	BL	2 mm	4.7 mm	Conical (7.5°)	2
Camlog (conelog)	Conelog Ti Base	BL	2 mm	4.7 mm	Conical (7.5°)	1
Outlink	TL	External Hex	NS	NS	External Hex	1
Straumann	Variobase	TL/BL	NS	NS	Conical (7°) / Synocta 45° external bevelled shoulder	1
Straumann	NR	BL	NS	NS	Conical (7°)	1

(Continues)

TABLE 5 (Continued)

Study	Patients at follow up (patients at baseline)	Number of TBA	Follow-up (months)	Material cemented to TBA	Cement	Survival of restoration of TBA at 12 months	Survival of implant at 12 months (%)	Implant placement/loading protocol
De Angelis et al. (2020)	19 (19)	19	36	Zirconia	Resin cement	19/19	100	4C
Trimpou et al. (2022)	21 (21)	21	12	Zirconia	Resin cement	21/21	100	1A
Lilet et al. (2022)	19 (20)	20	12	LDS	NR	19/19	100	1C
Guncu et al. (2022)	118 (118)	192	32	Zirconia	Self-curing resin cement	180/192	100	NR/NR
Joda et al. (2018)	10 (10)	10	36	LDS	NR	10/10	100	NR/NR
Salem et al. (2022)	30 (30)	30	24	10 Zirconia, 10 Resin modified, 10 PEEK with composite veneer	Self-curing resin cement	30/30	100	4C
Strasding et al. (2023)	55 (60)	54	12	26 LDS 28 Zirconia	Self-curing resin cement	54/54	98.3	4C+3C
Gehrke et al. (2023)	75 (75)	109	12	NR	NR	108/109	100	1A+4C

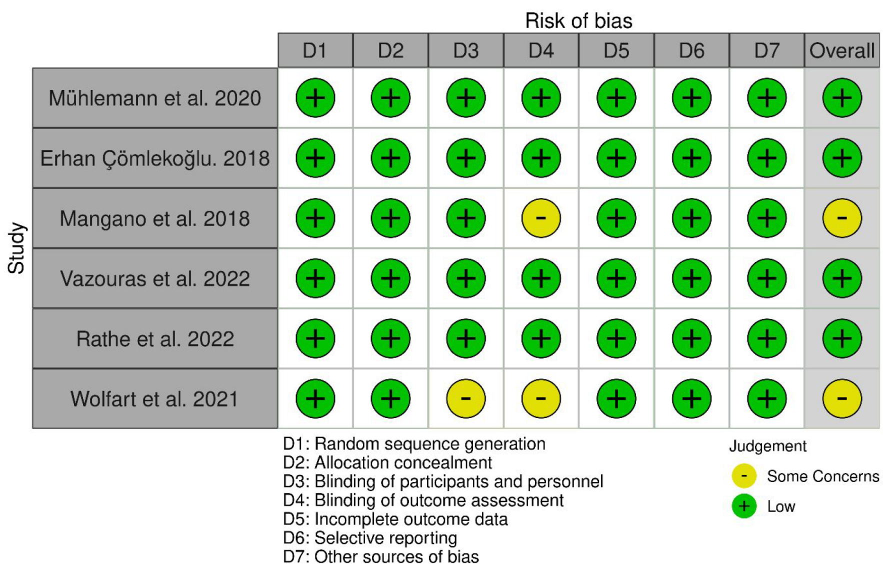

FIGURE 3 Risk of bias assessment according to the Cochrane Collaboration recommendations (Higgins et al., 2003).

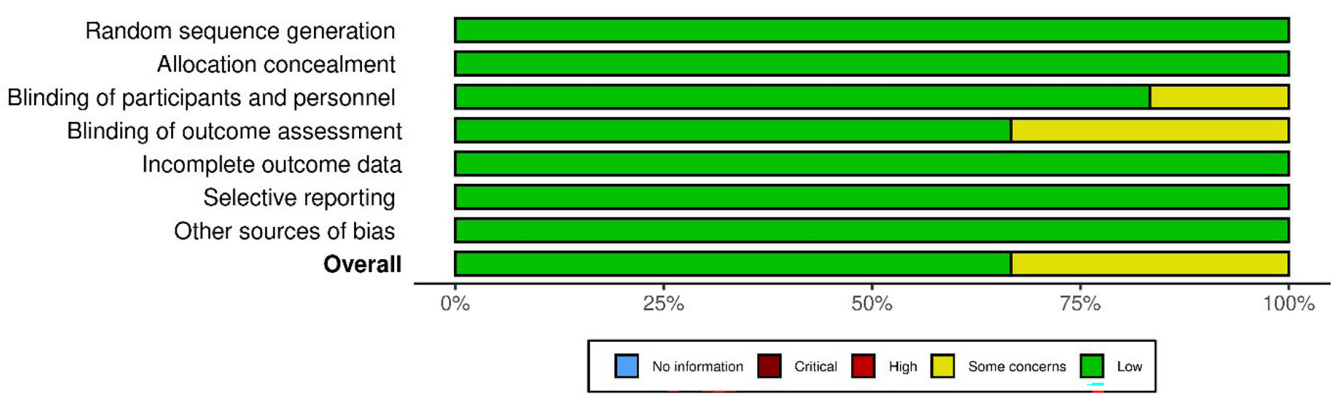

FIGURE 4 Unweighted summary plot of randomized clinical trials McGuinness and Higgins (2020).

Implant brand (type)	Ti-base type	Bone level (BL) / tissue level (TL)	Transmucosal height	Attachment height	Connection	Prostheses with 1 cement layer (1) or 2 cement layers (2)
Straumann	Ti base Dentsply Sirona	BL	NS	NS	Conical (7°)	1
Camlog (progressive line)	NR	BL	NS	NS	Conical (7.5°)	2
Straumann	Variobase®	BLX	NS	NS	Conical (7°)	1
Straumann	Variobase®	BL	NS	3.5 mm + 5.5 mm	Conical (7°)	1
Straumann	Variobase®	TL	NA	4 mm	Synocta 45° external bevelled shoulder	1
Virtonex	Titanium base	BL	NA	4 mm	Conical (7°)	2
Straumann	Variobase®	BL	NS	NS	Conical (7°)	1
DuoCone	Titanium Base	BL	1.5, 2.5, 3.5 mm	NR	Morse Taper	1

The cementation protocol, whether the abutment was sandblasted or primed, was not consistently reported.

Eight studies assessed aesthetic outcomes (Table 12). Three of the 29 studies assessed the PES and WES scores together with the mean ± standard deviation been reported respectively (8.5 ± 1.4 and 8.4 ± 2.0) (Bodereau et al., 2020; Krawiec et al., 2021). Two studies provided aesthetic outcomes utilizing PES only (Erhan Çömlekoğlu et al., 2018; Vazouras et al., 2022). Lithium disilicate superstructure prostheses maintained their colour over 12 months, but became duller and exhibited increased surface roughness (Gierthmuehlen et al., 2020). Vazouras et al. did comment that a zirconia superstructure as second layer exposed less titanium and increased the aesthetic outcomes of the implant prosthesis (Vazouras et al., 2022).

4 | DISCUSSION

The current systematic review investigated the survival rates of TBA with particular interest in biological complications, technical complications and aesthetic considerations. The present systematic and meta-analysis demonstrated a high survival rate after 12 months. The main technical problem leading to a remake of the restoration was debonding to the TBA. A limited number of RCTs assessed all the clinical outcomes; however, data were also extracted from prospective and retrospective studies to perform a meta-analysis on survival of TBA abutments and comparison to other abutments for prostheses survival and MBL loss.

Previous analysis on the difference between titanium and zirconia abutments under mechanical, biological and aesthetic aspects has not been statistically significant (Halim et al., 2022). The previously reported high short-term survival rate of 97.6% for monolithic and veneered single implant prosthesis (Pjetursson et al., 2021) was affirmed by this present systematic review. There has been a paucity of literature to support the clinical use of TBA and clinicians have been utilizing them through clinical 'experimentation'. This review is the first to focus exclusively on clinical studies regarding the performance of TBA in hope to clarify their use in clinical practice.

The concept of an early crestal bone remodelling response to establishing a biologic width or zone away from the implant-abutment micro gap is a well-accepted concept in implant dentistry (Hermann et al., 2001). Mattheos, Vergoullis, et al. (2021) recently revised the interrelationship of this complex in the literature as the implant supracrestal complex. This describes the anatomical complex of human tissue, technical component and bacteria extending through the transmucosal part of the implant prosthesis, and possible interrelationship between biological and technical complications (Mattheos, Vergoullis, et al., 2021). A consistent and reproducible connection of the implant-abutment to the endosseous implant reduced micromovement of the implant prosthesis and can lead to fewer biologic complications (Hamilton et al., 2013). A high incidence of BOP and PPD was reported in one of the included studies using non-genuine componentry as the genuine abutments were not available at the beginning of their study. The authors compared their abutments to the genuine TBA and noted an increased diameter and reduced height. This led to a design with a close vertical and horizontal distance between the restoration and the marginal bone around the two-piece implants including a cement gap, which was deemed responsible for a biologic reaction with increased bone remodelling (Stucki et al., 2021). The accuracy of fit of the crown restoration to the TBA is paramount in ensuring a minimal cement gap exists in the transmucosal portion. Pitta et al. analysed the bending movements between TBA and CAD/CAM customized abutments and found that the ultimate fracture point in both groups was through the abutment screw, but such high forces are unlikely to occur clinically (Pitta et al., 2021).

TABLE 6 Quality assessment of prospective and retrospective cohort studies based on Newcastle–Ottawa Scale (NOS).

	Selection				Comparability		Outcome			Score
Study (Author, year)	Representativeness of cases	Selection of controls (RCT—Control group of exposure from the same cohort)	Ascertainment of exposure	Demonstration outcome of interest not present at the start of the study	TBA	Implant fixture	Assessment of outcome	Follow-up long enough	Adequacy of follow-up	Total
Bodereau et al. (2020)					*	*		*	*	4
Chen and Pan (2019)			*	*	*	*	*	*	*	7
De Angelis et al. (2020)			*	*	*	*		*	*	6
Diéguez-Pereira et al. (2020)			*	*	*			*	*	5
Finelle et al. (2021)			*		*			*	*	4
Guncu et al. (2022)			*	*	*			*	*	5
Gierthmuehlen et al. (2020)			*	*	*	*		*	*	6
Joda, Ferrari, & Brägger (2017)			*	*	*	*		*	*	6
Krawiec et al. (2021)			*	*	*	*		*	*	6
Lerner et al. (2020)			*	*	*	*		*	*	6
Lilet et al. (2022)			*	*	*	*		*	*	6
T. Linkevicius et al. (2018)		*	*	*	*	*		*	*	7
Menchini-Fabris et al. (2020)		*	*	*	*	*		*	*	7
Strauss et al. (2022)			*	*	*	*		*	*	6
Trimpou et al. (2022)			*	*	*	*		*	*	6
Derksen and Wismeijer (2022)			*	*	*	*		*	*	6
Tomas Linkevicius et al. (2022)			*	*	*	*		*	*	6
Naumann et al. (2023)			*	*	*	*		*	*	6
Joda et al. (2018)			*	*	*	*	*	*	*	6
Salem et al. (2022)			*	*	*	*		*	*	6
Strasding et al. (2023)			*	*	*	*		*		5
Gehrke et al. (2023)			*	*	*	*	*	*	*	7

*Are assigned to the investigations that conform to the quality assessment criteria.

TABLE 7 Comparison of abutment survival for TBA and other abutments survival after 1 year of function.

Study	TBA survival		Other abutment survival		Odd ratio (OR)				Heterogeneity	
	Events	Total	Events	Total	OR	95% CI		*p*-value	I^2 (%)	*p*-value
Overall	136	141	126	128	0.74	0.21	2.63	.64	0	.99
Mühlemann et al. (2020)	38	38	36	36	1.06	0.02	54.56			
Erhan Çömlekoğlu et al. (2018)	7	8	8	8	0.29	0.01	8.37			
Mangano and Veronesi (2018)	23	25	23	25	1.00	0.13	7.18			
Vazouras et al. (2022)	16	18	7	7	0.44	0.02	10.34			
Wolfart et al. (2021)	28	28	28	28	1.00	0.02	52.15			
Rathe et al. (2022)	24	24	24	24	1.00	0.02	52.44			

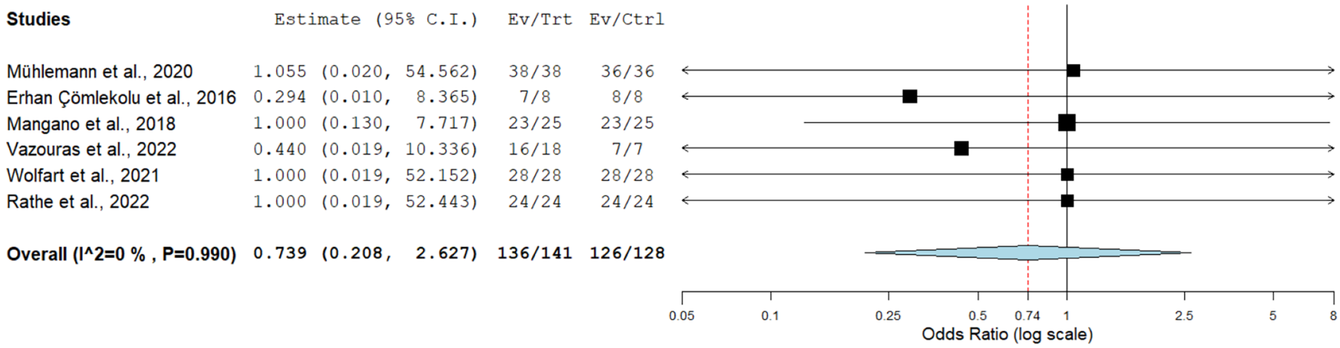

FIGURE 5 Forest plot meta-analysis of titanium base abutments survival compared to other abutments.

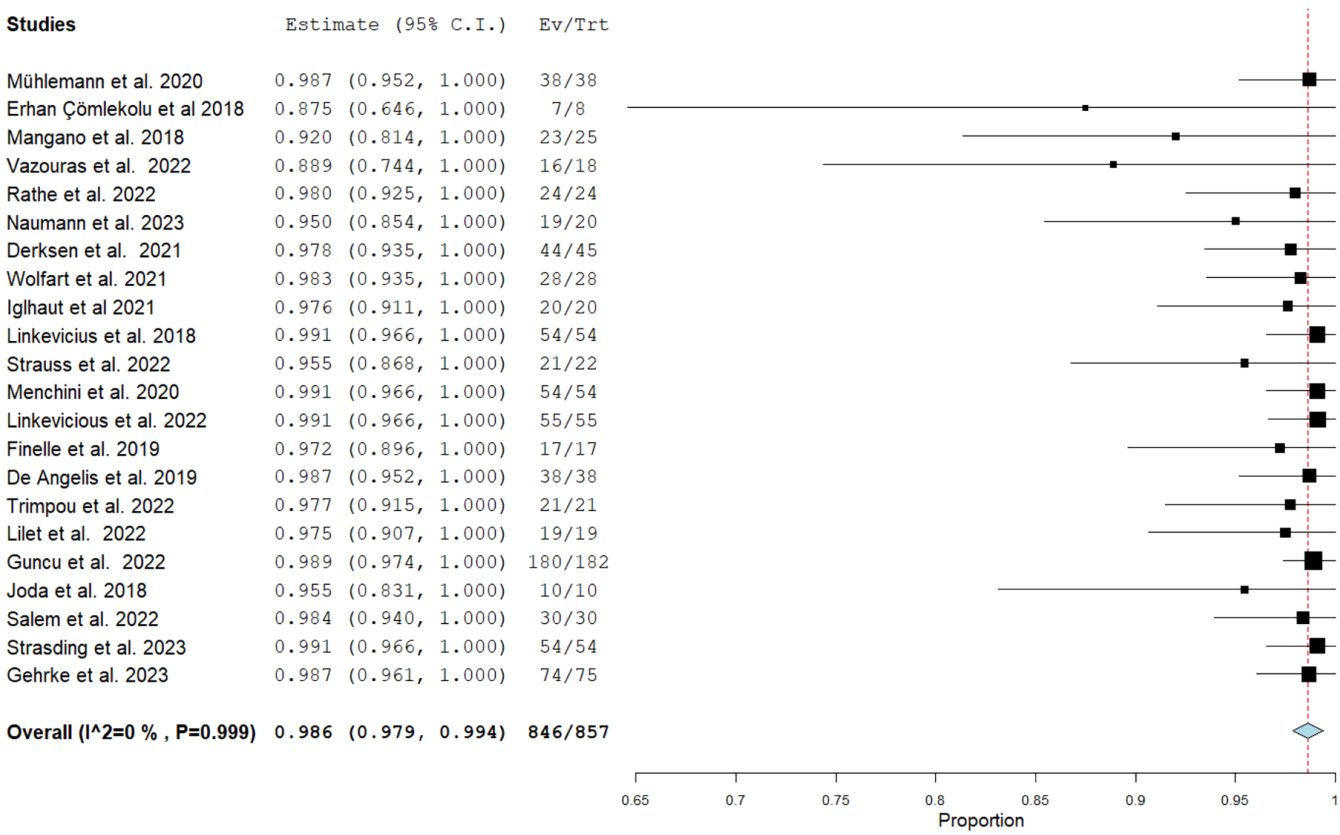

FIGURE 6 Forest plot meta-analysis of titanium base abutments abutment survival.

TABLE 8 Titanium base abutments (TBA) survival after 1 year of function.

Study	TBA survival						Heterogeneity	
	Events	Total	Estimate	95% CI		*p*-value	I^2 (%)	*p*-value
Overall	846	857	0.99	0.98	0.99	<.01	0	.99
Mühlemann et al. (2020)	38	38	0.99	0.83	1.00			
Erhan Çömlekoğlu et al. (2018)	7	8	0.88	0.46	0.98			
Mangano and Veronesi (2018)	23	25	0.92	0.73	0.98			
Vazouras et al. (2022)	16	18	0.89	0.65	0.97			
Rathe et al. (2022)	24	24	0.98	0.75	1.00			
Naumann et al. (2023)	19	20	0.95	0.72	0.99			
Derksen and Wismeijer (2022)	44	45	0.98	0.86	1.00			
Wolfart et al. (2021)	28	28	0.98	0.78	1.00			
Iglhaut et al. (2021)	20	20	0.98	0.71	1.00			
Linkevicius et al. (2018)	54	54	0.99	0.87	1.00			
Strauss et al. (2022)	21	22	0.95	0.74	0.99			
Menchini-Fabris et al. (2020)	54	54	0.99	0.87	1.00			
Linkevicius et al. (2022)	55	55	0.99	0.87	1.00			
Finelle et al. (2021)	17	17	0.97	0.68	1.00			
De Angelis et al. (2020)	38	38	0.99	0.83	1.00			
Trimpou et al. (2022)	21	21	0.98	0.72	1.00			
Lilet et al. (2022)	19	19	0.98	0.70	1.00			
Guncu et al. (2022)	180	182	0.99	0.96	1.00			
Joda et al. (2018)	10	10	0.96	0.83	1.01			
Salem et al. (2022)	30	30	0.98	0.94	1.02			
Strasding et al. (2023)	54	54	0.99	0.97	1.01			
Gehrke et al. (2023)	74	75	0.99	0.96	1.01			

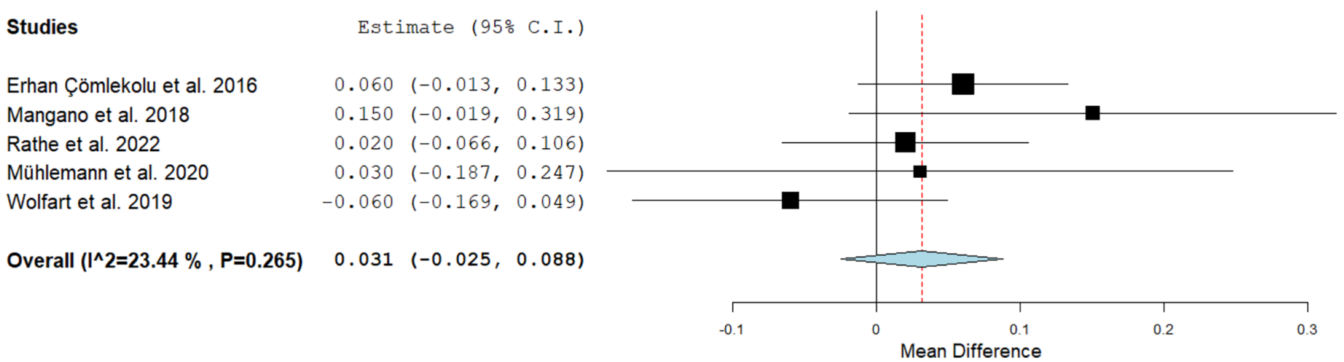

FIGURE 7 Forest plot meta-analysis of marginal bone level.

Manufacturers of TBA can standardize the cement gap within their prescribed digital library, while allowing for adequate ventilation of cement. The age of the milling tools (Payaminia et al., 2021); CAD milling strategies (Zimmermann et al., 2018); and surface treatment protocol (Arce et al., 2018) are factors that can influence the accuracy of the internal fitting surface of the implant prosthesis. Industrialization of the process standardizes these parameters, unlike traditional manual processes where the dental technician can easily influence the intimacy of fit. Selecting and implementing validated workflows to produce such restorations with proprietary manufacturing files is essential. Crown separation from the TBA was observed as the major complication and was categorized as a failure in this review, as the implant prosthesis was required to be remade. Due to the inconsistent follow-up periods reported on TBA, the results were taken after 12 months in function and 10 TBAs were reported to have a loss of retention. This result seems to be similar to the reported 1.97% annual complication rate of loss of retention in a similar systematic review (Pjetursson et al., 2021).

Cemented crowns have a higher risk for peri-implant diseases compared to screw-retained restoration because excess cement

TABLE 9 Comparison of marginal bone levels (MBL) (mm).

Study	TBA			Other abutments			MD					Heterogeneity	
								95% CI					
MBL	Number	Mean	SD	Number	Mean	SD	MD	Lower	Upper	p-value	Weighted (%)	I^2 (%)	p-value
Overall							0.03	−0.03	0.88	.28		23.44	.265
Mangano and Veronesi (2018)	25	−0.39	0.29	25	−0.54	0.32	0.15	−0.02	0.32		19.60		
Erhan Çömlekoğlu et al. (2018)	16	−0.12	0.10	16	−0.18	0.11	0.06	−0.01	0.13		23.53		
Rathe et al. (2022)	24	−0.07	0.13	24	−0.09	0.17	0.02	−0.06	−0.11		23.15		
Mühlemann et al. (2020)	38	−0.19	0.90	36	−0.22	0.66	0.03	−0.33	0.38		11.45		
Wolfart et al. (2021)	26	−0.13	0.16	27	−0.07	0.24	−0.06	−0.17	0.05		22.28		

Note: All values were taken at the same follow-up time of 12 months.

Abbreviations: MD, mean difference; SD, standard deviation.

is not accessible and cement penetrates in submucosal regions particularly with soft tissue healing periods shorter than 4 weeks (Staubli et al., 2017). When crown margins are located more than 1–2 mm submucosally the complete removal of cement remnant is unlikely (de Brandão et al., 2013; C. Lemos et al., 2016; Staubli et al., 2017). Titanium base abutments within the selected studies reported transmucosal heights ranging from 0.3 to 2.4 mm with a highly polished interface cement gap of 50–100 µm (Mattheos, Janda, et al., 2021). The location of the flat shoulder being near the implant-abutment interface has raised the concern that adhesive resin cement around TBA is associated with an increased risk of breakdown, biofilm formation and subsequent biological complications (Heitz-Mayfield & Salvi, 2018; Nissan et al., 2006, 2011). The differing transmucosal heights allow for clinicians and dental technicians to shift the location of the cement gap distanced from the implant-abutment interface (Linkevicius et al., 2018). Linkevicius et al. assessed the difference between different transmucosal heights of TBA short (0.7 mm) versus high (2.4 mm), and reported positive changes in MBL of +0.13 mm and + 0.37 mm for the short and high abutments, respectively, from the time of placement to 1-year follow-up. Due to the lack in statistical difference, the authors concluded that the height of the transmucosal segment of the TBA may not affect biological outcomes (Linkevicius et al., 2022). Gehrke et al. also assessed TBA with differing transmucosal heights (1.5 mm, 2.5 mm and 3.5 mm). Radiographic MBL was assessed on the mesial and distal and the authors reported less MBL loss when transmucosal abutment heights of 2.5 mm were utilized. The authors also investigated different abutment diameters, 3.5 and 4.5 mm, but without significantly different outcomes (Gehrke et al., 2023). The surface topography of the transmucosal segment of the implant prosthesis has not shown to be significant in affecting the TBA outcome (Rompen et al., 2006). In vitro studies on cement surfaces demonstrated that the cement gap should be smooth and an oxygen inhibition layer removed to increase cell viability of human gingival fibroblasts (Rohr et al., 2022; Rohr et al., 2020).

Titanium base abutments classified as CAD/CAM stock abutments offer the opportunity to select the height of the transmucosal segment so that the abutment shoulder with the corresponding restoration and cement margin is distant from the marginal bone, while allowing an emergence profile that facilitates an aesthetic outcome and cleanability. Above the abutment shoulder, the selected restorative material, such as zirconia, lithium disilicate or polymer-infiltrated ceramics, can be customized based on the desired clinical emergence profile (de Melo Moreno et al., 2022). When comparing differing materials around the emergence profile of an implant-abutment prosthesis complex, zirconia has reduced plaque retention and demonstrates a better quality of soft tissue attachment when used as an abutment material (Enkling et al., 2022). This may play a role in the reduction of soft tissue inflammation and bleeding on probing values when compared to titanium over-time (Sanz-Sánchez et al., 2018). Individualization of sulcus contours is a highly desirable and TBA have the benefits

TABLE 10 Biological outcomes.

Study	Implant survival rates at 12 months (%)	Biological outcomes
Erhan Çömlekoğlu et al. (2018)	100	MBL after 24 months was greater in t group than c PPD and BOP insignificant differences between the groups
Tomas Linkevicius et al. (2022)	98.3	MBL short TBA 0.6 mm, high TBA 0.45 mm PPD and BOP insignificant differences between groups
Derksen and Wismeijer (2022)	97.8	BOP, PPD, MBL not commented on
Mühlemann et al. (2020)	97.4	MBL, BOP, PPD No significant differences between the groups were detected
Wolfart et al. (2021)	100	GI and MBL (loss between 0.03 and 0.15 mm) no significant differences between groups PI: TBA (96.6%) and cemented (64.3%) at 12 months At 12 months, BOP screw retained 14.2% and cement retained 17.9% Cement detected on radiograph at baseline in cemented group (6.9%)
Rathe et al. (2022)	100	MBL, BOP no significant differences between the groups PPD c group showed significant deepening than t group
Mangano and Veronesi (2018)	100	BOP c group 8% t group 4% MBL c group 0.54 ± 0.32 mm t group 0.39 ± 0.29 mm not statistically significant
Bodereau et al. (2020)	100	BOP, PPD, MBL not commented on
Chen and Pan (2019)	100	No BOP or suppuration MBL 31 implants had low amounts of bone loss, 1 implant lost 2.1 mm
Diéguez-Pereira et al. (2020)	100	BOP, PPD, MBL not commented on
Gierthmuehlen et al. (2020)	100	No BOP, PPD and MBL not commented on
Iglhaut et al. (2021)	100	No Significant difference between groups PPD TBA group 3.45 ± 0.57 mm c group 3.50 ± 0.95 mm BOP TBA group 30.8% c group 26.7%
Joda, Ferrari, and Brägger (2017)	100	PPD 3.5 ± 0.6 mm BOP 19.5 ± 1.9% PI 20.6 ± 2.2% MBL 2.0 ± 0.0 mm
Krawiec et al. (2021)	100	MBL 0.19 ± 0.29 mm (thin biotype) 0.24 ± 0.24 mm (thick biotype) PPD 2.17 ± 0.53 mm (thin biotype) 2.04 ± 0.37 mm (thick biotype)
Lerner et al. (2020)	100	BOP 1.9%
T. Linkevicius et al. (2018)	100	MBL 1.25 ± 0.80 mm (thin biotype) 0.98 ± 0.42 mm (medium biotype) 0.43 ± 0.37 mm(thick biotype)
Meijndert et al. (2021)	96.7	MBL 0.07 ± 0.12 mm No significant differences in bleeding index or GI
Strauss et al. (2022)	91.7	MBL 0.32 ± 0.36 mm PPD 3.3 ± 0.08 mm BOP 31.1 ± 26.4%
Naumann et al. (2023)	100	MBL, PPD, BOP no individually commented on
Vazouras et al. (2022)	90.9	Peri-implant soft tissue thickness
Menchini-Fabris et al. (2020)	100	NR
Finelle et al. (2021)	100	Gingival recession 0.53 ± 0.35 mm MBL 0.79 ± 0.51 mm
Joda et al. (2018)	100	No biological outcomes PI, PPD and BOP recorded but unable to distinguish test and control groups.
Salem et al. (2022)	100	PI, BOP PPD, MDL assessed and given a score No biological complications
Strasding et al. (2023)	98.3	BOP: 0.27 ± 0.30% PI 0.17 ± 0.2% PPD 3.6 ± 0.8 mm.
Gehrke et al. (2023)	100	MBL comparing abutment diameter 3.5 mm −0.57 ± 0.53 mm (mesial) and − 0.66 ± 0.53 (distal) 4.5 mm −0.78 ± 0.75 mm (mesial) and − 0.75 ± 0.76 (distal) MBL comparing transmucosal abutment height 1.5 mm −1.13 ± 0.39 mm (mesial) and − 1.15 ± 0.43 (distal) 2.5 mm −0.62 ± 0.61 mm (mesial) and − 0.66 ± 0.60 (distal) 3.5 mm −0.25 ± 0.64 mm (mesial) and − 0.26 ± 0.65 (distal)

Abbreviations: BOP, bleeding on probing; c, control; GI, Gingival Index; MBL, marginal bone loss; NR, not reported.; PI, Plaque Index; PPD, pocket probing depth; t, test.

TABLE 11 Technical outcomes.

Study	Criteria	Abutment fracture	Screw loosening	Prosthesis complication
Wolfart et al. (2021)	NA	No	Yes 1 TBA restoration (3%)	No chipping or restoration fail Similar rate of loss of contact points between groups Both groups, TBA cemented extra orally and TBA cemented intra orally, lost proximal contact points 18% Both groups, TBA cemented extra orally and TBA cemented intra orally, lost occlusal contacts 32%
Erhan Çömlekoğlu et al. (2018)	NA	No	No	Two temporary crowns decemented from TBA: group t
Derksen and Wismeijer (2022)	NA	No	2 TBA abutment (4.9%)	1 screw loosening, 1 debonding from TBA
Tomas Linkevicius et al. (2022)	USPHS	No	No	None reported
Mühlemann et al. (2020)	USPHS	Yes (Not reported which group)	Yes (Not reported which group)	4 minor veneering chipping in c group. Technical complication rate of 11.1% (includes incidences of chipping of veneering ceramic, fracture of crown, fracture of abutment, fracture of abutment screw, loosing of abutment screw, loss of occlusal filling and debonding from abutment) Proximal contact point, 3 crowns lost in t group and 1 crown in the c group Occlusal contact point, 4 crowns in t group and 6 in c group Occlusal wear; more in c group than t.
Mangano and Veronesi (2018)	NA	No	No	Veneering chipping in 1 TBA No technical complications in c group
Chen and Pan (2019)	NA	No	No	Veneering porcelain chipping 6.2% Crown debonding 9.3%
Gierthmuehlen et al. (2020)	USPHS	No	No	No chipping, cracks, fractures, debondings or marginal deterioration Surface roughness 9 crowns 20.5%
Joda, Ferrari, & Brägger (2017)	FIPS	No	No	No technical complications
Lerner et al. (2020)	NA	No	No	Loss of connection between hybrid abutment and fixture 1.8% Crown decemented from two-piece abutment 0.9% Marginal adaptation, interproximal contact points and occlusal contacts scored from 1 to 5 Marginal adaptation 4.41 ± 0.7 Interproximal Contacts 4.46 ± 0.6 Occlusal Contact 3.89 ± 0.8
Strauss et al. (2022)	USPHS	No	Yes (1 incidence)	3 cases of minor veneering chipping, 1 major veneering chipping (replacement of restoration) 1 abutment loosening
Naumann et al. (2023)	FIPS	No	No	1 debonding of TBA
Vazouras et al. (2022)	NA	Yes	No	Zirconia abutment fracture cemented to TBA (2 cases)
Joda et al. (2018)	FIPS	No	No	FIPS 8.0 ± 0.8, no technical complications
Salem et al. (2022)	FIPS	No	No	1 resin matrix crown debonding from intermediate coping, 1 PEEK/composite minor chipping
Strasding et al. (2023)	USPHS	No	No	3 patients minor chipping LDS restorations
Gehrke et al. (2023)	NA	Yes (1 incidence)	No	1 abutment fracture

Abbreviations: NA, not applicable; t, test; TBA, titanium base abutments.

of a CAD/CAM customized abutment. While this may suit some clinical situations, in more aesthetic regions of the mouth, the clinician needs the ability to customize the emergence profile to match the individual clinical situation. Aesthetic success is the goal of restoratively driven treatment planning for dental implant therapy. When achieved, it contributes to higher patient-reported

TABLE 12 Aesthetic outcomes.

Study	Indices	Aesthetic outcomes
Erhan Çömlekoğlu et al. (2018)	PES	No difference between groups Mean ± SD: c: 9.25 ± 0.93 t: 9.94 ± 1.12
Mühlemann et al. (2020)	NA	PFM (c) group colour matched significantly inferior to Zirconia TBA (t) group
Vazouras et al. (2022)	PES, ΔE	PES: TBA 10.88 ± 0.88; grey titanium 9.68 ± 1.41; pink 10.12 ± 1.13 ΔE: TBA 6.46 ± 1.43; grey titanium 11.25 ± 2.98; pink 9.90 ± 2.51
Wolfart et al. (2021)	NA	Colour match and colour retention were better in TBA group than cemented
Bodereau et al. (2020)	PES, WES	Mean ± SD: WES 7 ± 1.5, PES 7.5 ± 0.8
Krawiec et al. (2021)	PES, WES	Thick biotype PES: 9.56 0 ± .53 WES: 9.89 ± 0.33 Thin biotype PES: 9.48 ± 0.70 WES: 9.7 ± 0.54
Lerner et al. (2020)	NA	Scored 1–5: Chromatic and aesthetic integration 4.15 ± 0.7
Meijndert et al. (2021)	PES, WES	Median PES 6, WES 8

Abbreviations: c, control; NA, not applicable; SD, standard deviation; t, test.

outcomes (Vazouras et al., 2022). The ability for clinicians to highly customize the emergence profile to suit the individual clinical situation is essential. The general consensus within the included studies state that regardless of soft tissue thickness, TBAs provide similar aesthetic outcomes to full zirconia abutments (Asgeirsson et al., 2019; Chen & Pan, 2019; Erhan Çömlekoğlu et al., 2018; Mangano & Veronesi, 2018).

One of the limitations of the current review is the minimal amount of information available with short 1-year follow-up periods on the clinical outcomes of TBA when compared to other abutments. The recent literature has not kept pace with the rapid expansion and development of different types of 'genuine' company TBAs. There has also been a rapid proliferation of 'non-genuine' alternatives of TBAs for clinical use with varying geometries; different transmucosal heights and retentive features. The author recognizes that there is a bias in collating many variable abutments, confounded with a short follow-up period. More research is required to assess different geometry designs, cementation protocols for the dental technician and varied tolerances of TBA fit to their survival rates. A further comparison between TBA and the anatomical customized abutments should be further completed to ascertain which clinical scenarios the abutment is indicated when more clinical data become available.

5 | CONCLUSION

Based on the findings of this systematic review, single implant prostheses restored with a TBA have high short-term survival rates. Similar early survival rates and marginal bone level changes are shown when TBA are compared to other abutments. However, limited data are available to guide the clinician on the tolerance of fit to a TBA and the implications of variable TBA geometry have on survival.

AUTHOR CONTRIBUTIONS

JC, CE and WD conceived ideas; JC, CE and WD collected the data; JC, CE and WD analysed the data; JC, CE, NZ and WD led the writing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

None.

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