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SYSTEMATIC REVIEW

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Influence of mobility on the long-term risk of tooth extraction/loss in periodontitis patients. A systematic review and meta-analysis

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Abstract

The aim of this systematic review (SR) was to assess whether tooth mobility (TM) increases the risk of tooth extraction/loss. The protocol was registered in PROSPERO database (CRD42023485425). The focused PECO questions were as follows: (1) "In patients with periodontitis, undergoing periodontal treatment, are teeth affected by mobility at higher risk of being extracted/lost compared to non-mobile teeth, with a minimum follow-up of 10 years?" and (2) "In these patients, does varying degrees of tooth mobility increase the risk of tooth extraction/loss, with a minimum follow-up of 10 years?". Results were reported according to PRISMA statement. Electronic and manual searches were conducted to identify longitudinal studies. The different assessments of tooth mobility were pooled into three groups: TM0: Undetectable tooth mobility, TM1: Horizontal/Mesio-distal mobility ≤1 mm, TM2: Horizontal/Mesio-distal mobility >1 mm or vertical tooth mobility. Tooth loss was the primary outcome. Various meta-analyses were conducted, including subgroup analyses considering different follow-up lengths and the timing of TM assessment, along with sensitivity analyses. A trial sequential analysis was also performed. Eleven studies were included (1883 patients). The mean follow-up range was 10–25 years. The weighted total of included teeth, based on the sample size, was 18 918, with a total of 1604 (8.47%) extracted/lost teeth. The overall rate of tooth extraction/loss increased with increasing mobility: TM0 was associated with a 5.85% rate (866/14822), TM1 with the 11.8% (384/3255), TM2 with the 40.3% (339/841). Mobile teeth (TM1/TM2) were at an increased risk for tooth extraction/loss, compared to TM0 (HR: 2.85; [95% CI 1.88–4.32]; $p < .00001$). TM1 had a higher risk than TM0 (HR: 1.96; [95% CI 1.09–3.53]; $p < .00001$). TM2 had a higher risk than TM1 (HR: 2.85; [95% CI 2.19–3.70]; $p < .00001$) and TM0 (HR: 7.12; [95% CI 3.27–15.51]; $p < .00001$). The results of the tests for subgroup differences were not significant. Sensitivity meta-analyses yielded consistent results with other meta-analyses. Within the limits of the quality of the studies included in the meta-analyses, mobile teeth were at higher risk of being extracted/lost in the long-term and higher degrees of TM significantly influenced clinicians' decision to extract a tooth. However, most teeth can be retained in the long-term and thus TM should not be

considered a reason for extraction or a risk factor for tooth loss, regardless of the degree of TM.

KEYWORDS
long term, tooth loss, periodontitis, tooth loss, tooth mobility, tooth prognosis

1 | INTRODUCTION

Periodontitis is a chronic multifactorial inflammatory disease characterized by the progressive destruction of the tooth-supporting apparatus.[1] Untreated periodontitis may result in tooth loss and represents the main cause of tooth loss in adult patients.[2]

Various clinical factors have been advocated to contribute to tooth loss in periodontal patients, including both patient-related factors (i.e., smoking habit, compliance) and tooth-related factors level (i.e., periodontal pocket depth, clinical attachment loss, furcation involvement, tooth mobility). Several investigations have attempted to assess which clinical factors are associated with an increased risk of tooth extraction/loss in the long term.[3,4] Among these factors, tooth mobility (TM) has been proposed to increase the risk of a tooth loss/extraction, although its impact remains unclear.

TM is typically evaluated by measuring the amplitude of crown displacement resulting from the application of a defined force (i.e., 0.1 *N*).[5] The magnitude of this displacement has been used to differentiate between physiological and pathological tooth mobility and various classifications of TM have been proposed.[6,7]

TM may be associated with a masticatory dysfunction and patient discomfort[8] and is considered one of the factors contributing to defining the stage of periodontitis.[1] Additionally, previous clinical trials have suggested that TM may influence outcomes following periodontal therapy.[9]

Evidence indicates that TM is a risk factor for future attachment loss during the long-term supportive therapy.[10] Moreover, a clinical trial has demonstrated that controlling mobility through occlusal adjustment in patients treated for periodontitis may impact the clinical attachment level gain post-treatment.[11]

Furthermore, some randomized clinical trials have indicated that TM may negatively affect the outcome of periodontal regeneration.[12,13] Although evidence is inconclusive, splinting mobile teeth has been proposed as part of the clinical management preceding regenerative therapy.[14]

The most recent systematic review on the management of mobile teeth concluded that tooth splinting does not improve survival of mobile teeth in patients with advanced periodontitis, and the effects of occlusal adjustment, beyond clinical attachment gain, remain unclear.[15]

Different authors have reported discordant results regarding the impact of TM on tooth loss.[16,17] However, the most recent systematic review found risk ratio of 3.71 for mobile teeth being lost at a 3-years follow-up.[18] No systematic review has evaluated the influence of TM on tooth loss in the long term.

Therefore, the primary aim of this systematic review (SR) was to evaluate whether tooth mobility increases the risk of a tooth extraction/loss in the long term in periodontally treated patients. The secondary aim was to evaluate if different degrees of tooth mobility increase the risk of tooth extraction/loss.

2 | METHODS

This systematic review was conducted according to the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analysis).[19] The review protocol was registered in PROSPERO database (CRD42023485425).

2.1 | Focus question

The PECO method and guidelines of the Center for Evidence-Based Medicine (University of Oxford)[20] were utilized to formulate focused questions:

1. "In patients with periodontitis, undergoing periodontal treatment, are teeth affected by mobility at a higher risk of being extracted/lost, compared to non-mobile teeth, with a minimum follow-up of 10 years?"

Population: teeth in adult human patients, affected by and treated for periodontitis.

Exposure: tooth mobility. All assessment methods/classification systems for TM were considered.

Comparison: absence of tooth mobility.

Outcomes: tooth loss.

2. "In patients with periodontitis, undergoing periodontal treatment, do different degrees of tooth mobility increase the risk of tooth extraction/loss, with a minimum follow-up of 10 years?"

Population: teeth in adult human patients, affected by periodontitis, undergoing treatment.

Exposure: tooth mobility. All assessment methods/classification systems for TM were considered.

Comparison: different degrees of mobility.

Outcomes: tooth loss.

Eligibility Criteria.

Inclusion criteria:

- Diagnosis of periodontitis.
- Case series studies with at least 20 patients.
- Clear definition of the methods used for tooth mobility assessment.
- Tooth mobility measured at least at baseline of the study; (i.e., the assessment of TM could have happened both before all periodontal interventions or after active periodontal treatment).
- Minimum 10 years follow up.
- English language.
- Regular Supportive Periodontal Care (SPC). All SPC protocols were accepted.
- Exclusion criteria:
- Case reports, animal studies, in vitro studies.
- Studies not clearly reporting the number of teeth extracted/lost for mobile and non-mobile teeth groups and for different degrees of mobility.

2.2 | Information sources and search strategy

Three online databases (PUBMED, EMBASE, and GOOGLE SCHOLAR) were searched up to January 7, 2024. (For detailed information on the search strategy see Appendix S1).

Journals (*Journal of Clinical Periodontology*, *Journal of Periodontology*, *Journal of Periodontal Research*) were hand searched from January 2014 to January 2024. References of included studies and relevant SRs were also screened.

2.3 | Selection process

Articles found by these means were uploaded into Endnote 20 (Clarivate Analytics), a reference manager software for duplicate removal, screening, and selection. Two reviewers (M.P. and C.R.) independently screened records by title and abstract, and then eligible papers were evaluated in full text. Disagreements were resolved by a third reviewer (L.B.).

2.4 | Data collection process and data items

A customized table was used to summarize information from included studies. For each study, the following information was considered: authors, study design, publication year, country, follow-up, number of patients, number of teeth, TM assessment, number of teeth extracted/lost, degree of TM, and number of teeth extracted/lost according to the initial TM grade. Additionally, informations on periodontal diagnosis, active periodontal treatment, SPC, and the moment and reason for tooth extraction were also collected whenever available. Two attempts were made to contact authors for missing or unclear data.

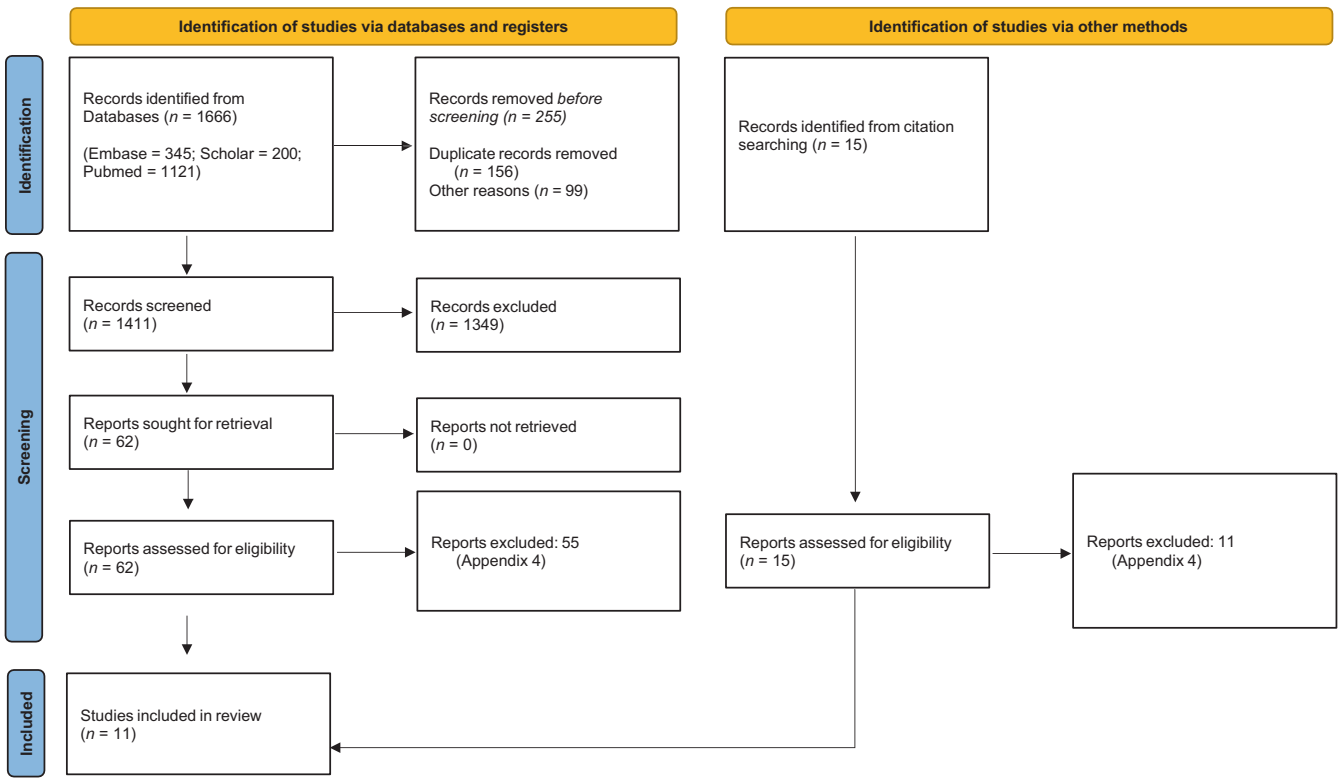


FIGURE 1 PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources.

2.5 | Risk of bias assessment

Two reviewers (C.R. and M.P.) independently assessed the risk of bias using the modified Newcastle-Ottawa scale[21] for observational clinical studies and Cochrane Collaboration's Tool RoB 2.0 for RCTs.[22] Disagreements were resolved by a third reviewer (L.B.) for the final decision. Agreement between reviewers was assessed using Cohen's kappa coefficient (k).

2.6 | Effect measures and synthesis methods

In order to make data comparable between studies using different classifications, taking into account the differences and overlaps between the two classifications used by all included studies,[6,7] different tooth mobility assessments were pooled into three categories:

TM0: Undetectable tooth mobility (corresponding to Miller and Nyman grade 0).

TM1: Horizontal/Mesio-distal mobility ≤1 mm (corresponding to Miller grade 1 and 2 and Nyman grade 1).

TM2: Horizontal/Mesio-distal mobility >1 mm or vertical tooth mobility (corresponding to Miller grade 3 and Nyman grade 2 and 3).

Meta-analyses were performed for each category and all the possible comparisons were made (i.e., TM0 vs TM, whichever the grade, TM0 vs TM1, TM1 vs TM2, TM0 vs TM2,).

The variables were registered at tooth level. The arms were weighted according to the sample size.[23] To compare survival rates between patient groups, hazard ratio (HR) and 95%CI were calculated as described by Tierney et al.[24] Subgroup meta-analyses were conducted based on follow-up duration and timing of TM assessment (i.e., before or after active periodontal therapy, APT).

The heterogeneity was assessed by means of the I^2 statistics (0%–40% low heterogeneity, 30%–60% moderate heterogeneity, 50%–90% substantial heterogeneity, and 75%–100% considerable heterogeneity).[25]

Sensitivity analyses were performed when indicated to explore the robustness of the results and the potential sources of heterogeneity.

Publication bias or selective reporting was evaluated using funnel plots and Egger's regression intercept test.[26]

Statistical analyses were conducted using the RevMan version 5.3 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014) and the STATA version 15.0.

Trial sequential analysis was performed using TSA software version 0.9 beta (http://www.ctu.dk/tsa) to calculate the required information size (RIS).

3 | RESULTS

The search strategy initially identified 1411 articles. Following screening of titles and abstract, 62 articles underwent full-text evaluation, and 15 papers were retrieved from hand search. Consequently, 77 articles were subjected to the eligibility process. Finally, 11 articles were included (Figure 1) Details of excluded full-text articles are provided in Appendix S2. The Cohen's kappa value for global inter-reviewer agreement was 0.74.

3.1 | Study characteristics

This systematic review included 11 retrospective studies.[17,27–36] No RCTs were included. The minimum follow-up was 10 years (Shi, 2020), while the longest follow-up was 25 years (Agudio, 2023). Information regarding country, setting, and funding is available in Appendix S3 Table 1 summarizes the results of individual studies, while Table 2 provides a comprehensive overview of the diagnosis and treatment of included patients. All patients underwent comprehensive periodontal treatment and long-term SPC, with personalized recall intervals. However, detailed strategies for managing mobile teeth were reported in only a few papers.

3.2 | Results of individual studies

A total of 1883 patients were included, accounting for a total of 28.748 teeth. At final follow-up, 2.292 teeth had been extracted/lost (7.97% of the total sample). The tooth loss rate across included studies ranged from a minimum of 1.7%[27] to a maximum of 24.8%.[34] Weighted according to sample size, the included teeth totaled 18 918, with 1604 (8.47%) extracted/lost teeth. The overall rate of tooth extraction/loss increased as mobility categories increased: TM0 was associated with a 5.85% rate (866/14822), TM1 with the 11.8% (384/3255), TM2 with the 40.3% (339/841).

3.3 | Risk of bias in studies

The quality of the included papers is summarized in Table 3. Some papers reached the highest score, indicating a low risk of bias,[17,31,32] while others exhibited lower methodological quality, scoring 7 out of 9. The primary shortcomings concerned the control of confounding factors (i.e., treatment of TM, tooth extracted/lost for other reasons), which were often unreported in the majority of the studies.

3.4 | Results of syntheses

Eight different meta-analyses were conducted, considering various degrees of TM, and subgroups for the length of follow-up and the timing of TM assessment (i.e., before or after APT).

The first meta-analysis compared tooth loss between non-mobile teeth (TM0) and mobile teeth, regardless of grade (TM1/TM2) (Figure 2): mobile teeth were at higher risk of being extracted/

TABLE 1 Results of individual studies.

Authors	N° of patients	Follow-up (Years)	Mobility Classification	N° of Teeth		N. Teeth MOB 0		N. Teeth MOB 1		N. Teeth MOB 2		N. Teeth MOB 3	
				Total	Lost	Total	Lost	Total	Lost	Total	Lost	Total	Lost
Agudio 2023[a]	134	25	Miller	4083	371 (9.1%)	3799	289 (7.6%)	158	24 (15.9%)	91	29 (31.9%)	35	29 (82.8%)
Faggion 2007[b]	198	11.8	Nyman	3245	334 (10.3%)	2291	121 (5.3%)	519	64 (12.3%)	344	91 (26.5%)	91	58 (63.7%)
Graetz 2015[b]	379	18.3	Nyman	2357	585 (24.8%)	1832	339 (18.5%)	358	143 (39.9%)	103	57 (55.3%)	64	46 (71.9%)
Graetz 2017[b]	57	17.4	Nyman	399	97 (24.3%)	281	43 (15.3%)	77	27 (35.1%)	24	13 (54.2%)	17	14 (82.4%)
Graetz 2018[b]	57	11	Nyman	1186	139 (11.7%)	883	69 (7.8%)	158	29 (18.3%)	93	22 (23.7%)	52	19 (36.5%)
Martinez-Canut 2015[a]	500	20	Nyman	9427	221 (2.3%)	6499	46 (0.7%)	2657	100 (3.8%)	241	58 (24.1%)	30	17 (56.6%)
McGuire 1999[a]	52	14	Miller	1043	47 (4.5%)	977	33 (3.4%)	32	2 (6.25%)	27	10 (37%)	7	2 (28.6%)
Miller 2014[b,c]	102	24	Miller	816	177 (21.7%)	–	–	–	–	53	29 (54.7%)	40	28 (70%)
Petsos 2021[a]	97	10.2	Nyman	2323	40 (1.7%)	2018	20 (0.99%)	251	9 (3.6%)	50	8 (16%)	4	3 (75%)
Saleh 2023[a]	168	25	Miller	3869	177 (4.6%)	3305	116 (3.5%)	500	47 (9.4%)	54	12 (22.2%)	10	2 (20%)
Shi 2020[a]	139	10	Miller	478	104 (21.7%)	332	32 (9.6%)	90	44 (48.9%)	49	22 (44.9%)	7	6 (85.7%)

[a]All teeth were lost due to periodontitis.

[b]Reasons for tooth extraction/loss were unavailable or not attributable to different degrees of TM.

[c]Miller et al. reported the total of teeth lost for both M0 and M1 mobility degree.

TABLE 2 Adjunctive information about study diagnosis, treatment rendered to the included patients, timing of TM assessment and timing of tooth extraction.

Authors	Study Design	Diagnosis		Active Periodontal Treatment	Supportive Periodontal Care	Assessment of TM	Timing of tooth extraction
Agudio 2023	Retrospective	Stage 1/2: 40 Stage 3: 110 Stage 4: 4	Grade A: - Grade B: 77 Grade C: 77	NSPT MWF when necessary	Individualized intervals of 3–6 months.	Before APT At the end of APT 25y	During APT: 160 After APT: 201
Faggion 2007	Retrospective	–	–	NSPT AF in 136 patients	No details	Before APT	During APT: 137 After APT: 197
Graetz 2015	Retrospective	AgP: 68 ChP: 311	–	NSPT AF if indicated	Individualized intervals of 3–12 months	Before APT	During APT: 152 After APT: 433
Graetz 2017	Retrospective	AgP	–	NSPT AF if indicated	Individualized intervals of 3–12 months	Before APT	During APT: 31 After APT: 66
Graetz 2018	Retrospective	ChP: 49 AgP: 8	–	NSPT AF if indicated	Individualized intervals of 3–12 months	Before APT	N/A
Martinez-Canut 2015	Retrospective	ChP: 400 AgP: 100	–	NSPT Surgical treatment in 410 patients (MWF, ORS, Root Resection, Periodontal Regeneration, depending on the case)	Individualized intervals of 4–6 months	After APT	After APT
McGuire 1999	Retrospective	ChP	–	NSPT ORS	Individualized intervals of 2–3 months	After APT	After APT
Miller 2014	Retrospective	ChP	–	NSPT MWF on almost all M0 teeth	No details	Before APT	N/A
Petsos 2021	Retrospective	Stage 3: 76 Stage 4: 21	Grade A: - Grade B: 31 Grade C: 66	NSPT (Full Mouth) Surgery in case of remaining PD≥6 mm	Individualized intervals based on PRA	Before APT At the end of APT	During APT: 37 After APT: 119
Saleh 2023	Retrospective	Stage 1: 22 Stage 2: 41 Stage 3: 87 Stage 4: 18	Grade A: 21 Grade B: 112 Grade C: 35	NSPT Surgery when necessary	Individualized intervals of 3 months further adapted based on individual factors	At the end of APT	After APT
Shi 2020	Retrospective	Stage 3: 47 Stage 4: 92	Grade A: - Grade B: 6 Grade C: 133	NSPT	Individualized intervals based on PRA	Before APT	N/A

Abbreviations: AF, Access Flap; AgP, Aggressive Periodontitis; ChP, Chronic Periodontitis; MWF, Modified Widman Flap; NSPT, Non-surgical Periodontal Treatment; ORS, Osseous Resective Surgery; PRA, Periodontal Risk Assessment (Lang and Tonetti, 2003).

lost, compared to non-mobile teeth (HR: 2.85; [95% CI 1.88–4.32]; $p < .00001$). The heterogeneity was moderate.

The second meta-analysis compared tooth loss between non-mobile teeth (TM0) and teeth affected by grade 1 TM (Figure 3): teeth with TM1 were at a higher risk of being extracted/lost (HR: 1.96; [95% CI 1.09–3.53]; $p < .00001$). The heterogeneity was substantial.

The third meta-analysis compared tooth loss between teeth affected by grade 1 TM and grade 2 TM (Figure 4): teeth with TM2 showed higher risk of being extracted/lost (HR: 2.85; [95% CI 2.19–3.70]; $p < .00001$). The heterogeneity was low.

The fourth meta-analysis compared tooth loss between non-mobile teeth and teeth affected by grade 2 TM (Figure 5): teeth with TM2 exhibited a higher risk of being extracted/lost, independently

TABLE 3 Results for modified Newcastle-Ottawa score.

	Selection				Comparability		Outcome			Total score
Author	Representativeness of cohort	Selection of non-exposed cohort	Ascertainment of exposure	Outcome of interest absent at baseline	Control of confounding factors (Periodontal treatment)	Control of confounding factors (TM Management)	Assessment of outcome	Length of follow-up	Lost to follow-up	
McGuire 1999	X	X	X	X	X	X	X	X		8
Faggion 2007	X	X	X	X	X			X	X	7
Miller 2014		X	X	X	X		X	X	X	7
Graetz 2015		X	X	X	X		X	X	X	7
Martinez-Canut 2015	X	X	X	X	X	X	X	X	X	9
Graetz 2017	X	X	X	X	X	X		X	X	8
Graetz 2018	X	X	X	X	X	X	X	X	X	9
Shi 2020		X	X	X	X		X	X	X	7
Petsos 2021	X	X	X	X	X		X	X	X	8
Agudio 2023	X	X	X	X	X	X	X	X	X	9
Saleh 2023	X	X	X	X	X		X	X	X	8

of follow-up (HR: 7.12; [95% CI 3.27 to 15.51]; $p < .00001$). The heterogeneity was considerable.

3.5 | Subgroup Analyses for follow-up length

Regarding the comparison between TM0 and mobile teeth, the test for subgroup differences indicated no statistically significant differences between different follow-up lengths. ($p = .42$; $I^2 = 0\%$). Interestingly, the heterogeneity was lower for longer follow-ups (Figure 2).

Similar, non-significant results were observed for other comparisons (TM0 vs TM1, $p = .84$, $I^2 = 0\%$; TM1 vs TM2, $p = .55$, $I^2 = 0\%$; TM0 vs TM2: $p = .41$, $I^2 = 0\%$) (Figures 3, 4, 5).

3.6 | Subgroup Analyses for timing of TM assessment

Although a visual evaluation of the forest plot for these subgroup analyses may suggest a potentially higher impact of TM on the decision to perform an extraction after APT, the tests for subgroup differences failed to reveal statistically significant differences. (TM0 vs mobility, $p = .14$, $I^2 = 52.9\%$; TM0 vs TM1, $p = .85$, $I^2 = 0\%$; TM1 vs TM2, $p = .18$, $I^2 = 45.6\%$; TM0 vs TM2: $p = .18$, $I^2 = 43.9\%$) (Figure 6).

3.7 | Sensitivity analyses

The sensitivity meta-analyses, considering only tooth extraction/loss during SPC, yielded consistent results with the other meta-analyses. Eight studies were included. (Forest plots are shown in Appendix S4).

TM0 vs Mobility: HR = 6.22; 95% CI: 2.39–16.21; $p = .0002$; $I^2 = 92\%$.

TM0 vs TM1: HR = 1.94; 95% CI: 1.47–2.51; $p < .00001$; $I^2 = 0\%$.

TM1 vs TM2: HR = 2.86; 95% CI: 2.19–3.74; $p < .00001$; $I^2 = 0\%$.

TM0 vs TM2: HR = 8.22; 95% CI: 2.52–26.80; $p = .0005$; $I^2 = 84\%$.

Further sensitivity analyses were performed only considering tooth loss for periodontal reason including 6 studies (Forrest plots are shown in Appendix S5).

TM0 vs Mobility: HR = 7.98; 95% CI: 3.48–18.28; $p < .00001$; $I^2 = 0\%$.

TM0 vs TM1: HR = 2.82; 95% CI: 1.53–5.18; $p = .0009$; $I^2 = 75\%$.

TM1 vs TM2: HR = 5.65; 95% CI: 2.03–15.77; $p = .0009$; $I^2 = 0\%$.

TM0 vs TM2: HR = 15.14; 95% CI: 4.76–48.14; $p < .00001$; $I^2 = 77\%$.

3.8 | Trial sequential analysis

The evidence obtained from this meta-analysis was considered to have high power, as indicated by TSA analysis. The z-curve crossed

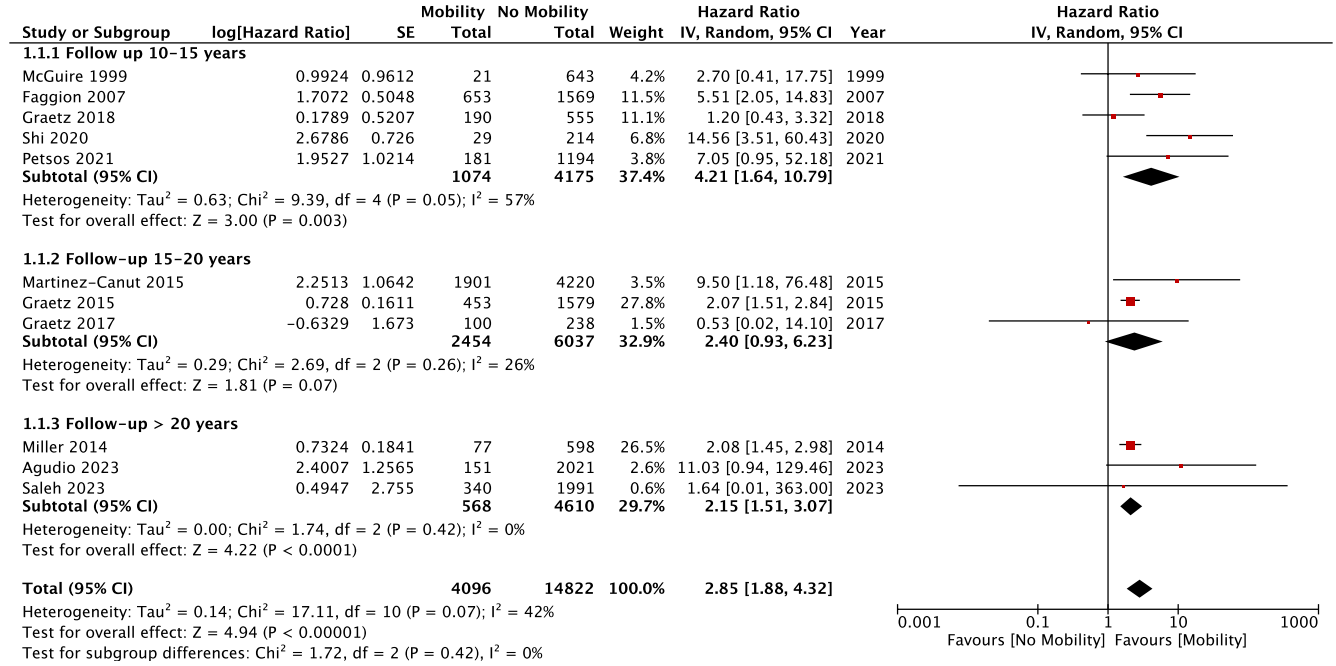


FIGURE 2 Meta-analysis of the included studies, grouped according to the length of follow-up: HR for tooth extraction/loss: M0 vs Mobility (whichever the grade).

both the alpha-spending function and the conventional boundary, and it also reached the required information size (RIS) threshold (Figure 7).

3.9 | Publication bias

Visual inspection of the funnel plots (Appendices S6–S9) indicated a low risk of publication bias among the included studies. Likewise, the result of Egger's test did not demonstrate statistically significant evidence of publication bias ($p > .05$).

4 | DISCUSSION

Tooth hypermobility can lead to masticatory dysfunction and patient discomfort[1] and could be the cause of tooth loss or influencing the clinician's decision to extract a tooth.

The primary aim of this SR was to evaluate the impact of TM on the long-term risk of a tooth extraction/loss. Only studies with a minimum follow-up of 10 years were included, with the maximum follow-up being 25 years. A total of 1883 patients were considered in the analysis. The included teeth, weighted according to the sample size, were 18 918, for a total of 1604 (8.47%) extractions. Mobile teeth were found to be nearly three times more likely to be extracted/lost compared to non-mobile teeth (HR: 2.85; [95% CI 1.88–4.32]; $p < .00001$) with moderate heterogeneity (I^2=42%). These findings are substantially in agreement with a recent SR assessing predictors for tooth extraction/loss in periodontitis patients. The authors included four studies with a minimum follow-up of 3 years reporting an OR of 3.71 for mobile teeth compared to non-mobile teeth.[18] Moreover, both prospective and retrospective studies assessing risk factors for tooth loss have suggested that mobile teeth may be at higher risk of being extracted/lost.[34,37]

To explore the impact of different degrees of TM, which was the secondary outcome of this SR, three meta-analyses were performed. The HR for tooth extraction/loss significantly increased with the degree of TM. Specifically, TM2 showed a 7-fold increase in the risk of being extracted/lost compared to TM0. Similarly, in a recent study involving 135 patients with at least 5 years of follow-up, the authors reported a higher risk for tooth loss with increasing grade of TM.[37]

According to these results, it seems that mobile teeth are more exposed to extraction or loss and that the risk increases with the severity of TM. Therefore, TM seems to be a valuable prognostic indicator for tooth extraction/loss. However, it is worth to mention that, despite these results, a significant percentage of hypermobile teeth were retained in the long term, especially in TM1 and TM2 groups (88.2% and 59.7% respectively). Therefore, the findings of this SR warrant caution, suggesting that in many instances, even hypermobile teeth can be preserved in the long term. Thus, TM should not be considered a risk factor for tooth extraction/loss.

TM may be associated with a higher likelihood for tooth loss in the long term, as evidenced in this SR. However, it may not represent the reason for tooth loss. Therefore, TM should not be considered as an absolute indication for tooth extraction at baseline, unless additional clinical parameters are evaluated. In fact, several aspects may be related to tooth mobility, such as the periodontal inflammation, the height of the supporting tissues, and the width of the periodontal ligament.[38]

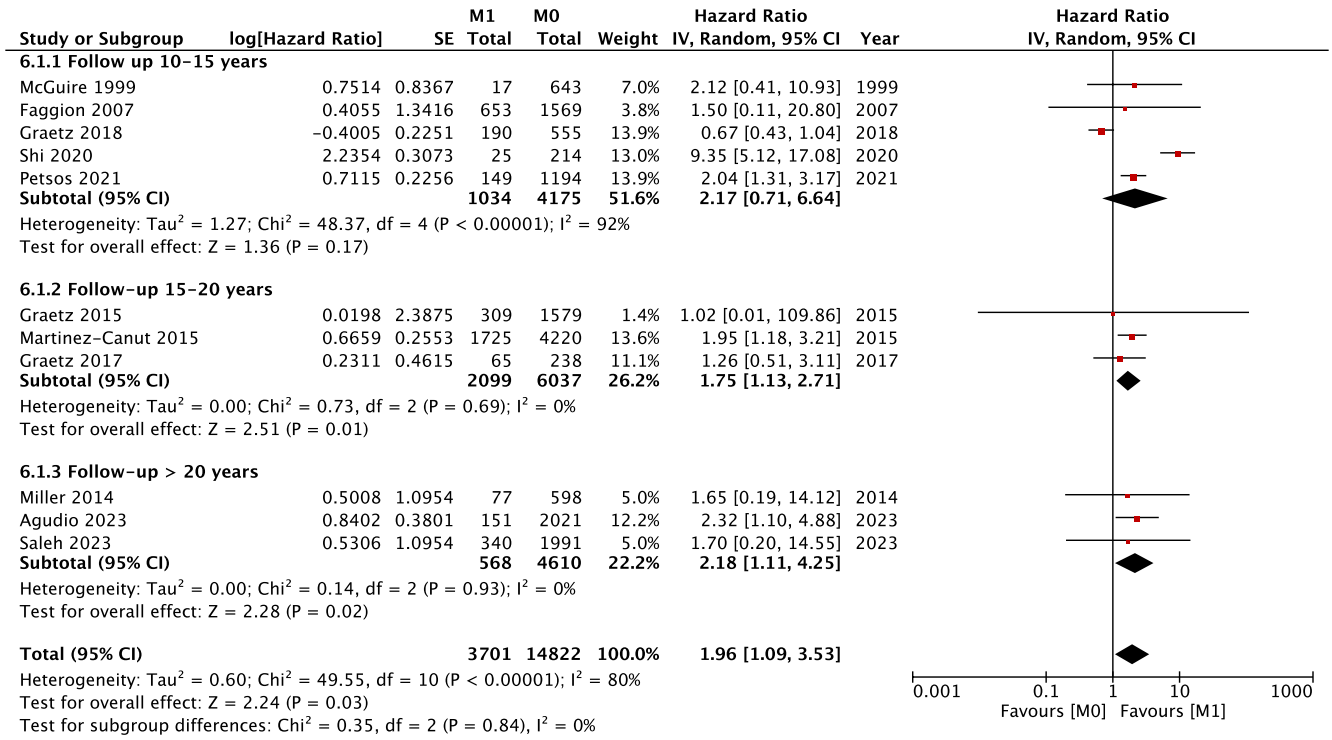


FIGURE 3 Meta-analysis of the included studies, grouped according to the length of follow-up: HR for tooth extraction/loss: M0 vs M1.

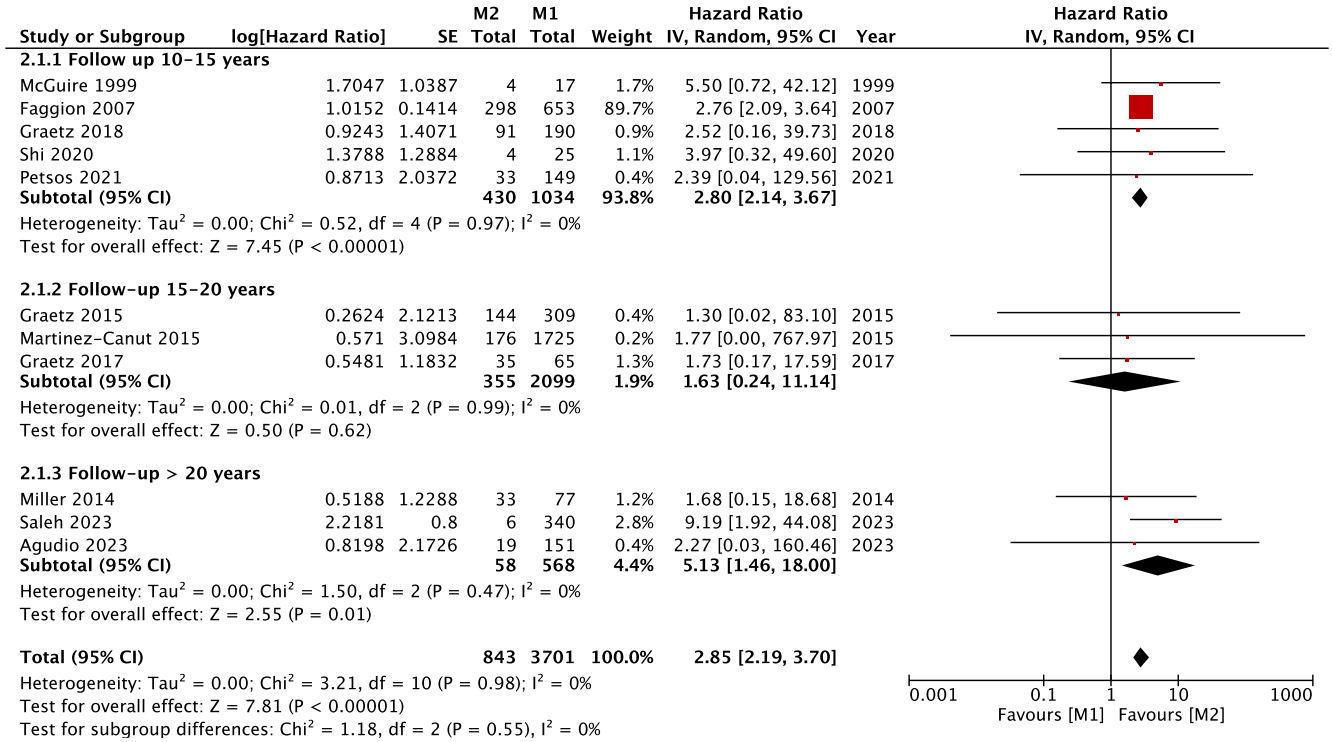


FIGURE 4 Meta-analysis of the included studies, grouped according to the length of follow-up: HR for tooth extraction/loss: M1 vs M2.

In periodontal patients, i.e., in presence of attachment loss, the widening of periodontal ligament may be due to secondary occlusal trauma.[39] Furthermore, the inflammatory changes could impair the adaptive capacity of the periodontal tissues to the occlusal forces. Consequently, it has been suggested that TM cannot be used as reliable indicator for tooth prognosis before initiating treatments aimed

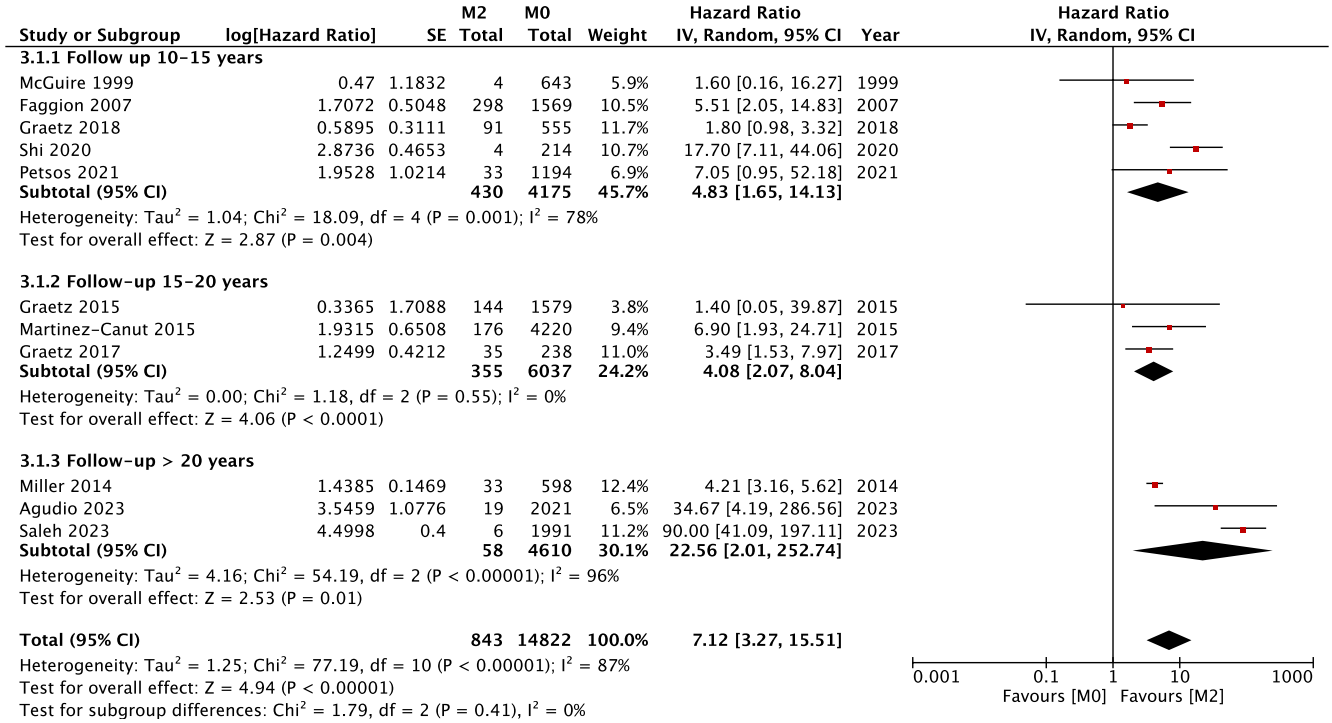


FIGURE 5 Meta-analysis of the included studies, grouped according to the length of follow-up: HR for tooth extraction/loss: M0 vs M2.

at the biofilm removal and control.[15] The significant influence of periodontal inflammation may lead to a higher baseline degree of TM.[40] Therefore, it is advisable to repeat the clinical assessment of TM after each step of periodontal treatment.[41]

Consequently, it is possible to speculate that, if the included studies measured TM after active periodontal treatment, the result might have differed, potentially showing a reduced number of mobile teeth, but a higher likelihood of tooth extraction/loss. Subgroup analyses dealing with the timing of TM assessment (i.e., before or after the APT) failed to find statistically significant differences. However, a visual evaluation of the forest plots suggests a higher impact of TM on the decision to perform an extraction if TM was assessed after APT. It may be speculated that, if the periodontal treatment (both non-surgical and/or surgical) fails to stabilize a mobile tooth, there may be a higher tendency towards extraction in the long term.

Remarkably, no statistically significant difference was detected for the risk of tooth extraction/loss between TM1 and TM0 when TM was assessed before APT (HR: 1.80; 95%CI [0.48–6.80]; $p = .39$; $I^2 = 90\%$), suggesting that mobile teeth should not be extracted before undergoing periodontal treatment.

The control of periodontal infection is crucial in preventing the periodontal breakdown and ultimately reducing the risk of tooth loss.[41,42] Only studies performing regular SPC were included in this SR.[43,44] Indeed, a retrospective study demonstrated that patients who are non-compliant with SPC responded less favorably to periodontal treatment compared to compliant patients[45] also in case of similar periodontal conditions at baseline.

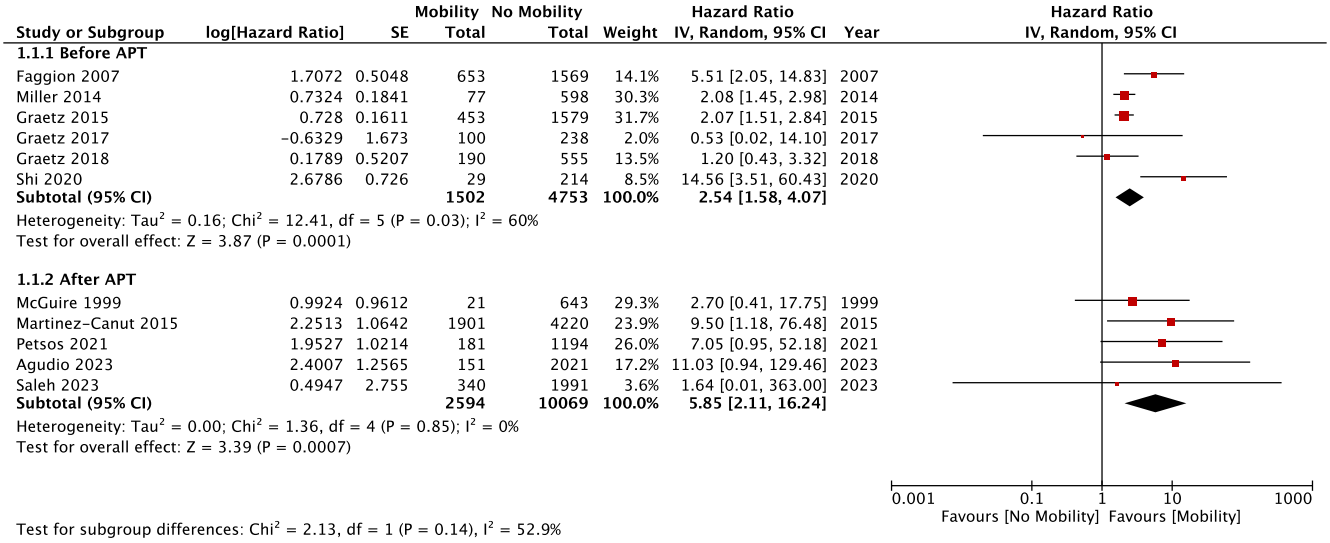
While a statistical evaluation of the impact of SPC on the risk of extraction for mobile teeth was not within the scope of this SR due to variations in SPC frequency among studies, it can be assumed that the majority of patients included in this review received instructions for achieving adequate plaque control during their long-term follow-up. It is possible to speculate that many mobile teeth were extracted before the beginning of SPC. However, sensitivity analyses considering only teeth extracted during the SPC confirmed the results of the overall meta-analyses.

Despite the great heterogeneity observed among studies, which may reflect the different clinical decision at baseline (i.e., whether to extract or retain a severely compromised tooth), all included studies reported higher rates of tooth extraction/loss for mobile teeth.

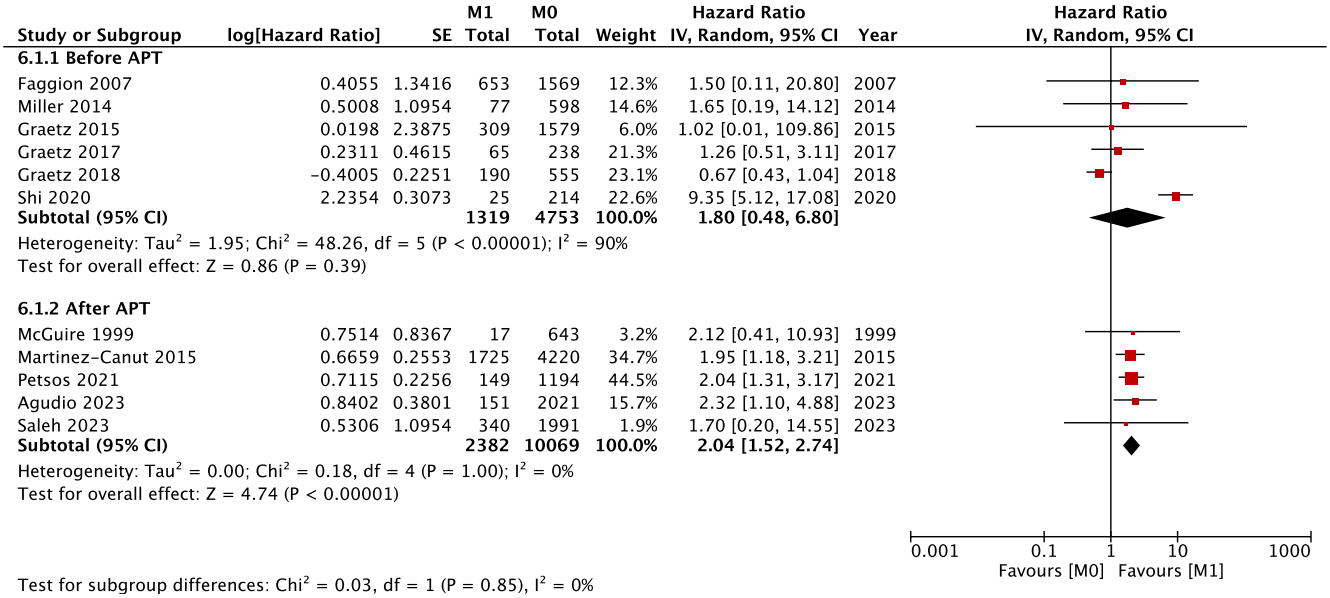
It could be argued that longer the follow-up, greater the likelihood of tooth extraction/loss. Taking into account the length of follow-up, subgroup analyses were performed. Three groups were considered (i.e., 10–15 years, 15–20 years, >20 years). The meta-analyses failed to find statistically significant differences. This lack of significance may be attributed to the inclusion criteria, which required studies to have a minimum follow-up of 10 years. Additionally, the precise timing of extractions during specific follow-up intervals could not be determined, potentially masking the impact of time on the risk of tooth loss. Graetz et al., in their analysis of survival rate curves, reported a consistent trend for tooth extraction/loss for mobile teeth also from ten up to 25 years of follow-up.[30]

Another relevant factor influencing TM is trauma from occlusion. The impact of occlusal trauma on a reduced periodontium has been studied in classic investigations on animal models.[46,47]

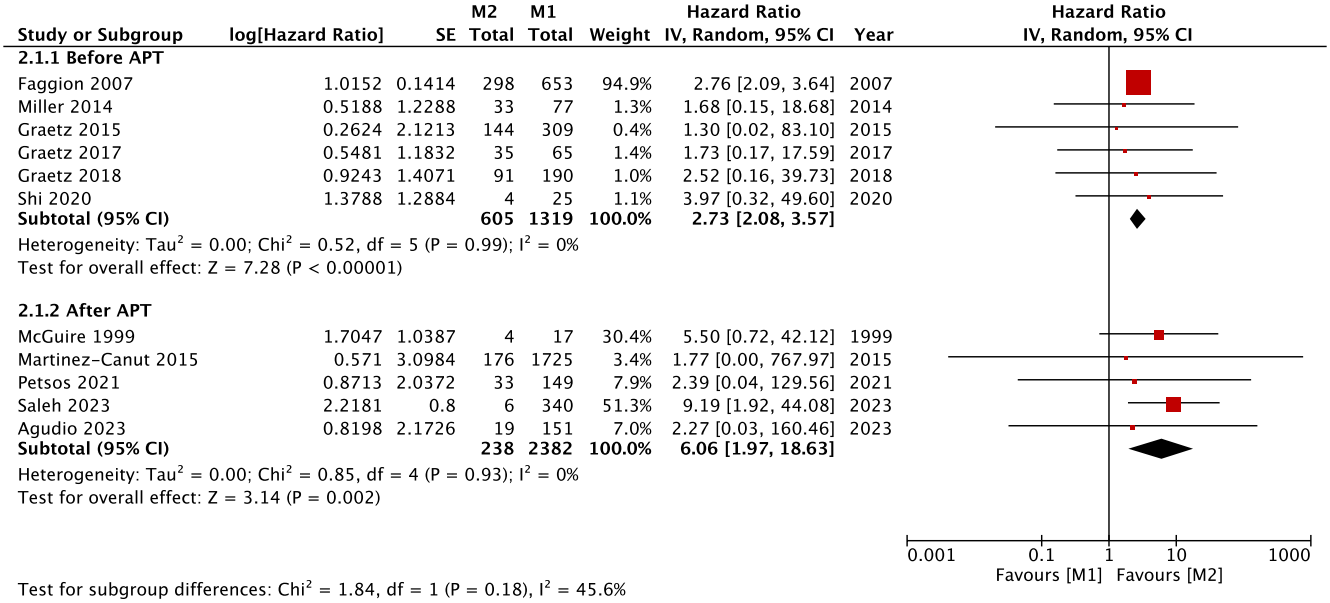
However, aside from periodontal regenerative treatment,[14] there is an ongoing debate and insufficient evidence regarding the



Test for subgroup differences: $Chi^2 = 2.13$, df = 1 (P = 0.14), $I^2 = 52.9\%$



Test for subgroup differences: $Chi^2 = 0.03$, df = 1 (P = 0.85), $I^2 = 0\%$



Test for subgroup differences: $Chi^2 = 1.84$, df = 1 (P = 0.18), $I^2 = 45.6\%$

FIGURE 6 Subgroup meta-analyses of the included studies according to the timing of TM assessment (i.e., before or after the APT).

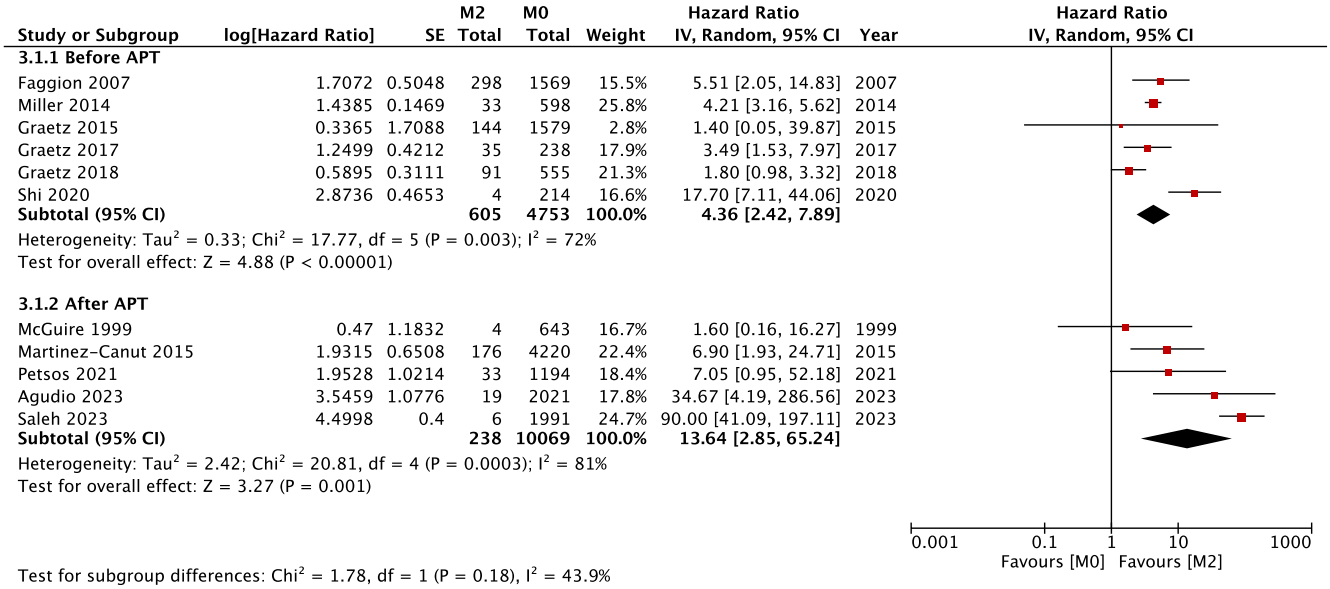


FIGURE 6 (Continued)

impact of the management of occlusal forces on the outcomes of periodontal therapy and tooth loss.

In this regard, two main treatment options have been proposed: tooth splinting (TS) of two or more teeth into a rigid unit[48] and Occlusal Adjustment (OA) in order to reduce occlusal over-load.[49]

A recent systematic review tried to assess the impact of these treatments on tooth loss, reporting inconclusive results due to the paucity of well-controlled studies.[15] The studies included in this SR provided different treatments in order to manage occlusal trauma: Agudio et al.[32] performed TS exclusively on maxillary or mandibular anterior sextants when at least two teeth exhibited hypermobility, Graetz et al.[31] performed TS in all cases of hypermobility reporting no differences in survival between splinted and non-splinted teeth. Conversely, Martinez-Canut et al.[17] and McGuire and Nunn[35] exclusively performed OA to remove any sign of fremitus. No data regarding the impact of this treatment on overall survival rate were available. Due to this heterogeneity and lack of comprehensive data, it was impossible to assess the impact of TS and OA treatments on tooth loss of mobile teeth. However, TS and OA may be beneficial and commonly considered components of treatment strategies,[15] even though there is missing information in the included literature when it comes to management of TM during different steps of periodontal therapy.

Unfortunately, an analysis for tooth loss based on tooth type (i.e., non-molars vs molars; or single-rooted vs multi-rooted) was not feasible due to limited data availability. Only Martinez-Canut[17] reported data regarding the loss of mobile molars compared with other teeth affected by TM. The reported rate of tooth loss was 19% for molars and 6% for incisors. These findings support existing evidence suggesting that the interaction between TM and Furcation involvement of multi-rooted teeth may contribute to increase the loss of attachment in the long term.[10] On the other hand, Miller et al.,[36] Graetz et al.[30] and Shi et al.[28] exclusively included molars and reported different HRs. Particularly, Shi et al. reported the highest HR among the included studies. This was the only study treating the teeth by means of the solely non-surgical treatment.

Similarly, considering the amount of residual bone, none of the included studies allowed an analysis stratified according to TM. It could be speculated that reduced periodontal support may be associated with higher grade of TM. Several studies have demonstrated that the extent of bone loss serves as a relevant prognostic indicator. In a 10-year follow-up study, Tonetti et al. demonstrated that residual periodontal support is a predictor of survival of molars affected by furcation involvement.[50] Additionally, Carnevale et al., in a study with a mean 7.8 years SPT following active periodontal treatment, found that the extracted teeth had a mean bone loss of 76% of the total root length.[51]

Although this SR has several strengths, mostly relying on the long-term follow-up within the included studies and in the wide sample size, some methodological considerations should be noted. The clinical assessment of tooth mobility has been a historical issue in periodontal research. Several methods have been proposed in order to reduce the intra and inter-examiner variability. In particular, Muhlemann et al. used intraorally attached dial indicators to determine the degree of crown excursions produced by known static forces, a technique called *periodontometry*.[5] Nevertheless, the routine use of this device is uncommon in clinical practice. To overcome this limitation, as a result, TM is typically assessed clinically through categorization into different degrees.[52]

Although different classifications of TM have been proposed, all the included studies referred to Miller[6] or Nyman.[7] These two classifications have some differences in describing TM.

Considering the differences and overlaps, the different TM assessments were pooled into 3 categories (i.e., TM0, TM1, TM2),

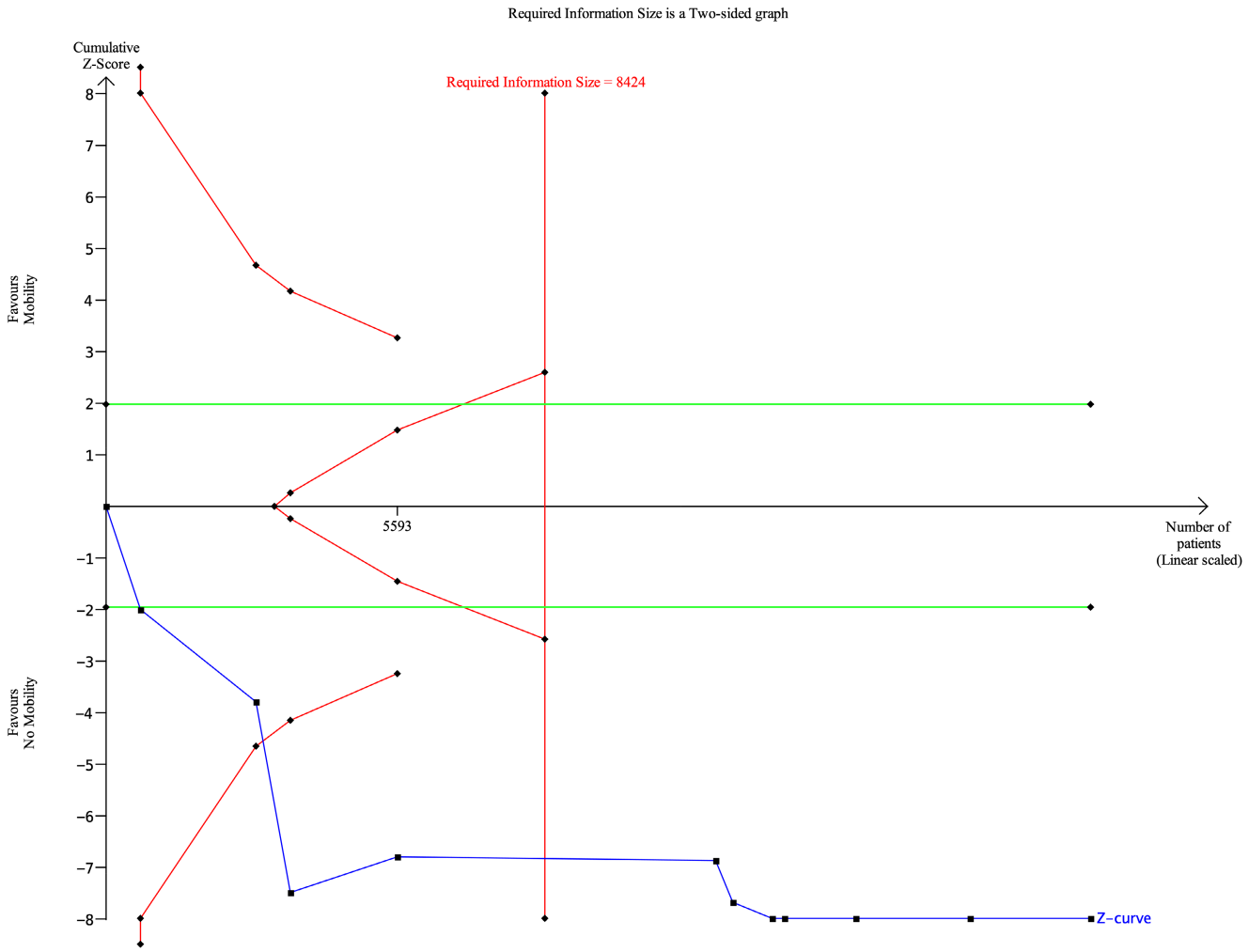


FIGURE 7 Results of the TSA.

with the aim to overcome the limitations related to the different assessments among studies. Nevertheless, this approach may limit the generalizability of our findings and underscores the need for a standardized approach to TM assessment to facilitate future research.

Another limitation of this SR is that, although the influence of different follow-up lengths was investigated by means of the subgroup analyses, and that sensitivity analyses accounted for teeth lost during SPC, it was impossible to determine the exact moment in which the extractions were performed. Moreover, only six of the included studies clearly reported the number of teeth extracted for periodontal reasons. Although the sensitivity analyses confirmed the overall results, a more accurate estimate of TM on periodontal prognosis would have been preferred.

Furthermore, all included papers were retrospective, which potentially increases the risk of selection bias and the substantial and considerable heterogeneity observed in the meta-analyses further complicates the interpretation of results.

Finally, as discussed above, several confounding factors, such as the type of treatment to control TM, were often not addressed across studies potentially influencing the observed outcomes.

Future research should focus on long-term prospective studies, providing information about the clinical management of TM, the cases in which the teeth were extracted/lost due to TM and the exact moment of tooth extraction during SPC.

5 | CONCLUSIONS

The findings in this SR suggest that:

1. Mobile teeth are at a higher risk of being extracted or lost in the long term, and the severity of TM (i.e., TM1, TM2) significantly influences the clinicians' decision regarding tooth extraction.
2. TM itself should not be considered a pathology. Despite the association between TM and increased risk of tooth extraction/loss, even mobile teeth have the potential to be retained in the long term (>20 years) and TM itself (regardless of the degree) should not be considered a reason for extraction, especially if associated risk factors leading to TM can be addressed during the steps of periodontal therapy.

AUTHOR CONTRIBUTIONS

Conceptualization, L.B., C.R., M.P., G.O., F.C.; data curation, M.P., C.R., G.G.; methodology, L.B., G.O., F.C.; formal analysis, C.R., M.P.; investigation, M.P., G.G., C.R., L.B.; writing – original draft preparation, C.R., M.P., and L.B.; writing – review and editing, F.C., R.C., M.DM., G.O.; supervision, F.C., G.O.; project administration, F.C., G.O. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, [LB], upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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