Does head and cervical posture correlate to malocclusion? A systematic review and meta-analysis

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Abstract

Background

The association of head and cervical posture with malocclusion has been studied for many years. Despite extensively encouraging researches, no conclusive evidence has been reached for clinical application.

Objective

To identify the question “Does head and cervical posture correlate to malocclusion?”, a systematic review and meta-analysis based on the available studies were carried out (PROSPERO registration number: CRD42022319742).

Methods

A search of PubMed, Embase, Cochrane Library, and the grey literature was performed without language restrictions. The study screening, data extraction, risk-of-bias evaluation and methodological quality assessment were performed by two independent investigators. When a disagreement arose, a third author was consulted.

Results

6 original cross-sectional studies involving 505 participants were included, which were of moderate methodological quality. NL/VER in Class II group and NL/CVT in Class III group showed significant differences compared to Class I group, but no significant differences were observed in most of the variables like NSL/VER, OPT/CVT, OPT/HOR, CVT/HOR, NSL/OPT, NSL/CVT, NL/OPT in Class II and III groups.
Conclusions
The results suggested that the current research evidence is not sound enough to prove the association of head and cervical posture with sagittal malocclusion. Better controlled design and a larger sample size are required for clarifying this question in future study.

Introduction
Poor posture of head and neck is considered to be one of the major causes for myofunctional disorders in craniofacial region. When abnormal posture of head and neck takes place during active growth stage of patient, the normal development of craniofacial structure may be disrupted due to biomechanical and anatomical connection between neck muscles and craniofacial structure [1–4]. Moreover, according to the previous epidemiologic studies, patients suffering from neck disorders showed a higher percentage of craniomandibular disorders, which are often accompanied by malocclusion [5–8]. Therefore, a hypothesis that head and cervical posture correlates to malocclusion was put forward and widely reported in the field of orthodontics and orthopedics [9]. For example, emerging evidence reported that children with Class II malocclusion, which were characterized by a convex profile with a retrognathic mandible and/or a prognathic maxilla, have an obviously higher head extension upon the spinal column, while a significant lower cervical lordosis angle was observed in subjects with Class III malocclusion, which showed a concave profile with a prognathic mandible and/or a retruded maxilla, suggesting that an alteration in cranio-cervical posture has a close association with sagittal malocclusion [10–17]. Therefore, various conservative and physical therapies for abnormal head and cervical posture correction, such as postural continuous monitoring, transcutaneous electrical nerve stimulation (TENS), bracing, and smart posture corrective orthosis, show a great potential for prevention of the development of sagittal malocclusion [18–20].

Despite encouraging results obtained from a number of studies, the hypothesis that the correlation of head and cervical posture with malocclusion was still challenged by some researchers [9, 21–23]. A typical viewpoint is that most of current studies neglected the possible confounding effect of age [24, 25], which may contribute to the change in degree of cervical lordosis, so the abnormal jaw relation may be ascribed to the developmental disorder rather than poor cervical posture. Considering these debates, the evidence for a clear correlation of cranio-cervical posture with malocclusion is in great demand, because proper understanding their relationship is of fundamental importance for diagnosis, prevention and treatment of malocclusion in patients with abnormal cranio-cervical posture [26]. To our knowledge, a review about the relationship postural disorders associated with dentofacial morphology was published by Huggare in 1998 [27]. A series of systematic reviews about the relationship of occlusion with posture as well as the relationship of cervical posture associated with craniofacial morphology were reported during 1999–2017 [1, 23, 26, 28, 29]. However, these reviews were mainly based on discussion of previous anecdotes, case reports and epidemiological studies, lacking quantitative evaluation on relevant topic. Different from previous reviews, the purpose of the present study is to focus on elucidating the relationship of head and cervical posture with malocclusion, which is of particular interest to the practitioners of orthodontics and orthopedics. Moreover, qualitative and quantitative assessments are simultaneously performed on the currently existing evidence to improve the validity and reliability of conclusion.
Materials and methods

Protocol and registration

The protocol of this meta-analysis was registered in the US National Institute of Health’s (NIH; Bethesda, Maryland, USA) International Prospective Register of Systematic Reviews research database (https://www.crd.york.ac.uk/PROSPERO, Protocol: CRD42022319742.) and was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (see Table A in the S1 Appendix).

Search strategy

Electronic databases including Embase, Pubmed and Cochrane library, and the gray literature by Google Scholar search were searched up to April 2022 without language limitation. The search strategy consisted of Medical Subject Headings (MeSH), a mix of free-text terms and keywords. Relevant free terms and keywords applied for malocclusion are “Angle’s classification”, “angle class ii malocclusion”, “angle class iii malocclusion”, “jaw occlusion” etc. The terms used for head and cervical posture included “head posture”, “head position”, “cervical posture”, “cervical position”, “neck posture”, “craniocervical posture”, “cervical curvature”, “cervical lordosis”, “cervical vertebrae”. Moreover, a manual search was also performed on the relevant references. The search strings were built (see Table B in the S1 Appendix).

After searching the above databases, all identified documents were imported into Endnote software. Two authors independently identified the relevant studies according to the eligibility criteria. Duplicates and irrelevant articles which did not meet the inclusion criteria were removed. When discrepancies occurred, a third author resolved the disagreement in accordance with the inclusion criteria until a final consensus was achieved.

Eligibility criteria

All studies were evaluated for eligibility based on the following PICO model: (P) the patients diagnosed with malocclusion without a history of orthodontic treatment were included; (I) not applicable; (C) the group of Class I malocclusion (subjects with a normal sagittal jaw relationship) was applied as the control to assess the relationship of cranio-cervical posture with Class II and III malocclusion; (O) Outcome measures consisted of craniovertical angles, cervicohorizontal angles, craniocervical angles and cervical curvature obtained by cephalometric analysis. In addition, all postural variables were measured in natural head position (NHP) to reduce the influence of intracranial reference planes like Sella Nasion (SN) and Frankfort Horizontal (FH) planes, which was adopted worldwide because of its good stability and reproducibility [30–33]. Observational studies including cross-sectional studies, cohort studies, and case-control studies were screened out for evaluation. Other factors such as gender, age and ethnicity were not restricted. Books, case reports, reviews, animal studies were excluded. The detailed eligibility criteria were listed as Table 1.

Data items and collection

Two researchers independently performed the data extraction according to the eligibility criteria. When disagreement arose, two researchers discussed until consensus was achieved. To ensure that included studies are reliable for the critical appraisal, the published paper should provide enough information to meet the criterion, which comprised race, sample size, age, gender, assessment method, and relevant outcome indicators.

In the present study, the reference points and lines were traced according to the analytical method described by Solow and Tallgren [34]. Nine cephalometric variables representing the
craniovertical, cervicohorizontal and craniocervical postural relationships and the cervical column curvature (NSL/VER, NL/VER, OPT/HOR, CVT/HOR, NSL/OPT, NSL/CVT, NL/OPT, NL/CVT, OPT/CVT) were collected and analyzed (see Fig A in the S1 Appendix). The head posture was defined as the craniovertical angle between the head and the true vertical (NSL/VER and NL/VER). The cervical column inclination was determined by cervicohorizontal angles, which formed by the upper cervical and the true horizontal (OPT/HOR and CVT/HOR). The craniocervical posture was determined by craniocervical angles, which formed by the posture of head and cervical column (NSL/OPT, NSL/CVT, NL/OPT, NL/CVT). The angle formed by OPT and CVT indicates cervical curvature. The descriptions of reference points, lines, and angles used in our study were summarized (see Table C in the S1 Appendix).

Risk of bias and quality assessment

Two authors independently evaluated the quality of selected articles based on an adapted form of Joanna Briggs Institute (JBI) critical appraisal checklist [35] and compared the results of evaluation until agreement was reached. Discrepancies in the assessment were resolved by discussion until consensus was reached. Quality assessment was focused on the purpose of study, sample selection, inclusion and exclusion criteria, characteristics of subject, reliability and validity of outcome measurement, appropriate external validity, ethical issue, statistical method, and outcome and research value.

According to JBI critical appraisal tool, each topic would be scored individually. A score of 0 indicates no mention of the topic, 1 point signifies a brief mention of the clause but no specificity, and 2 points indicate not only a reference to the clause but also a detailed description of it. Eventually, a score higher than 70% of the total score is typically defined as a high-quality study. Considering that there is no standard for the range of medium and low-quality scores, two reviewers defined the quality score range based on the calculation method. Studies scoring 14–20 are considered to be of high quality, 8–14 of moderate quality, and less than 8 of low quality.

Data synthesis

The collected data were meta-analyzed using Review Manager Software (RevMan, version 5.4; Nordic Cochrane Center, Cochrane Collaboration, Denmark). The continuous variable data were calculated by the mean difference (MD) and its 95% confidence interval (95% CI), and \( p < 0.05 \) was considered as statistically difference. The heterogeneity among studies was
evaluated by $I^2$ statistic, which describes true variation across studies as a percentage, with values of 25%, 50%, and 75% considered low, moderate, and high heterogeneity, respectively [36, 37]. If there was no significant heterogeneity ($p \geq 0.05, I^2 \leq 50%$), the meta-analysis was expressed using a fixed-effects model. If there was significant heterogeneity ($p < 0.05, I^2 > 50%$), the sources of heterogeneity were eliminated for further analysis. When heterogeneity still existed, a random-effects model was adopted. Publication bias was not tested due to small number of the included studies.

Results

Study selection and characteristics

The search of selected databases provided a total of 1460 publications. After removing duplicates and ineligible articles, 39 articles were selected as potential studies based on the evaluation of their abstracts. Finally, a total of 6 studies involving 505 individuals were included for review and meta-analysis after reading full-text [38–43]. No other observational studies like case-control or cohort studies that met the inclusion criteria were found. 3 of the 6 articles measured head posture (NSL/VER, NL/VER), 3 of the 6 studies measured cervical curvature (OPT/CVT), all of the 6 studies measured cervical spine inclination (OPT/HOR, CVT/HOR), 2 of the 6 studies measured craniocervical posture (NSL/OPT, NSL/CVT, NL/OPT, NL/CVT). The process of study selection was presented in Fig 1.

All included publications were cross-sectional studies. It was noted that in one of the included studies, the posture variables were discussed in two age groups (9–11 years old, and above 18 years old), respectively. In this study, the average age of all subjects was 13.49 years, and the sample size of group between 9 and 11 years old was larger than the other. Therefore, the former age group (9–11 years old) was selected for data collection and analysis [41].

In addition, there are some questions remaining to be answered including uneven sample size distribution, inappropriate study design, and possible confounders. For example, there were only 6 subjects in Class III group, which had 37 fewer subjects than Class II group [38]. Moreover, potential confounding factors such as ethnicity, age, gender were not sufficiently taken into account in the included studies. The participants came from four different countries. One study did not mention the nationality of subjects, and only two studies showed that subjects were from the same country, Iran [38, 39, 41]. Only one [41] study analyzed the data from different age subgroups, while the other five studies analyzed data without age distinction, thus leading to a greater heterogeneity. The main characteristics of the included articles were displayed in Table 2.

Risk of bias within studies

Results from the JBI quality assessment tool were shown in Table 3. Since none of included studies provided sufficient information to assess the quality and conformed to the principle of blinded randomized controlled trial, most of studies scored at 8–10 without reaching the required scores of high-quality standards.

Meta-analysis

The meta-analysis was conducted based on the data from 6 included studies. Since postural variables used in each study were different, they were discussed separately in this analysis. The difference of 9 posture variables among participants with Class I, II, and III malocclusion and the forest plot of their association were shown as below, and Class I group was used as control (Figs 2–5). To clarify the difference of overall postural variables among patients with Class I,
II, and III malocclusion, the statistical heterogeneity between studies was explored and assessed using $I^2$ test. Subgroup analysis was not performed, because most of studies did not distinguish the differences of confounding factors like age, gender and ethnicity among groups.

**Cervical curvature.** The value of OPT/CVT showed no significant differences in Class II and III groups compared to Class I group due to the presence of a significant high heterogeneity ($I^2 = 93\%, p = 0.34$ in Class II group; $I^2 = 91\%, p = 0.95$ in Class III group) (Fig 2). After removing the source of heterogeneity in Class II group, the value of OPT/CVT in Class II group showed a significant difference compared to Class I group ($I^2 = 0\%; MD = 2.94, 95\% CI
p < 0.00001), implying that the study reported by Tauheed, as the source of heterogeneity, has a negative impact on the result of OPT/CVT.

**Cervical column inclination.** All six articles measured cervical column inclination changes (OPT/HOR, CVT/HOR) in Class I, II, and III malocclusion [38–43]. A strong heterogeneity was found in Class III group of OPT/HOR (Fig 3B), and then the random effect model was applied. When the source of heterogeneity was excluded [42], the value of OPT/HOR in Class III group still showed no significant differences (When not excluded: $I^2 = 66\%$, MD = -0.27, 95% CI [-2.17 to 1.63]; $p = 0.78$. After excluding heterogeneity: $I^2 = 31\%$, MD = -1.04,

| Region                          | participants | Age (years) | Gender | Assessment                      | Variables | Variables | Variables | Conclusions                                                                 |
|---------------------------------|--------------|-------------|--------|---------------------------------|-----------|-----------|-----------|----------------------------------------------------------------------------|
| China                           | 90 participants Class I: 30 Class II: 30 Class III: 30 | 11–14 Male: 45 Female: 45 | Lateral cephalometric radiographs | OPT/CVT | NSL/VER NL/VER OPT/HOR NSL/OPT NL/OP NL/CTV | Tendencies: skeletal Class II: more extended head; skeletal Class III: flexed head |
| Bernal et al. (2017)             | - 107 participants Class I: 58 Class II: 43 Class III: 6 | 6–11 Male: 52 Female: 55 | Lateral cephalometric radiographs | - NSL/VER NL/VER OPT/HOR - | - The relationship between cervical postural variables and different malocclusion: no differences |
| Qidar et al. (2017)              | Indian-controlled Kashmir area 90 participants Class I: 32 Class II: 31 Class III: 27 | 15–35 Male: 43 Female: 47 | Lateral radiographs | OPT/CVT | - OPT/HOR - | 1. Skeletal Class II: OPT/CVT increased 2. Head was backwardly positioned in Class I compared to Class III |
| Tauheed et al. (2019)            | Pakistani 63 participants Class I: 22 Class II: 21 Class III: 20 | 11–22 Male: 25 Female: 38 | Lateral radiographs | OPT/CVT | - OPT/HOR - | 1. Skeletal malocclusion differs in their cervical postures, especially cervical curvature. 2. Skeletal Class III: straighter cervical columns |
| Hedayati et al. (2013)           | Iran 102 participants Class I: 32 Class II: 40 Class III: 30 | 15–18 - Lateral radiographs | - | NSL/VER NL/VER OPT/HOR NSL/OPT NL/OP NL/CTV | Tendencies: more forward head posture and incline their head in toward the chest (ventral) in skeletal Class III |
| Nik et al. (2011)                | Iran 53 participants Class I: 7 Class II: 24 Class III: 22 | 9–11 - Lateral radiographs | OPT/CVT | - OPT/HOR - | 1. Class II: cervical column posture 2. Age have not affected the curvature and cervical posture |

Abbreviations: craniovertical angles (CVA); cervicohorizontal angles (CHA), craniocevical angles (CCA).
95% CI [-2.49 to 0.41]; p = 0.16) (Fig 3B). Despite weak (Fig 3A and 3C), even no heterogeneity (Fig 3D) among the groups, the result of OPT/HOR in Class II group as well as the changes of CVT/HOR both in Class II and Class III groups showed no significant differences compared to Class I group.

### OPT/CVT

#### A

| Study or Subgroup | class II | class I | Mean Difference |
|-------------------|----------|---------|-----------------|
| Liu et al. 2016   | 7.78     | 5.79    | 0.17 [-1.73, 2.07] |
| Nik et al. 2011   | 6.95     | 4.31    | 3.53 [1.79, 5.27] |
| Qadir et al. 2017 | 6.7      | 3.8     | 2.72 [1.65, 3.79] |
| Tauheed et al. 2019| 3.86     | 2.67    | -1.44 [-2.40, -0.49] |

Total (95% CI): 197
Heterogeneity: Tau² = 6.01; Ch² = 42.88, df = 3 (P < 0.00001); I² = 93%
Test for overall effect: Z = 0.95 (P = 0.34)

#### B

| Study or Subgroup | class III | class I | Mean Difference |
|-------------------|-----------|---------|-----------------|
| Liu et al. 2016   | 5.97      | 4.06    | -1.84 [-3.23, -0.55] |
| Nik et al. 2011   | 5.36      | 2.71    | 1.94 [0.62, 3.26] |
| Qadir et al. 2017 | 5.75      | 3.98    | 1.77 [0.71, 2.83] |
| Tauheed et al. 2019| 3.45     | 2.06    | -1.85 [-2.89, -0.81] |

Total (95% CI): 190
Heterogeneity: Tau² = 4.14; Ch² = 34.95, df = 3 (P < 0.00001); I² = 91%
Test for overall effect: Z = 0.07 (P = 0.95)

Fig 2. Forest plot of the association between cervical curvature and Class I, II, and III malocclusion.

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Head posture. Half of the studies measured the head posture (NSL/VER, NL/VER) in Class II and III groups (Fig 4) [38–40]. However, a strong heterogeneity was found between Class II and III groups (Fig 4A, 4B and 4D). For NSL/VER variable, there was a strong heterogeneity in Class II group (heterogeneity: \( I^2 = 70\% \)), so the random effect model was adopted. No matter the heterogeneous sources were excluded or not, the value of NSL/VER showed no significant differences compared to Class I group [40], (When not excluded, \( I^2 = 70\% \), MD = 1.21, 95% CI [-0.63 to 3.05]; \( p = 0.2 \). When excluded, \( I^2 = 0\% \), MD = 0.39, 95% CI [-0.59 to 1.36]; \( p = 0.44 \) (Fig 4A). Likewise, a strong heterogeneity was detected in Class III group of NSL/VER (\( I^2 = 92\% \)). When the heterogeneous sources were excluded, the NSL/VER value showed a significant difference in Class III group compared to Class I group (When not excluded, MD = -0.01, 95% CI [-3.79 to 3.77]; \( p = 1.00 \). After excluding, \( I^2 = 46\% \), MD = -2.27, 95% CI [-3.34 to -1.21]; \( p < 0.0001 \) (Fig 4B) [39].

For NL/VER variable, a significant difference and a moderate heterogeneity was showed Class II group compared to Class I group (\( I^2 = 45\% \), MD = 1.27, 95% CI (0.36 to 2.18), \( p = 0.006 \) (Fig 4C). Meanwhile, a strong heterogeneity was presented in Class III group (\( I^2 = 93\% \), MD = -0.41,
95% CI [-4.34 to 3.52]; p = 0.84), NL/VER was demonstrated a significant difference in Class III group after excluding heterogeneity ($I^2 = 41\%$, MD = -2.67, 95% CI [-3.78 to -1.55]; $p < 0.00001$) compared to Class I group. It is indicated that the study reported by Hedayati et al. is the sources of heterogeneity and exerts an influence on the result (Fig 4D) [39].

**Craniofacial posture.** 2 included articles measured the craniofacial angles (NSL/OPT, NSL/CVT, NL/OPT, NL/CVT) in Class I, II and III malocclusion (Fig 5). NL/OPT and NL/CVT showed a weak heterogeneity in Class III group, while other variables in Class II and III groups exhibited a strong heterogeneity (Fig 5A–5E and 5G). Although NL/CVT variables in Class III group showed a statistical difference compared to Class I group ($I^2 = 0\%$, MD = -1.8, 95% CI [-3.45 to -0.15]) (Fig 5H), considering only 2 studies analyzed craniofacial angles (NSL/OPT, NSL/CVT, NL/OPT, NL/CVT) and a greater heterogeneity among groups, thus the analysis is not powerful enough to draw conclusions.

**Discussion**

Proper posture of head and neck is maintained by a balanced tension of soft tissue (facial skin and muscles) between craniofacial bones, myofascial structures and dental occlusion according to the "soft tissue stretching" theory [34]. It is well known that muscular balance in craniofacial region plays a critical role in the development of dentofacial complex. Muscular imbalance caused by myofunctional disorders is often regarded as a contributing factor for abnormal position of teeth and jaw bones, such as in case of mouth breathing, incorrect lip seal and infantile swallowing [44–50]. In the previous epidemiologic observations, many patients with Class II and III malocclusion showed an altered head and neck posture. Therefore, the hypothesis that the head and cervical posture is correlated to malocclusion was proposed and widely discussed in the field of orthodontics [12, 15, 51, 52]. Based on this
hypothesis, dental practitioners may prevent or treat malocclusion through correction of poor head and cervical posture. Although a number of positive outcomes were reported to prove this hypothesis, the entire orthodontic community can still not reach a consensus on this question "Does head and cervical posture correlate to malocclusion?", most concern has focused on the design in the present studies, which may compromise the reliability of conclusion. To assist orthodontist to make accurate judgment on this issue, there is a great demand for a systematic qualitative and quantitative assessment on the relevant evidence in electronic databases.

Currently, the available data regarding the association of head and cervical posture with malocclusion was mainly obtained from the cephalometric measurement rather than experimental research. Until now, nearly thirty variables [40] were developed to determine the association of head and cervical posture with craniofacial morphology and malocclusion, of which only nine cephalometric variables representing the craniovertical, cervicohorizontal and craniovertical postural relationships and cervical column curvature (NSL/VER, NL/VER, OPT/HOR, CVT/HOR, NSL/OPT, NSL/CVT, NL/OPT, NL/CVT, OPT/CVT) were widely accepted and applied for relevant measurement. However, the craniofacial and dentofacial development is a complex and dynamic process. The current parameters obtained from 2-dimensional measurement are far from the comprehensive evaluation of the position relationship between each component in craniofacial region. With the wide application of cone beam computed tomography (CBCT) and raster-stereography technique in dental clinics, more postural variables based on 3-dimensional measurement are needed to take into account, which may better reflect the association of head and cervical posture with malocclusion during development stage [21, 53]. Risk of bias is the possibility that characteristics of study design or conduct of the study will give misleading results. Generally, ethnicity, gender and age are the potential impact factors for the development of head and cervical posture [24, 25, 54, 55]. To eliminate risk of bias caused by these factors, they should be carefully examined when designing clinical studies. In the current study, 6 cross-sectional studies were finally screened out and synthesized in the meta-analysis after systematic review and identification. Unfortunately, no studies have discussed all of these influence factors. 2 studies mentioned the ethnicity when selecting subject [39, 41]. Only one study set gender subgroup and compared the difference between and in gender subgroup, although no significant differences were observed between boys and girls [38]. Moreover, most of articles did not discuss the age subgroup. Since the development of children may be affected by various genetic and environmental factors, studies without consideration of these factors may lead to bias in data interpretation. It is noteworthy that a previous study clearly pointed out that the abnormal jaw relation may be ascribed to the developmental disorder rather than poor cervical posture. Therefore, a great heterogeneity among the studies was observed in the meta-analysis, suggesting the low power of the available studies to prove the association of head and cervical posture with malocclusion.

Besides the common confounding factors like ethnicity, gender and age, various chronic diseases closely related to the change in head and cervical posture as well as malocclusion should be also taken into account when evaluating the results of studies regarding the relationship of head and cervical posture with malocclusion. For example, the obstruction of nasopharyngeal airway caused by various diseases like adenoids, nasal allergy and obstructive sleep apnea adequacy has been reported to have a close relationship with head and cervical posture [44–46, 56]. To maintain the airway patency, the head posture will be unconsciously extended in the patients with the obstruction of nasopharyngeal airway, which is indicated by an increase of the craniovertical angles. When the obstruction caused by these respiratory diseases was cured timely, the abnormal head and cervical posture can return to its normal position, or else the head and cervical posture as well as the related malocclusion may be
irreversibly formed [57, 58]. Another disease that should be paid attention is temporomandibular joint disturbance syndrome (TMJDs), which have a high prevalence in children and adolescents. Patients with TMJDs often suffer from various musculoskeletal disorders involving masticatory muscles, TMJ, and surrounding structures. Although the etiology of TMJDs is still not clarified, many studies reported that TMJDs involving dysfunction of masticatory muscles may be correlated to the development of abnormal head and cervical posture [59, 60], since TMJ is connected to the cervical region via muscles and ligaments. Moreover, it is widely accepted that there is an interrelationship between malocclusion and TMJDs [61] in the field of orthodontics. Therefore, it is necessary to consider the potential impact of chronic diseases like respiratory diseases and TMJDs on the conclusion when assessing the association of head and cervical posture with malocclusion. According to the systematic review, all included studies considered the potential impact of these diseases when setting inclusion criteria, but the exclusion method was mainly based on the medical records, so the patients without obvious symptoms or signs in the latent stage of diseases may be included, probably resulting in the misinterpretation of data. With the advancement of medical technology, non-invasive techniques like Cone Beam Computed Tomography (CBCT), Magnetic Resonance Imaging (MRI), and Electromyogram (EMG) have been successfully applied for diagnose of nasopharyngeal diseases or TMJDs in their latent period. Therefore, to provide more objective evidence when grouping subjects, examination method such as CBCT, MRI and EMG are recommended in the future studies, which may be beneficial for the uniformity control of subjects.

**Limitations and strengths**

Based on the above discussion, this study has two major limitations. Firstly, although all of the included studies were of moderate quality, the evidence obtained from the included studies is far from the high-quality standards for clinical trials, which was revealed in the results of this meta-analysis. As shown in Figs 2 and 4, large heterogeneity was observed in OPT/CVT, NSL/VER and NL/VER, which significantly affect the results of OPT/CVT in Class III group. After excluding the source of heterogeneity in OPT/CVT, NSL/VER and NL/VER of Class III group, the results showed a significant difference, but the valid number of participants was simultaneously reduced, which may result in the compromised reliability of data interpretation. Furthermore, no significant differences between cervical posture and Class I, II, and III malocclusion were found (Fig 3). Although the change of NL/VER in Class II group showed a significant difference compared to Class I group (Fig 4C), it was not sufficient to obtain a rigorous conclusion, because only two variables of head posture were eligible. Secondly, since most of studies did not distinguish the potential confounding factors like age, gender and ethnicity among groups, no subgroup analysis was performed. Therefore, further investigations including clinical trial and experimental research are needed to prove the hypothesis regarding the relationship of head and cervical posture with malocclusion. To address the issues found in the present documents, future studies are recommended to introduce techniques like CBCT, MRI, raster-stereography or EMG to assist subject inclusion and exclusion. Moreover, researchers should be more critical in subject grouping and sample size estimation to minimize heterogeneity caused by various confounding factors.

**Conclusion**

Due to the low methodological quality, race difference, and small sample sizes, the results from studies included in our review must be interpreted with caution. Findings of this systematic review and meta-analysis suggested that head and cervical posture may be correlated to Class
II and III malocclusion, however, the current available evidence is not sound enough to support this conclusion. Therefore, the clinical practitioners should pay attention when applying any methods based on this hypothesis to treat sagittal malocclusion via correction of abnormal head and cervical posture. To better clarify the role of head and cervical posture on the development of sagittal malocclusion, large scale prospective studies with high methodological quality and minimal heterogeneity are recommended in the future.

Supporting information
S1 Appendix. Supplementary material.

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