Long-Term Comprehensive Results of Four-Implant-Supported Overdentures and Fixed Complete Dentures: A Systematic Review and Meta-analysis

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Purpose: To integrate the medium-term outcomes of four-implant-supported overdentures (IODs) and full-arch fixed restorations (IFRs) in the maxilla. ***Materials and Methods***: The search was performed in PubMed, Embase, and Cochrane databases, complemented by manual search. The inclusion criteria were at least 10 maxillary edentulous patients restored by IOD or IFR with at least 5 years of follow-up. Risk of bias (RoB) 2 and Newcastle-Ottawa Scale (NOS) tools were used to assess RoB. The implant survival rate (ISR) was calculated as the primary outcome. Prothesis survival rate, marginal bone loss (MBL), and complications were the secondary outcomes. ***Results:*** A total of 16 studies with 5,568 implants met the criteria (9 implants on IODs, 7 implants on IFRs). The weighted ISR of IODs was 94.5% (95% CI [92.1%, 96.9%]; I^2 = 84.22%), and subgroup analysis was performed on the attachment system and study type. The weighted ISR of IFRs was 98.5% (95% CI [97.4%, 99.5%]; I^2 = 77.88%). For prosthesis survival, the rate of 85.0% in IODs was lower than that of 99.9% in IFRs. MBL after 5 years was −0.27 ± 1.31 mm in IODs and −1.20 ± 0.76 mm in IFRs. Retention loss (0.34 per patient) and dislodgment/fracture of the acrylic teeth (0.09 per patient) were the most common complications in IODs and IFRs, respectively. ***Conclusions:*** Despite the variance of baseline, IFRs had a relatively higher implant and prothesis survival rate than IODs, whereas IODs had less MBL at the 5th year and a higher incidence of complications. Both maxillary IODs and IFRs have predictable medium-term clinical results. *Int J Oral Maxillofac Implants 2025;40:751–765. doi: 10.11607/jomi.11175*

Keywords: dental implants, edentulous maxilla, implant-supported prostheses, systematic review

Implant-supported dental prostheses have been performed during the last two decades, which has led to substantial improvements in edentulous patients' general satisfaction and quality of life.[1,2] Regarding implant-supported rehabilitation, there are two major modalities: implant-supported overdentures (IODs) and implant-supported full arch fixed restorations (IFRs).

Implant prostheses performed in the edentulous maxilla are confronted with more limitations than that in the mandible due to the relatively low bone quality, large volume change after progressive resorption, and sinus pneumatization.[3–5] Therefore, compared with the convincing implant treatment modality in the mandible, many details of implant-supported restorations in the maxilla have not been confirmed.[6]

In the past, there have been many debates about the appropriate number of implants applied in maxillary implant-supported dentures. In IODs, with the existing information about implant survival rate (ISR) and patient-reported outcome measures (PROMs) from systematic reviews, it is widely accepted that four IODs are a high cost-benefit and prevalent approach.[7,8] Besides, maxillary four-implant-supported IFRs with adequate anterior and posterior distances (A-P distances) have also been performed widely for a long period of time.[9–11]

Although there have been many publications on four IODs and IFR in edentulous maxilla, the medium-term outcomes have not been conclusively addressed, and well-defined indications for choosing between the two approaches are still lacking. Consequently, this systematic review aimed to integrate the medium-term survival rate of implants and prostheses, marginal bone loss (MBL), and complications to form a comprehensive evaluation.

MATERIALS AND METHODS

The systematic review was performed by consulting the Preferred Reporting Items for Systematic Reviews

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and Meta-Analyses (PRISMA) statement and the Cochrane Handbook for Systematic Reviews of Interventions (registration no.: CRD42022313564 [PROSPERO database]).[12,13]

Eligibility Criteria

The population, intervention, comparison, outcome, and time duration (PICOT) question referred to the following:

- **P** *(population)*: Patients with an edentulous maxilla
- **I** *(intervention)*: Performing maxillary implant-supported prostheses
- **C** *(comparison)*: The difference between four-IODs and four-implant-supported IFRs
- **O** *(outcome)*: The medium-term ISR was the primary outcome, and the secondary outcome was the protheses survival rate, marginal bone loss (MBL), and complications
- **T** *(time duration)*: Minimum of 5 years of follow-up

Inclusion and Exclusion Criteria

The following inclusion criteria were used: *(1)* At least 10 patients with fully edentulous maxilla's that were rehabilitated with IOD or IFR supported by four implants; *(2)* medium-term follow-up (at least 5 years); *(3)* randomized clinical controlled trials (RCTs), nonrandomized clinical controlled trials (CCTs), prospective studies, and retrospective studies; *(4)* articles published in English from January 2000 to October 2023; *(5)* when the same author published more than one paper on the data from the same group of patients, the one with the larger sample size or the newer one was included; and *(6)* outcome included ISR or implant loss.

The following exclusion criteria were used: *(1)* In vitro studies, *(2)* treatments supported by implants of other numbers, and *(3)* studies on irregular implants prostheses, such as zygomatic implants, pterygoid implants, and mini-implants.

Search Strategy

The literature search was performed in PubMed (MEDLINE), Embase, and the Cochrane database from January 2000 to October 2023, including English-language publications only. The following query was integrated and searched in the literature databases: ((jaw, edentulous OR mouth, edentulous OR mouth, toothless OR edentul*) AND (dental OR denture* OR oral OR mouth) AND (four AND implant*) OR "all on 4" OR "all on four") AND maxilla*).

Meanwhile, to include additional eligible publications, a manual search was performed in the reference lists of articles and reviews on similar topics.

Selection Process

The search was completed on October 1, 2023, and duplicate articles were removed using the Endnote X9 software (Thompson Reuters). Three reviewers (R.L., X.J., and M.G.) independently screened the titles and abstracts from the literature search, and the full texts of the remaining articles were reviewed. Only articles that met the selection criteria were processed for quality assessment and data extraction. Once disagreement appeared, the other two researchers (F.W., Y.W.) were consulted.

RoB and Quality Assessment

The quality of parallel and crossover RCTs were assessed by the corresponding RoB 2 tool.[14] For cohort studies, scores of selection, comparability, and outcome were calculated using the Newcastle-Ottawa cale (NOS) tool.[15]

Data Collection

Two independent reviewers (R.L., M.G.) extracted data and compiled it in Microsoft Excel. Completed sheets were compared and discussed. The following information was retrieved: study design, participant details, treatment process, and reported outcomes.

ISR was defined as the percentage of implants still present and not mobile at the follow-up visits. Implant-supported prostheses with severely compromised function or no longer supported by enough implants were considered a failure, which directly affects the prosthesis survival rate. MBL at the 5th year was regarded as the quantitative indicator to reflect on medium-term peri-implant parameters, referring to the change of distance from the implant shoulder to the coronal point of bone-to-implant contact. Mechanical complications include any complications related to retention system, implants, and prostheses. Biologic complications included soft and hard tissue diseases. The mean follow-up time was directly extracted from other studies or calculated through lifetable.

Statistical Analysis

Statistical heterogeneity among studies was evaluated by Q-test based on Cochran chi-square test and the I^2 statistic. Statistical heterogeneity was assessed as substantial if I^2 was > 50%, and a random-effects model was applied; otherwise, a fixed-effects model was applied. All meta-analyses were performed in an open meta-analyst software.[16] The cumulative survival estimate was determined through the aggregation of proportion data from all studies that were included. This estimate offers a unified summary metric of the survival rate of implants and prostheses across the entire body of research.

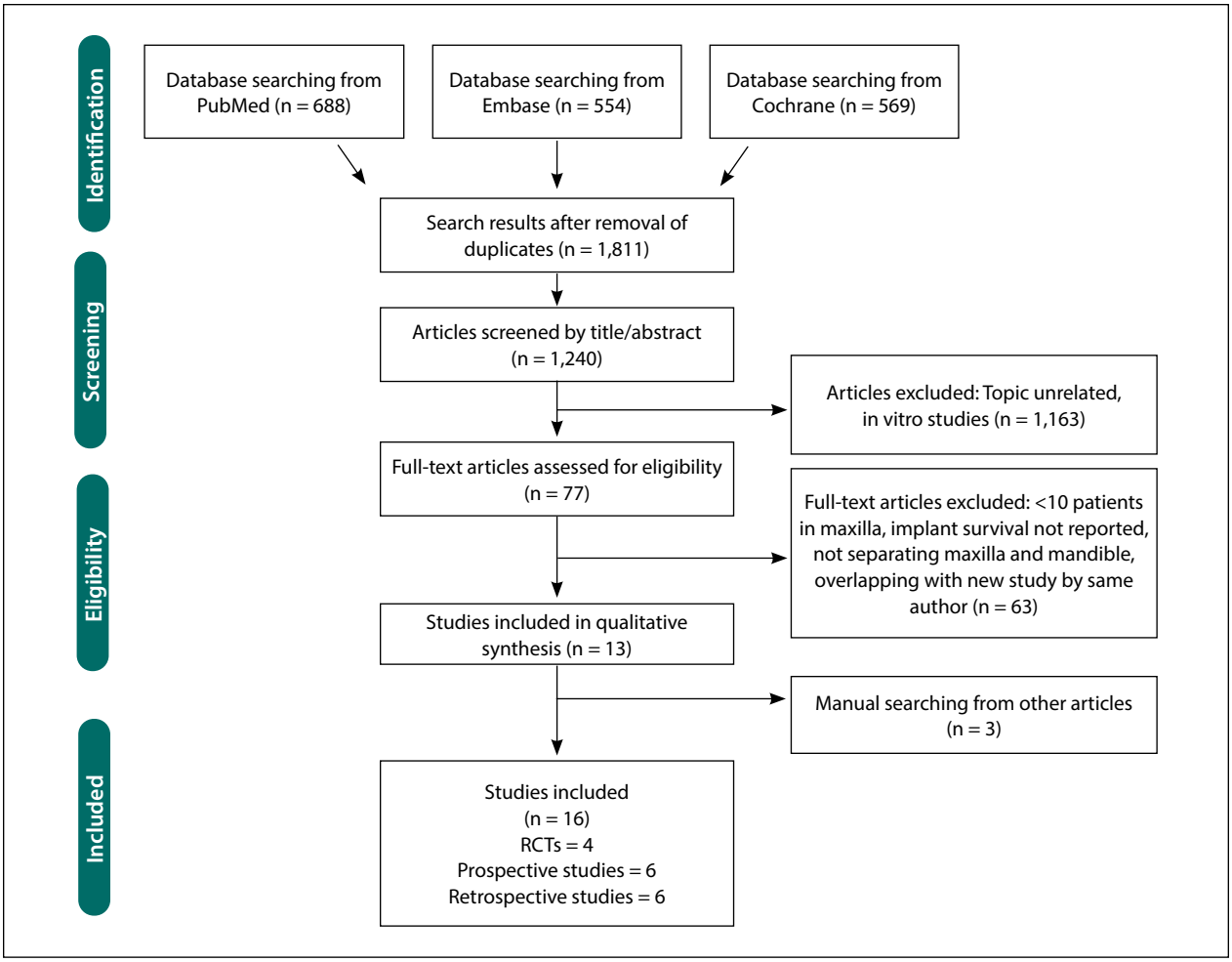

Fig 1 PRISMA flowchart.

MBL measured at the 5th year was extracted, and the mean value and SD were formulated in SPSS 25.0 (IBM). Positive MBL values implied bone gain and the negative one implied bone loss.

The mechanical and biologic complication incidence (ratio) was calculated in patients' level, and the Student's *t*-test was used to compare the means between the two groups. In all analyses, $P < .05$ (two-tailed) was considered statistically significant.

RESULTS

The searching and screening process is shown in Fig 1. After an electronic search, a total of 1,811 articles were retrieved (688 from PubMed, 554 from Embase, and 569 from Cochrane), and 1,240 articles remained after duplicates were removed. A total of 1,163 studies on other topics and in vitro were excluded after screening the titles and abstracts. A total of 77 full-text articles were obtained, and 64 articles were excluded for the following: < 10 patients in maxilla, ISR not reported, not separating maxilla and mandible, and overlapping patient cohorts. The remaining 13 articles, and an additional three articles from the manual search, met the final inclusion criteria with a total of 5,568 implants (9 implants on IODs; 7 implants on IFRs), but none of them made direct comparisons between IODs and IFRs. There were four RCTs (three on IODs,[18–20] one on IFRs),[21] six prospective studies (four on IODs,[22–25] two on IFRs),[26,27] and six retrospective studies (two on IODs,[28,29] four on IFRs).[30–33]

Assessment of Overall and Individual RoB

The quality of four RCTs was assessed by the RoB 2 tool, and overall judgement of them were all assessed as having "some concerns". Among all the domains, only one study had "some concerns" in bias for selection of the reported result, and the others had a "low risk" of bias[18] (Fig 2). For cohort studies, the NOS tool was used. Apart from two studies having the total score of seven (regarded as high-quality studies),[27,30] the others

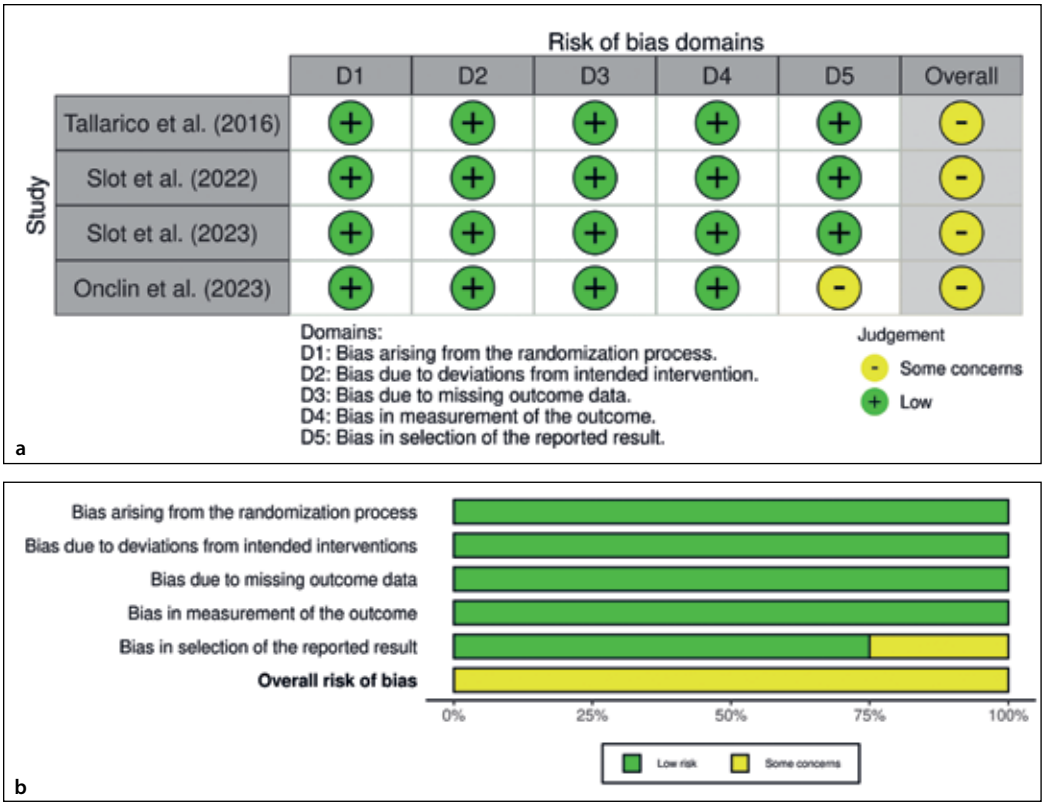

Fig 2 RoB in crossover and parallel RCTs: *(a)* RoB of each included RCT and *(b)* overall RoB.

had the scores between four to six (regarded as middle quality studies). No controls considered in these studies were the reason they lost the scores in comparability (Table 1).

Patient Selection

Nearly all the studies included criteria on patients' general health condition, which offered the premise for implant surgery. In 11 studies, it was requested that patients should not have a history of radiotherapy to the head and neck region or not be treated late. Uncontrolled diabetes and the use of bisphosphonate were exclusion criteria in eight studies. Regarding life habits, only four studies totally excluded patients who smoked, and six studies included mild to moderate smokers (smoking ≤ 20 cigarettes/d). Furthermore, five studies have a restriction on bruxism.

Regarding age, edentulous patients restored by IOD (mean age: 63.3 years) were older than patients restored by IFR (mean age: 60.6 years). There seemed to be no clear discrepancy in patients' sex. In addition, patients in most studies finished their follow-up, but dropouts still appeared in five studies (Table 2).

Surgery and Restoration Process

Among 16 studies, 14 recorded the length of the implant (7 in IODs, 7 in IFRs) and nearly all the implants had a length over 8 mm except two studies(one in IODs,[25] and one in IFRs).[33] Regarding the diameter of the implant, four studies (three on IODs,[24,25,29] one on IFRs)[33] used implants with a diameter of 3.3 mm (defined as a *narrow-diameter implant*). Thirteen studies provided implant surface information, and none of them chose a smooth surface. Regarding bone augmentation, four of the IODs studies performed this procedure but only one study in the IFRs mentioned it. The following bone graft materials were chosen: organic bovine bone (Bio-Oss, Geistlich Pharma AG), maxillary tuberosity, and iliac crest. Among the 10 studies that used a minimally invasive procedure, five implemented a surgical template for accurate implant position and angle, and the other study used a flapless or a mini-flap approach along with guided surgery[21] (Table 3).

In the IODs group, seven studies presented detailed information about the healing period, and all studies kept implants submerged. Three to nine months later, a definitive prostheses procedure was initiated. Six studies on IODs recorded information about palatal design: two studies with partial palatal coverage,[24,29] and four studies with no palatal coverage.[18–20,28] Regarding the design details of IODs, the retention system varied in each study (bar, locator, or double crown). In two studies, more than one attachment system was used (Table 4). In the IFRs group, all studies involved immediate loading protocol, with acrylic resin or metal-reinforced acrylic resin provisional prostheses delivered within 48

Table 1 Quality Assessment of NOS of Included Cohort Studies

	Selection				Comparability	Outcome			
Study	Representativeness of exposed cohort	Selection of nonexposed cohort	Ascertainment of exposure	Outcome of interest not present at start	Comparability on the basis of the design or analysis	Assessment of outcome	Long-enough follow-up	Adequacy of follow-up of cohorts	Score
Bouhy et al[25] (2023)	*		*	*		*	*	*	6
Ferrer et al[22] (2020)	*		*	*		*	*	*	6
Lian et al[29] (2019)	*		*			*	*	*	5
Frisch et al[28] (2015)	*		*			*	*	*	5
Mangano et al[24] (2011)	*		*	*		*	*	*	6
Ferrigno et al[23] (2002)	*	*		*		*	*	*	6
Ayna et al[30] (2021)	*		*			*	*	*	7
Gherlone et al[27] (2018)	*	*	*	*		*	*	*	7
Hopp et al[33] (2017)	*		*			*	*		4
Balshi et al[31] (2014)	*	*				*	*		6
Cavalli et al[32] (2012)	*		*			*	*		4
Agliardi et al[26] (2010)	*	*		*		*	*		5

*Statistically significant.

hours after implant surgery. Differences appeared in the manufacturing process and material of the prostheses and teeth (Table 5).

ISR

In the IODs group, only two studies had an ISR below 90%,[22,25] which resulted in a weighted cumulative ISR of 94.5% (95% CI: [92.1% to 96.9%]; I^2 = 84.22%) in 1,020 implants (ranging from 76.3% to 100%). Four studies solely reported on the splinted attachment system,[19,20,23,24] two studies reported on a nonsplinted attachment system,[25,28] and three studies on more than one attachment system.[18,22,29] A subgroup analysis on the attachment system was performed, which showed an ISR of 89.2% (95% CI: [81.7% to 96.7%]; I^2 = 87.78%) for the nonsplinted attachment cohort and 97.2% (95% CI: [95.0% to 99.3%]; I^2 = 76.51%) for the splinted attachment cohort (Appendix Fig 1a; all appendix figures can be found in the online version of this article). As for the subgroup analysis on study type, the ISR of RCTs in IODs was 98.0% (95% CI: [95.8% to 100.0%]; I^2 = 75.69%) and that of observational studies (retrospective and prospective studies) was 91.2% (95% CI: [86.8% to 96.5%]; I^2 = 83.78%) (Appendix Fig 1b). For IFRs, most studies had an ISR above 95%, leading to a weighted cumulative ISR of 98.5% (95% CI: [97.4% to 99.5%]; I^2 = 77.88%) in 4,508 implants, with a range from 94.2% to 100% (Appendix Fig 2). In addition, all included studies in the IFRs group employed two axial implants and two tilted implants. Only two studies in the IFRs group reported the separative ISR of axial and tilted implants,[27,33] and they showed no difference between these two kinds of implants.

In the IODs group, 62 implant losses were reported in 7 studies,[18,22–25,28,29] of which 14 failed to form osseointegration at the healing stage (called *early failure*). For the IFRs group, four studies reported 107 implant losses[21,26,31,33] but only two studies offered detailed information on implant loss, showing that all the recorded implants (n = 15) encountered early failure.

Table 2 Basic Information of Studies Included

Study (year)	Study design	Denture on four implants	No. of edentulous maxillary patients / implants	Dropout of patients	Age of patient (mean)	Sex (M / F)	General health condition (habits and diseases)	Mean / maximum follow-up time	Outcomes reported
Onclin et al[18] (2023)	RCT	IOD (bar) IOD (locator)	25 / 100 25 / 100	5 2	60.1 years 63.8 years	13 M / 12 F 13 M / 12 F	ASA I–II; no smoking; no history of radiotherapy to the head and neck region, preprosthetic surgery, or previous loss of implant in maxilla	5 / 5 years	Survival rate, MBL, and complication
Slot et al[20] (2023)	RCT	IOD	25 / 100	6	59.7 years	15 M / 10 F	ASA I–II; no smoking; no history of radiotherapy in the head and neck region, preprosthetic surgery, previous implant placement, or sinus pathology	10 / 10 years	Survival rate, MBL, and complication
Slot et al[19] (2022)	RCT	IOD	33 / 132	7	61.6 years	10 M / 23 F	ASA I–II; no smoking; no history of radiotherapy to the head and neck region, preprosthetic surgery, previous implant placement, or sinus pathology	10 / 10 years	Survival rate, MBL, and complication
Bouhy et al[25] (2023)	Prospective study	IOD	30 / 120	3	66.4 years	17 M / 13 F	ASA I–II; smokers (< 10 cigarettes/ day)	5 / 5 years	Survival rate, MBL, and complication
Ferrer et al[22] (2020)	Prospective study	IOD (bar) IOD (locator)	10 / 40 10 / 40	0	72 years	NR	ASA I; no bruxism, TMJ disorders and no use of bisphosphonates	11.4 / 14 years	Survival rate and complication
Lian et al[29] (2019)	Retrospective study	IOD (bar) IOD (locator)	15 / 60 18 / 72	2	60 years	8 M / 7 F 12 M / 6 F	Smoke ≤ 15 cigarettes/day; no history of radiotherapy to the head and neck region; no uncontrolled systemic diseases	6.4 / 9.3 years	Survival rate, MBL, and complication
Frisch et al[28] (2015)	Retrospective study	IOD	20 / 80	0	63.45 years	13 M / 7 F	3 smokers, 2 diabetic patients, and 7 heart disease patients	5.6 / 15.1 years	Survival rate, MBL, and complication
Mangano et al[24] (2011)	Prospective study	IOD	38 / 152	0	NC	NC	Smoke ≤ 15 cigarettes/day; no uncontrolled diabetes or neurologic diseases	5 / 5 years	Survival rate and complication

Table 2 *(cont)* **Basic Information of Studies Included**

Study (year)	Study design	Denture on four implants	No. of edentulous maxillary patients / implants	Dropout of patients	Age of patient (mean)	Sex (M / F)	General health condition (habits and diseases)	Mean / maximum follow-up time	Outcomes reported
Ferrigno et al[23] (2002)	Prospective study	IOD	16 / 64	0	NC	NC	Smoke ≤ 15 cigarettes/day; no bruxism; no drug or alcohol abuse; no chemotherapy; no history of radiotherapy to the head and neck region; no uncontrolled diabetes or systemic diseases	6.1 / 10 years	Survival rates
Tallarico et al[21] (2016)	RCT	IFR	20 / 80	0	66.8 years	10 M / 10 F	Smoke ≤ 10 cigarettes/day; no uncontrolled diabetes; no bisphosphonate therapy; no history of radiotherapy to the head and neck region	5 / 5 years	Survival rate, MBL, and complication
Ayna et al[30] (2021)	Retrospective study	IFR	34 / 136	0	61 years	NR	ASA I–II; no smoking; no bruxism; no drug or alcohol abuse; no uncontrolled diabetes, osteoporosis, or psychiatric disorders; no use of bisphosphonates or corticosteroids; no radiotherapy to the head and neck region in the last 24 months	6 / 6 years	Survival rate, MBL, and complication
Gherlone et al[27] (2018)	Prospective study	IFR	12 / 48	0	NC	NC	Healthy; smoke ≤ 15 cigarettes/day; no steroid or bisphosphonate therapy; no radiotherapy to the head and neck region in the last 5 years	5 / 5 years	Survival rate and MBL
Hopp et al[33] (2017)	Retrospective study	IFR	891 / 3,564	0	56 years	364 M / 527 F	No active chemotherapy or radiotherapy	5 / 5 years	Survival rate, MBL, and complication
Balshi et al[31] (2014)	Retrospective study	IFR	75 / 300	NR	NR	NC	NC	5 / 5 years	Survival rate
Cavalli et al[32] (2012)	Retrospective study	IFR	34 / 136	NR	58.7 years	16 M / 18 F	ASA I–II; no severe bruxism or clenching; no radiotherapy to the head and neck region in the last 60 months	3.2 / 6.1 years	Survival rate and MBL

Table 2 *(cont)* **Basic Information of Studies Included**

Study (year)	Study design	Denture on four implants	No. of edentulous maxillary patients / implants	Dropout of patients	Age of patient (mean)	Sex (M / F)	General health condition (habits and diseases)	Mean / maximum follow-up time	Outcomes reported
Agliardi et al[26] (2010)	Prospective study	IFR	61 / 244	NR	NC	NC	ASA I–II; no severe bruxism or clenching; no uncontrolled diabetes or systemic diseases; no radiotherapy to the head and neck region in the last 12 months	1.8 / 5 years	Survival rate, MBL, and complication

NC = not clear; NR = not reported; ASA = American Society of Anesthesiologists' Physical Status Classification.

Table 3 Implant Information of Studies Included

Study (year)	No. of total implants / loss	Survival rate of implant	MBL at the fifth year (baseline)	Length / diameter of implant	Implant system	Surface	Implant area	Bone augmentation (material)	Minimally invasive procedure?
Onclin et al[18] (2023)	80 / 3 (bar) 92 / 10 (locator)	96.3% 89.5%	−0.99 ± 0.96 mm; −1.41 ± 1.38 mm (prothesis delivery)	NR / 3.5 mm	Nobel Biocare	NR	Anterior; posterior	GBR (organic bovine bone, maxillary tuberosity)	Surgical template
Slot et al[20] (2023)	100 / 0	100%	−0.5 ± 0.37 mm (prothesis delivery)	> 11 mm / 4 mm	OsseoSpeed 4.0 S	Rough	Anterior	GBR (organic bovine bone, maxillary tuberosity) on 14 patients	Surgical template
Slot et al[19] (2022)	132 / 0	100%	−0.58 ± 0.51 mm (prothesis delivery)	12 mm / 4.1 mm	Straumann Standard SLA implants	SLA	Posterior	Maxillary sinus augmentation (Iliac crest)	Surgical template
Bouhy et al[25] (2023)	108 / 21	80.6%	NR	6–12 mm / 3.3, 4.1, 4.8 mm	Standard implants, Roxolid	SLA	Anterior; posterior	No	NR
Ferrer et al[22] (2020)	40 / 3 (bar) 40 / 11 (locator)	72.5% 80.0%	NR	10 mm / 4 mm	Biomet 3i Certain	NR	NR	No	NR
Lian et al[29] (2019)	60 / 5 (bar) 72 / 2 (locator)	96.3% 89.5%	−1.30 ± 0.1 mm; −1.30 ± 0.2 mm (prothesis delivery)	10 mm/ 12 mm 3.3 mm/ 4.1 mm	ITI, Straumann	SLA	Anterior; posterior	GBR (organic bovine bone) on 7 patients	NR
Frisch et al[28] (2015)	80 / 1	98.75%	NC	9.5–17 mm / NR	NR	NR	Anterior	NR	NR
Mangano et al[24] (2011)	152 / 4	97.4%	−0.70 ± 0.53 mm (implant placement)	8–14 mm / 3.3–4.8 mm	Leone	High rutile Surface	Anterior; posterior	No	NR
Ferrigno et al[23] (2002)	64 / 6	90.6%	NR	NC	NC	NC	NC	NR	NR

Table 3 *(cont)* **Implant Information of Studies Included**

Study (year)	No. of total implants / loss	Survival rate of implant	MBL at the fifth year (baseline)	Length / diameter of implant	Implant system	Surface	Implant area	Bone augmentation (material)	Minimally invasive procedure?
Tallarico et al[21] (2016)	80 / 1	98.75%	–1.71 ± 0.42 mm (implant placement)	> 10 mm / 4 mm	Nobel Speedy Groovy	TiUnite	Anterior; posterior (tilted)	No	Flapless or mini-flap approach; guided surgery
Ayna et al[30] (2021)	136 / 0	100%	–1.43 ± 0.35 mm (ceramic); –2.15 ± 0.30 mm (acrylic) (implant placement)	13 mm/ 16 mm 4 mm / 4 mm	Nobel Biocare	TiUnite	Anterior; posterior (tilted)	No	Surgical template
Gherlone et al[27] (2018)	48 / 0	100%	–1.06 ± 0.57 mm (implant placement); –1.08 ± 0.45 mm (axial) –1.02 ± 0.67 mm (tilted)	13 mm/ 15 mm 3.8 mm / 4.5 mm	Winsix, Biosafin	Rough	Anterior; posterior (tilted)	No	NR
Hopp et al[33] (2017)	3,564 / 91	97.5%	–1.17 ± 0.77 mm (implant placement); –1.14 ± 0.71 mm (axial) –1.19 ± 0.82 mm (tilted)	7–18 mm / 3.3–5 mm	Branemark System MKIV/ MKIII/ Nobel Speedy Groovy	TiUnite	Anterior; posterior (tilted)	No	Surgical template
Balshi et al[31] (2014)	300 / 11	96.3%	NR	13–18 mm 3.75 mm / 4 mm	Nobel Biocare	TiUnite	Anterior; posterior (tilted)	No	NR
Cavalli et al[32] (2012)	136 / 0	100%	NR	10–15 mm / 4 mm	Branemark System MKIV / Nobel Speedy Groovy	TiUnite	Anterior; posterior (tilted)	No	NR
Agliardi et al[26] (2010)	244 / 4	98.4%	NR	10–18 mm / NR	Branemark System MKIV / Nobel Speedy Groovy	TiUnite	Anterior; posterior (tilted)	If needed	NR

Prosthesis Survival Rate

A total of 14 articles reported on the prosthesis survival rate (seven on IODs, seven on IFRs). In the IODs group, seven studies reported the prosthesis survival rate between the range of 57.8% to 100%. Therefore, the weighted survival rate was 85.0% (95% CI: [76.5% to 93.5%]; $I^2 = 73.32\%$). A subgroup analysis displayed that the weighted protheses survival rate was 90.3% (95% CI: [82.0% to 98.5%]; $I^2 = 45.69\%$) in observational studies and 77.0% (95% CI: [55.8% to 98.2%]; $I^2 = 86.87\%$) in RCTs (Appendix Fig 3). In the IFRs group, the protheses survival rate was much higher: one study had a 99% survival rate,[31] another study had a 99.8% survival rate, and the other six studies had a 100% survival rate.[33] Therefore, a weighted survival rate of 99.9% (95% CI: [99.6% to 100.0%]; $I^2 = 0\%$) was calculated (Appendix Fig 4).

MBL

To research medium-term bone change around implants, the value of MBL at the fifth year was extracted from nine studies (five on IODs,[18–20,24,29] four on IFRs).[21,27,30,33] The mean MBL at the 5th year of IODs was –0.27 mm (SD = 1.31), and was –1.20 mm (SD = 0.76) for IFRs. Among five studies in the IODs group, the attachment systems of three studies were bars,[19,20,29] and the other two studies employed both nonsplinted locator and splinted bar systems.[18,24] One study showed

Table 4 Prosthetic Information of Studies on IODs

Study (year)	Survival rate of prosthesis	Opposing arch	Healing period	Time of prosthesis delivery	Attachment of overdenture	Type of prosthesis	Mechanical / biologic complications (no. of patients)
Onclin et al[18] (2023)	95.0% 91.3%	NR	Implant submerged	3 m	Locator or milled ovoid titanium bar with distal extensions	Without palatal coverage; cobalt-chromium framework	Retention loss (replacement of attachment matrices n = 4), abutment screw loosening (n = 1 in locator); prothesis fracture (tooth fracture repair: n = 2 in locator; prosthesis base fracture repair (n= 1 in bar); peri-implant mucositis (n = 11 in locator, n = 3 in bar); peri-implantitis (n = 6 in locator, n = 1 in bar)
Slot et al[20] (2023)	57.9%	IOD	Implant submerged	3 m	Milled titanium egg-shaped bar	Without palatal coverage; cobalt-chromium framework	NC
Slot et al[19] (2022)	73.1%	IOD	Implant submerged	3 m	Milled titanium egg-shaped bar	Without palatal coverage; cobalt-chromium framework	NC
Bouhy et al[25] (2023)	85.2%	NT	Implant submerged	3 m	Locator	Acrylic denture without metal	Retention loss of the locator system (changes of nylon retention inserts: n = 12); prothesis fracture (n = 12); reline (n = 6), new overdenture (n = 4), modification (n = 9); peri-implant mucositis: bleeding on probing (n = 10); peri-implantitis (n = 2)
Ferrer et al[22] (2020)	80%	IOD	NR	NR	Locator or bar	NR	Retention loss of the locator system (change of nylon retention inserts: n = 10); change denture caps (n = 4); change of abutment (n = 7); retention loss of the bar (screw loosening or fracture of the retention rider clips: n = 3); screw loosening (n = 2 in bar); prothesis fracture (n = 6 in locator; n = 2 in bar); relining (n = 3 in locator); dental wear (n = 2 in bar)
Lian et al[29] (2019)	NR	NT, CP, ISP	Implant submerged; complete relined denture	3 – 6 m	Locator or dolder bar	Partial palatal coverage; metal framework	Retention loss of locator (change of denture caps: n = 6; loss of male stud attachment: n = 2); retention loss of bar (reactivation of bar clip: n = 7, bar fracture: n = 1); screw loosening in locator (n = 2); screw loosening in bar (n = 2); prothesis fracture (n = 2 in locator; n = 2 in bar); relining or marginal adaption (n = 9 in locator; n = 6 in bar); peri-implantitis (n = 2 in locator; n = 2 in bar)
Frisch et al[28] (2015)	100%	CP, CD	Implant submerged	3 – 4 m	Marburg double crown with an additional retention element (TK Snap)	Without palatal coverage; cobalt-chromium-molybdenum alloy framework	Retention loss of TK Snap retention (n = 3); loose abutment (n = 2); screw loosening in telescopic crown (n = 6); prothesis fracture (n = 5); relining (n = 3); veneer repair (n = 2); dental wear (n = 1); others (n = 2); peri-implant mucositis: bleeding on probing (n = 15); peri-implantitis (n = 2)
Mangano et al[24] (2011)	NR	NR	Implant submerged; complete relined denture	5 m	Egg-shaped dolder gold bar	Partial palatal coverage; metal framework	NC
Ferrigno et al[23] (2002)	87.50%	NC	NR	NR	Dolder bar	NR	NR

NT = natural teeth; CP = conventional prosthesis; CD = complete denture; ISP = implant-supported prosthesis; TC = telescopic crown; m = month; w = week.

Table 5 Prosthetic Information of Studies on IFRs

Study (y)	Survival rate of prostheses	Opposing arch	Healing period	Time of prosthesis delivery	Framework of definitive prostheses	Crown of definitive prostheses	Mechanical / biologic complications (no. of patient[s])
Tallarico et al[21] (2016)	100%	NT, CP, ISP	Immediate loading; acrylic or metal-acrylic prostheses	Provisional: immediately; Final: 5 m	Titanium or zirconia CAD/CAM framework	NR	Veneer repair (n = 3); pain and swelling without suppuration (n = 1)
Ayna et al[30] (2021)	100%	NT, ISP	Immediate loading; acrylic prostheses	Provisional: 24 h; Final: 3 m	Chrome-molybdenum framework	Metal-ceramic or acrylic resin teeth	Dislodgment of the acrylic teeth (n = 4); screw loosening (n = 1); detachment of the veneering material (n = 3)
Gherlone et al[27] (2018)	100%	NR	Immediate loading; bar-acrylic prostheses	Provisional: immediately; Final: 4 m	A new type of prefabricated bar	NR	NR
Hopp et al[33] (2017)	99.80%	NT, CP, ISP	Immediate loading; high-density acrylic prostheses	Provisional: the day of surgery; Final: 6 m	Titanium framework	All-ceramic alumina or acrylic resin teeth	No reports on mechanical complications. Peri-implant mucositis (n = 189); peri-implantitis (n = 95); fistula (n = 4); infection (n = 24); abscess (n = 1) of 209 patients
Balshi et al[31] (2014)	98.60%	NR	Immediate loading; acrylic prostheses	Provisional: the day of surgery; Final: 4–5 m	Milled titanium framework	Lithium disilicate teeth	NR
Cavalli et al[32] (2012)	100%	NR	Immediate loading; acrylic prostheses	Provisional: 48 h; Final: 4–6 m	Titanium framework	Composite resin teeth	Repair of tooth fracture (n = 9); prosthesis base fracture repair (n = 1); prosthetic screw loosening (n = 1); peri-implant mucositis (n = 4); peri-implantitis (n = 2); TMJ pain (n = 2)
Agliardi et al[26] (2010)	100%	NT, ISP, CP	Immediate loading; acrylic prostheses	Provisional: 3 h; Final: 4–6 m	Prostheses from CAD/CAM Procera system	NR	No mechanical complications occurred in the definitive restoration phase

NT = natural teeth; CP = conventional prosthesis; ISP = implant-supported prosthesis; m = month; w = week; h = hour..

no difference in MBL between locator (–1.30 ± 0.1 mm) and bar (–1.30 ± 0.2 mm),[29] whereas the other study had significantly different MBL in locator (–1.41 ± 1.38 mm) and bar (–0.99 ± 0.96 mm).[18] Among four studies in the IFRs group, only two reported on separate MBL for axial and tilted implants, resulting in a mean MBL in the tilted group (–1.18 ± 0.81 mm) and axial group (–1.13 ± 0.70 mm).[27,33]

Complications

In the IODs group, five studies reported 141 mechanical complications in 143 patients,[18,22,25,28,29] and five studies reported 77 biologic complications in 141 patients.[18–20,28,29] Therefore, during the entire follow-up period, the mean incidence of mechanical complications in IODs was 0.99 per patient (ranging from 0.19 to 1.59 per patient) and 0.54 per patient for biologic complications (ranging from 0.12 to 0.85 per patient). *Retention loss* refers to the breakdown of the retention system without involving abutment screw loosening, and it was the most frequent mechanical complication in the IODs group (0.34 per patient), followed by prothesis fracture (0.23 per patient) and abutment screw loosening (0.11 per patient). As for the varied attachment

system, four cohorts used the locator system, three used bar, and one used Marburg double crowns with a TK Snap retention have reported on the mechanical complications. The mean mechanical complication rate of nonsplinted (locator and double crown) IODs (1.10 per patient) is higher than that of splinted (bar) IODs (0.54 per patient), but there is no statistically significant difference between them ($P = .25$). The mean biologic complication rate of nonsplinted IODs (three cohorts in locator, one in double crown: 0.54 per patient) and splinted IODs (four cohorts in bar: 0.47 per patient) is comparable ($P = .79$).

For IFRs, the provisional prostheses would be replaced by the definitive prostheses that were reinforced by metal framework or manufactured from the CAD/CAM Procera system (Nobel BioCare). Therefore, only the mechanical complications occurred in the definitive restoration phase are listed in Table 5. In the IFRs group, four studies reported 22 mechanical complications in 149 patients,[21,26,30,32] resulting in a mean incidence of 0.15 per patient (with a range from 0 to 0.32 per patient). Note that the incidence of mechanical complications in IFRs is significantly lower than that of IODs ($P = .007$). Dislodgement or fracture of the acrylic resin teeth made up a large part (0.09 per patient). Three IFRs studies reported 218 biologic complications in 945 patients,[21,32,33] so the mean incidence of biologic complications was 0.23 per patient (ranging from 0 to 0.24 per patient). For both IODs and IFRs, the most prevalent biologic complication was peri-implant mucositis but IODs group experienced significantly more biologic complications ($P = .009$).

DISCUSSION

The choice of treatment protocol for edentulous patients might have different impacts on time, cost consumption, and the patients' quality of life. At the outset, IOD was deemed the rescue method in the presence of implant failure and inadequate conditions for IFR.[34] However, a later study revealed that whether a maxillary IOD restoration was planned or unplanned, patients reported a high level of satisfaction.[35] In addition, IOD rehabilitation is an appropriate choice in patients with insufficient lip support, a gummy smile, and adverse bone dimensions.[36] Oral hygiene might be easy to maintain by detaching the prostheses to clean, leading to a predicable peri-implant prognosis.[37] Above all, both IOD and IFR are the mainstream methods, so the indications of treatment should be taken into sufficient consideration before implant placement.

Lower bone density poses more challenges for the restoration of edentulous maxilla's than it does for mandibles. As early as 1993, Simons et al[38] reported a preliminary case of four implants in the anterior maxilla supporting an overdenture, offering an alternative restoration for absorbed maxilla. For IFR, after Maló et al[11] developed the all-on-four concept for the maxilla, the four implant-supported IFRs was widely implemented. Great improvements in patient satisfaction and maximum bite force in the IOD and IFR were revealed, compared with those in the complete denture.[39,40]

Regarding systematic reviews on related topics, Kern et al[10] reported implant loss in maxillary and mandibular implants supporting fixed and removable dentures. They provided a comprehensive analysis of implant loss while neglecting other outcomes. Their results indicated that the implant loss rate was lower in fixed restorations than in removable restorations, which was consistent with the present study. In our study, IODs with nonsplinted attachments had a relatively lower ISR than those with splinted attachments. However, according to Di Francesco et al,[41] a slightly higher ISR of the nonsplinted four-implant-supported maxillary overdentures cohort (98.9%) was presented, compared with that of the splinted cohort (97.7%).[41] In addition, Mañes Ferrer et al[22] performed IODs on patients with a mean age of 72 years and followed up for 5 to 14 years, reporting the lowest ISR (76.3%) in all included studies. This shed light on the influence of patients' age and self-cleaning ability. Individual conditions have a nonnegligible impact on prognosis, so oral instruction and preventive methods should be offered for patients at potential risk. Although length and diameter of implants were recorded, there was insufficient evidence to conclude whether they have an impact on the survival and other outcomes due to a lack of clear reporting on the endpoints related to implant dimensions. One included study noted no statistically significant difference in ISR based on implant length or diameter.[25]

In our study, the weighted prosthesis survival rate of IODs (85%) was lower than that of IFRs (99.9%), which was in accordance with the ISR. The IFRs group showed a low failure rate of prostheses but all the studies were followed up for only 5 or 6 years, which indicated the need for a longer-term assessment.

The MBL measured at the 5th year was reported in nine studies (five on IODs, four on IFRs), which referred to the medium-term indicator for bone loss around implants. All these studies used the real dimension of the implant as a reference to rectify the distortion. In the IODs group, the mean MBL at the 5th year was –0.27 mm (SD = 1.31), with baseline set on the day of implant placement or protheses delivery (see Table 3). Among them, two employed both nonsplinted and splinted systems.[18,29] One study showed no difference in MBL between locator (–1.30 ± 0.1 mm) and bar (–1.30 ± 0.2 mm),[29] whereas the other study had a significantly different MBL between locator cohort (–1.41 ± 1.38 mm)

and bar cohort (–0.99 ± 0.96 mm).[18] Controversy still exists regarding the impact of attachment type on MBL in the maxilla. In the IFRs group, four studies reported MBL at the 5th year, resulting in a mean value of –1.20 mm (SD = 0.76), and they all set the implant placement as baseline. Two studies gave a separate record on MBL around straight and tilted implants,[27,33] revealing no significant difference between them, which was similar to the results reported by Lin et al.[42] During the first year after placement, bone loss occurred faster, with a value of approximately –1.5 mm.[43] It might explain why the IFRs group set implant placement as the baseline, as it had a higher MBL value than the IODs group. However, the limited number of studies on IODs and IFRs is not sufficient to draw strong conclusions on MBL. Given the high heterogeneity (I^2) among studies, the weighted mean ± SD was used instead of a forest plot to present the MBL data, indicating that caution should be taken when interpreting the pooled values.

The present study found that the bone augmentation procedure was primarily performed on patients with IOD. Detailed information was provided in four studies on the following materials: organic bovine bone (Bio-Oss, Geistlich Pharma AG), maxillary tuberosity, and iliac crest were used.[18–20,29] In IFRs, tilted implants played an alternative role for bone grafts by reaching more posterior arches and anchoring the cortical bone of the anterior wall of the sinus.[11] A 3D finite element analysis on four implants indicated a decreased stress value in bone around tilted implants compared to axial implants.[44]

Immediate loading was defined as loading within 1 week after implant placement,[45] which was first conducted by Schnitman et al in 1990.[46] Among the included IFRs studies, all studies adopted this loading protocol and achieved predicable clinical outcomes. However, for IODs, conventional loading was usually performed. Kappel et al[47] reported that overdentures with nonsplinted retention systems were confronted with more risks with immediate loading than with conventional loading.

Previous meta-analysis studies revealed no statistically significant difference in the prosthetic and biologic complications between splinted and nonsplinted groups,[41,42] which is consistent with our research. Interestingly, IODs cohorts (0.99 per patient) have a significantly higher incidence of mechanical complications than IFRs cohorts (0.15 per patient). Retention loss was the most frequent mechanical complication in the IODs group (0.34 per patient) but it can be amended by replacing the broken elements of the retention system, which rarely incurs irreversible damage on rehabilitations. The main reasons for the failure of prostheses in our studies were implant failure and excessive wear or fracture of the dentures. Peri-implant diseases were reported in seven studies, which emphasized the importance of oral hygiene instruction and regular clinical visits. IODs cohorts have a significantly higher incidence of biologic complications than IFRs. Considering that the criteria of peri-implant diseases varied among studies, we had reservations about these results.

Limitations of the Evidence

Heterogeneity in reporting outcomes was notable across the studies, which challenged comparisons. However, we tried to account for several factors that led to heterogeneity, including RCTs versus observational studies (ie, by performing subgroup analysis). Among the nine studies on IODs, only two were retrospective studies, whereas the majority of studies on IFRs were retrospective (4 out of 7). This discrepancy in study design may contribute to heterogeneity in the level of evidence. Furthermore, the study of the IFRs with the lowest rating in terms of study quality has the largest number of followed-up implants,[33] suggesting the conclusion should be interpreted with caution.

Limitations of the Review

The present study has several limitations. No included study performed direct comparisons between IODs and IFRs, so the baseline of both groups might be varied. In addition, four of the included studies were RCTs, and the others were observational studies, which leads to a relatively low level of evidence. Although all the included studies had a report on the primary outcome (ISR), data of the other outcomes was far from sufficient. The studies in the IFRs group were followed up for only 5 or 6 years, whereas those in the IOD group had significantly longer follow-up durations. This highlights the need for longer-term studies in IFRs.

Implications for Practice and Future Research

This study gave a systematic review and meta-analysis on the outcomes of four IODs and IFRs, and the medium-term performance of them were acceptable. Through this study, we also found that there is a need for more solid research on the following: *(1)* direct comparison of the clinical outcomes between IODs and IFRs, *(2)* a longer follow-up time for the IFR cohort, and *(3)* more studies with MBL over medium-term follow-ups.

CONCLUSIONS

With the limits of our study, predicable clinical outcomes were revealed for four implants supported maxillary overdentures and full arch fixed restorations. We integrated numerical outcomes and reviewed qualitative information systematically from studies on IODs and IFRs. We found that IFRs had a relatively higher

implant and protheses survival rate. IODs had less MBL in the 5th year with a nonuniform baseline. Retention loss was the most frequent mechanical complication in IODs, and the fracture of the prostheses or teeth was the most predominant one in IFRs. Peri-implant mucositis occurred the most in biologic complications for both groups, which highlighted the importance of oral hygiene instruction. However, the results should be interpreted with caution due to the variance in baseline and relatively low levels of evidence.

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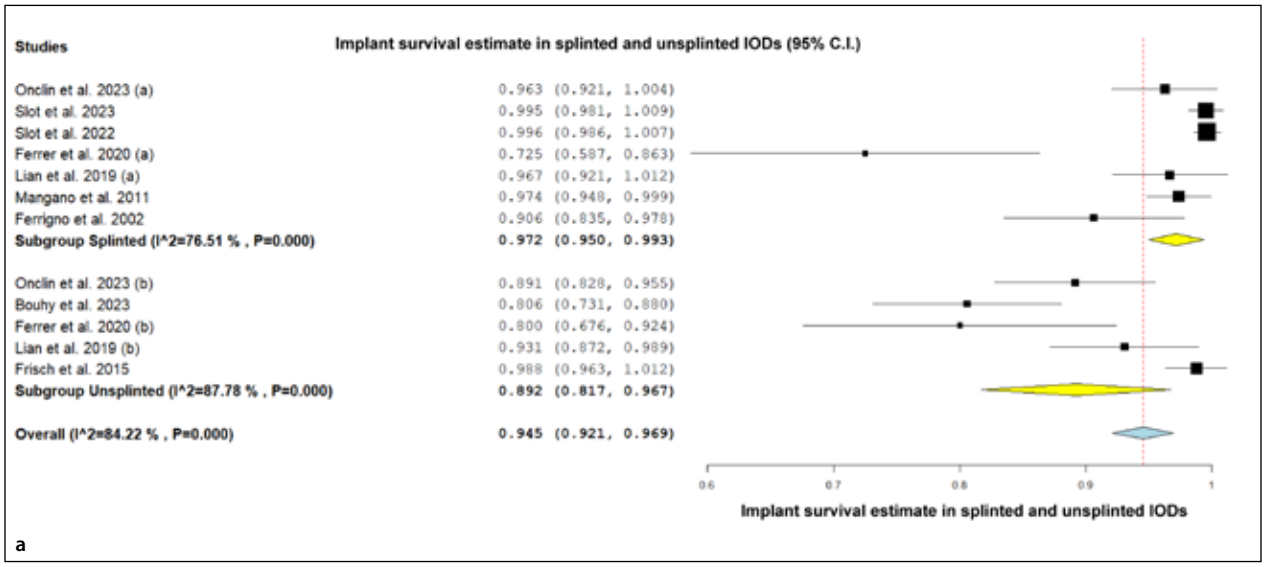
Rong Lan and Meisha Gul contributed equally to this work.

REFERENCES

1. Zembic A, Tahmaseb A, Wismeijer D. Within-subject comparison of maxillary implant-supported overdentures with and without palatal coverage. Clin Implant Dent Relat Res 2015;17:570–579.
2. Kroll P, Hou L, Radaideh H, et al. Oral health-related outcomes in edentulous patients treated with mandibular implant-retained dentures versus complete dentures: Systematic review with meta-analyses. J Oral Implantol 2018;44:313–324.
3. Volpe S, Di Girolamo M, Pagliani P, Zicari S, Sennerby L. Osteotome-induced blood clot and subsequent bone formation with the use of collagen sponge for integration of single dental implants into the atrophied posterior maxilla: A retrospective follow-up of 36 implants after 5 to 13 years. Int J Dent 2022;2022:6594279.
4. Pereira E, Messias A, Dias R, Judas F, Salvoni A, Guerra F. Horizontal resorption of fresh-frozen corticocancellous bone blocks in the reconstruction of the atrophic maxilla at 5 months. Clin Implant Dent Relat Res 2015;17(suppl 2):S444–S458.
5. Oliveira MR, Gonçalves A, Gabrielli MAC, de Andrade CR, Vieira EH, Pereira-Filho VA. Evaluation of alveolar bone quality: Correlation between histomorphometric analysis and lekholm and zarb classification. J Craniofac Surg 2021;32:2114–2118.
6. Raghoebar GM, Meijer HJ, Slot W, Slater JJ, Vissink A. A systematic review of implant-supported overdentures in the edentulous maxilla, compared to the mandible: How many implants? Eur J Oral Implantol 2014;7(suppl 2):S191–S201.
7. Di Francesco F, De Marco G, Capcha EB, et al. Patient satisfaction and survival of maxillary overdentures supported by four or six splinted implants: A systematic review with meta-analysis. BMC Oral Health 2021;21:247.
8. Di Francesco F, De Marco G, Gironi Carnevale UA, Lanza M, Lanza A. The number of implants required to support a maxillary overdenture: A systematic review and meta-analysis. J Prosthodont Res 2019;63:15–24.
9. Daudt Polido W, Aghaloo T, Emmett TW, Taylor TD, Morton D. Number of implants placed for complete-arch fixed prostheses: A systematic review and meta-analysis. Clin Oral Implants Res 2018;29(suppl 16):S154–S183.
10. Kern JS, Kern T, Wolfart S, Heussen N. A systematic review and meta-analysis of removable and fixed implant-supported prostheses in edentulous jaws: Post-loading implant loss. Clin Oral Implants Res 2016;27:174–195.
11. Maló P, Rangert B, Nobre M. All-on-4 immediate-function concept with Brånemark System implants for completely edentulous maxillae: A 1-year retrospective clinical study. Clin Implant Dent Relat Res 2005;7(suppl 1):S88–S94.
12. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ 2021;372:n71.
13. Cumpston M, Li T, Page MJ, Chandler J, et al. Updated guidance for trusted systematic reviews: A new edition of the Cochrane Handbook for Systematic Reviews of Interventions. Cochrane Database Syst Rev 2019;10:ED000142.
14. Sterne JAC, Savović J, Page MJ, et al. RoB 2: A revised tool for assessing risk of bias in randomised trials. BMJ 2019;366:l4898.
15. Wells GA, Wells G, Shea B, Shea B, O'Connell D, Peterson J, et al. (eds). The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Non-randomised Studies in Meta-Analyses. The Ottawa Hospital, 2014.
16. Wallace BC, Dahabreh IJ, Trikalinos TA, Lau J, Trow P, Schmid CH. Closing the Gap between methodologists and end-users: R as a computational back-rnd. J Statistical Software 2012;49:1–15.
17. Lin X, Yu X, Wang F, Wu Y. Marginal bone level change of immediately restored implants with simultaneous guided bone regeneration: A systematic review. Clin Implant Dent Relat Res 2023;25:1112–1137.
18. Onclin P, Boven GC, Vissink A, Meijer HJ, Raghoebar GM. Maxillary implant overdentures retained with bars or solitary attachments: A 5-year randomised controlled trial. J Prosthodont Res 2023;67:400–409.
19. Slot W, Raghoebar GM, Cune MS, Vissink A, Meijer HJA. Maxillary bar overdentures on four or six posterior implants: 10-year results from a randomized clinical trial. Clin Oral Implants Res 2022;33:1147–1156.
20. Slot W, Raghoebar GM, Cune MS, Vissink A, Meijer HJA. Maxillary overdentures supported by four or six implants in the anterior region: 10-year randomized controlled trial results. J Clin Periodontol 2023;50:36–44.
21. Tallarico M, Meloni SM, Canullo L, Caneva M, Polizzi G. Five-year results of a randomized controlled trial comparing patients rehabilitated with immediately loaded maxillary cross-arch fixed dental prosthesis supported by four or six implants placed using guided surgery. Clin Implant Dent Relat Res 2016;18:965–972.
22. Mañes Ferrer JF, Fernández-Estevan L, Selva-Otaolaurruchi E, Labaig-Rueda C, Solá-Ruíz MF, Agustín-Panadero R. Maxillary implant-supported overdentures: Mechanical behavior comparing individual axial and bar retention systems. A cohort study of edentulous patients. Medicina (Kaunas) 2020;56:139.
23. Ferrigno N, Laureti M, Fanali S, Grippaudo G. A long-term follow-up study of non-submerged ITI implants in the treatment of totally edentulous jaws. Part I: Ten-year life table analysis of a prospective multicenter study with 1286 implants. Clin Oral Implants Res 2002;13:260–273.
24. Mangano C, Mangano F, Shibli JA, Ricci M, Sammons RL, Figliuzzi M. Morse taper connection implants supporting "planned" maxillary and mandibular bar-retained overdentures: A 5-year prospective multicenter study. Clin Oral Implants Res 2011;22:1117–1124.
25. Bouhy A, Lamy M, Altaep Y, Lambert F. Maxillary implant overdenture retained by four unsplinted attachments and opposed by a natural or fixed dentition: Five-year clinical outcomes. A prospective case series. Clin Oral Implants Res 2023;34:285–296.
26. Agliardi E, Panigatti S, Clericò M, Villa C, Malò P. Immediate rehabilitation of the edentulous jaws with full fixed prostheses supported by four implants: Interim results of a single cohort prospective study. Clin Oral Implants Res 2010;21:459–465.
27. Gherlone EF, Sannino G, Rapanelli A, Crespi R, Gastaldi G, Capparé P. Prefabricated bar system for immediate loading in edentulous patients: A 5-year follow-up prospective longitudinal study. Biomed Res Int 2018;2018:7352125.
28. Frisch E, Ziebolz D, Ratka-Krüger P, Rinke S. Double crown-retained maxillary overdentures: 5-year follow-up. Clin Implant Dent Relat Res 2015;17:22–31.
29. Lian M, Zhao K, Wang F, Huang W, Zhang X, Wu Y. Stud vs bar attachments for maxillary four-implant-supported overdentures: 3- to 9-year results from a retrospective study. Int J Oral Maxillofac Implants 2019;34:936–946.
30. Ayna M, Karayürek F, Jepsen S, et al. Six-year clinical outcomes of implant-supported acrylic vs. ceramic superstructures according to the All-on-4 treatment concept for the rehabilitation of the edentulous maxilla. Odontology 2021;109:930–940.

31. Balshi TJ, Wolfinger GJ, Slauch RW, Balshi SF. A retrospective analysis of 800 Brånemark System implants following the All-on-Four™ protocol. J Prosthodont 2014;23:83–88.
32. Cavalli N, Barbaro B, Spasari D, Azzola F, Ciatti A, Francetti L. Tilted implants for full-arch rehabilitations in completely edentulous maxilla: A retrospective study. Int J Dent 2012;2012:180379.
33. Hopp M, de Araújo Nobre M, Maló P. Comparison of marginal bone loss and implant success between axial and tilted implants in maxillary All-on-4 treatment concept rehabilitations after 5 years of follow-up. Clin Implant Dent Relat Res 2017;19:849–859.
34. Ekfeldt A, Johansson LA, Isaksson S. Implant-supported overdenture therapy: A retrospective study. Int J Prosthodont 1997;10:366–374.
35. Kronström M, Widbom C, Soderfeldt B. Patient evaluation after treatment with maxillary implant-supported overdentures. Clin Implant Dent Relat Res 2006;8:39–43.
36. Zitzmann NU, Marinello CP. Treatment plan for restoring the edentulous maxilla with implant-supported restorations: Removable overdenture versus fixed partial denture design. J Prosthet Dent 1999;82:188–196.
37. Kuoppala R, Näpänkangas R, Raustia A. Outcome of implant-supported overdenture treatment--A survey of 58 patients. Gerodontology 2012;29:e577–584.
38. Simons AM, Campbell Z. The implant-supported overdenture prosthesis for the edentulous maxilla. J Oral Implantol 1993;19:39–42.
39. Oh SH, Kim Y, Park JY, Jung YJ, Kim SK, Park SY. Comparison of fixed implant-supported prostheses, removable implant-supported prostheses, and complete dentures: Patient satisfaction and oral health-related quality of life. Clin Oral Implants Res 2016;27:e31–37.
40. van Kampen FM, van der Bilt A, Cune MS, Bosman F. The influence of various attachment types in mandibular implant-retained overdentures on maximum bite force and EMG. J Dent Res 2002;81:170–173.
41. Di Francesco F, De Marco G, Sommella A, Lanza A. Splinting vs not splinting four implants supporting a maxillary overdenture: A systematic review. Int J Prosthodont 2019;32:509–518.
42. Lin WS, Eckert SE. Clinical performance of intentionally tilted implants versus axially positioned implants: A systematic review. Clin Oral Implants Res 2018;29(suppl 16):S78–S105.
43. Girolamo MD, Calcaterra R, Gianfilippo RD, Arcuri C, Baggi L. Bone level changes around platform switching and platform matching implants: A systematic review with meta-analysis. Oral Implantol (Rome) 2016;9:1–10.
44. Bevilacqua M, Tealdo T, Menini M, et al. The influence of cantilever length and implant inclination on stress distribution in maxillary implant-supported fixed dentures. J Prosthet Dent 2011;105:5–13.
45. Esposito M, Grusovin MG, Willings M, Coulthard P, Worthington HV. The effectiveness of immediate, early, and conventional loading of dental implants: A Cochrane systematic review of randomized controlled clinical trials. Int J Oral Maxillofac Implants 2007;22:893–904.
46. Schnitman PA, Wohrle PS, Rubenstein JE. Immediate fixed interim prostheses supported by two-stage threaded implants: Methodology and results. J Oral Implantol 1990;16:96–105.
47. Kappel S, Giannakopoulos NN, Eberhard L, Rammelsberg P, Eiffler C. Immediate loading of dental implants in edentulous mandibles by use of Locator® attachments or Dolder® bars: Two-year results from a prospective randomized clinical study. Clin Implant Dent Relat Res 2016;18:752–761.

APPENDIX



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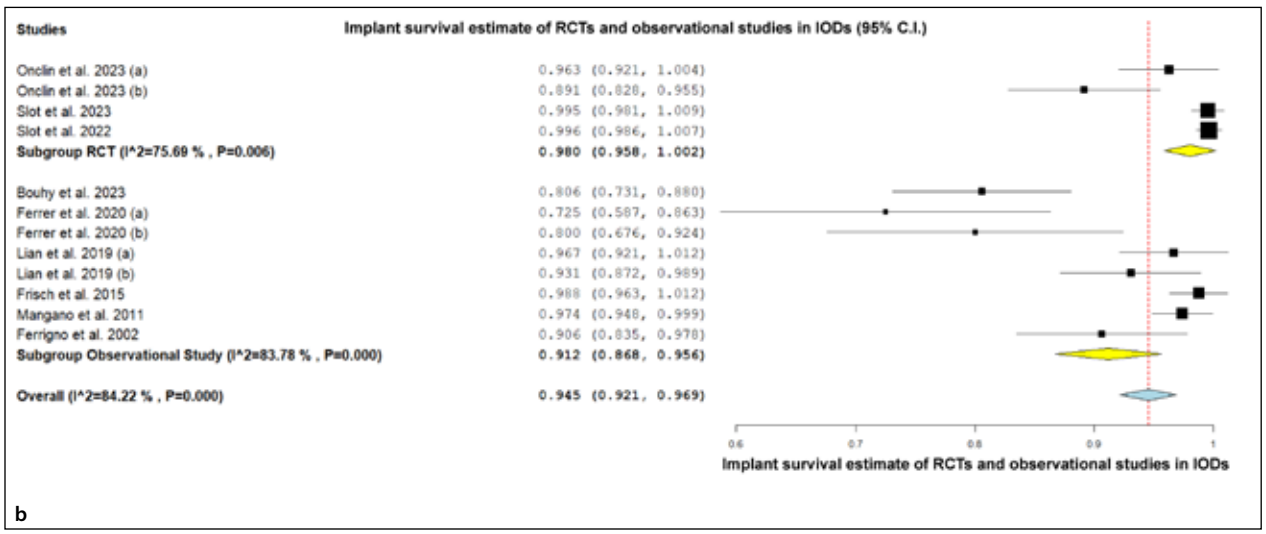
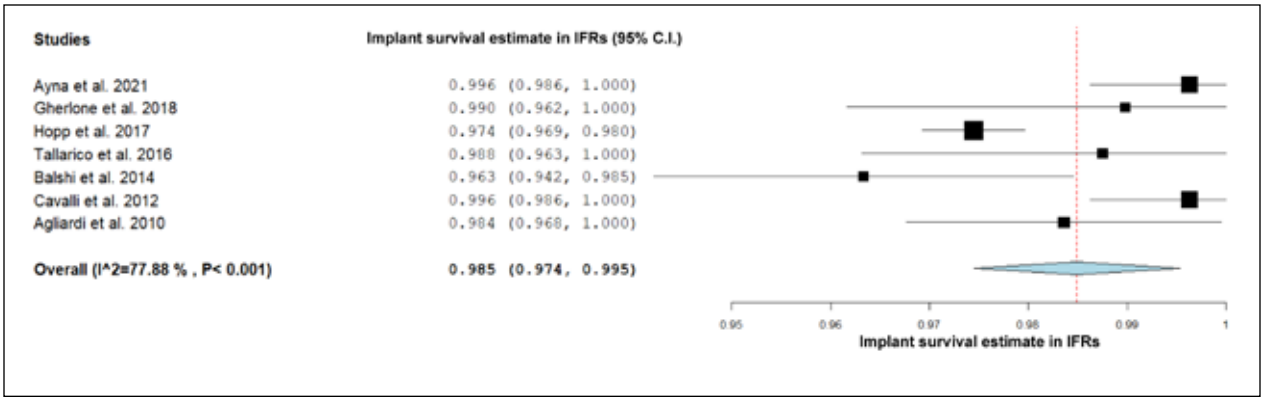
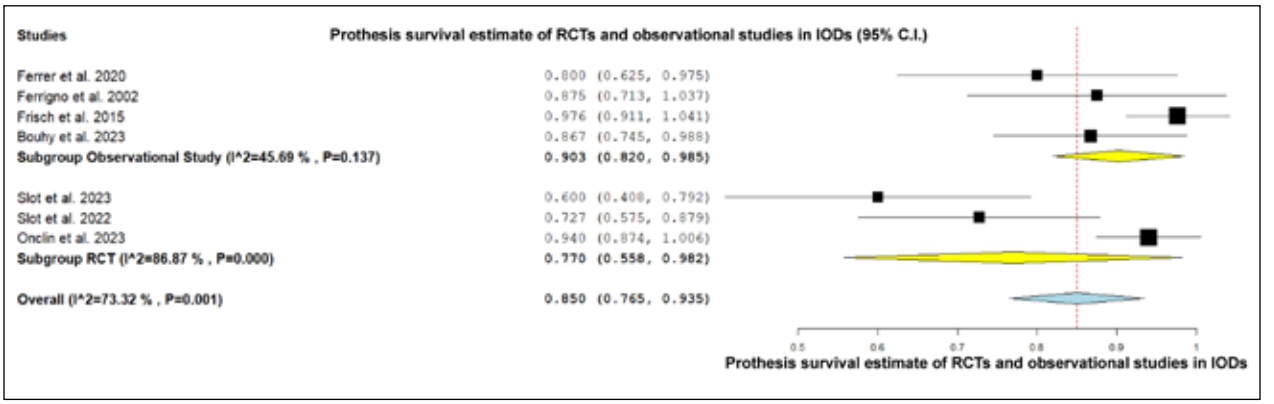


b

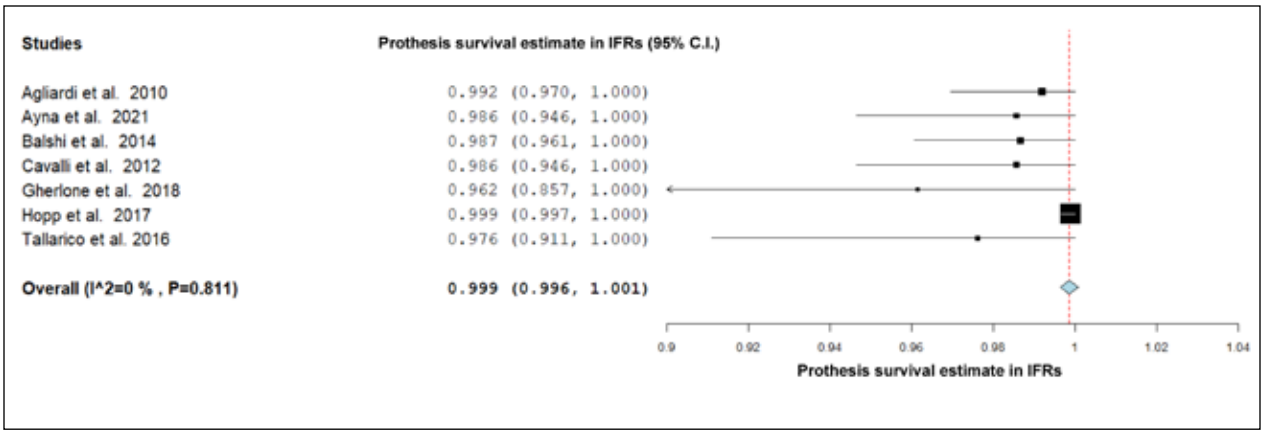
Appendix Fig 1 Forest plot of weighted ISR of IOD cohort. *(a)* The subgroup analysis of the splinted and nonsplinted IODs cohort. *(b)* The subgroup analysis of RCTs and observational studies in IODs.



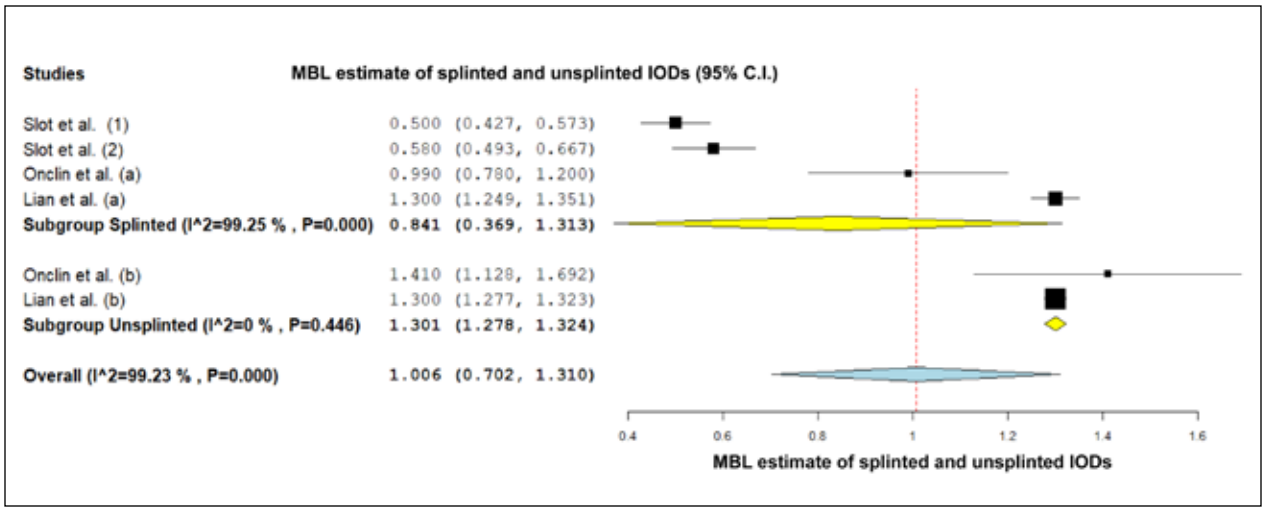
Appendix Fig 2 Forest plot of weighted ISR of IFR cohort.



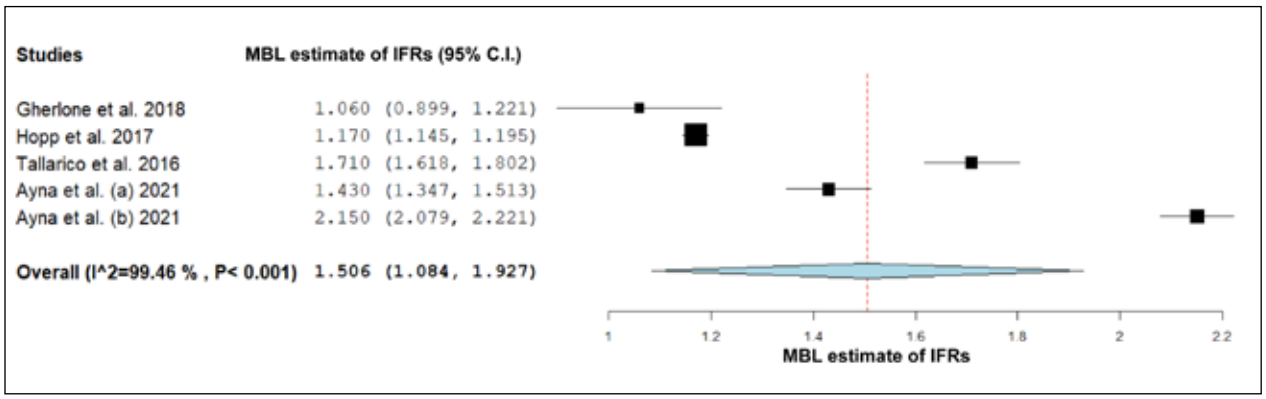
Appendix Fig 3 Forest plot of weighted prothesis survival rate of RCTs and observational studies in IODs.



Appendix Fig 4 Forest plot of weighted prothesis survival rate of IFR cohort.



Appendix Fig 5 Forest plot of weighted MBL of splinted and nonsplinted IODs.



Appendix Fig 6 Forest plot of weighted MBL of IFRs.