EFORT open reviews

SPINE | 8:10 | 771–780

Relationship between stomatognathic alterations and idiopathic scoliosis: a systematic review with meta-analysis of observational studies

Francisca Gámiz-Bermúdez[1], Alfonso Javier Ibáñez-Vera[2], Esteban Obrero-Gaitán[2], Irene Cortés-Pérez[2], Noelia Zagalaz-Anula[2] and Rafael Lomas-Vega[2]

[1]Unidad de Gestión Clínica Adra, Distrito Sanitario Poniente de Almería, Avenida Picasso, Adra, Spain
[2]Department of Health Sciences, University of Jaen, Jaen, Spain

Correspondence should be addressed to A J Ibáñez-Vera
Email
ajibanez@ujaen.es

- *Purpose:* The objective of this systematic review was to assess a possible relationship between stomatognathic alterations and idiopathic scoliosis (IS).
- *Design:* This study is a systematic review with meta-analysis of observational studies.
- *Methods:* The protocol of this systematic review with meta-analysis was registered in PROSPERO (CRD42022370593). A bibliographic search was carried out in the Pubmed (MEDLINE), Scopus, Web of Science and CINAHL databases using the MeSH terms 'Scoliosis' and 'Stomatognathic Disease'. The odds ratio (OR) of prevalence and standardized mean difference (SMD) were used to synthesize the results.
- *Results:* Of 1592 studies located, 14 studies were selected with 3018 subjects (age: 13.9 years). IS was related to Angle's class II (OR = 2.052, 95% CI = 1.236–3.406) and crossbite (OR = 2.234, 95% CI = 1.639–3.045). Patients with malocclusion showed a higher prevalence of IS than controls (OR = 4.633, 95% CI = 1.467–14.628), and subjects with IS showed high overjet (SMD = 0.405, 95% CI = 0.149–0.661) and greater dysfunction due to temporomandibular disorders (SMD = 1.153, 95% CI = 0.780–1.527).
- *Conclusion:* Compared with healthy controls, subjects with IS have twice the risk of suffering from occlusion disorders, present greater temporomandibular dysfunction and have a greater overjet in the incisors. Moreover, subjects with malocclusion have an IS prevalence up to four times higher. The systematic orofacial examination of patients with IS should be recommended.

Keywords

- scoliosis
- adolescent idiopathic scoliosis
- temporomandibular joint disorders
- stomatognathic diseases
- occlusal dysfunction
- malocclusion
- mandibular diseases

EFORT Open Reviews
(2023) **8**, 771–780

Introduction

Adolescent idiopathic scoliosis (AIS) is the most prevalent paediatric orthopaedic malformation, affecting 2–3% of adolescents (1). This three-dimensional spine deformity must be at least 10° in the coronal plane as measured with the Cobb method (2) to fulfil the diagnostic criteria for IS, with a high risk of development and progression (3). Despite research efforts, no curative treatment is currently available, as the understanding of its aetiology is still challenging. Several hypotheses have been suggested, such as structural musculoskeletal alterations specifically related to growth and development (4), genetic transmission (5), vitamin D (6) or melatonin deficiency (7) and vestibular alterations (8, 9). The wide heterogeneity among these hypotheses suggests that several disturbances could contribute to this spine deformity.

One of the lines of research in recent years has investigated the possible alteration of motor control in children with IS. It has been suggested that subjects with spinal deviation could present an alteration in postural balance measured through the movements of the centre of body pressure (10), having ruled out that IS could be due to an isolated alteration of the vestibular system (11).

In postural control regulation, several systems are involved, such as the visual, vestibular and somatosensory systems. The stomatognathic system plays an important role in this last system, as the inputs received from this system contribute to postural control and balance response (12). In a review in 2019, Langella *et al.* concluded that the available evidence did not clarify the possible relationship between spinal deformity and malocclusion (13), although it is accepted that altered perception caused by a temporomandibular disorder could bias the information received by postural control centres in the central nervous system through the trigeminal nerve, causing abnormal postural responses (14). In this sense, a recent study found that a few months after orthognathic surgery the orientation of the head in the frontal plane improves, and that after these drastic mandibular changes, the weight of proprioceptive signals linked to the mandibular system can increase to constitute a new frame of reference to orient the head in space and improve static postural stabilization (15). However, to date the reviews focused largely on studies that analysed the relationship between craniofacial morphology and the appearance of scoliosis, and the quantity and homogeneity of the studies did not allow a statistical integration of the results of the different studies.

Considering stomatognathic alterations as a plausible aetiology of IS, the aim of this systematic review is to analyse the existence of a relationship between alterations in the stomatognathic system and idiopathic scoliosis.

Materials and methods

Review design

This systematic review with meta-analysis was conducted in accordance with the recommendations of the Meta-Analysis of Observational Studies in Epidemiology (MOOSE) Group guidelines (16), the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (17) and the Cochrane Handbook for Systematic Reviews of Interventions (18). The protocol of this review was previously registered in PROSPERO (code CRD42022370593).

Literature search and bibliographical sources

Two authors (ICP and AJIV) independently performed a literature search up to October 2022 in the PubMed (MEDLINE), SCOPUS, Web of Science (WOS) and CINAHL Complete databases. The database searches were accompanied by additional searches of other sources, such as previously published articles, abstracts and conference proceedings, expert articles and grey literature. For the search strategy, we identified two search domains: scoliosis and stomatognathic diseases. In accordance with the Medical Subject Headings (MeSH) for MEDLINE, the key words employed were 'scoliosis', 'temporomandibular joint disorders' and 'stomatognathic diseases'. In addition, our search strategy included synonyms and input terms related to the key words, such as 'idiopathic scoliosis', 'adolescent idiopathic scoliosis', 'crossbite', 'malocclusion' or 'occlusal dysfunction'. The Boolean operator 'AND' was used to join conditions, and 'OR' was used to combine synonyms within the search strategy. Filters related to language, publication date and free full-text access were not set. A third expert author (RLV) revised the bibliographic search and resolved doubts. Table 1 shows the search strategy used in each database.

Study selection: inclusion and exclusion criteria

Two blinded reviewers (ICP and FGP) independently screened the titles and abstracts of all references retrieved in each database and any additional sources. When one of the authors identified an article with the potential for inclusion in the qualitative synthesis, this article was examined in detail by two authors. All disagreements were resolved by a third author (RLV).

A study was included in the present systematic review when it met all of the following inclusion criteria: (i) observational studies, such as cross-sectional, cohort, and case–control studies; (ii) sample composed of patients with scoliosis; (iii) comparison with healthy subjects; (iv) analysis of the morphology or function of the stomatognathic apparatus before any therapy and (v) studies analysing the prevalence of scoliosis in patients with malocclusion in comparison with patients without malocclusion. The exclusion criteria were as follows: (i) studies carried out in animals; (ii) observational studies without a comparison group; (iii) a comparison group including both subjects with and without IS and (iv) studies that did not analyse the morphology or function of the stomatognathic system.

Table 1 Search strategy used in each database.

Databases	Search strategy
PubMed, MEDLINE	(scoliosis[mh] OR scoliosis[tiab] OR idiopathic scoliosis[tiab] OR adolescent idiopathic scoliosis[tiab]) AND (temporomandibular joint disorders[mh] OR temporomandibular joint disorders[tiab] OR stomatognathic diseases[mh] OR stomatognathic diseases[tiab] OR craniomandibular disorders[mh] OR craniomandibular disorders[tiab] OR mandibular diseases[mh] OR mandibular diseases[tiab] OR dental occlusion[mh] OR dental occlusion[tiab] OR malocclusion[mh] OR malocclusion[tiab] OR occlusal dysfunction[tiab] OR crossbite[tiab])
SCOPUS	TITLE-ABS-KEY ('scoliosis' OR 'idiopathic scoliosis') AND TITLE-ABS-KEY ('temporomandibular joint disorders' OR 'stomatognathic diseases' OR 'craniomandibular disorders' OR 'mandibular diseases' OR 'occlusal dysfunction')
Web of Science	TOPIC (*scoliosis* OR *idiopathic scoliosis*) AND TOPIC (*temporomandibular joint disorders* OR *stomatognathic diseases* OR *mandibular diseases* OR *occlusal dysfunction*)
CINAHL Complete	AB (scoliosis OR idiopathic scoliosis) AND AB (temporomandibular joint disorders OR stomatognathic diseases OR mandibular diseases OR occlusal dysfunction)

Data extraction

Two authors (ICP and FGB) independently collected data from the included studies in a standardized Microsoft Excel data-collection form. To resolve disagreements, a third author was consulted (RLV). We extracted the following data: authorship, publication date, country, total sample size, number of participants in each group (cases and controls or healthy subjects), age, sex and time since diagnosis. We collected data on the variable of interest, the measurement tool used, and the main findings reported by each study.

Outcomes

The main variable was the count of subjects with and without scoliosis in which the presence of malocclusion was determined by Angle's class or the presence of transverse malocclusion as both unilateral and bilateral crossbite. In Angle's classification, class I corresponds to the standard occlusion called orthognathia, class II (divisions 1 and 2) corresponds to a retrognathia or short jaw, and class III corresponds to an elongation of the jaw called prognathism (19). Measures such as open bite or overjet as well as diagnosis of temporomandibular disorder were also of interest. The overjet can be defined as the horizontal distance in millimetres between the upper and lower incisors (20). We also intended to analyse the prevalence of scoliosis in subjects who did or did not have stomatognathic alterations.

Methodological quality assessment

To evaluate the quality of the studies included in this review, the Newcastle–Ottawa Scale (NOS) was applied (21). The domains explored by this scale are 'selection of study groups' (maximum, 4 stars), 'comparability of groups' (maximum, 2 stars) and 'ascertainment of exposure/outcome' (maximum, 3 stars). The quality classification of the included studies according to NOS score is low (score 1–3), moderate (score 4–6), and high quality (score 7–9) (22). Quality scores ranged from 0 (lowest) to 9 stars (highest) (23).

Statistical analysis

Two researchers were responsible for the design and development of the statistical analysis (EOG and RLV). Due to the heterogeneity in pathologic conditions and their characteristics and following the recommendations of Cooper *et al.* (2009) (24), we chose the DerSimonian and Laird random effects model to estimate the overall pooled effect with its 95% CI to improve the generalizability of the findings (25). For continuous variables, the pooled effect was estimated using Cohen's standardized mean difference (SMD) calculation (26), which can be interpreted in three levels of effect intensity: small (SMD = 0.2), medium (SMD = 0.5) and large (SMD > 0.8) (27). To analyse the prevalence of occlusal disorders in scoliosis cases vs healthy controls and the prevalence of scoliosis in patients with and without stomatognathic disorders, we calculated the prevalence odds ratio (OR) together with its 95% CI. The findings were displayed graphically using forest plots resulting from each analysis (28). Heterogeneity analysis was performed by calculating the Higgins *Q*-test and degree of inconsistency (I^2), which classifies heterogeneity as low (<25%), medium (25–50%) or large (>50%), as well as by calculating its *P*-value ($P < 0.1$ indicates high heterogeneity) (29, 30). Risk of publication bias was assessed using funnel plot asymmetry (31) and Egger's test ($P < 0.1$ indicates possible risk of publication bias) (32). We used MedCalc Statistical software to carry out the analysis (MedCalc® Statistical Software version 20.110, MedCalc Software Ltd, Ostend, Belgium; https://www.medcalc.org; 2022) with a 95% CI.

Results

A total of 14 studies (33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46) met the eligibility criteria and were included in the review (Fig. 1). In total, 3018 subjects were included with a mean age of 13.39 years. Of these subjects, 823 were scoliosis cases who were compared to 1898 healthy controls and 133 subjects with occlusion disorder who were compared to 164 subjects without malocclusion. Table 2 shows the main characteristics of the included studies, and Table 3 shows the quality of the included studies assessed with the Newcastle–Ottawa Scale.

Malocclusion in patients with IS

Angle's class II

Six studies (33, 34, 39, 40, 41, 42) including 476 IS patients and 1100 controls examined the presence of Angle's class II bite in both groups. The OR (2.052, 95% CI = 1.236–3.406; $P = 0.005$) indicated a twofold higher rate of type 2 malocclusion in subjects with IS. Heterogeneity between medium and large and a possible publication bias were found. The data can be seen in Table 4 and are displayed graphically in Fig. 2.

Crossbite

Six studies (33, 39, 40, 41, 42, 43) including 482 IS patients and 1726 controls examined the presence of crossbite in both groups. The OR (2.234, 95% CI = 1.639–3.045; $P < 0.0001$) indicated a more than twofold higher rate of crossbite in subjects with IS. The data did not show

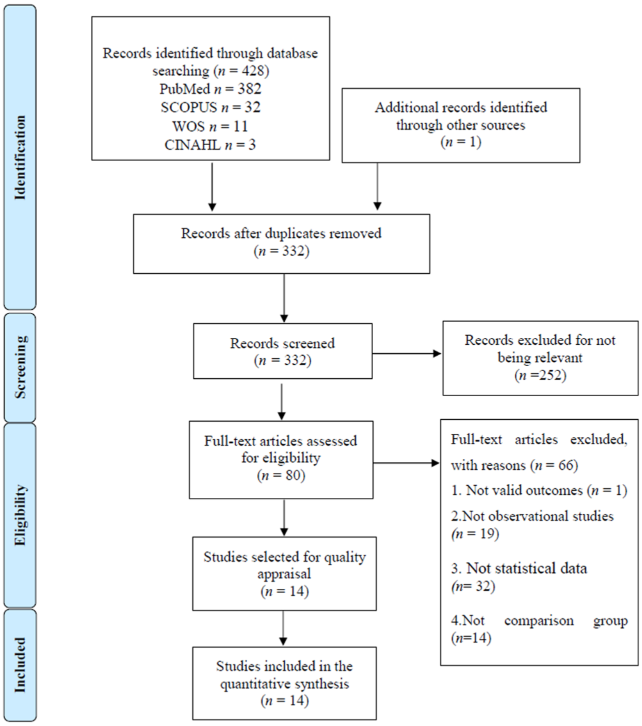

Figure 1
Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart for the systematic literature search and study selection process.

any heterogeneity, and no significant publication bias was found. The data can be seen in Table 4 and are displayed graphically in Fig. 3.

Overjet

Three studies (40, 44, 45) including 110 IS patients and 144 controls evaluated the mean overjet in both groups. The SMD (0.405, 95% CI = 0.149–0.661; P = 0.002) indicated a medium effect with more pronounced overjet in IS patients. The data did not show any heterogeneity, and no significant publication bias was found. The data can be seen in Table 4 and are displayed graphically in Fig. 4.

Temporomandibular disorder

Two studies (35, 46) including 59 IS patients and 71 controls evaluated the presence of TMD by measuring the mean Fonseca Anamnestic Index in both groups. The SMD (1.153, 95% CI = 0.780 to 1.527; $P < 0.0001$) was significant but indicated a very small effect with a higher dysfunction in IS patients. The data did not show any heterogeneity, and a possible publication bias was found. The data can be seen in Table 4 and are displayed graphically in Fig. 5.

IS in patients with malocclusion

Any type of malocclusion

Three studies (36, 37, 38) including 133 patients and 164 controls examined the presence of IS in patients with malocclusion. The OR (4.633, 95% CI = 1.467–14.628; P = 0.010) indicated more than fourfold higher risk of IS in subjects with any type of malocclusion. The data did not show any heterogeneity, and no significant publication bias was found. The data can be seen in Table 4 and are displayed graphically in Fig. 6.

Discussion

Research into IS that helps to understand the aetiological factors and increase the treatment success rate is needed. Evidence points to a multifactorial aetiology, which results in a challenging multidisciplinary approach. To the best of our knowledge, this is the first meta-analysis to analyse the relationship between IS and stomatognathic alterations. Our search found 14 studies that investigated these relationships, finding a significant relationship between the presence of Angle's class II and crossbite in subjects with IS, a greater distance between the upper and lower incisors (overjet), and greater dysfunction due to TMD. It was also found that among subjects with malocclusion, the prevalence of IS could be four times higher than among subjects with normocclusion.

The studies found and included in our review were mostly cross-sectional studies that failed to provide a temporal relationship between the presence of stomatognathic disorders and the appearance of IS, so our findings cannot be interpreted as a clear causal relationship. However, our findings can be interpreted in the context of some longitudinal investigations in which the causal relationship can be glimpsed. In fact, one of the papers included in our review (35) provided data from a retrospective cohort of subjects with hereditary orthodontic anomalies in which a prevalence of scoliosis of 20% was found, which is 14 times higher than the prevalence in the population of reference, estimated at 1.4%. In isolated studies such as this one, some degree of causation can be estimated as long as the orthodontic abnormalities were present before the onset of the scoliotic curve.

Several authors have investigated the causal relationship between dental occlusion and spines in animals. D'Attilio *et al.* (2014) applied a resin pad on the right molar of rats. The result showed the development of a spinal scoliotic curve in just a week, a condition that was restored in 83% of rats in another week after changing the resin pad to the opposite side molar (47). Similar results were observed in another study, which performed a unilateral molar extraction in rats that caused an

Table 2 Main characteristics of the included studies.

Study	Country	Study type	Measurements	Subjects			Controls		
				Total, *n*	F, *n*	Age†, years	Total, *n*	F, *n*	Age†, years
Huggare *et al.* (44)	Finland	CSS	Archs width, overbite, overjet	22	16	17.8 (12–34)	22		17.8 (12–34)
Pećina *et al.* (43)	Yugoslavia	CSS	Deep bite, crossbite, open bite	202	173	7–17	640	350	7–17
Ben-Bassat *et al.* (33)	Israel	CSS	Angle's class, midline deviation	96	79	13.9 ± 3.5	703	–	–
Segatto *et al.* (40)	Hungary/ Germany	CCS	Angle's class, overjet, overbite, midline deviation	28	–	14.7 ± 2.3	68	–	14.8 ± 0.11
Kostenko *et al.* (34)	Ukraine	CSS	Angle's class, dentognathic anomalies	200	169	12–15	25	21	12–15
Laskowska *et al.* (39)	Poland	CSS	Angle's class, crossbite, open bite, deep bite	80	71	14.2 ± 2.03	61	29	12.6 ± 1.9
Sambataro *et al.* (42)	Italy	CSS	Angle's class, crossbite, midline deviation	18	11	9.8 ± 0.8	102	14	9.8 ± 0.8
Zhang *et al.* (41)	China	CSS	Angle's class, unilateral crosbite, midline deviation	58	51	14.8 (12.4–20.2)	152	–	15.2 (12.2–18.6)
Lewandowska *et al.* (45)	Poland	CSS	Overjet, canine deviation, midline deviation	60	60	14.0 ± 1.3	54	54	14.3 ± 1.6
Glowacki *et al.* (35)	Poland	CSS	TMD disability, Fonseca AI	30	30	12.43 ± 1.83‡	42	42	12.43 ± 1.83‡
Uçar *et al.* (46)	Turkey	CSS	Fonseca AI, Helkimo Index	29	29	14.7 ± 1.9	29	29	14.9 ± 2.0
Lippold *et al.* (38)	Germany	CSS	Angle's class	22*	–	5.0 ± 0.11	37	–	5.0 ± 0.11
Korbmacher *et al.* (37)	Germany	CSS	Unilateral crossbite	55	22	7.0 ± 2.08	55	–	–
Sofyanti *et al.* (36)	Indonesia	ROS	Angle's class	56*		22.36 ± 3.02	72	–	22.1 ± 3.01

*Class II/III; †values are mean ± S.D. or range; ‡age at start.
AI, Anamnestic Index; CCS, case–control study; CSS, cross-sectional study; F, females; ROS, retrospective observational study; TMD, temporomandibular disorder.

alteration of normal spinal curves (48). These findings clearly suggest that the postural inputs recorded by the trigeminal nerve deeply influence the spinal curvature, probably by producing an alteration in the erector spinal muscular tone (49).

A recent systematic review by Langella *et al.* focused on the association between malocclusion and spinal deformity and determined that the literature tends to support a higher prevalence of occlusal alterations in IS patients (13). Despite this, the authors moderate this conclusion, as the studies used presented a high risk of bias (13). The variability and heterogeneity of the nine studies reported by Langella *et al.* do not allow us to reach a definitive conclusion or perform any statistical integration of the results. Our review is supported by 14 observational studies that allow us to state consistent conclusions based on the presence of stomatognathic alterations and the statistical integration of the results.

Some orthodontic interventions have been performed in patients with spine deviations to assess the possible relationship. Lippold *et al.* concluded that early treatment by maxillary expansion therapy for lateral posterior

Table 3 Newcastle–Ottawa Scale (NOS) score for methodological quality assessment of observational studies.

Study	S1	S2	S3	S4	C	E1	E2	E3	Total scale	Quality
Ben-Bassat *et al.* (33)	*	*	*	–	*	*	*	–	6	Moderate
Glowacki *et al.* (35)	–	*	*	*	**	*	*	*	8	High
Huggare *et al.* (44)	*	*	*	*	**	*	*	*	9	High
Korbmacher *et al.* (37)	–	*	–	–	**	*	–	*	5	Moderate
Kostenko *et al.* (34)	*	–	–	–	**	*	*	*	6	Moderate
Laskowska *et al.* (39)	*	*	–	*	**	*	*	*	8	High
Lewandowska *et al.* (45)	*	*	*	*	**	*	*	*	9	High
Lippold *et al.* (38)	*	*	*	*	**	*	–	*	8	High
Pecina *et al.* (43)	*	*	*	*	**	*	*	*	9	High
Sambataro *et al.* (42)	*	*	*	*	*	*	–	*	8	High
Segatto *et al.* (40)	*	*	–	*	**	*	*	–	7	High
Sofyanti *et al.* (36)	*	*	–	–	**	*	–	*	6	Moderate
Uçar *et al.* (46)	*	*	–	–	**	*	*	*	7	High
Zhang *et al.* (41)	*	*	–	*	**	*	*	*	8	High

Table 4 Main results of the all meta-analyses.

	K	Scoliosis	Controls	*n*	SMD	OR	95% CI	*t*	*z*	*P*	Heterogeneity		Publication bias	
											Q test	I^2	Egger	*P*
Overjet	3	110	144	254	0.405		0.149–0.661	3.116		0.002	0.3679	0.00%	−1.3502	0.5158
Fonseca	2	59	71	130	1.153		0.780 – 1.527	6.111		<0.001	0.0003	0.00%	−0.2823	<0.0001
Class II	6	241/476	402/1100	1576		2.052	1.236–3.406		2.779	0.005	12.1153	58.73%	3.2379	0.0605
Crossbite	6	96/482	256/1726	2208		2.234	1.639–3.045		5.089	<0.001	0.4146	0.00%	0.2540	0.4667
Scoliosis	3	14/133*	4/164	297		4.633	1.467–14.628		2.614	0.009	0. 4345	0.00%	−0. 1617	0.9491

*Malocclusion.
I^2, degree of inconsistency; *K*, number of comparisons; OR, odds ratio; SMD, standardized mean difference; *t*, *t*-value.

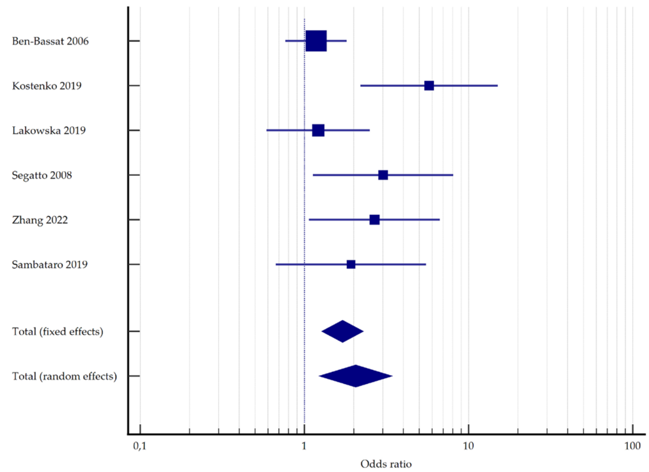

Figure 2
Forest plot showing the odds of subjects with scoliosis to suffer from Angle's class II.

crossbite did not produce any significant change in the spinal curves of the 31 children in the intervention group (50). On the other hand, Piancino *et al.* assessed the effects of orthodontic therapy based on the rapid palatal expansion technique on juvenile/adolescent idiopathic scoliosis (51), observing that the Cobb angle worsened in participants during the treatment when compared with baseline and improved after removing the treatment compared with the curve angle during the treatment. Based on the previous information, we could expect that not all spinal deformities are related to the stomatognathic system (50) but almost all IS seems to be related to this system (51). Our findings agree with the study by Piancino *et al.* (51) as we observed that subjects with malocclusion present up to four times higher prevalence of scoliosis.

The findings of this review could be explained by the fact that the altered inputs from the stomatognathic system of patients with malocclusion are recorded by the trigeminal nerve, so the central nervous system could process an output or postural response that influences spine muscle tone (49, 52). In contrast, we found that subjects with IS present greater temporomandibular dysfunction and have twice the risk of suffering from occlusion disorders such as overjet in the incisors. Although these associations do not allow us to determine the direction in which the influence between temporomandibular disorder and scoliosis occurs, they do show a clear feedback influence.

Nonetheless, the literature supports that the aetiology of AIS could be varied, as there is not an exclusive and common cause. The first hypothesis to be considered was a growth and/or development disorder due to its appearance during adolescence or childhood (4). Zhu *et al.* observed a vitamin D deficiency among

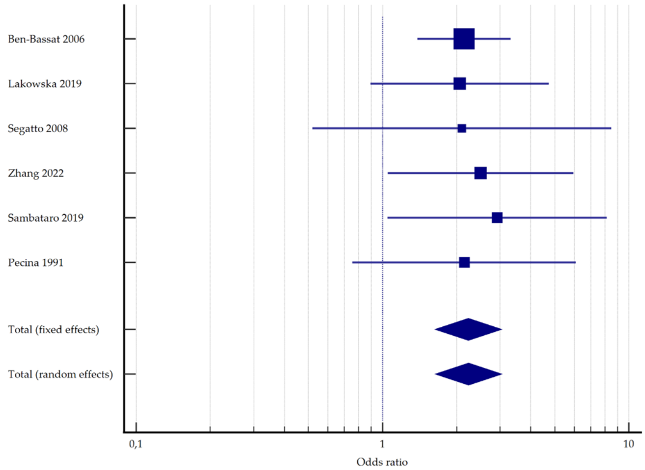

Figure 3
Forest plot showing the odds of scoliosis subjects to suffer from crossbite.

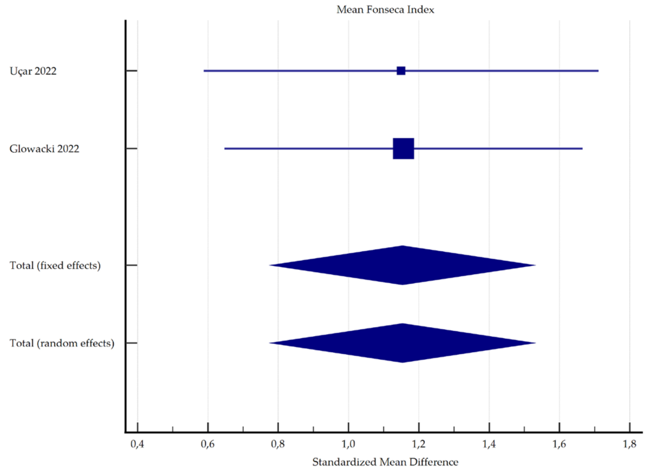

Figure 5
Forest plot SMD of Fonseca Anamnestic Index score between subjects with or without IS.

subjects with IS that could influence the regulation of calcium–phosphorus metabolism, a condition that would affect the normal growth of human bone (6) Several genetic associations have been shown, finding up to 20 loci significantly associated with IS (5). Among them, a gene polymorphism of melatonin receptor 1B is present in subjects with IS, which seems to be related to the appearance of the deformity but not the severity of the curve (7).

Further recent research suggested a deeper origin related to how postural information is managed by the central nervous system. The stomatognathic system, which we address in this study, the vestibular system (8) and the visual system (53) must be considered. Ulusoy *et al.* found significant differences in the macular choroidal thickness of children with IS. The thinner the choroidal thickness is, the more severe the scoliosis angle (53). Karaca *et al.* showed that the thinness of the choroid can cause anisometropic amblyopia, which implies an asymmetry of vision in both eyes that could cause the development of the scoliotic curve (54). Another recent study found an increased risk of developing scoliosis in children with strabismus, indicating a possible causal relationship between visual disturbances and spinal disorders (55). With respect to the vestibular system, Cortés-Pérez *et al.* reported that the presence of morphological alterations of the vestibular system is significantly related to scoliosis (56). However, not only could morphological alterations of the vestibular system be derived in IS but

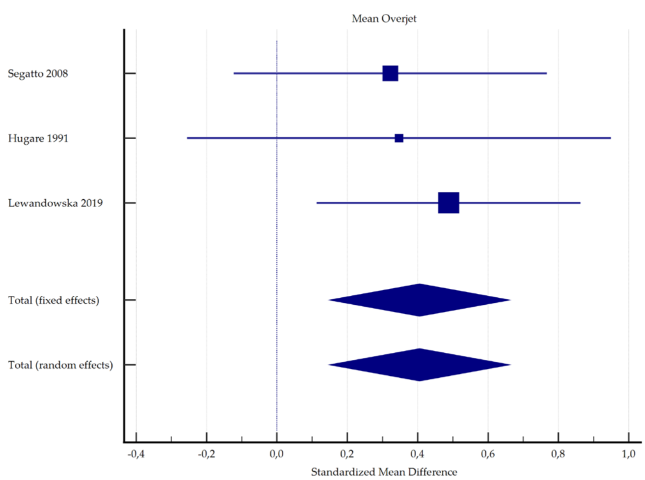

Figure 4
Forest plot showing the SMD of overjet in subjects with or without IS.

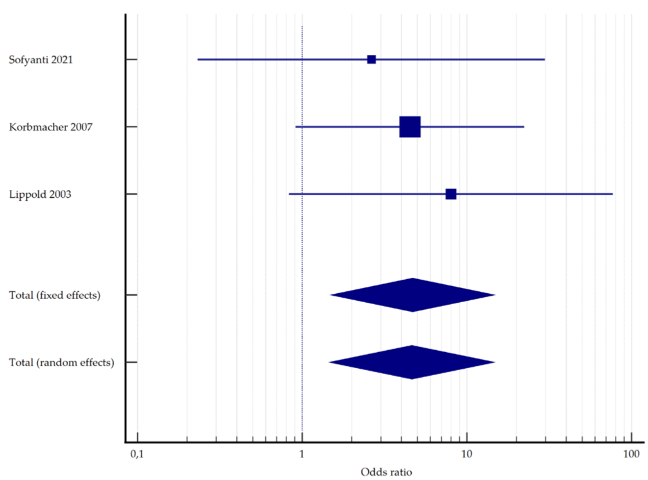

Figure 6
Forest plot showing the odds of scoliosis in subjects with or without malocclusion.

also alterations in vestibular function according to Le Berre *et al.*, who observed alterations in the perception of the gravitational vertical in IS subjects (8). The sum of this evidence forces us to consider IS a multi-aetiological disorder that requires a deep and detailed evaluation to understand what approach will offer the best benefit to the patient.

This review has some limitations derived mainly from the type of included studies. First, the inclusion of cross-sectional studies does not allow the establishment of causal relationships between scoliosis and alterations of the stomatognathic system. Second, some meta-analyses in this review included a small number of studies and subjects, precluding conclusive results. Third, some meta-analyses in this review showed some publication bias, which also limits the scope of the conclusions drawn. In the future, studies that investigate the temporal sequence of cause and effect between disorders of the spine and the stomatognathic system and analytical observational studies, mainly prospective cohorts, that analyse the influence of occlusal manipulations on the scoliotic curve should be carried out.

Conclusions

Subjects with scoliosis have twice the odds of having occlusion disorders, such as Angle class II and crossbite, than subjects without scoliosis. Patients with IS also present a greater distance or overjet between the upper and lower incisors, as well as greater dysfunction due to temporomandibular disorders. On the other hand, the prevalence of IS among subjects with malocclusion could be up to four times higher. The data are especially consistent regarding the relationship between crossbite and scoliosis and, with a much smaller sample, in the higher prevalence of IS in subjects with any type of malocclusion, since these two analyses did not show heterogeneity or publication bias. In light of the results of this review, it can be recommended to start new prospective studies with a sufficient sample to investigate the possible causal relationship between disorders of the stomatognathic system and IS. The inclusion of the orofacial examination and the search for temporomandibular dysfunction in the evaluation protocols of patients with IS is also justified.

ICMJE conflict of interest statement

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

Funding statement

This research did not receive any specific grant from any funding agency in the public, commercial, or not-for-profit sector.

References

1. **Altaf F, Gibson A, Dannawi Z & Noordeen H**. Adolescent idiopathic scoliosis. *BMJ* 2013 **346** f2508. (https://doi.org/10.1136/bmj.f2508)

2. **Romano M, Minozzi S, Zaina F, Saltikov JB, Chockalingam N, Kotwicki T, Hennes AM & Negrini S**. Exercises for adolescent idiopathic scoliosis: a cochrane systematic review. *Spine* 2013 **38** E883–E893. (https://doi.org/10.1097/BRS.0b013e31829459f8)

3. **Sud A & Tsirikos AI**. Current concepts and controversies on adolescent idiopathic scoliosis: Part I. *Indian Journal of Orthopaedics* 2013 **47** 117–128. (https://doi.org/10.4103/0019-5413.108875)

4. **Dimeglio A & Canavese F**. The immature spine: growth and idiopathic scoliosis. *Annals of Translational Medicine* 2020 **8** 22. (https://doi.org/10.21037/atm.2019.11.134)

5. **Kou I, Otomo N, Takeda K, Momozawa Y, Lu HF, Kubo M, Kamatani Y, Ogura Y, Takahashi Y, Nakajima M**, ***et al.*** Genome-wide association study identifies 14 previously unreported susceptibility loci for adolescent idiopathic scoliosis in Japanese. *Nature Communications* 2019 **10** 3685. (https://doi.org/10.1038/s41467-019-11596-w)

6. **Zhu Q, Chen J, Chen C, Wang H & Yang S**. Association between calcium-phosphorus balance and adolescent idiopathic scoliosis: a meta-analysis. *Acta Orthopaedica et Traumatologica Turcica* 2019 **53** 468–473. (https://doi.org/10.1016/j.aott.2019.08.012)

7. **Qiu XS, Tang NLS, Yeung HY, Lee KM, Hung VWY, Ng BKW, Ma SL, Kwok RH, Qin L, Qiu Y**, ***et al.*** Melatonin receptor 1B (MTNR1B) gene polymorphism is associated with the occurrence of adolescent idiopathic scoliosis. *Spine* 2007 **32** 1748–1753. (https://doi.org/10.1097/BRS.0b013e3180b9f0ff)

8. **Le Berre M, Pradeau C, Brouillard A, Coget M, Massot C & Catanzariti JF**. Do adolescents with idiopathic scoliosis have an erroneous perception of the gravitational vertical? *Spine Deformity* 2019 **7** 71–79. (https://doi.org/10.1016/j.jspd.2018.05.004)

9. **Zagalaz-Anula N, León-Morillas F, Andradre-Ortega JA, Ibáñez-Vera AJ, de Oliveira-Sousa SL & Lomas-Vega R**. Case report: conservative treatment of adolescent idiopathic scoliosis can alter the perception of verticality. A preliminary study. *Frontiers in Pediatrics* 2020 **8** 609555. (https://doi.org/10.3389/fped.2020.609555)

10. **Dufvenberg M, Adeyemi F, Rajendran I, Oberg B & Abbott A**. Does postural stability differ between adolescents with idiopathic scoliosis and typically developed? A systematic literature review and meta-analysis. *Scoliosis and Spinal Disorders* 2018 **13** 19. (https://doi.org/10.1186/s13013-018-0163-1)

11. **Catanzariti JF, Agnani O, Guyot MA, Wlodyka-Demaille S, Khenioui H & Donze C**. Does adolescent idiopathic scoliosis relate to vestibular disorders? A systematic review. *Annals of Physical and Rehabilitation Medicine* 2014 **57** 465–479. (https://doi.org/10.1016/j.rehab.2014.04.003)

12. **Ferrillo M, Marotta N, Giudice A, Calafiore D, Curci C, Fortunato L, Ammendolia A & de Sire A**. Effects of occlusal splints on spinal posture in patients with temporomandibular disorders: a systematic review. *Healthcare* 2022 **10** 739. (https://doi.org/10.3390/healthcare10040739)

13. **Langella F, Fusini F, Rossi G, Villafañe JH, Migliaccio N, Donzelli S & Berjano P**. Spinal deformity and malocclusion association is not supported by high-quality studies: results from a systematic review of the literature. *European Spine Journal* 2019 **28** 1638–1651. (https://doi.org/10.1007/s00586-019-05896-4)

14. **Oliveira SSI, Pannuti CM, Paranhos KS, Tanganeli JPC, Laganá DC, Sesma N, Duarte M, Frigerio MLMA & Cho SC**. Effect of occlusal splint and therapeutic exercises on postural balance of patients with signs and symptoms of

temporomandibular disorder. *Clinical and Experimental Dental Research* 2019 **5** 109–115. (https://doi.org/10.1002/cre2.136)

15. Paya-Argoud M, Tardieu C, Cheynet F, Raskin A & Borel L. Impact of orthognathic surgery on the body posture. *Gait and Posture* 2019 **67** 25–30. (https://doi.org/10.1016/j.gaitpost.2018.09.019)

16. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, Moher D, Becker BJ, Sipe TA & Thacker SB. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA* 2000 **283** 2008–2012. (https://doi.org/10.1001/jama.283.15.2008)

17. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, *et al.* The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021 **372** n71. (https://doi.org/10.1136/bmj.n71)

18. Higgins J & Green S *Cochrane Handbook for Systematic Reviews of Interventions*. London: The Cochrane Collaboration 2011.

19. Saccucci M, Tettamanti L, Mummolo S, Polimeni A, Festa F & Tecco S. Scoliosis and dental occlusion: a review of the literature. *Scoliosis* 2011 **6** 15. (https://doi.org/10.1186/1748-7161-6-15)

20. Ergieg SO, Sudhir V, Shibu T, Fanas S & Ashok M. The mean overjet in libyan children and the relationship between increased overjet and incisors trauma. *Indian Journal of Dental Research* 2020 **31** 967. (https://doi.org/10.4103/ijdr.ijdr_361_19)

21. Wells G, Shea B & O'Connel D. *The Newcastle-Ottawa Scale (NOS) for Assessing the Quailty of Nonrandomised Studies in Meta-analysis* 2009. Available at: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp

22. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *European Journal of Epidemiology* 2010 **25** 603–605. (https://doi.org/10.1007/s10654-010-9491-z)

23. Lo CK-L, Mertz D & Loeb M. Newcastle-Ottawa Scale: comparing reviewers' to authors' assessments. *BMC Medical Research Methodology* 2014 **14** 45. (https://doi.org/10.1186/1471-2288-14-45)

24. Cooper H, Larry H & Valentine J. *The Handbook of Research Synthesis and Meta-analysis*. New York: Russell Publishing Sage Foundation 2009.

25. DerSimonian R & Laird N. Meta-analysis in clinical trials. *Controlled Clinical Trials* 1986 **7** 177–188. (https://doi.org/10.1016/0197-2456(86)90046-2)

26. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. New York: Academic Press 1977.

27. Faraone SV. Interpreting estimates of treatment effects: implications for managed care. *P and T* 2008 **33** 700–711.

28. Rücker G & Schwarzer G. Beyond the forest plot: the drapery plot. *Research Synthesis Methods* 2021 **12** 13–19. (https://doi.org/10.1002/jrsm.1410)

29. Higgins J, Thompson S, Deeks J & Altman D. Statistical heterogeneity in systematic reviews of clinical trials: a critical appraisal of guidelines and practice. *Journal of Health Services Research and Policy* 2002 **7** 51–61. (https://doi.org/10.1258/1355819021927674)

30. Higgins JPT, Thompson SG, Deeks JJ & Altman DG. Measuring inconsistency in meta-analyses. *BMJ* 2003 **327** 557–560. (https://doi.org/10.1136/bmj.327.7414.557)

31. Sterne JAC & Egger M. Funnel plots for detecting bias in meta-analysis: guidelines on choice of axis. *Journal of Clinical Epidemiology* 2001 **54** 1046–1055. (https://doi.org/10.1016/s0895-4356(01)00377-8)

32. Egger M, Smith GD, Schneider M & Minder C. Bias in meta-analysis detected by a simple , graphical test measures of funnel plot asymmetry. *BMJ* 1997 **315** 629–634. (https://doi.org/10.1136/bmj.315.7109.629)

33. Ben-Bassat Y, Yitschaky M, Kaplan L & Brin I. Occlusal patterns in patients with idiopathic scoliosis. *American Journal of Orthodontics and Dentofacial Orthopedics* 2006 **130** 629–633. (https://doi.org/10.1016/j.ajodo.2005.01.032)

34. Kostenko YY, Melnyk VS, Horzov LF & Potapchuk AM. Relationship between idiopathic scoliosis of the spine and dentognathic anomalies in adolescents. *Wiadomosci Lekarskie* 2019 **72** 2117–2120. (https://doi.org/10.36740/WLek201911111)

35. Glowacki J, Latuszewska J, Okret A, Skowron N, Misterska E & Opydo-Szymaczek J. Temporomandibular joint disorders in females with adolescent idiopathic scoliosis: long-term effects of Milwaukee brace treatment. *Journal of Clinical Medicine* 2022 **11**. (https://doi.org/10.3390/jcm11061721)

36. Sofyanti E, Boel T & Sihombing ARN. The correlation between back posture and sagittal jaw position in adult orthodontic patients. *Journal of Taibah University Medical Sciences* 2021 **16** 63–69. (https://doi.org/10.1016/j.jtumed.2020.10.009)

37. Korbmacher H, Koch L, Eggers-Stroeder G & Kahl-Nieke B. Associations between orthopaedic disturbances and unilateral crossbite in children with asymmetry of the upper cervical spine. *European Journal of Orthodontics* 2007 **29** 100–104. (https://doi.org/10.1093/ejo/cjl066)

38. Lippold C, van den Bos L, Hohoff A, Danesh G & Ehmer U. Interdisciplinary study of orthopedic and orthodontic findings in pre-school infants. *Journal of Orofacial Orthopedics / Fortschritte der Kieferorthopädie* 2003 **64** 330–340. (https://doi.org/10.1007/s00056-003-0236-4)

39. Laskowska M, Olczak-Kowalczyk D, Zadurska M, Czubak J, Czubak-Wrzosek M, Walerzak M & Tyrakowski M. Evaluation of a relationship between malocclusion and idiopathic scoliosis in children and adolescents. *Journal of Children's Orthopaedics* 2019 **13** 600–606. (https://doi.org/10.1302/1863-2548.13.190100)

40. Segatto E, Lippold C & Végh A. Craniofacial features of children with spinal deformities. *BMC Musculoskeletal Disorders* 2008 **9** 169. (https://doi.org/10.1186/1471-2474-9-169)

41. Zhang H, Ma J, Zhang Z, Feng Y, Cai C & Wang C. Occlusal deviations in adolescents with idiopathic and congenital scoliosis. *Korean Journal of Orthodontics* 2022 **52** 165–171. (https://doi.org/10.4041/kjod21.259)

42. Sambataro S, Bocchieri S, Cervino G, La Bruna R, Cicciù A, Innorta M, Torrisi B & Cicciù M. Correlations between malocclusion and postural anomalies in children with mixed dentition. *Journal of Functional Morphology and Kinesiology* 2019 **4** 45. (https://doi.org/10.3390/jfmk4030045)

43. Pećina M, Lulić-Dukić O & Pećina-Hrncević A. Hereditary orthodontic anomalies and idiopathic scoliosis. *International Orthopaedics* 1991 **15** 57–59. (https://doi.org/10.1007/BF00210536)

44. Huggare J, Pirttiniemi P & Serlo W. Head posture and dentofacial morphology in subjects treated for scoliosis. *Proceedings of the Finnish Dental Society. Suomen Hammaslaakariseuran Toimituksia* 1991 **87** 151–158.

45. Lewandowska J, Opydo-Szymaczek J, Mehr K & Głowacki J. Bilateral dentoalveolar asymmetries in female patients with adolescent idiopathic scoliosis. *Acta of Bioengineering and Biomechanics* 2019 **21** 53–62. (https://doi.org/10.37190/ABB-01457-2019-01)

46. Uçar İ, Batın S, Arık M, Payas A, Kurtoğlu E, Karartı C, Seber T, Çöbden SB, Taşdemir H & Unur E. Is scoliosis related to mastication muscle asymmetry and temporomandibular disorders? A cross-sectional study. *Musculoskeletal Science and Practice* 2022 **58** 102533. (https://doi.org/10.1016/j.msksp.2022.102533)

47. D'Attilio M, Filippi MR, Femminella B, Festa F & Tecco S. The influence of an experimentally-induced malocclusion on vertebral alignment in rats: a controlled pilot study. *Cranio* 2005 **23** 119–129. (https://doi.org/10.1179/crn.2005.017)

48. Ramirez-Yanez GO, Mehta L & Mehta NR. The effect of dental occlusal disturbances on the curvature of the vertebral spine in rats. *Cranio* 2015 **33** 217–227. (https://doi.org/10.1179/2151090314Y.0000000017)

49. Wilczyński J. Relationship between muscle tone of the erector spinae and the concave and convex sides of spinal curvature in low-grade scoliosis among children. *Children* 2021 **8**. (https://doi.org/10.3390/children8121168)

50. Lippold C, Moiseenko T, Drerup B, Schilgen M, Végh A & Danesh G. Spine deviations and orthodontic treatment of asymmetric malocclusions in children. *BMC Musculoskeletal Disorders* 2012 **13** 151. (https://doi.org/10.1186/1471-2474-13-151)

51. Piancino MG, MacDonald F, Laponte I, Cannavale R, Crincoli V & Dalmasso P. Juvenile/adolescent idiopatic scoliosis and rapid palatal expansion. A pilot study. *Children* 2021 **8**. (https://doi.org/10.3390/children8050362)

52. Cuccia A & Caradonna C. The relationship between the stomatognathic system and body posture. *Clinics* 2009 **64** 61–66. (https://doi.org/10.1590/s1807-59322009000100011)

53. Ulusoy DM, Akkaya S & Batın S. Evaluation of choroidal changes in adolescent idiopathic scoliosis using enhanced depth imaging optical coherence tomography. *Clinical and Experimental Optometry* 2020 **103** 320–323. (https://doi.org/10.1111/cxo.12932)

54. Karaca EE, Çubuk MÖ, Akçam HT, Uzun F & Yüksel E. Choroidal thickness in Turkish children with anisometric amblyopia. *Seminars in Ophthalmology* 2017 **32** 291–296. (https://doi.org/10.3109/08820538.2015.1068343)

55. Zhu B, Wang X, Fu L & Yan J. Pattern strabismus in a tertiary hospital in Southern China: a retrospective review. *Medicina (Kaunas)* 2022 **58**. (https://doi.org/10.3390/medicina58081018)

56. Cortés-Pérez I, Salamanca-Montilla L, Gámiz-Bermúdez F, Obrero-Gaitán E, Ibáñez-Vera AJ & Lomas-Vega R. Vestibular morphological alterations in adolescent idiopathic scoliosis: a systematic review of observational studies. *Children* 2022 **10**. (https://doi.org/10.3390/children10010035)