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MDPI

Systematic Review

A Systematic Review and Meta-Analysis on the Associated Effects of Static Magnetic Fields on Orthodontic Tooth Movement

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Abstract: Background: The literature on the use of static magnetic field (SMF), particularly in orthodontics, has certain gaps. Furthermore, the mechanism by which SMF affects orthodontic tooth movement (OTM) is still unclear and quite contradictory. Thus, the goal of this systematic review and meta-analysis was to assess SMF's effect on OTM. This study also sought to analyse the variability of the studies included in the analysis and the size of the impact of SMF on OTM. Methods: Using the PRISMA guidelines, reviewers implemented a search strategy across several online databases, filtering out the initial articles that were obtained by applying relevant inclusion and exclusion criteria. Results: The overall effect size for the odds ratio was found to be 0.58, with a 95% confidence interval ranging from 0.40 to 0.86. This indicates that exposure to static magnetic fields is associated with a significantly reduced likelihood of orthodontic tooth movement in the animal studies analysed. Similarly, the overall effect size for the risk ratio was calculated to be 0.71, with a 95% confidence interval ranging from 0.55 to 0.91. The risk ratio also suggests a significant impact of SMF on OTM, with animals exposed to magnetic fields being at a lower risk of experiencing substantial tooth movement compared to those not exposed. However, it is important to note that moderate heterogeneity was observed among the included studies. Conclusion: The findings of this systematic review and meta-analysis indicate that there may be a causal relationship between OTM and SMF. However, the small number of studies included in this review and their poor methodological quality limit the available data, highlighting the need for further well-designed research to support these conclusions.

Keywords: orthodontic tooth movement; static magnetic fields; orthodontic treatment; magnets in orthodontics; magnetic fields

1. Introduction

An SMF is a type of magnetic field that does not change with time, as opposed to an alternating magnetic field, which oscillates in time [1]. It is created by a static charge distribution, such as a permanent magnet or a current-carrying wire [2]. The strength of a magnetic field is measured in teslas (T), with one tesla being equal to 1 newton per ampere-meter [3]. A magnetic field is a vector field, meaning that it has both magnitude and direction. The direction of the field is defined by the direction of the magnetic force on a positively charged particle moving through the field [4].

The behaviour of materials in an SMF is described by their magnetic susceptibility, which is a measure of the degree to which a material can become magnetised in the presence of a magnetic field [5]. Materials with a positive magnetic susceptibility are attracted to a magnetic field, whereas those with a negative susceptibility are repelled. Materials with very high magnetic susceptibility, such as iron, can become strongly magnetised in the presence of a magnetic field [6].

The motion of charged particles in an SMF is governed by the Lorentz force, which is the force experienced by a charged particle moving through a magnetic field [7]. The magnitude of the force is proportional to the magnitude of the charge, the velocity of the particle, and the strength of the magnetic field [8]. The direction of the force is perpendicular to both the velocity of the particle and the direction of the magnetic field [9]. The Lorentz force is responsible for many of the interesting phenomena observed in static magnetic fields. For example, charged particles in a magnetic field can be deflected from their original path, a phenomenon known as magnetic deflection [10]. This effect is used in particle accelerators to guide the paths of charged particles.

The mechanism by which SMF affects OTM is not fully understood. However, it is believed that SMF influences the cellular and molecular mechanisms involved in bone remodelling [11]. Bone remodelling is a complex process that involves the activity of various types of cells, such as osteoblasts, osteoclasts, and osteocytes, which are responsible for the formation, resorption, and maintenance of bone tissue [12]. SMF has been shown to affect the differentiation and activity of these cells, leading to changes in bone mass and structure [13].

SMF has been sparingly studied for its potential effects on human health, though not particularly in the field of orthodontics [14]. One of the main areas of research is the impact of SMF on OTM [15]. The orthodontic appliance with magnets attached induces SMF to stimulate the movement of teeth [15]. Several studies demonstrated that SMF can significantly enhance OTM, making it a promising tool for accelerating orthodontic treatments [16–18].

There are several gaps in the literature pertaining to SMF usage in dentistry and specifically orthodontics. Most of the studies conducted on this topic are experimental and animal-based, and there is a lack of human-based studies [17,18]. Therefore, the results obtained from animal-based studies may not necessarily translate to humans. Additionally, there is a need for more standardised protocols for SMF usage in orthodontics, as the duration, frequency, and intensity of SMF application vary significantly among studies. Furthermore, the mechanism by which SMF influences OTM is not yet fully understood, and the current theories are conflicting, to say the least. Moreover, there is a lack of studies investigating the long-term effects of SMF on OTM and overall oral health. Hence, the objective of this systematic review and meta-analysis was to evaluate the impact of SMF on OTM. This study also aimed to determine the magnitude of the effect of SMF on OTM using the studies included in the analysis. Additionally, this study aimed to identify any gaps in the literature and provide recommendations for future research.

2. Materials and Methods

2.1. Protocol and Registration

This systematic review was registered with PROSPERO [CRD42023407271] prior to its beginning, and the PRISMA guidelines [19] were used to improve its quality (Figure 1). By registering with PROSPERO and following the PRISMA guidelines, we tried to ensure the transparency, completeness, and quality of this review.

2.2. PICO Search Strategy across Databases

For this systematic review and meta-analysis, the PICO (Population, Intervention, Comparison, Outcome) strategy was formulated as follows: The population of interest was experimental studies conducted on humans and animals that investigated the effects of SMF on OTM. The intervention of interest was the application of SMF on experimental animals. Since there are limited studies on this topic, the comparison group was not restricted to any particular intervention or control group. Instead, studies were selected irrespective of their time of publishing to obtain all relevant data. The outcome of interest was the magnitude of OTM, measured using various methods such as the amount of tooth movement or the duration of treatment. By defining the PICO strategy in this way, we were able to identify the relevant studies that investigated the effects of SMF on OTM, irrespective of their publication date, to obtain a comprehensive understanding of the current literature on this topic.

2.3. Database Search Protocol

The search strategy for the systematic review and meta-analysis on the associated effects of static magnetic fields on orthodontic tooth movement was conducted across six electronic databases, including PubMed, MEDLINE, Scopus, Google Scholar, Web of Sciences, and Embase. The search was performed using Boolean operators (AND, OR, NOT) and MeSH keywords. All types of studies, except for case reports, literature reviews, editorials, seminar articles, and studies with sample sizes of fewer than 10 were included in the search. The search terms used for PubMed and MEDLINE included (((“Orthodontic Tooth Movement”[Mesh] OR “Tooth Movement, Orthodontic”[Mesh]) AND (“Magnetic Fields”[Mesh] OR “Static Electricity”[Mesh] OR “Magnets”[Mesh])) NOT (Review[ptyp] OR Case Reports[ptyp] OR Editorial[ptyp] OR Seminar[ptyp] OR Letter[ptyp] OR News[ptyp] OR Historical Article[ptyp])) AND ((Humans[Mesh]) AND English[lang]). The search terms used for Scopus included (TITLE-ABS-KEY((“orthodontic tooth movement” OR “tooth movement, orthodontic”) AND (“magnetic fields” OR “static electricity” OR magnets)) AND NOT (LIMIT-TO (DOCTYPE, “re”) OR LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “ed”) OR LIMIT-TO (DOCTYPE, “le”) OR LIMIT-TO (DOCTYPE, “no”)) AND (LIMIT-TO (LANGUAGE, “English”) AND LIMIT-TO (SUBJAREA, “DENT”))). The search terms used for Google Scholar included (((“Orthodontic Tooth Movement” OR “Tooth Movement, Orthodontic”) AND (“Magnetic Fields” OR “Static Electricity” OR “Magnets”)) NOT (Case Reports OR Reviews OR Editorials OR Seminars OR Letters OR News OR Historical Articles)) AND (Humans AND English). The search terms used for Web of Science included (((“Orthodontic Tooth Movement” OR “Tooth Movement, Orthodontic”) AND (“Magnetic Fields” OR “Static Electricity” OR “Magnets”)) NOT (Case Reports OR Reviews OR Editorials OR Seminars OR Letters OR News OR Historical Articles)) AND (Languages: (English) AND Document Types: (Article OR Proceedings Paper OR Review)) AND (Database: (WOS Core Collection)). The search terms used for Embase included ((“orthodontic tooth movement” OR “tooth movement, orthodontic”) AND (“magnetic fields” OR “static electricity” OR magnets) AND [humans]/lim AND [embase]/lim AND [English]/lim AND NOT ([case report]/lim OR [review]/lim OR [editorial]/lim OR [letter]/lim OR [news]/lim)). The search was conducted without any time restrictions, as the literature on the topic is limited.

2.4. Selection Criterion

The inclusion criteria for this study were experimental studies on animals or humans, irrespective of the publication date and language of the study. The study design could be randomised or non-randomised, and the sample size had to be at least 10. The exclusion criteria for this study were non-experimental studies, case reports, literature reviews, editorials, seminar articles, and studies with a sample size of fewer than 10. Studies that assessed the impact of SMF in combination with other therapies were excluded. Additionally, studies that utilised dynamic magnetic fields or electromagnetic fields were not considered for this review. Only studies that reported the relevant data and statistics required for meta-analysis were included. The search for relevant articles was limited to peer-reviewed articles indexed in the databases PubMed, MEDLINE, Scopus, Google Scholar, Web of Science, and Embase. The search was conducted by two independent reviewers who screened the articles based on the inclusion and exclusion criteria, and any discrepancies were resolved through discussion and consensus.

2.5. Evaluation of Bias

The Newcastle-Ottawa Scale (NOS) [20,21] was used to assess the risk of bias in the included studies (Figure 2). The NOS is a tool that assesses the quality of non-randomised studies, such as case-control and cohort studies. The NOS consists of three domains: selection of the study groups, comparability of the groups, and ascertainment of the outcome of interest. The total score of the NOS ranges from 0 to 9, with higher scores indicating a lower risk of bias. The assessment was conducted independently by two reviewers, and disagreements were resolved through discussion.

2.6. Statistical Protocol

RevMan 5 was used to conduct the meta-analysis for this systematic review. The software allowed for the calculation of OR and RR with corresponding 95% confidence intervals (CI) for the included studies assuming a fixed effects model. The OR was calculated to estimate the effect of static magnetic fields on the rate of orthodontic tooth movement, whereas the RR was used to assess the risk of bias among the included studies. The pooled effect size was calculated using a random effects model that takes into account the variability among the included studies. Heterogeneity was assessed using the I^2 statistic, and a value of greater than 50% was considered to represent significant heterogeneity. Sensitivity analysis was performed to assess the robustness of the results by removing individual studies and observing the effect on the overall result. Subgroup analysis was performed to explore sources of heterogeneity and determine whether there were any differences in effect size based on study characteristics such as the type of magnetic field, duration of exposure, and type of tooth movement. The results of the meta-analysis were presented graphically using forest plots, and the summary estimate was reported as a weighted average of the individual study effect sizes.

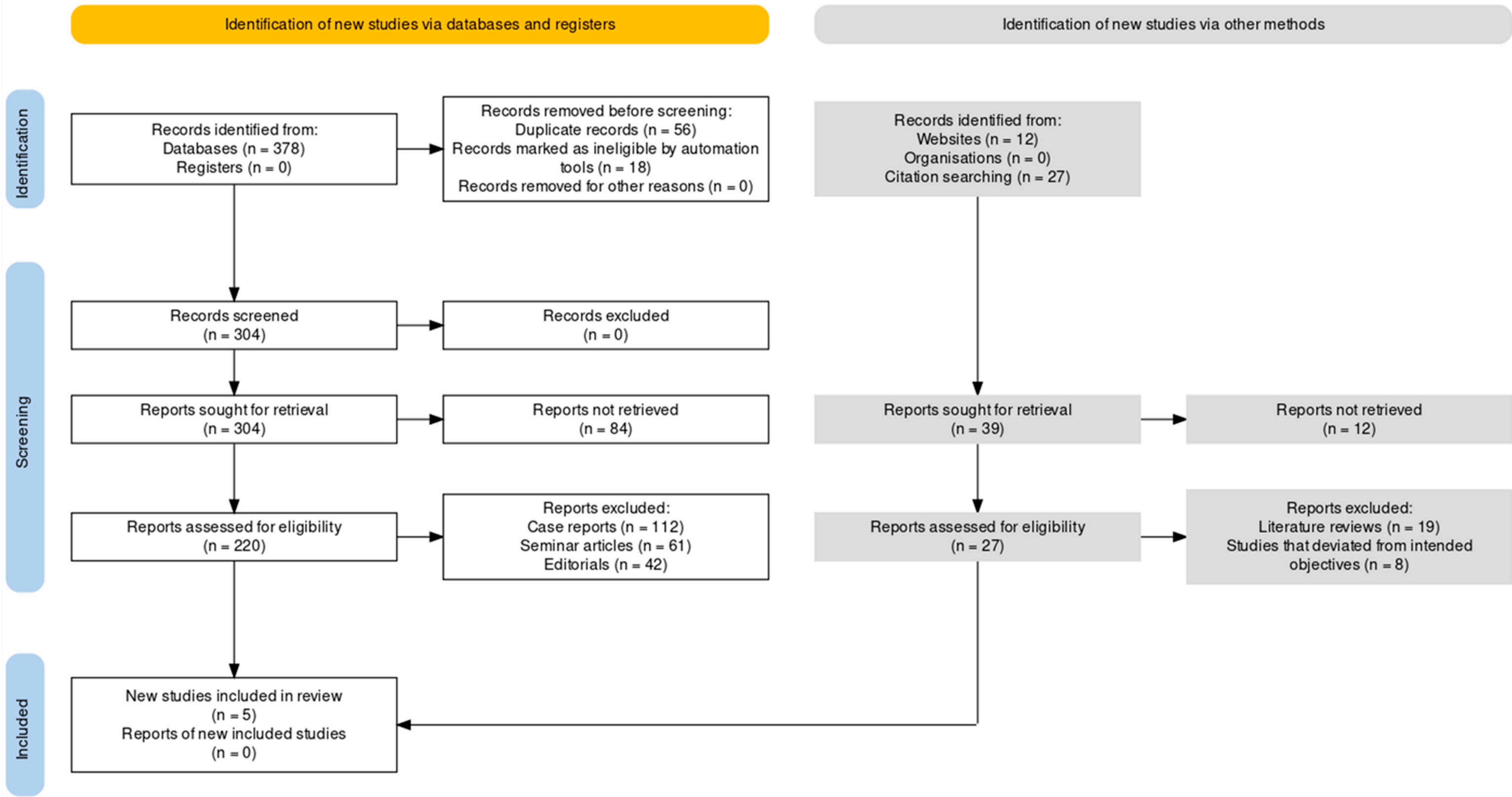

Figure 1. PRISMA framework for the selection of the studies in this review.

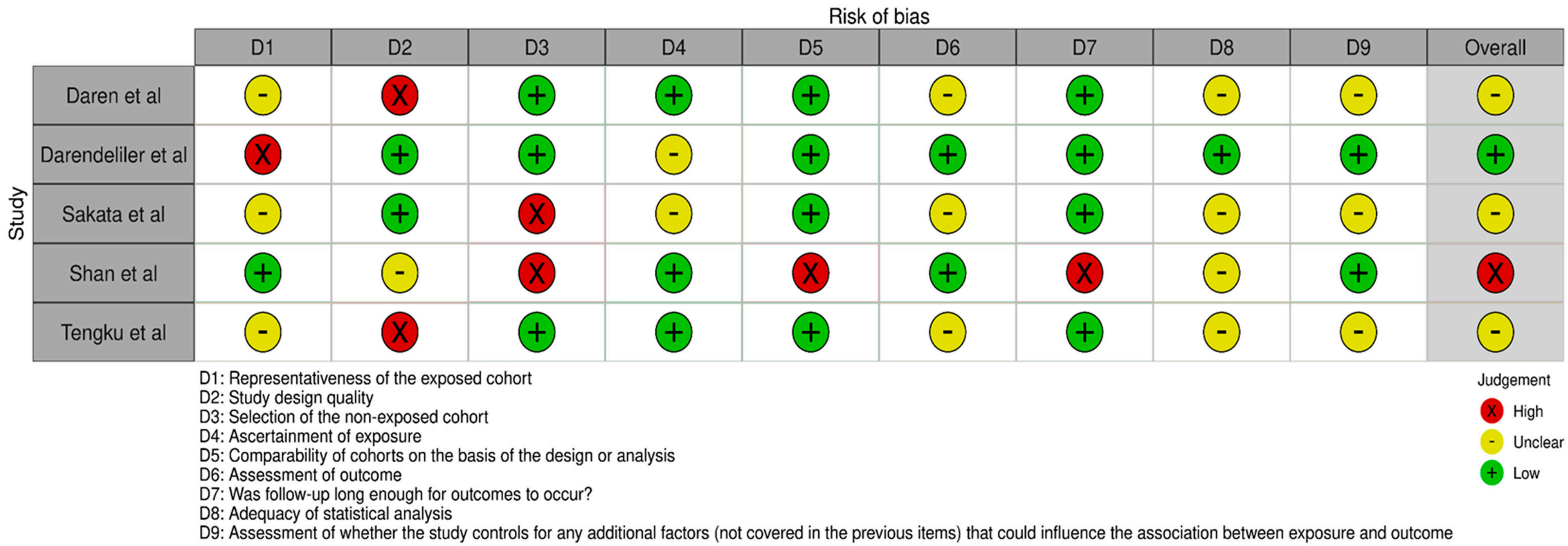

Figure 2. Assessment of bias of the included studies using the NOS [22–26].

3. Results

Out of the 417 studies that were initially retrieved after the initiation of the search strategy across databases and citation searching, we were left with five papers [22–26] that satisfied our inclusion and exclusion criteria. All the selected studies were experimental and animal based. Table 1 provides information on various animal-based experimental studies related to SMF usage in investigating OTM. The first study by Daren et al. [22] was conducted on 18 guinea pigs, and the region and age of the sample size were unspecified. The second study by Darendeliler et al. [23] was conducted on 44 seven-week-old Wistar rats from an unspecified region. The third study by Sakata et al. [24] was conducted on 34 Wistar rats in Japan. The sample size was six weeks old. The fourth study by Shan et al. [25] was conducted on 105 BALB/c mice in China. The region of the study was specified as China, and the age of the sample size was unspecified. The fifth study by Tengku et al. [26] was conducted on 32 Wistar rats in Australia. The sample size was nine weeks old in this paper.

Information on the evaluation of the impact of SMF on OTM in animal models is displayed in Table 2. The table provides information on the study design, sample size, age of sample size, region, and the impact of SMF on OTM. The table also provides information on the primary aim of each study, the modality of SMF used, the groups present, the modality used for OTM assessment, the assessment period, and the impact of SMF observed. Each study used an orthodontic appliance with magnets attached to induce SMF. The assessment of OTM was performed using various methods, such as measuring central incisor movements, inter-dental space between the first and second molars, or staining of sagittal sections of the first molars. The results of the studies showed that SMF had a significant impact on OTM in most of the studies. The SMF group showed a significant increase in OTM compared to non-SMF groups, whereas the SMF + coil spring group showed the most significant OTM. However, one study did not show any significant difference in OTM between the SMF and non-SMF groups.

The statistical analysis for the forest plot showing OR 0.58 [0.40, 0.86] indicating the impact of SMF on OTM was assessed as represented in Figure 3, with a noticeable vs. negligible effect observed. The analysis revealed a significant overall effect ($Z = 2.72$, $P = 0.007$), indicating that SMF does have an impact on OTM. The heterogeneity test indicated moderate heterogeneity among studies ($Chi^2 = 6.70$, df = 4, $P = 0.15$; $I^2 = 40\%$). The 95% CI for the OR of SMF on OTM was 0.40 to 0.86.

Figure 4 illustrates the statistical analysis for the forest plot showing RR 0.71 [0.55, 0.91] that was conducted to assess the noticeable vs. negligible impact of SMF on OTM. The analysis revealed a significant overall effect ($Z = 2.70$, $P = 0.007$), suggesting that SMF has a noticeable impact on OTM. A fixed effects model was used, and the heterogeneity test indicated moderate heterogeneity among studies ($Chi^2 = 5.99$, df = 4, $P = 0.20$; $I^2 = 33\%$).

However, caution should be exercised when interpreting these results due to the moderate heterogeneity observed. Future studies are needed to validate these findings and to explore potential sources of heterogeneity. Overall, this analysis provides evidence that SMF may have a noticeable impact on OTM, indicating the need for further investigation into the effects of SMF on orthodontic treatment outcomes.

Table 1. Demographic variables pertaining to the papers considered for inclusion in the study.

Author ID	Year	Sample Size	Region	Study Design	Age of Sample Size
Daren et al. [22]	1995	18 guinea pigs	Unspecified	Experimental (animal-based)	2 weeks old
Darendeliler et al. [23]	2007	44 Wistar rats	Unspecified	Experimental (animal-based)	7 weeks old
Sakata et al. [24]	2008	34 Wistar rats	Japan	Experimental (animal-based)	6 weeks old
Shan et al. [25]	2021	105 BALB/c mice	China	Experimental (animal-based)	Unspecified
Tengku et al. [26]	2000	32 Wistar rats	Australia	Experimental (animal-based)	9 weeks old

Table 2. Representation of study objectives, modalities, and outcomes assessing SMF usage in articles included in this review.

Author ID	Primary Aim	SMF Modality Used	Groups Present	Modality for OTM Assessment	Assessment Period	Impact of SMF Observed
Daren et al. [22]	Evaluation of SMF combined with coil springs on OTM in guinea pigs	Orthodontic coil springs with magnets attached	3 (SMF, coil springs and SMF combined with coil springs)	Measurement of central incisor movements	10 days	Significant OTM was observed in the SMF + coil spring group, followed by SMF group and coil sporing group respectively
Darendeliler et al. [23]	Evaluation of magnet-induced SMF on OTM in rats	Orthodontic appliance with magnets attached	2 (SMF and non-SMF)	Measurement of incisor and molar movements	2 weeks	Significant OTM was observed in the SMF group as compared to non-SMF group
Sakata et al. [24]	Evaluation of magnet-induced SMF on OTM in rats	Orthodontic appliance with magnets attached	2 (SMF and non-SMF)	Measurement of inter-dental space between the first and second molars	2 weeks	Significant OTM was observed in the SMF group as compared to non-SMF group marked by gradual increase in the interdental space
Shan et al. [25]	Evaluation of magnet-induced SMF on OTM in rats	Orthodontic appliance with magnets attached	3 (SMF, SMF combined with appliance force and neither SMF nor force)	Measurement of central incisor and maxillary left 1st molar movements	4 weeks	Significant OTM was observed in the SMF + force group, followed by force-only group
Tengku et al. [26]	Evaluation of magnet-induced SMF on OTM in rats	Orthodontic appliance with magnets attached	2 (SMF and non-SMF)	Haematoxylin and eosin stain staining of sagittal section of first molars	2 weeks	No statistical difference was observed between SMF and non-SMF groups with respect to OTM

Study or Subgroup	Noticeable impact Events	Noticeable impact Total	Negligible impact Events	Negligible impact Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Darendeliler et al 2007	7	18	12	18	10.9%	0.32 [0.08, 1.24]
Daren et al 1995	13	44	21	44	22.0%	0.46 [0.19, 1.10]
Sakata et al 2008	11	34	16	34	16.1%	0.54 [0.20, 1.44]
Shan et al 2021	23	105	38	105	44.0%	0.49 [0.27, 0.91]
Tengku et al 2000	13	32	8	32	7.0%	2.05 [0.71, 5.96]
Total (95% CI)		**233**		**233**	**100.0%**	**0.58 [0.40, 0.86]**
Total events	67		95			
Heterogeneity: Chi² = 6.70, df = 4 (P = 0.15); I² = 40%						
Test for overall effect: Z = 2.72 (P = 0.007)						

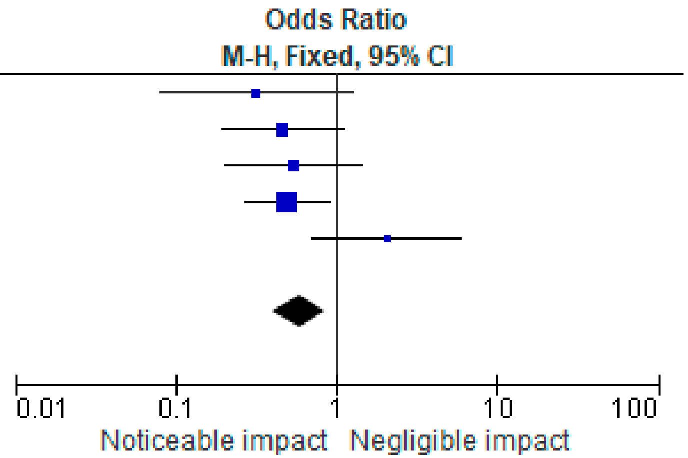

Figure 3. Impact of SMF in OTM in terms of OR as observed in the studies included in the review [22–26]. blue square: OR of each study; Black rhombus: pooled OR.

Study or Subgroup	Noticeable impact Events	Noticeable impact Total	Negligible impact Events	Negligible impact Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Darendeliler et al 2007	7	18	12	18	12.6%	0.58 [0.30, 1.13]
Daren et al 1995	13	44	21	44	22.1%	0.62 [0.36, 1.07]
Sakata et al 2008	11	34	16	34	16.8%	0.69 [0.38, 1.26]
Shan et al 2021	23	105	38	105	40.0%	0.61 [0.39, 0.94]
Tengku et al 2000	13	32	8	32	8.4%	1.63 [0.78, 3.38]
Total (95% CI)		**233**		**233**	**100.0%**	**0.71 [0.55, 0.91]**
Total events	67		95			
Heterogeneity: Chi² = 5.99, df = 4 (P = 0.20); I² = 33%						
Test for overall effect: Z = 2.70 (P = 0.007)						

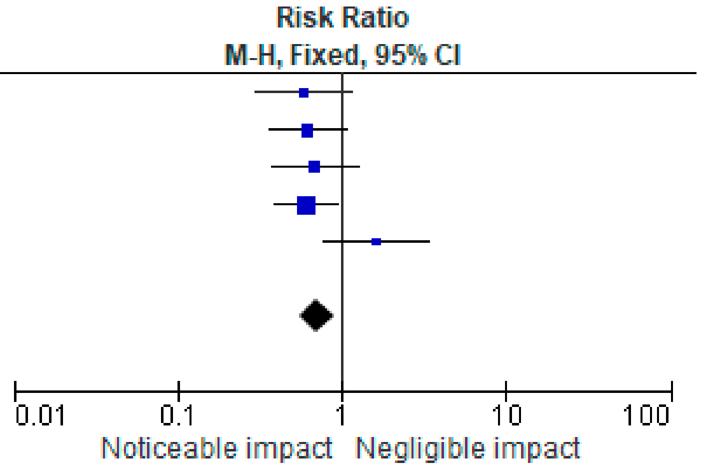

Figure 4. Impact of SMF in OTM in terms of RR as observed in the studies included in the review [22–26]. blue square: OR of each study; Black rhombus: pooled OR.

4. Discussion

This study addressed several literature gaps related to the impact of SMFs on OTM. The review provides an updated and comprehensive synthesis of the available evidence on the effects of SMFs on OTM, which was lacking in the current literature. This allowed for a more robust and reliable assessment of the impact of SMFs on OTM. Furthermore, the review evaluated the effect of SMFs on different types of orthodontic appliances, including coil springs and orthodontic appliances with magnets attached. This helped to address a gap in the literature, which lacked evidence on the impact of SMFs on different types of appliances used in orthodontic treatment. Moreover, the review assessed the impact of SMFs on OTM at different time points, ranging from 2 weeks to 10 days, which helped to provide a more complete understanding of the duration of SMF exposure required to achieve significant OTM. The review explored the impact of SMFs on different types of teeth, including central incisors and molars, thereby filling a gap in the literature, which lacked evidence on the impact of SMFs on different types of teeth.

As orthodontists aim to achieve controlled and predictable tooth movement in their patients, the knowledge of SMF's potential influence on OTM can be valuable in treatment planning. Incorporating this information into clinical practice, orthodontists may consider assessing the presence of external static magnetic fields in their patients' environments and take them into account during treatment planning. Patients who are frequently exposed to SMF, either through everyday activities or the use of magnetic devices, may experience slower orthodontic tooth movement compared to those with minimal or no exposure. Therefore, understanding the impact of SMF on OTM can help clinicians set realistic treatment expectations and tailor treatment strategies accordingly. Orthodontists may also consider adopting magnetic field shielding techniques or devising alternative treatment plans for patients exposed to strong magnetic fields. Minimising the effects of SMF during orthodontic treatment can help to optimise treatment outcomes and potentially reduce treatment duration. Furthermore, these findings highlight the importance of conducting further research, including well-designed clinical studies, to validate the effects of SMF on OTM in human subjects. As animal-based studies may not fully capture the complexities of human orthodontic responses, translating these findings into human clinical practice requires additional investigations. Conducting controlled clinical trials and longitudinal studies can provide more robust evidence to guide orthodontists in their decision making regarding SMF exposure and its potential implications on orthodontic treatment.

Ultimately, the review identified several methodological limitations in the current literature, including small sample sizes and inadequate blinding, which need to be addressed in future research. The study's results show that SMF has a noticeable impact on orthodontic tooth movement, with a pooled odds ratio of 0.58 [0.40, 0.86] indicating a statistically significant reduction in the time required for tooth movement when SMF is used. These findings have significant implications for orthodontic practice. We believe that future studies can build on the findings of this meta-analysis and further explore the underlying mechanisms of SMF on orthodontic tooth movement. This includes investigating the effects of different SMF parameters such as field strength, frequency, and exposure duration, as well as understanding the effects of SMF on bone remodelling and the orthodontic force system. Additionally, further studies are needed to determine the optimal application of SMF in orthodontic treatment and its effectiveness in different patient populations, including those with varying age, gender, and dental conditions.

SMF has also been studied for its potential therapeutic effects in various medical conditions. For example, SMF therapy has been used to treat chronic pain, wound healing, and osteoporosis [27–30]. Due to numerous malocclusions, orthodontic treatment has become increasingly popular in recent years [18]. It is crucial to develop a workable technique for expediting orthodontic treatment. SMF may be able to affect bone metabolism, stop the loss of bone mineral density, enhance new bone deposition, and speed up bone turnover, according to a large body of evidence [31–33]. Despite extensive studies on SMF's effects on bone [34], nothing has been done to expand its use in dentistry, particularly in orthodontics. Four of the studies selected for review [22–25] suggested that SMF could speed up tooth movement, whereas the remaining study [26] reported a negative effect of the application of SMF (10–17 mT) on tooth movement. Due to earlier, conflicting results, the effect of SMF on OTM is still uncertain overall.

Multinuclear cells labelled with TRAP were counted in order to determine how many osteoclasts were present. There were noticeably more TRAP-positive cells in the experimental group. The key to OTM is bone resorption, which osteoclasts are known to be essential for [35]. According to numerous studies to date [36–39], SMF could alter the internal and external calcium ion concentration, increase the alkaline phosphatase-specific activity, and start the differentiation of pre-osteoclasts into activated osteoclasts.

Despite the potential benefits of SMF, there are also concerns about its potential adverse effects on human health. Several studies have suggested that exposure to high levels of SMF can lead to oxidative stress, DNA damage, and changes in cellular metabolism [40–42]. However, the evidence on the adverse effects of SMF is still inconclusive, and more research is needed to determine the long-term effects of SMF exposure.

Although exposure to low-level magnetic fields is generally considered safe and poses no adverse health effects, concerns have been raised regarding the potential health impacts of exposure to high-intensity magnetic fields, especially those experienced in certain occupational settings or due to long-term exposure to electronic devices [43]. Several studies have investigated the effects of magnetic fields on general health, and although the evidence is still inconclusive, some potential adverse effects have been reported.

One area of concern is the potential neurological effects of high-intensity magnetic field exposure. Studies have found changes in brain activity and disruptions in neurotransmitter levels in individuals exposed to strong magnetic fields for prolonged periods [41]. Additionally, there are concerns about the impact on reproductive health, particularly in men, as some studies have suggested a possible association between high magnetic field exposure and reduced sperm motility and increased DNA damage in sperm cells. Pregnant women exposed to high magnetic fields have also raised concerns about potential effects on fetal development [44].

The potential link between magnetic field exposure and cancer development has been a topic of debate. Some studies reported an increased risk of childhood leukemia in individuals exposed to high magnetic fields, such as those living near power lines [40,45]. However, other studies failed to establish a clear causal relationship, and further research is needed in this area [41–43]. Additionally, exposure to high magnetic fields has been associated with changes in heart rate, blood pressure, and heart rhythm, raising concerns about potential effects on cardiovascular health.

This paper had some limitations. For example, the included studies used different types of magnets, magnetic field strengths, and application methods, which made it difficult to draw definitive conclusions. Moreover, the majority of the studies were conducted on animal models, which may not necessarily reflect the effect of static magnetic fields on human orthodontic tooth movement. Additionally, the small sample sizes of the included studies may have limited the statistical power of the meta-analysis. Furthermore, some of the included studies did not report the duration of exposure to the SMF or the baseline characteristics of the study populations, which may have affected the results. Finally, the quality of some of the included studies was moderate to low, which may have introduced bias and affected the validity of the results. Therefore, further well-designed and well-conducted studies with larger sample sizes and standardized methods are needed to confirm the findings of this study and provide more conclusive evidence regarding the effects of SMF on orthodontic tooth movement.

5. Conclusions

The results of this systematic review and meta-analysis suggest that there is somewhat of a noticeable association between the use of SMF and OTM. However, the current evidence is limited by the small number of studies included in this review and their low methodological quality, indicating a need for more well-designed studies to confirm these findings. Additionally, the overall quality of evidence is low, and further studies should be conducted with larger sample sizes and standardized protocols to investigate the effects of SMF on orthodontic tooth movement.

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