Interventions to facilitate the successful eruption of impacted maxillary incisor teeth due to the presence of a supernumerary: A systematic review and meta-analysis

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Introduction: A failure of maxillary incisor eruption is commonly attributed to the presence of a supernumerary tooth. This systematic review aimed to assess the percentage of impacted maxillary incisors that successfully erupt after surgical removal of supernumerary teeth with or without other interventions. **Methods:** Systematic literature searches without restrictions were undertaken in 8 databases for studies reporting any intervention aimed at facilitating incisor eruption, including surgical removal of the supernumerary alone or in conjunction with additional interventions published up to September 2022. After duplicate study selection, data extraction, and risk of bias assessment according to the risk of bias in nonrandomized studies of interventions and Newcastle-Ottawa scale, random-effects meta-analyses of aggregate data were conducted. **Results:** Fifteen studies (14 retrospective and 1 prospective) were included with 1058 participants (68.9% male; mean age, 9.1 years). The pooled eruption prevalence for removal of the supernumerary tooth with space creation or removal of the supernumerary tooth with orthodontic traction was significantly higher at 82.4% (95% confidence interval [CI], 65.5-93.2) and 96.9% (95% CI, 83.8-99.9) respectively, compared with removal of an associated supernumerary only (57.6%; 95% CI, 47.8-67.0). The odds of successful eruption of an impacted maxillary incisor after removal of a supernumerary were more favorable if the obstruction was removed in the deciduous dentition (odds ratio [OR], 0.42; 95% CI, 0.20-0.90; $P = 0.02$); if the supernumeraries were conical (OR, 2.91; 95% CI, 1.98-4.28; $P < 0.001$); if the incisor was in the correct position (OR, 2.19; 95% CI, 1.14-4.20; $P = 0.02$), at the level of the gingival third (OR 0.07; 95% CI, <0.01-0.97; $P = 0.04$) and had incomplete root formation (OR, 9.02; 95% CI, 2.04-39.78; $P = 0.004$). Delaying removal of the supernumerary tooth 12 months after the expected eruption time of the maxillary incisor (OR, 0.33; 95% CI, 0.10-1.03; $P = 0.05$) and waiting >6 months for spontaneous eruption after removal of the obstacle (OR, 0.13; 95% CI, 0.03-0.50; $P = 0.003$) was associated with worse odds for eruption. **Conclusions:** Limited evidence indicated that the adjunctive use of orthodontic measures and removal of supernumerary teeth might be associated with greater odds of successfull impacted incisor eruption than removal of the supernumerary tooth alone. Certain characteristics related to supernumerary type and the position or developmental stage of the incisor may also influence successful eruption after removal of the supernumerary. However, these findings should be viewed with caution as our certainty is very low to low because of bias and heterogeneity. Further well-conducted and reported studies are required. The results of this systematic review have been used to inform and justify the iMAC Trial. (Am J Orthod Dentofacial Orthop 2023;■:■-■)

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Absence or failure of eruption within the maxillary permanent incisor dentition can have a negative impact on facial or dental esthetics and potentially reduce self-esteem.[1] Failure of maxillary incisor eruption manifests in the early mixed dentition and can be attributed to agenesis of the affected incisor, idiopathic noneruption, delayed resorption of the primary predecessor, root dilaceration secondary to previous trauma, or impaction secondary to local pathology that causes displacement of the incisor crypt or crowding within the maxillary arch.[2] However, the most common cause of failed maxillary incisor eruption is impaction due to the presence of a supernumerary tooth in the anterior maxilla.[3]

Supernumerary teeth are more commonly found in the maxilla, with a prevalence reported at 2.6%, and resulting in delayed or failed eruption in 43% of affected maxillary central incisor teeth.[4] On the basis of morphology and shape, supernumerary teeth can be classified as conical (small and peg-shaped), tuberculate (larger and barrel-shaped), supplemental (duplications of teeth in the normal series), and odontoma (hamartomatous malformations which may be complex or compound).[4-9] Conical (mesiodens-type) supernumeraries account for up to 89.6% of all supernumerary teeth and are frequently present in the anterior maxilla.[6,10,11] Typically conical in shape[6,11-13] with either a normal[6,13] or inverted vertical position,[6,12,14,15] they are commonly unerupted[6,13,14] and often palatal.[4,6,11,15] Conversely, the frequency of other supernumerary tooth types is lower and reported as tuberculate (4.0%-14.1%),[6,12,13,16,17] supplemental (6.9%-22.0%)[6,13,16,17] and odontoma (6.4%-12.0%).[6,16] Moreover, tuberculate-type supernumeraries are more often associated with maxillary incisor impaction and failed eruption.[4,7] The impact of a supernumerary tooth on adjacent structures and the occlusion is dependent on the morphology, size, eruption, and location within the dental arch.[4,7]

Management strategies for children with impacted maxillary incisor teeth due to a supernumerary tooth generally involve a multidisciplinary approach—coordinating surgical removal of the supernumerary tooth with surgical exposure and bonding of the impacted tooth or teeth, with or without space creation within the anterior maxillary arch, and postsurgical orthodontic traction or some combination.[18] Historically, removing the supernumerary tooth alone has been a common treatment approach; however, wide variation in success rates has been reported.[19-22] Importantly, after the removal of the supernumerary alone, 30%-54% of impacted maxillary incisors require further surgical intervention to facilitate their eruption.[19,21-23] Simply removing the supernumerary tooth alone does not seem to ensure successful eruption of the affected maxillary incisor, and importantly, the time taken for the incisor to erupt is subject to great variation.[24] Conversely, surgical exposure combined with orthodontic traction has been reported to be more predictable in terms of successful eruption.[25] However, periodontal outcomes with this approach can be compromised depending on the type of surgical exposure performed.[26,27] Overall, high-quality evidence for the effectiveness of these interventions is lacking.[18,24]

A previous quantitative review investigating the success of interventions to facilitate eruption of impacted maxillary incisors due to the presence of supernumerary teeth focused on the effectiveness of removal of the supernumerary tooth only.[28] This systematic review aimed to assess the percentage of impacted maxillary incisors that successfully erupt after surgical removal of supernumerary teeth with or without any other interventions. Specific objectives were to identify factors (related to patient, incisor, supernumerary type, and intervention type) associated with the impacted incisor's successful eruption.

MATERIAL AND METHODS

Protocol and registration

The protocol for this review was developed a priori and registered in the Prospective Register of Systematic Reviews (CRD42020225634). This review is reported in accordance with the updated Preferred Reporting Items for Systematic reviews and Meta-Analyses statement (Supplementary Appendix I).[29] All post-hoc changes to the protocol have been documented (Supplementary Appendix II).

Eligibility criteria

On the basis of the Participants, Interventions, Comparison, Outcome, and Studies framework, the following eligibility criteria were employed: (1) patients aged <18 years, of any gender or ethnicity who present with unerupted maxillary incisor teeth because of the presence of overlying supernumerary teeth in the anterior maxilla; (2) any intervention aimed to facilitate incisor eruption, including surgical removal of the supernumerary tooth or teeth alone or in conjunction with additional interventions; (3) comparisons between different interventions or single interventions without a comparison group; (4) successful eruption of the unerupted maxillary incisor within the dental arch (assessed clinically); and (5) retrospective and prospective, observational

cohort studies (single-group or comparative), randomized clinical trials, or case-control studies involving human participants. Review articles, letters, case reports or series (<10 patients), opinion pieces, in-vitro studies, and studies involving participants who have a history of orthodontic treatment, have undergone growth modification, or have systematic diseases or craniofacial abnormalities were excluded. The primary outcome of this systematic review was the percentage of impacted maxillary incisors that successfully erupt into the dental arch after the intervention.

Information sources, search strategy, and study selection

The following 8 electronic databases were searched with no language or publication date restrictions from inception up to October 31, 2021, and updated on September 30, 2022: MEDLINE (via PubMed), The Cochrane Library (CDSR, CENTRAL, and DARE), OVID, Virtual Health Library (including Bibliography Brazilian Dentistry and LILACS), Scopus, ISI Web of Knowledge, Embase, and ClinicalTrials.gov. In addition, the Directory of Open Access Journals, Digital Dissertations (searched via UMI Proquest), metaRegister of Controlled Trials, WHO trials search portal, and Google Scholar were searched manually. The search strategy was developed with the assistance of a health care librarian. The initial search term strategy resulted in a limited number of articles. On advice from the health care librarian, broader search terms were used to increase the chances of identifying potentially relevant articles (Supplementary Appendix III). Hand-searching the citation lists of the full-text articles eligible for inclusion was also performed.

Study selection, data items, and collection

All search results were imported to Rayyan software (www.rayyan.ai). Using this software, 2 authors (J.S. and K.M.) independently screened titles and abstracts. After the removal of duplicates and excluded articles, full texts of studies fulfilling the eligibility criteria were reviewed. Any disagreements regarding study eligibility at the screening and review stage were resolved by discussion with a third author (M.T.C.). Data extraction using a prepiloted data collection form was undertaken independently by 3 authors (J.S., K.M., F.W.), with disagreements resolved by consensus discussion and with the assistance of a fourth author (M.T.C.). The following outcomes were collected: study characteristics (design, setting, country), number, mean age and gender of participants, type and form of supernumerary present, number and site of unerupted maxillary incisors, radiographic investigation taken, radiographic position (vertical and axial inclination), root developmental stage of incisor, type of intervention, number of maxillary incisor teeth that successfully erupted (per number of patients or number of maxillary incisors), time (months) taken for the unerupted maxillary incisor to erupt (defined as time calculated between the start of treatment intervention and successful eruption of the tooth) and number of maxillary incisor teeth that failed to erupt.

Risk of bias assessment

The risk of bias (RoB) of nonrandomized comparative and single-group cohort studies was assessed using the Risk Of Bias In Nonrandomized Studies of Interventions (ROBINS-I)[30] and the Newcastle-Ottawa scale, respectively.[31] The ROBINS-I tool assessed the following domains: confounding, selection bias, bias in measurement classification of interventions, bias because of deviations from intended interventions, bias because of missing data, bias in the measurement of outcomes, and bias in the selection of the reported result. In contrast, the Newcastle-Ottawa scale assessed the following domains of study quality: participant selection (4 items), comparability (1 item), and outcome (3 items). Each study is awarded 1 star for each item in the participant selection and outcome domains and a maximum of 2 stars for comparability. RoB assessment was undertaken independently by 2 authors (J.S., F.W.), with any disagreements resolved by discussion with a third author (M.T.C.).

Data synthesis and summary measures

To maximize data yield, we attempted to include all studies independent of reporting completeness, and data was calculated by ourselves when necessary. A single-group meta-analysis for pooled average eruption rate (1-group pooling), followed by a pairwise meta-analysis (2-group comparison) with an odds ratio (OR) and corresponding 95% confidence interval (CI), was undertaken. A random-effects model was chosen a priori (based on clinical and statistical reasoning), and a restricted maximum likelihood estimator (except for a bootstrapped-random-effects estimator for event rates) was used to calculate the average distribution of effect sizes, whereas 95% prediction intervals were calculated for meta-analyses involving ≥3 studies to incorporate heterogeneity in a possible range of clinical outcomes that can be expected.

All P values were 2-sided ($\alpha = 0.05$, except for between-study or between-subgroups heterogeneity

tests in which $\alpha = 0.10$), and all analyses were conducted by 1 author (S.N.P.) in R statistical software (version 4.0.4; R Foundation for Statistical Computing, Vienna, Austria), with an openly provided dataset through Zenodo (https://doi.org/10.5281/zenodo.7315004).

Additional analyses, RoB across studies, and quality of evidence

The extent and/or impact of between-study heterogeneity was assessed visually on the forest plots and by calculating the τ^2 and the I^2 statistics (with 95% CI), respectively, and also considering localization and/or direction of the heterogeneity. If ≥10 studies were included, reporting biases (including the possibility of small-study effects and publication bias) were assessed via contour-enhanced funnel-plots and Egger's test. If the presence of bias was detected, an explanation was sought, and a sensitivity analysis was undertaken by including only bias-free and/or the most precise studies.

Possible sources of heterogeneity in the meta-analyses were identified by prespecified mixed-effects subgroup analyses and random-effects meta-regression if at least 5 studies were included for a specific comparison. Predefined and analyses included subsets according to the patient (gender, dental development, age), obstruction (type and number), incisor impaction (site and root development), and follow-up period.

Within and across-study RoB was incorporated in the results of the meta-analysis (1) in formulating clinical recommendations and (2) by conducting appropriate sensitivity analyses. The quality of clinical recommendations were rated using Grades of Recommendations, Assessment, Development, Evaluation (GRADE)[32] and revised summary of findings tables.[33] Forest plots of pairwise comparisons were augmented with contours denoting the magnitude of observed effects to assess heterogeneity, clinical relevance, and imprecision.

Sensitivity analyses

Robustness of the results was checked with sensitivity analysis on the basis of (1) inclusion or exclusion of studies with methodological shortcomings or signs of bias, (2) inclusion or exclusion of nonrandomized trials, (3) improvement of the GRADE classification, and (4) inclusion or exclusion of large-scale studies (arbitrarily set at >40 patients per group).

RESULTS

Study selection and characteristics

Overall, the literature search identified 1878 results (Fig 1). After removing duplicates, 1234 titles and abstracts were screened, and a total of 91 full-text articles were subsequently evaluated with a further 30 excluded. The full texts of 62 articles were reviewed against the eligibility criteria with reasons for exclusion documented (Supplementary Appendix IV), and 15 studies (14 retrospective and 1 prospective) were included in the final analysis (Table I).

Within this sample, the clinical settings of the retrospective studies (n = 14) were: hospital (n = 9; 64.3%), a combination of sites (n = 3; 21.5%), practice-only (n = 1; 7.1%), and university-only (n = 1; 7.1%). The majority were conducted in European countries (n = 11; 78.7%), with 1 study performed in Israel (n = 1; 7.1%), South Korea (n = 1; 7.1%), and Great Britain or Australia (n = 1; 7.1%) respectively. The total number of patients across the 14 studies was 980, with a mean age of 9.1 years (n = 9) and a predominance for males (n = 433; 70.6%) compared with females (n = 180; 29.4%). Nine hundred and ninety-six supernumeraries were reported (n = 10) associated with 945 impacted incisors (n = 10). Across the included studies (Table I), the types of supernumeraries were: conical (n = 8; 378), tuberculate (n = 7; 237), odontoma (n = 8, 68), supplemental (n = 6; 43), and not reported (n = 3, 36). Root development of the unerupted incisors was primarily incomplete (n = 3; 228) compared with complete formation (n = 3; 46). In all studies, the primary intervention was the surgical removal of the supernumerary. In 5 studies, either an additional space-preserving (space maintainer) or space-opening intervention was performed, or surgical exposure of the incisor and orthodontic traction was initiated. However, for most studies, the decision to add intervention to the removal of the supernumerary tooth was not reported in terms of extraction timing (in particular, if different treatments were assigned from the start or adjunct interventions were added if surgical removal alone was unsuccessful). Successful incisor eruption was reported at the tooth or patient level in 9 and 5 studies, respectively. The number of successfully erupted maxillary incisors at the tooth and the patient level was reported at 737 (n = 9) and 135 (n = 5), respectively. In contrast, the number of unerupted maxillary incisors after the intervention at the tooth level was 211 (n = 6) and 80 (n = 4) at the patient level.

The single prospective study was undertaken in a combined hospital and university setting in Italy. Sixty-two patients (30 males, 32 females) with a mean age of 8.6 years and 74 impacted incisors were included. Root development of the incisors in this sample was primarily incomplete (n = 50). The number of successfully erupted maxillary incisors at the patient level was 39

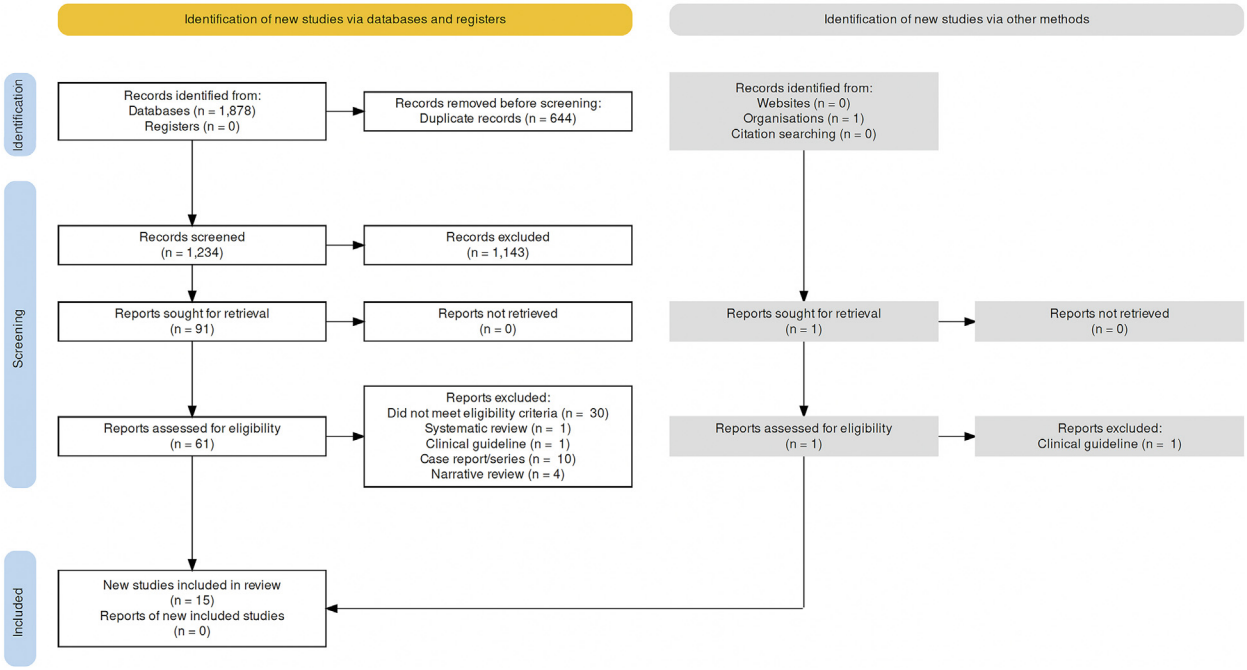

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for study selection.

(62.9%). None of the included studies reported any adverse events (Table I).

RoB of included studies

The RoB assessment for the included studies is shown in Tables II and III. Nine studies[2,19,20,25,34-38] were rated at moderate RoB, whereas the remaining 5 studies[21-23,39,40] were rated as having a high RoB. In all studies, the primary reasons for downgrading internal validity were lack of fulfillment of the selection of the nonexposed group and comparability items. In addition, 2 studies were downgraded because of issues with the ascertainment of exposure and assessment of outcome. A further 3 studies were downgraded on the basis of not reporting the outcome duration (Table II; Supplementary Appendix V). The single included prospective nonrandomized study[41] was rated with a low RoB overall (Table III) (Supplementary Appendices VI and VII).

Results of individual studies, data synthesis, reporting biases, and certainty of the evidence

The pooled estimate (single-group meta-analysis) for successful eruption of unerupted maxillary incisors after removal of an associated supernumerary tooth only was estimated at 57.6% (11 studies; 95% CI, 47.8-67.0). Conversely, the successful eruption estimate for removal of the supernumerary tooth with space measures and removal of the supernumerary tooth with orthodontic traction was significantly higher at 82.4% (1 study; 95% CI, 65.5-93.2) and 96.9% (1 study; 95% CI, 83.8-99.9), respectively (Table IV; Fig 2). In the presence of an odontoma, the eruption success (34.4%; 4 studies; 95% CI, 18.5-51.9) was significantly lower compared with when other types of the supernumerary tooth (61.1%; 9 studies; 95% CI, 49.5-72.1) were impeding eruption of the incisor (Table V; Fig 3). In addition, when a conical supernumerary tooth was removed, there was a significantly higher success of eruption of the unerupted incisor (72.2%; 6 studies; 95% CI, 60.0-83.0) compared with when a tuberculate-type supernumerary tooth was removed (44.7%; 6 studies; 95% CI, 28.6-61.4) (Table VI; Fig 4).

Within-study comparisons[2,20,25,34-36] (pairwise meta-analyses) were also performed for several characteristics (patient, obstruction, incisor impaction, or treatment) associated with incisor eruption (Table VII). The odds of the successful eruption of an unerupted maxillary incisor after removal of a supernumerary were more favorable if the obstruction was removed in the deciduous dentition rather than the mixed dentition (OR, 0.42; 95% CI, 0.20-0.90; $P = 0.02$), if conical supernumeraries were present rather than tuberculate types (OR, 2.91; 95% CI, 1.98-4.28; $P < 0.001$) (Fig 5),

Table I. Characteristics of included studies[‡]

Study	Design, setting, country*	Patients (male/female), age, y[†]	SUP	Incisors	Impaction side (L/M/R):N	Radiographs	Radiographic SUP position	Developmental stage	SUP removal	SPC	EXP/TRA	Unit	Erupted incisors	Time to erupt, mo	Unerupted incisors
Ashkenazi et al[34§]	rCOH, Hosp/Uni, IL	53 (31/22), 9.2	69 (13C, 22O; 10S; 21T; 3NR)	69 CI/LI	35/0/34	LC, OPT, PA, USO	NR	NR	☑	–	–	TTH	Overall: 25/69 CI: 21/69	23.0	44/69
Betts et al[35§]	rCOH, Hosp/Pract, MT	47 (30/17), 10.6	26 (4O, 22NR)	53 CI/LI	27/0/26	PA	NR	NR	A-B: ☑	A: – B: –	A: – B: ☑	TTH	A: Overall: 19/22 A: O: 2/4 B: 13/19	NR	NR
Bodenham[2‖]	rCOH, Hosp, GB	14 (NR), 9.2	NR	NR	NR	PA	NR	1 CR, 13 IR	☑	–	–	PAT	Overall: 11/14	20.0	3/14
Bryan et al[36§]	rCOH, Hosp, GB	55 (NR), NR	66 (38C, 3O, 8S, 17T)	66 CI/LI (62 CI; 4 LI)	NR	OPT, PA, USO	57 <30°, 9 30°-60°	NR	A-D: ☑ (D: +PC)	A: MNT B: OPN C: – D: –	A: – B: – C: – D: –	TTH	A: 10/66 B: 21/66 C: 59/66 D: 33/55	A: NR B: NR C: 9.2 D: NR	7/66
Chaushu et al[25§]	rCOH, Uni/Pract, IL	29 (NR), NR	NR	32 CI/LI	NR	CBCT, OPT, PA	NR	NR	☑	–	☑	TTH	31/32	18.0	1/32
Foley[20§]	rCOH, Hosp, GB	118 (87/31), 8.8	137 (88C, 10S, 39T)	133 CI/LI	NR	NR	5B, 112P, 20W	33CR, 100IR	☑	–	–	TTH	91/133	NR	39/133
Jung et al[37§]	rCOH, Hosp, KR	193 (144/49), 7.4	241 (182C, 14O, 7S, 38T)	226 CI/LI	NR	CBCT, OPT	1B, 185P, 55W	NR	A-C: ☑	A: – B: – C: OPN	A: – B: ☑ C: ☑	TTH	A: 186/226 B: 8/226 C: 32/226	NR	NR
Leyland et al[19‖]	rCOH, Hosp, GB	43 (35/8), 9.1	56 (15C, 5O, 23T)	NR	20/12/11	NR	10B, 31P, 2W	NR	A-D: ☑	A: – B: OPN C: OPN D: –	A: – B: – C: ☑ D: ☑	PAT	A: 21/43 B: 4/43 C: 15/43 D: 3/43	A: 18.0 B: NR C: NR D: NR	NR
Lygidakis et al[38§]	rCOH, Pract, GR	34 (NR), NR	43 (16C, 10O, 3S, 14T)	34 CI	NR	OPT, PA, USO	NR	NR	A-B: ☑	A: – B: OPN	A: ☑ B: –	TTH	A: 25/34 B: 9/34	A: 9.9 B: 8.2	NR
Mason et al[21§]	rCOH, Hosp, GB	100 (NR), 9.3	100 (1C, 9O, 5S, 85T)	127 CI	NR	LC, OPT, PA, USO	99P, 1W	12CR, 115IR	☑	–	–	TTH	66/100	NR	34/100
Patchett et al[23§]	rCOH, Hosp, AU/GB	135 (NR), NR	172	172 CI/LI	NR	LC, OPT, PA, USO	NR	NR	☑	–	–	TTH	86/172	NR	86/172[†]
Pavoni et al[41‖]	pCOH, Hos/Uni, IT	62 (30/32), 8.6	62 (36O, 26NR)	60 CI, 14 LI	NR	OPT	NR	14 CR (DS G), 50 IR (DS F)	A-B: ☑	A: OPN B: -	A: – B: –	PAT	A: 28/34 B: 11/28	A: 7.5 B: 9.5	NR
Ravn & Nielsen[39‖]	rCOH, Hosp, DK	63 (47/16), NR	NR	NR CI	NR	NR	NR	NR	☑	–	–	PAT	25/63	NR	38/63
Smailiene et al[40‖]	rCOH, Hosp, LT	33 (19/14), 9.58	NR	33 CI	NR	OPT	NR	NR	☑	–	–	PAT	21/33	16.1	12/33
Witsenburg & Boering[22‖]	rCOH, Uni, NL	63 (40/23), 8.8	86 (25C, 7I, 1O, 19PM, 11NR)	NR	34/0/44	NR	NR	NR	A-C: ☑	A: – B: – C: OPN	A: – B: ☑ C: –	PAT	A: 31/63 B: 1/63 C: 3/63	NR	A: 27/63 B: – C: –

SUP, supernumerary; *L*, left; *M*, midline; *R*, right; *SPC*, space measure; *EXP*, exposure; *TRA*, traction; *rCOH*, retrospective cohort study; *Hosp*, hospital; *Uni*, university; *C*, conical; *O*, odontoma; *S*, supplemental; *T*, tuberculate; *NR*, not reported; *CI*, central incisor; *LI*, lateral incisor; *LC*, lateral cephalometry; *OPT*, orthopantogram; *PA*, periapical; *USO*, upper standard occlusal; *TTH*, teeth; *Pract*, private practice; *B*, buccal; *CR*, complete root; *IR*, incomplete root; *PAT*, patient; *PC*, primary canine; *MNT*, maintenance; *OPN*, opening; *CBCT*, cone-beam computed tomography; *P*, palatal; *W*, within-arch; *DS*, Demirjan stage.

*Countries given with their ISO Alpha-2 codes; [†]Required further intervention; [‡]No study reported on adverse events; [§]Number erupted per impacted maxillary incisors; [‖]Number erupted per patient.

Table II. RoB assessment using the Newcastle-Ottawa Scale

Study	Representativeness	Selection of the nonexposed	Ascertainment of exposure	Changes in outcome	Comparability	Assessment of outcome	Duration of outcome	Adequacy of outcome	★
Ashkenazi et al[34]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	★ (a)	★ (a)	6
Betts et al[35]	★ (a)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	★ (a)	★ (b)	6
Bodenham[2]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	★ (a)	★ (a)	6
Bryan et al[36]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	★ (a)	★ (a)	6
Chaushu et al[25]	★ (a)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	★ (a)	★ (a)	6
Foley[20]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	★ (a)	★ (b)	6
Jung et al[37]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	★ (a)	★ (b)	6
Leyland et al[19]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	★ (a)	★ (a)	6
Lygidakis et al[38]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	★ (a)	★ (a)	6
Mason et al[21]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	◯	★ (a)	5
Patchett et al[23]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	◯	★ (a)	5
Pavoni et al[41]	★ (b)	◯ (c)	★ (a)	★ (a)	◯	★ (a)	◯	★ (a)	5
Ravn & Nielsen[39]	★ (b)	◯ (c)	◯ (c)	★ (a)	◯	◯ (c)	★ (a)	★ (a)	4
Smailiene et al[40]	★ (b)	◯ (c)	◯ (c)	★ (a)	◯	◯ (c)	★ (a)	★ (a)	4

Note. The circle indicates not undertaken/or reported.

Table III. RoB assessment per domain using Risk of Bias In Nonrandomized Studies of Interventions

Study	Bias because of confounding	Bias in the selection of participants in the study	Bias in the classification of interventions	Bias because of deviations from intended interventions	Bias because of missing data	Bias in the measurement of outcomes	Bias in the selection of the reported result	Overall RoB
Pavoni et al[41]	Low	Low	Low	Low	Low	Low	Low	Low

Table IV. Single-group meta-analyses of eruption success according to administered treatment

No.	Studies	Treatment	Rate (95% CI)	Tau^2 (95% CI)	I^2 (95% CI)	Prediction	$P_{subgroup}$ value
1	11	Removal	57.6% (47.8-67.0)	0.02 (0.01-0.08)	89% (82-93)	23.1%, 88.4%	<0.001
2	1	Removal and space measures	82.4% (65.5-93.2)	–	–	–	
3	1	Removal and ortho-traction	96.9% (83.8-99.9)	–	–	–	

if the unerupted incisor was in the correct position rather than the midline (OR, 2.19; 95% CI, 1.14-4.20; $P = 0.02$), if the unerupted incisor was at the level of the gingival third of the adjacent tooth roots rather than the apical third (OR, 0.07; 95% CI, <0.01-0.97; $P = 0.04$), if the unerupted incisor had Cvek category 4 root development rather than category 1 (OR, 0.17; 95% CI, 0.04-0.66; $P = 0.01$), and if the incisor had incomplete rather than complete root formation (OR, 9.02; 95% CI, 2.04-39.78; $P = 0.004$) (Supplementary Appendix VIII). Clinically, delaying removal of the supernumerary tooth 12 months after the expected date of the eruption of the unerupted maxillary incisor (OR, 0.33; 95% CI, 0.10-1.03; $P = 0.05$) and waiting >6 months for spontaneous eruption after removal of the obstacle (OR, 0.13; 95% CI, 0.03-0.50; $P = 0.003$) was associated with worse odds for incisor eruption. The relationship between the midline and the buccal-palatal position of the unerupted incisor, the vertical orientation of the supernumerary, and the number of supernumeraries present did not seem to predicate the likelihood of incisor eruption (Supplementary Appendices IV-XIII).

Source data was available from a single study[39] and re-analyzed. However, patient age and the number of supernumeraries did not affect the eruption success of incisors (Supplementary Appendix XIV). Sensitivity analyses according to the inclusion of studies with methodological shortcomings or signs of bias or studies with adequate sample size (>40 patients) (sensitivity analysis) were undertaken (Supplementary Appendix XV), and a significant difference for the comparison of tuberculate (control) vs conical supernumerary according to the adequacy of outcome measurement was observed.

The overall certainty of the available evidence per GRADE recommendations was appraised across different comparisons and outcomes affecting successful incisor eruption (Table VIII). All outcomes were downgraded

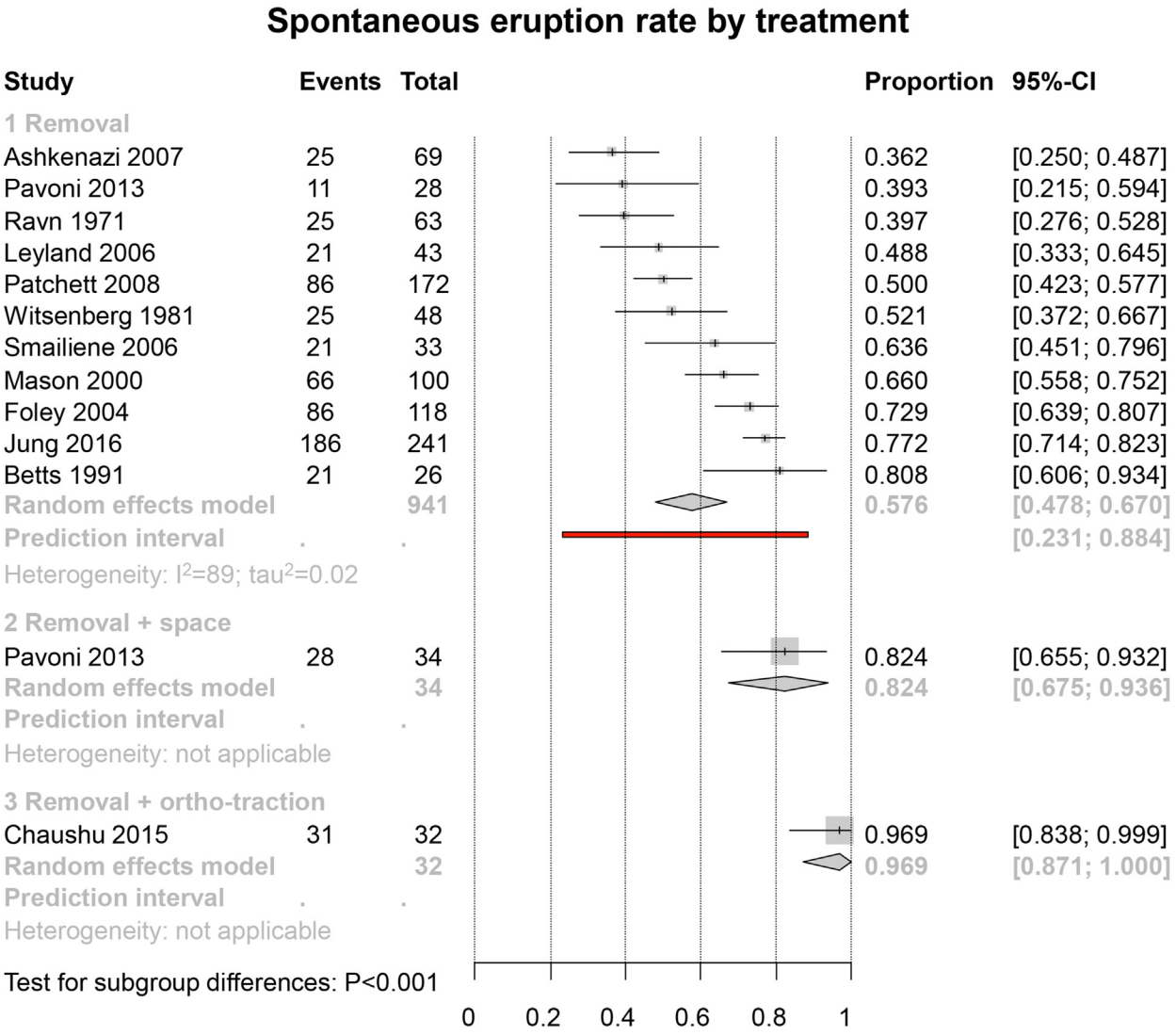

Fig 2. Forest plot for single-group meta-analysis of eruption success according to administered treatment.

Table V. Single-group meta-analyses of eruption success after obstruction removal according to obstruction type

No.	*Studies*	*Obstruction*	*Rate (95% CI)*	*Tau² (95% CI)*	*I² (95% CI)*	*Prediction*	$P_{subgroup}$ *value*
1	4	Odontoma	34.4% (18.5-51.9)	0 (0-1.32)	34% (0-77)	4.0%-72.4%	0.01
2	9	Supernumerary	61.1% (49.5-72.1)	0.03 (0.01-0.11)	90% (83-94)	21.8%-93.6%	

by 2 levels due to methodological issues possibly associated with RoB. The outcome supernumerary form (odontoma vs supernumerary) was further downgraded due to inconsistency. A high or moderate level of certainty of the evidence was not found in relation to any of the outcomes or comparisons, which means that future studies might change our confidence in these comparisons.

DISCUSSION

Interpretation of the results in the context of other evidence

To our knowledge, this is the first systematic review to compare the effectiveness of interventions to facilitate eruption of impacted maxillary incisor teeth due to the presence of a supernumerary. Between the 3

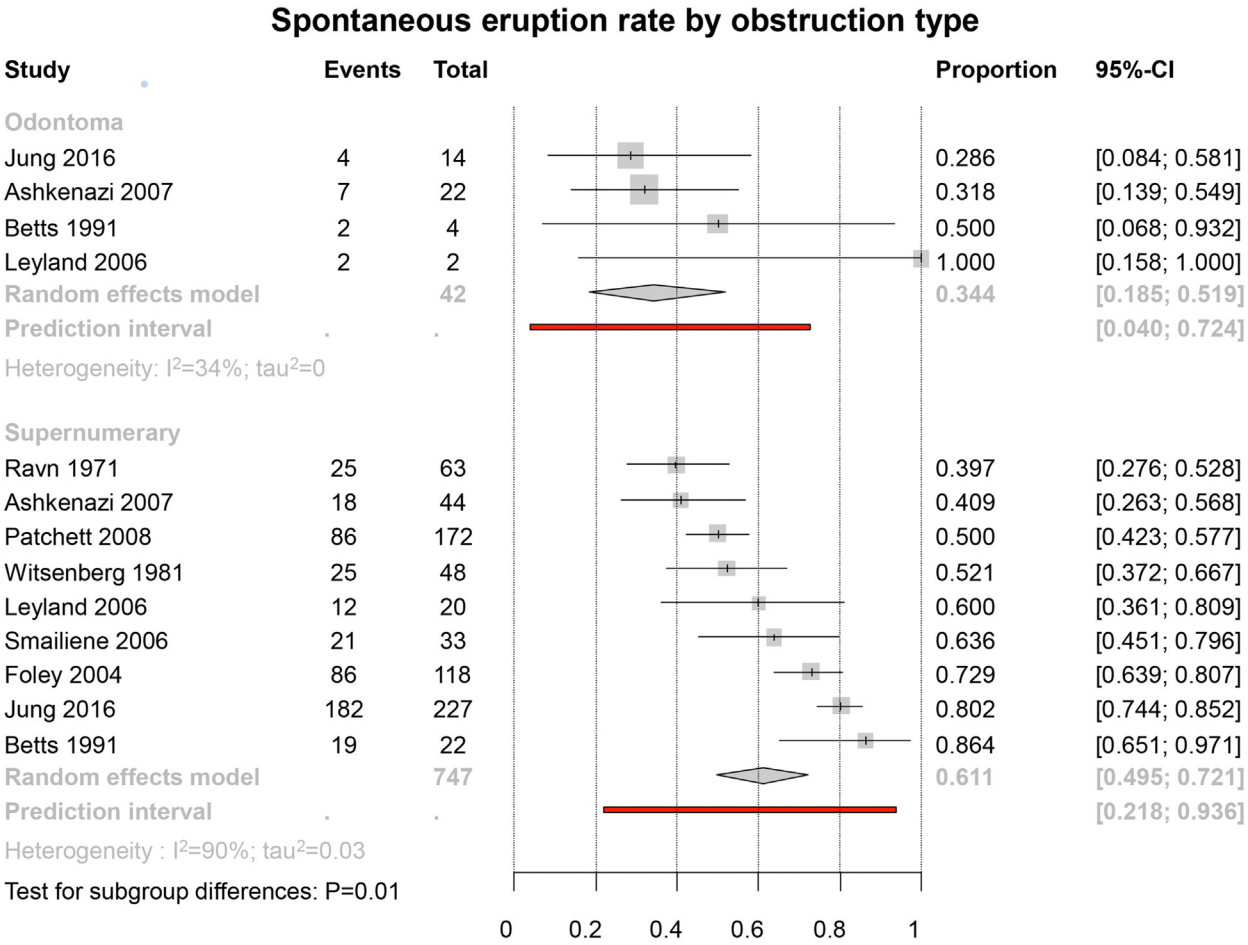

Fig 3. Forest plot for single-group meta-analysis of eruption success after obstruction removal according to obstruction type.

Table VI. Single-group meta-analyses of eruption success after removal of supernumerary according to supernumerary form

No.	*Studies*	*Supernumerary*	*Rate (95% CI)*	*Tau² (95% CI)*	*I² (95% CI)*	*Prediction*	$P_{subgroup}$ *value*
1	6	Tuberculate	44.7% (28.6-61.4)	0.03 (0.01-0.24)	79% (54-90)	2.1%-93.1%	0.009
2	6	Conical	72.2% (60.0-83.0)	0.02 (0-0.12)	75% (44-89)	33.0%-98.6%	

interventions, removal of the supernumerary tooth only, removal of the supernumerary, and space creation or removal of the supernumerary and orthodontic traction to the impacted incisor, significant differences in the percentage of impacted incisor eruption were evident. The pooled estimate for the successful eruption of the incisor after the removal of the supernumerary was 57.6%. However, a high degree of heterogeneity was evident between the studies included in this estimate. In addition, the wide 95% CIs suggest unpredictability regarding the effectiveness of this intervention. The reported estimate is lower than the findings of a previous quantitative review which reported an estimate of 65.5%.[28] However, it should be considered that the latter is an unweighted average value calculated by the authors from the findings of the included studies and does not correspond to proper meta-analysis.[28]

Conversely, the use of orthodontic appliances to either maintain or create space (space measures) or to apply orthodontic traction resulted in a higher eruption rate of the impacted incisor. These estimates should be interpreted with caution as they are based on the

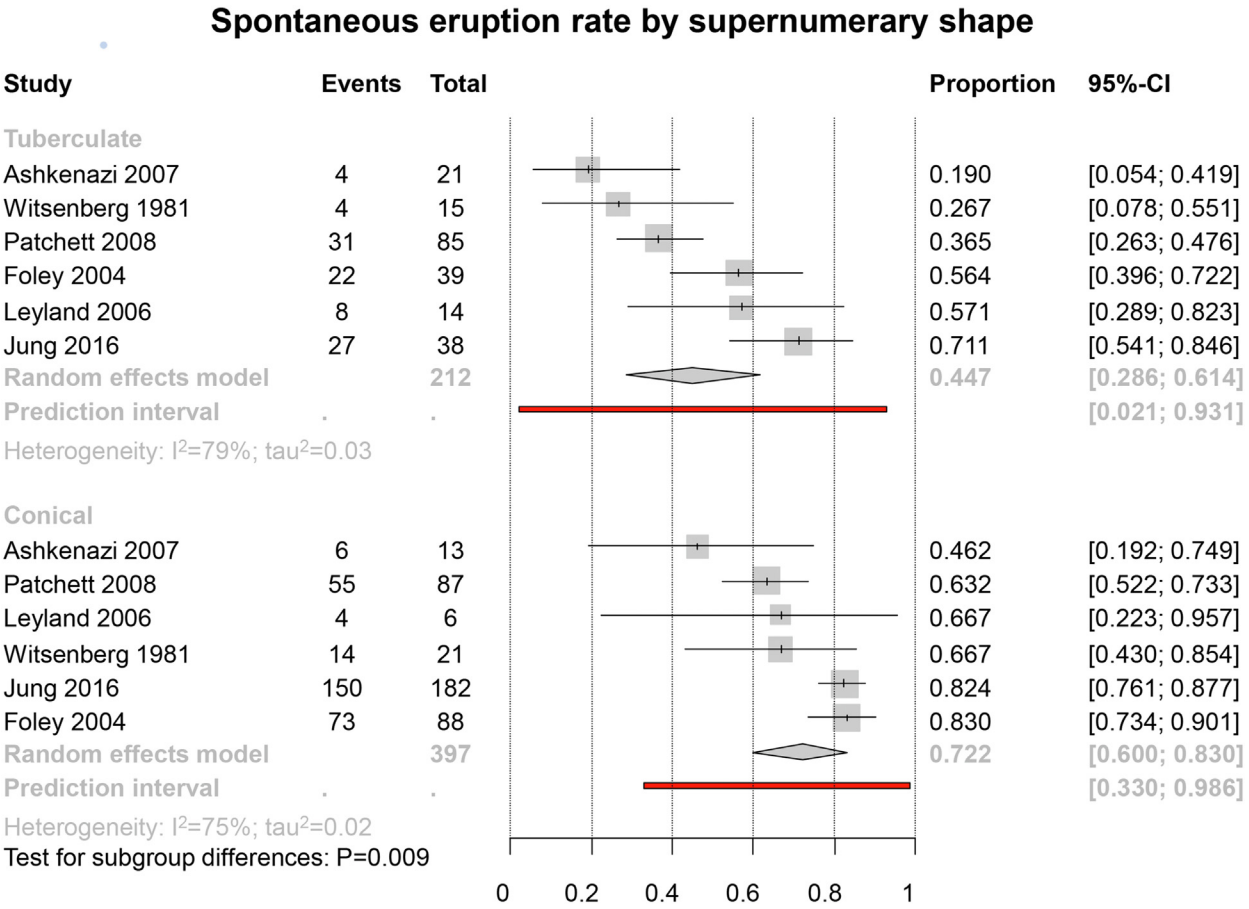

Fig 4. Forest plot for single-group meta-analysis of eruption success after removal of supernumerary according to supernumerary shape.

findings of 2 single studies. However, this appears to support using additional orthodontic treatment mechanics to facilitate the eruption of unerupted teeth. Indeed, the use of orthodontic appliances to facilitate the eruption of impacted incisors has been advocated.[24] An orthodontic appliance should create space within the dental arch before surgery. At the time of removal of the supernumerary, an attachment is then bonded onto the impacted incisor. After surgery, the appliance is used to apply directional traction to the incisor.[24] A key step in this treatment modality is creating space.[42] Ironically, this also may explain why the eruption rate after removal of the supernumerary is lower in comparison, as it is unclear from the studies whether sufficient space is present or, indeed, has been created within the dental arch to accommodate the incisor.

It has been well-established that the type and form of supernumerary are associated with incisor impaction. A higher incidence of incisor impaction is associated with tuberculate-type supernumeraries compared with conical[4,7] and when odontomas are present.[43] Interestingly, this also seems to impact the success of incisor eruption, with a lower eruption success evident when an odontoma or tuberculate supernumerary is removed. Clinically, this may indicate that the chances of incisor eruption are low and that further treatment should be planned from the outset in these patients.

From a clinical perspective, it would be useful to be aware of the appropriate time to monitor the eruption of the impacted incisor after the initial intervention. Unfortunately, most studies included in this review failed to report a clearly defined observation period after the intervention, which negated any further subgroup and meta-regression analyses. However, based on the findings of a single study, an observation of 6 months appears to be the maximum timeframe to monitor the eruption of the impacted incisor after the removal of the supernumerary before considering further clinical

Table VII. Pairwise meta-analyses on eruption success according to various patient, obstruction, impaction tooth, or treatment characteristics

No.	*Category*	*Control*	*Experimental*	*Studies*	*OR (95% CI)*	*Tau^2 (95% CI)*	*I^2 (95% CI)*	*Prediction*	P *value*
1	Patient	Male	Female	1	2.16 (0.76-6.14)	–	–	–	0.15
2	Patient	Deciduous dentition	Mixed dentition	1	0.42 (0.20-0.90)	–	–	–	0.02
3	Patient	Aged ≤ 6 y	Aged >6 y	1	1.33 (0.11-15.53)	–	–	–	0.82
4	Patient	Aged ≤ 7 y	Aged >7 y	1	0.90 (0.25-3.24)	–	–	–	0.88
5	Patient	Aged ≤ 8 y	Aged >8 y	1	1.34 (0.49-3.68)	–	–	–	0.57
6	Patient	Aged ≤ 9 y	Aged >9 y	1	1.33 (0.36-4.95)	–	–	–	0.67
7	Patient	Aged ≤ 10 y	Aged >10 y	1	1.54 (0.09-25.84)	–	–	–	0.76
8	Patient	Earlier than eruption	0-6 mo after	1	0.55 (0.07-4.01)	–	–	–	0.55
9	Patient	Earlier than eruption	6-12 mo after	1	0.23 (0.04-1.42)	–	–	–	0.11
10	Patient	Earlier than eruption	>12 mo after	1	0.33 (0.10-1.03)	–	–	–	0.05
11	Obstruction	Odontoma	Supernumerary	4	3.01 (0.79-11.40)	1.02 (0-33.69)	62% (0-87)	0.02, >100	0.11
12	Obstruction	Tuberculate supernumerary	Conical supernumerary	6	2.91 (1.98-4.28)	0 (0-0.78)	0% (0-75)	1.69-5.03	<0.001
13	Obstruction	1 supernumerary	2 supernumeraries	1	1.13 (0.36-3.47)	–	–	–	0.84
14	Obstruction	1 supernumerary	3 supernumeraries	2	0.52 (0.08-3.47)	0.89 (–)	36% (–)	–	0.50
15	Obstruction	1 supernumerary	>3 supernumeraries	1	0.67 (0.10-4.48)	–	–	–	0.68
16	Impaction	Within-arch	Labial	2	1.23 (0.11-14.11)	0 (–)	0% (–)	–	0.87
17	Impaction	Within-arch	Palatal	2	1.99 (1.07-3.68)	0 (–)	0% (–)	–	0.61
18	Impaction	Labial	palatal	2	0.84 (0.13-5.25)	0 (–)	0% (–)	–	0.85
19	Impaction	Position: midline	Position: central incisor	1	2.19 (1.14-4.20)	–	–	–	0.02
20	Impaction	Position: midline	Position: lateral incisor	1	0.67 (0.19-2.35)	–	–	–	0.53
21	Impaction	Position: midline	Position: lateral/ central	1	5.32 (0.28, >100)	–	–	–	0.26
22	Impaction	Oriented	Inverted	2	1.19 (0.33-4.24)	0.67 (–)	79% (–)	–	0.79
23	Impaction	Oriented	Transverse	1	1.32 (0.53-3.26)	–	–	–	0.55
24	Impaction	Oriented	Horizontal	1	4.57 (0.23-89.68)	–	–	–	0.32
25	Impaction	Vertical: gingival third of root	Vertical: middle third of root	1	0.36 (0.04-3.70)	–	–	–	0.39
26	Impaction	Vertical: gingival third of root	Vertical: apical third of root	1	0.07 (<0.01-0.97)	–	–	–	0.04
27	Impaction	Cvek category 1	Cvek category 2	1	0.78 (0.22-2.81)	–	–	–	0.70
28	Impaction	Cvek category 1	Cvek category 3	1	0.76 (0.25-2.30)	–	–	–	0.62
29	Impaction	Cvek category 1	Cvek category 4	1	0.17 (0.04-0.66)	–	–	–	0.01
30	Impaction	Cvek category 1	Cvek category 5	1	1.05 (0.04-28.57)	–	–	–	0.98
31	Impaction	Mature	Immature	2	9.02 (2.04-39.78)	0.84 (–)	74% (–)	–	0.004
32	Follow-up	Duration ≤6 mo	Duration >6 mo	1	0.13 (0.03-0.50)	–	–	–	0.003
33	Follow-up	Duration ≤12 mo	Duration >12 mo	1	0.29 (0.07-1.31)	–	–	–	0.11
34	Follow-up	Duration ≤18 mo	Duration >18 mo	1	0.10 (<0.01-1.90)	–	–	–	0.12

interventions (Table VII). The odds of an incisor eruption were more favorable if the supernumerary was removed early during dental development. This is consistent with previous reports in which 100% of impacted incisors erupted within 1.8 years after surgical intervention before the age of 8 years. However, not all patients in this sample had a supernumerary obstructing the incisor.[3] The odds of successful eruption, if early intervention is provided, are probably also influenced by the stage of incisor root development. It has been suggested that in older patients there is a lack of tooth eruption potency with root development maturity[22]; hence, a more favorable outcome could be expected if the root is still immature. On this basis, delaying the removal of the supernumerary beyond the normally expected eruption date or waiting for the spontaneous eruption of the maxillary incisor appears to only delay inevitable further treatment.

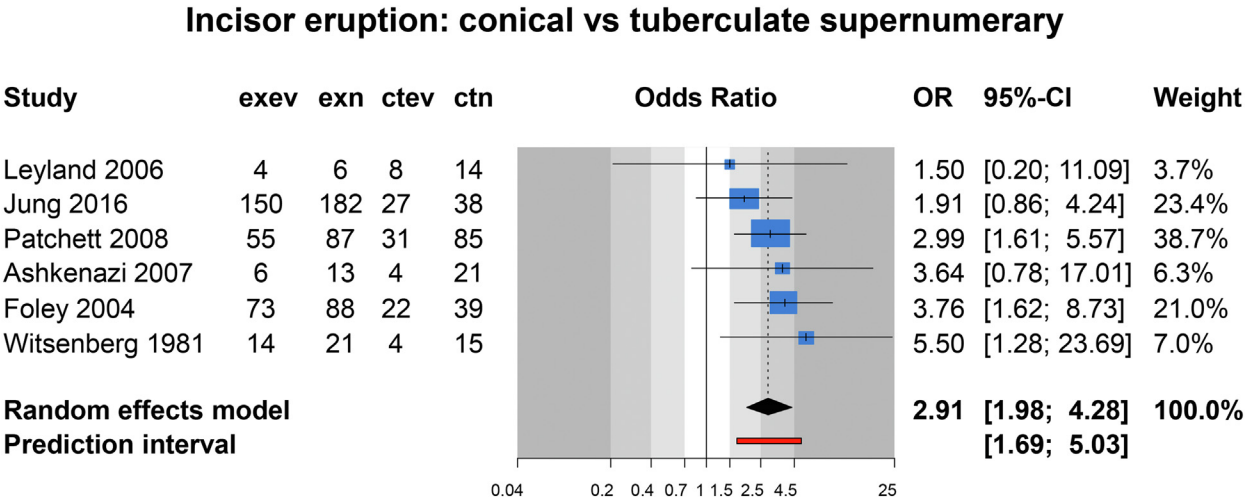

Fig 5. Forest plot for pairwise meta-analysis of eruption success after removal of supernumerary according to supernumerary shape.

Table VIII. Summary of findings table according to the GRADE approach

	Anticipated absolute effects (95% CI)				
Studies (patients)	*Control group*[†]	*Experimental group*	*Difference with PH*	*Quality of the evidence (GRADE)*[‡]	*What happens with PH*
1 study (241 incisors)	Deciduous dentition: 865/1000	Mixed dentition: 731/1000	134 incisors less (13-303 less)	⊕ ○ ○ ○ low[§]	Probably lower spontaneous eruption for incisors of patients in the mixed dentition
4 studies (355 incisors)	Odontoma: 344/1000	Supernumerary: 612/1000	268 incisors more (50 less to 513 more)	○ ○ ○ ○ very low[§,‖]	Little to no difference after removal of odontomas and supernumeraries
6 studies (609 incisors)	Tuberculate supernumerary: 447/1000	Conical supernumerary: 702/1000	255 incisors more (168-329 more)	⊕ ○ ○ ○ low[§]	Probably higher spontaneous eruption after removal of conical supernumeraries
2 studies (218 incisors)	Mature incisor (closed apex): 378/1000	Immature incisor (open apex): 846/1000	468 incisors more (176-582 more)	⊕ ○ ○ ○ low[§]	Probably higher spontaneous eruption for incisors with open apex
1 study (43 incisors)	Waiting period >6 mo: 706/1000	Waiting period >6 mo: 231/1000	475 incisors less (161-636 less)	⊕ ○ ○ ○ low[§]	Probably lower spontaneous eruption for incisors more than 6 mo after removal of the obstruction

Note. Exposure: various; Population: children with at least 1 impacted canine because of obstruction; Setting: hospitals, university clinics, and private practice (Australia, Israel, South Korea, Malta, Netherlands, and United Kingdom).
[†]Response in the control group is based on a random-effects meta-analysis of the control groups' risk; [‡]Starts from "high"; [§]Downgraded by 2 levels for high RoB because of methodological issues; [‖]Downgraded by 1 level for inconsistency, as studies were found on both sides of the forest plot.

The overall certainty of the available evidence as per GRADE recommendations was rated as very low to low. Common reasons for the downgrading of primary studies were related to the high RoB. This finding is similar to a wider assessment of oral health reviews in which, for all outcomes, 88% were rated as very low to low, with downgrading primarily because of study limitations (RoB) and imprecision.[44]

Strengths and limitations

Methods were employed to ensure this review was undertaken clearly and transparently. Prior registration of the protocol was undertaken.[45] The search strategy was performed under the guidance of a health care librarian, and as recommended in the literature,[46] no language restrictions were set and searching of gray literature were performed to increase the sensitivity of the search. It has been reported that the risk of bias assessment between reviewers can be inconsistent.[47,48] To circumvent this, the rationale for RoB judgments of primary studies should be fully documented by researchers.[49] For both prospective and retrospective studies included in the current review, the rationale for RoB judgments has been provided (Supplementary Appendices V-VII). Discrepancies between the final review and protocol are common in oral health systematic reviews.[50] To reduce selective reporting bias and aid transparency, all post-hoc protocol changes have been documented (Supplementary Appendix II).

Studies undertaken in a hospital, university, or practice setting were included to increase the applicability and generalizability of the results. However, methodological weaknesses were evident in the retrospective studies resulting in high heterogeneity and bias associated with the reported intervention estimates. Primarily the studies included in this review were observational and prone to methodological weaknesses. In addition, the design was typically a single cohort without a comparative group, with unclear reporting of the sampling of participants, consisted of different treatment interventions when it was unclear which treatment was undertaken prior and postremoval of the supernumerary, lacked comparison of one intervention vs another and with no consistent predefined study endpoints (ie, classification of successful eruption). Unsurprisingly, based on these factors, study quality was downgraded on the basis of selection of the nonexposed, comparability, and duration of the outcome. Incomplete reporting of the included studies precluded an assessment of preplanned subgroup and meta-regression analyses and identification of variables (mean time taken for eruption) associated with the outcome of interest.

The reporting of patient-centered outcomes has been advocated within the orthodontic literature.[51] Consistent with the wider literature,[52] these outcomes were often not reported in the studies included in this review. Furthermore, reporting of adverse events and cost-benefit analyses of interventions to manage this condition were absent. The need for high-quality prospective clinical trials reporting outcomes relevant to patients and clinicians is clear.

Implications of the results for practice, policy, and future research

Based on the current evidence, there appears to be no optimal treatment protocols for managing impacted maxillary central incisors in the presence of a supernumerary. The reported estimates suggest that the removal of the supernumerary tooth in conjunction with orthodontic treatment mechanics results in a higher eruption rate of the impacted maxillary incisor than the removal of the supernumerary alone. However, this is based on the results of a limited number of low-quality studies. Furthermore, the overall certainty of the available evidence as per GRADE recommendations was rated at very low to low. The uncertainty of the effectiveness of interventions is further highlighted by the fact that clinical noneruption of impacted incisors was observed.

A common criticism of systematic reviews is that they are plentiful in the literature but commonly conclude that there is a lack of high-quality randomized clinical trials.[53,54] Some authors have suggested that authors of systematic reviews need to take responsibility for undertaking clinical trials on the basis of their review findings.[54] Indeed, to reduce research waste,[55] undertaking a systematic review of the available evidence to justify a clinical trial is recommended.[56,57] The findings of this review have highlighted there is a clear need for high-quality clinical trials in this area. On this basis, the authors of this review have developed and registered a randomized clinical trial (ISRCTN12709966), the iMAC Trial,[58] which aims to assess the effectiveness of 2 interventions (orthodontic space opening alone vs orthodontic space opening with immediate traction) to erupt impacted maxillary central incisors due to the presence of a supernumerary tooth.

CONCLUSIONS

Limited evidence indicates that adjunctive use of orthodontic measures and removal of any associated supernumerary tooth or teeth might be associated with greater chances of an successful eruption of an impacted incisor compared with sole removal of the supernumerary alone. Characteristics related to the patient, type of obstruction, incisor impaction, or treatment may also influence successful incisor eruption after removal of the supernumerary. However, these findings should be viewed with caution as our certainty for these outcomes is very low to low because of the high-level bias and heterogeneity. Further well-conducted and well-reported studies that clearly allocate at the start patients to different treatment protocols and completely report

their results are required. The results of this systematic review have been used to inform and justify the iMAC Trial.

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AUTHOR CREDIT STATEMENT

Jadbinder Seehra contributed to conceptualization, methodology, investigation, original draft preparation, supervision, and manuscript review and editing; Khalid Mortaja contributed to investigation and manuscript review and editing; Fidaa Wazwaz contributed to investigation and manuscript review and editing; Spyridon N. Papageorgiou contributed to methodology, investigation, original draft preparation, and manuscript review and editing; Jonathon T. Newton contributed to original draft preparation and manuscript review and editing; and Martyn T. Cobourne contributed to project conceptualization, original draft preparation and manuscript review and editing.

SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ajodo.2023.01.004.

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