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ORIGINAL ARTICLE

Association between convergence insufficiency and temporomandibular disorder cross-sectional study

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Abstract

Objectives Evaluate whether there is an association between convergence insufficiency and temporomandibular disorder (TMD) and whether there is an association between pain and range of motion in different degrees of TMD.

Methods We evaluated 138 individuals with TMD and 46 without TMD using the Research Diagnostic Criteria for temporomandibular disorders, the Fonseca Anamnestic Index (FAI), Numeric Pain Rating Scale, and the measurement of mandibular range of motion (ROM). Convergence insufficiency was diagnosed using the convergence test and Convergence Insufficiency Symptom Survey. Analysis of variance was used to compare age and mandibular ROM. The Kruskal–Wallis was used to compare mandibular ROM and pain between groups. The chi-square test was used to evaluate associations between TMD subgroups and the FAI, sex, and ocular convergence.

Results The majority of individuals without TMD did not exhibit convergence insufficiency. The frequency convergence insufficiency was significantly higher among individuals with severe TMD ($p < 0.003$). Mean pain severity differed between individuals with and without TMD. Mandibular ROM diminished with the increase in TMD severity.

Conclusions Convergence insufficiency, age, the increase in pain, and the reduction in mandibular range of motion were associated with the degrees of TMD severity. Despite the significant associations between convergence insufficiency and both pain and TMD severity, these variables cannot be indicated as predictive factors due to the low variability in the linear regression analysis.

Clinical relevance The present findings can assist in decision making regarding the treatment of severe TMD and the evaluation of ocular convergence.

Keywords Temporomandibular joint disorders · Convergence insufficiency · Eye movement disorders

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Introduction

The eyes are capable of highly specialized movements, such as slow following movements and rapid, instantaneous changes from one point of fixation to another. Eye movements are the result of muscle action [1] and are controlled by the oculomotor (III), abducent (IV), and trochlear (VI) cranial motor nerves, the motor nuclei of which are situated in the brainstem.

The diversity of eye movements surpasses the capacity of the extraocular muscles (EOMs) but numerous nerve fibers connect in each of the EOMs, giving support to the movements. The simultaneous adduction movement of the eyes is denominated convergence, enabling the visualization of close objects at a distance of approximately 33 cm [2]. The near point of convergence is the closest point at which the eyes are capable of converging and does not commonly change with age [3]. Convergence insufficiency (CI) is characterized by the inability for the eyes to function together adequately when focusing on a nearby object [4, 5]. The prevalence of CI ranges from 1.75 to 33.0% [6].

Convergence insufficiency is seen as a negative factor with regard to quality of life and general health, as it contributes to low yield at work, at school, and during leisure activities [7]. The literature reports several tools for diagnosing CI and estimating the balance of the extrinsic musculature of the eyes. One such tool is the convergence test, the aim of which is to diagnose normal, sufficient, or insufficient convergence. Convergence of the eyes is normally symmetrical and simultaneous [8].

Some authors [9–12] have conducted anatomic studies relating the nuclear complex of the trigeminal nerve to other nuclei of the brainstem, linking trigeminal function to facial, hypoglossal, and cochlear function [13–16]. Others have found that vagal/parasympathetic function is related to the oculomotor system [17–20].

Besides anatomic evidence of connections between the oculomotor apparatus and the trigeminal system, some researchers have examined the clinical relation between dental treatments and the oculomotor system [21], showing that there may be an association between temporomandibular disorder (TMD) and oculomotor function. Monaco [22] found changes in ocular convergence in adults with TMD with limited maximum mouth opening, myofascial pain, neck pain, and pain in the shoulder area.

TMD is a heterogeneous group of conditions that affect the temporomandibular joint (TMJ), muscles of mastication and associated structures [23]. TMD is the most common cause of orofacial pain of a non-dental origin [24] and is considered an important public health problem due to its chronic nature and its interference with activities of daily living [25]. It is characterized by a triad of clinical signs that involve muscle and/or joint pain, joint noises, and restricted range of motion (ROM) and/or changes in the movement pattern of the mandible [26].

As changes in the TMJ may be related to the craniocervico-mandibular region and the structures that give origin to the nerves that command extraocular eye movements have proximity to the sensitive and motor part of the face, the primary objective of the present study was to evaluate whether there is an association between convergence insufficiency and TMD. The secondary objective was to evaluate whether there is an association between pain and mandibular ROM in different degrees of TMD. The underlying hypothesis is that there is an association between convergence insufficiency and TMD due to the proximity of the structures that control the sensitive and motor part of the face and the musculature of the ocular globe. The null hypothesis is that there is no association between convergence insufficiency and TMD. Specifically, we test the influence of clinical characteristics related to TMD and ocular convergence in a sample subdivided by degrees of TMD severity.

Materials and methods

Study design

A cross-sectional study was conducted with data collected between August 2018 and September 2019 at the Movement Analysis Research Support Center of the Nove de Julho University in São Paulo, Brazil. The study was designed to investigate whether individuals with TMD exhibit convergence insufficiency. Evaluations were performed using the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD), Fonseca Anamnestic Index (FAI), Numeric Pain Rating Scale (NPRS), Convergence Test, and Convergence Insufficiency Symptom Survey (CISS). Ocular convergence was the primary outcome of the study.

This study was performed in accordance with the guidelines that regulate research involving human subjects stipulated in Resolution nº 466/12 of the Brazilian National Board of Health and received approval from the ethics committee of Nove de Julho University (certificate number: 12416319.9.0000.5511).

Characterization of sample

A convenience sample was formed. For such, 204 individuals between 18 and 45 years of age were recruited, 184 of whom were eligible: 138 with TMD subdivided into three groups according to severity [27] (mild, moderate, and severe) and 46 without TMD. The inclusion criteria for group with TMD were a diagnosis based on the RDC/TMD [28], classification in the subgroups of myofascial pain (Ia and Ib), anterior disk displacement (IIa, IIb and IIc) with or without joint noises, arthralgia, osteoarthritis, and osteoarthrosis (IIIa, IIIb and IIIc) for at least 3 months and a maximum of 1 year and the

occurrence of pain in the facial region in the previous 6 months. Individuals with a clinical history of tumors in the craniofacial region, acute musculoskeletal disorders, recent dental surgery, infections, disorders associated with neck injuries, chronic systemic inflammatory or degenerative neurological disorders, or physiotherapeutic or dental treatment in the previous 3 months were excluded from the study.

The inclusion criteria for the group without TMD were a negative diagnosis of TMD based on the RDC/TMD [29], age between 18 and 45 years, and absence of any type of orofacial pain in the previous 12 months. Individuals with abnormal cognitive function or communication skills, those who took analgesics, anti-inflammatory agents, anxiolytics or antidepressants on a daily basis, those with headache or other chronic pain conditions, and pregnant women were excluded. The individuals without TMD served as the control group for comparisons to the group with TMD.

Evaluations

Evaluation of temporomandibular disorder – research diagnostic criteria for temporomandibular disorders

The two axes of the RDC/TMD were applied by a single examiner (physiotherapist) to all participants to determine the diagnosis of TMD [28]. The examiner had undergone training in accordance with the specifications of the International RDC/TMD Consortium (2010) [29] and had 6 years of experience in the use of this instrument. The possible diagnoses (which may be unilateral or bilateral) generated by the RDC/TMD are divided into groups and subgroups: Group I (subgroups a and b), Group II (subgroups a, b, and c), and/or Group III (subgroups a, b, and c). The levels of reliability and validity of the diagnostic items have previously been evaluated [30].

Assessment of severity of temporomandibular disorder – Fonseca Anamnestic Index

Only the group with TMD according to the RDC/TMD answered the FAI for the classification of TMD severity. The FAI is a patient history questionnaire that addresses symptoms of TMD and was not developed for diagnostic purposes [31]. This index is composed of 10 questions, each with three response options: "yes" (10 points), "sometimes" (5 points), and "no" (0 points). The item scores are totaled, enabling the classification of the severity of signs and symptoms of TMD: 0–15 points = absence of TMD; 20–40 points = mild TMD; 45–65 points = moderate TMD; and 70–100 points = severe TMD.

Assessment of pain intensity – numeric pain rating scale

The NPRS was used to assess pain intensity on a scale of 0 (no pain) to 10 (worst pain imaginable). The literature indicates that the NPRS has a higher quality of evidence regarding its scale properties compared with other pain measures, such as the Visual Analog Scale, verbal classification scale, and Brief Pain Inventory [32].

Assessment of mandibular range of motion – calipers

Mandibular ROM was measured with the aid of digital calipers (150 mm/6″; Starrett®) during maximum mouth opening without assistance, following the guidelines of the RDC/TMD (items 4 a, b, c, and d of the clinical examination (Axis I)). For such, the participant was seated in a chair, trunk erect, back completely supported, feet on the floor, and hands resting on thighs. Three readings of maximum mouth opening were performed. The mean of the three readings was calculated [33] and recorded, along with the presence/absence of pain during the movement.

Assessment of ocular convergence – convergence test

The convergence test was used as the main method for diagnosing CI and estimating the balance among the extrinsic muscles of the eyes. The test was performed with digital calipers (150 mm/6″; Starrett®) rather than another target to ensure greater precision. The operator supported the fixed arm of the calipers on the glabellum and moved the other arm toward the nose at the height of the eyes. The distance at which the two eyes diverged was recorded and interpreted as follows: 3.0–4.0 cm = normal; 4.1–6.9 cm = sufficient; and ≥ 7 cm = insufficient [34].

Assessment of frequency and types of symptoms – convergence insufficiency symptom survey

The CISS was developed for the Convergence Insufficiency Treatment Trial and is the first approved, reliable, valid, standardized tool for distinguishing individuals with CI from those with normal binocular vision, exhibiting high sensitivity [35]. The CISS has good psychometric properties and has been translated and adapted to the Portuguese language [7]. It has 15 items, each with five response options. The results are interpreted as follows: 0–10 points = normal binocular vision, 11–36 points = suspected CI, and 37–60 points = CI [36].

Statistical analysis

The Shapiro–Wilk test was used to determine the normality of the data. Univariate analysis of variance (ANOVA) with the

Bonferroni post-hoc test was used to compare age and mouth opening. The Kruskal–Wallis test with Dunn's post-hoc test was used to compare mouth opening and pain between the groups. Partial eta squared was used to calculate the effect size in both analyses (ANOVA and Kruskal–Wallis). The interpretation was based on the values established by Cohen (Cohen's d) as follows: less than 0.01 = small effect, approximately 0.06 = moderate effect, and larger than 0.14 = large effect [37]. The chi-square test was used to evaluate associations between TMD severity according to the FAI and both sex and ocular convergence and the effect size was tested by Cramer's V [38]. Linear regression analyses were performed to determine associations considering convergence insufficiency as the dependent variable and the following as the independent variables: age, pain (NRS), mouth opening (4a opening without assistance and without pain, 4b maximum opening without assistance, and 4c maximum opening with assistance), TMD severity (according FAI), and TMD diagnoses (RDC/TMD subtype myogenic, joint-related, or mixed). R^2 was used to assess the extent to which the independent variables in the model account for the variability in the dependent variable. The level of significance was set to 5% ($p < 0.05$) for all tests.

Results

The sample was composed of 138 individuals with TMD (77.46% women and 22.10% men) with a mean age of 26.51 ± 6.14 years and 46 individuals without TMD (28.2% women and 71.7% men) with a mean age of 25.52 ± 5.81 years.

Table 1 shows the classification of subgroups of temporomandibular function based on RDC/TMD in 138 individuals according to severity based on Fonseca Anamnestic Index.

Table 1 Classification of subgroups of temporomandibular function based on RDC/TMD in 138 individuals according to severity based on Fonseca Anamnestic Index

RDC/TMD subgroups	Fonseca subgroups		
	Mild TMD ($n = 46$)	Moderate TMD ($n = 46$)	Severe TMD ($n = 46$)
Ia	12 (26.08%)	22 (47.82)	18 (39.13%)
Ib	9 (19.56%)	13 (28.26%)	26 (56.52%)
IIa	9 (19.56%)	9 (19.56%)	9 (15.56%)
IIb	3 (6.52%)	0 (0%)	2 (4.34%)
IIc	4 (8.69%)	1 (2.17%)	2 (4.34%)
IIIa	10 (21.73%)	23 (50%)	28 (60.86%)
IIIb	5 (10.86%)	10 (21.73%)	28 (60.86%)
IIIc	4 (8.69%)	2 (4.34%)	2 (4.34%)

Subgroups Ia and IIIa were the most frequent among the individuals with mild and moderate TMD, whereas subgroups Ib, IIIa, and IIIb were the most frequent among those with severe TMD (Table 1).

Table 2 shows the demographic characteristics, maximum mouth opening, and pain measured using the Numeric Pain Rating Scale in 46 individuals without TMD and 138 individuals with TMD classified according to the Fonseca Anamnestic Index.

Significant differences were found between the healthy controls and individuals with different degrees of TMD severity based on the FAI with regard to age ($p < 0.001$) and pain ($p < 0.001$) (Table 2). For age, a significant difference was found between the healthy controls and individuals classified with severe TMD ($p < 0.05$, Bonferroni post-hoc test). Regarding pain, significant differences were found between the healthy controls and individuals in all TMD severity categories ($p < 0.01$, Dunn's post-hoc test). Moreover, maximum mouth opening diminished significantly with the increase in severity ($p < 0.01$, Dunn's post-hoc test).

Table 3 shows associations between temporomandibular function and sex, convergence, non-convergent side, and predominant chewing side in 46 individuals without TMD and 138 individuals with TMD classified according to Fonseca Anamnestic Index.

Table 3 displays the prevalence of ocular convergence among the different groups as follows: 91% of the individuals without TMD, 84.7% of those with mild TMD, and 89% of those with moderate TMD were classified as convergent. In contrast, ocular convergence was only found in 32.6% of the individuals with severe TMD ($p < 0.003$). We found a predominance of non-convergence on the right side in all groups except the individuals with moderate TMD. Regarding chewing preference, the right side was predominant in all groups, independently of TMD severity.

The linear regression model was performed to analyze the relationships between convergence insufficiency, and the independent variables had pain ($F(1182) = 10.20$, $p < 0.02$) and TMD severity ($F(1182) = 9.08$, $p < 0.003$; $R^2 = 0.04$) as the significant variables ($p < 0.05$), but the model was not strong ($R^2 = 0.05$ and $R^2 = 0.02$, respectively). No associations were found for age ($F(1182) = 2.71$, $p = 0.10$; $R^2 = 0.01$), mouth opening (4a, $F(1182) = 0.11$, $p = 0.74$; $R^2 = 0.001$; 4b, ($F(1182) = 0.12$, $p = 0.72$; $R^2 = 0.001$, 4c, ($F(1182) = 0.03$, $p = 0.85$; $R^2 < 0.001$), or TMD diagnoses ($F(1182) = 1.24$, $p = 0.26$; $R^2 = 0.007$).

Discussion

The aim of the present study was to determine whether there is an association between convergence insufficiency and TMD. Specifically, we tested the influence of clinical characteristics

Table 2 Demographic characteristics, maximum mouth opening, and pain measured using the Numeric Pain Rating Scale in 46 individuals without TMD and 138 individuals with TMD classified according to the Fonseca Anamnestic Index

Fonseca subgroups					*p* value(effect size)
No TMD($n = 46$)		Mild TMD($n = 46$)	Moderate TMD($n = 46$)	Severe TMD($n = 46$)	
Age (years)[a]	25.52 ± 5.81	23.30 ± 3.94	26.32 ± 7.09	29.91 ± 7.41*	< 0.0001 (0.13) †
Pain[b]	0.00 (0.00–0.00)	1.00 (0.00–2.00) *#	2.00 (0.00–4.00) *#	4.50 (2.75–7.00) *	< 0.0001 (0.45) †
Opening (mm)[a]					
4a	39.26 ± 10.74#	39.02 ± 9.94#	35.28 ± 10.37	30.03 ± 10.62	< 0.0001 (0.13) †
4b	48.18 ± 8.66#	47.66 ± 8.45#	47.00 ± 7.92#	40.02 ± 9.62	< 0.0001 (0.15) †
4c	51.51 ± 8.05#	51.55 ± 8.37#	51.20 ± 7.35#	43.75 ± 10.12	< 0.0001 (0.14) †

TMD, temporomandibular disorder; *4a*: opening without assistance and without pain (Item 4a of clinical examination (Axis I)); *4b*, maximum opening without assistance (item 4b of clinical examination (Axis I)); *4c*, maximum opening with assistance (Item 4c of clinical examination (Axis I))

[a] Mean and standard deviation (one-way ANOVA)

[b] Median and interquartile range (25–75%, ANOVA + Kruskal–Wallis)

* Significant difference compared with group without TMD

Significant difference compared with group with severe TMD

† Greater effect size (Cohen's d)

related to TMD and ocular convergence in a sample subdivided based on the degree of TMD severity. The results of the linear regression analysis indicate significant associations between convergence insufficiency and both pain and TMD severity. However, the data should be interpreted with caution due to the relatively low levels of variability found in the model (5% and 2%, respectively).

The Fonseca Anamnestic Index (FAI) was used to assess severity. Berni et al. [39] found a high degree of accuracy of this index for the diagnosis of myogenic TMD (area below the

Table 3 Associations between temporomandibular function and sex, convergence, non-convergent side and predominant chewing side in 46 individuals without TMD and 138 individuals with TMD classified according to Fonseca Anamnestic Index

Characteristic	No TMD	Fonseca subgroups			*p* value
		Mild TMD	Moderate TMD	Severe TMD	(effect size)
Sex					
Male	13 (28.2%)	15 (32.6%)	10 (21.7%)	6 (13%)	0.13 (0.09) †
Female	33 (71.7%)	31 (67.3%)	36 (78.2%)	40 (86.9%)	
Convergence					
Non-convergent	4 (8.6%)	7 (15.2%)	5 (10.8%)	16 (32.6%)	0.003* (0.15) #
Convergent	42 (91%)	39 (84.7%)	41 (89%)	30 (67.3%)	
Non-convergent side					
Left	15 (32.70%)	15 (32.70%)	29 (63.04)	15 (32.70%)	0.004* (0.16) #
Right	31 (67.39%)	31 (67.39%)	17 (36.95%)	31 (67.39%)	
Predominant chewing side					
Left	8 (17.39%)	8 (17.39%)	10 (21.73%)	13 (28.26%)	0.41 (0.07) †
Right	26 (60.86%)	27 (58.69%)	31 (67.39%)	26 (60.86%)	
Both	12 (26.08%)	11 (23.91%)	5 (10.86%)	7 (15.21%)	

* Significant association ($p < 0.05$, chi-squared test)

† Small effect size (Cramer's V)

Medium effect size (Cramer's V)

ROC curve, 0.940). The authors determined that the best cut-off point for the identification of myogenic TMD was 47.50, suggesting that scores of 50 to 100 identify individuals with this disorder. Bevilaqua-Grossi et al. [40] states that the FAI items addressing pain, joint sounds, and pain in the TMJ when chewing have the best capacity to distinguish individuals with severe TMD, reporting that greater functional harm to the structure indicates greater severity.

The findings confirm the underlying hypothesis that there is an association between convergence insufficiency and TMD, which may be explained by the proximity of the structures that control the sensitive and motor part of the face and the musculature of the ocular globe. Monaco et al. [22] also found altered ocular convergence in adults with TMD and myofascial pain, defending the theory that convergence may be influenced by the muscles of the face and neck. The prevalence of convergence insufficiency ranges from 1.75 to 33% [6]. This variability may be attributed to differences in the definition of CI, the diagnostic criteria employed and differences among populations.

In the present study involving a convenience sample, women accounted for 67 to 86% of the different subgroups of TMD. According to Dym and Israel [41], TMD is manifested disproportionally between the sexes. Epidemiological data reveal female-to-male proportions of 3:1 [26], 4:1 [42], and even 6:1 [43]. In women, this disorder is related to hormonal, biological, and psychosocial factors [44]. The differences between the sexes may also be influenced by the endocrine system [45].

In the present study, the increase in the severity of TMD was associated with an increase in pain intensity and a reduction in mandibular range of motion. This is in agreement with data described in the literature, as researchers have found greater pain symptoms in patients with severe TMD [46–48]. This may be explained mainly in women with TMD, as they have more nerve fibers that release 5-HT3A receptors (serotonin), an important pain transmitter that is found in high levels in the masseter muscle [49]. It may also be explained by genetic factors involved in the transport of serotonin that act as a catalyst in the pathological expression of TMD [50].

According to the RDC/TMD [28], three of the clinical criteria for identifying limited mandibular movement are mouth opening without assistance and without pain (Item 4a of the clinical examination (Axis I)), maximum mouth opening without assistance (Item 4b of the clinical examination (Axis I)) and maximum mouth opening with assistance (Item 4c of the clinical examination (Axis I)), which were determined in the present study. An inverse relation was found between mandibular ROM and TMD severity, demonstrating that greater severity of the condition leads to less mandibular ROM, which is in agreement with findings described in a previous study [33]. According to the literature [51], mouth opening less than 40 mm is classified as limited. However, there is variation in these measurements according to the RDC/TMD regarding Items 4 a, b, and c, as mouth opening can be measured with greater or less ROM depending on the verbal command. Nonetheless, the measurements referring to Item 4a in the present study are in agreement with descriptions in the literature [51].

The predominant chewing side was the right, ranging from 58.69 to 67.30%, independently of the degree of TMD severity. This result is in agreement with findings described in the literature [52], which reports that mastication performed preferably on one side can generate muscle disorders. However, the literature also reports that so-called healthy individuals with no morphofunctional abnormalities also have a preference for chewing on one side more than the other [53]. This is also in agreement with the present findings, as the individuals in the control group (without TMD) also chewed predominantly on the right side.

Curiously, the predominant non-convergence side was also the right, suggesting an association with the predominant chewing side. In an attempt to understand this predominance, we should consider that unilateral chewing directly compromises the stomatognathic system, generating an imbalance in the forces involving in chewing as well as alterations in the dental, muscular, and skeletal systems, which can lead to facial asymmetry [54], also compromising the intraorbital and extraorbital muscles. Some authors [9–12] have conducted anatomic studies relating the nuclear complex of the trigeminal nerve to other nuclei of the brainstem, linking trigeminal function to facial, hypoglossal, and cochlear function [13–16] and found a relation to the oculomotor system. This may explain the coinciding right-side predominance of both chewing and convergence insufficiency in the present investigation.

Conclusion

Based on the findings of the present study, convergence insufficiency, age, the increase in pain, and the reduction in the mandibular range of motion were associated with the degrees of TMD severity. Despite the significant associations between convergence insufficiency and both pain and TMD severity, these variables cannot be indicated as predictive factors due to the low variability in the linear regression analysis (pain, 5%; TMD severity, 2%).

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Authors' contributions Douglas Meira dos Santos: data collection and analysis, critical revision, and final approval of the manuscript. Ludmila Menezes Alves de Azevedo: screening of participants. Rita de Cássia das Neves Martins: screening of participants. Felipe Cunha Ricci: screening

of participants. Kelly Sayuri Yun Masuda: data collection. Erika Maria Muramoto do Nascimento: data collection. Cid Andre Fidelis de Paula Gomes: conception and design and final approval of the manuscript. Fabiano Politti: data analysis. Itana Lisane Spinato: data analysis. Daniela Aparecida Biasotto-Gonzalez: conception and design, statistical analysis, manuscript writing, and final approval of the manuscript.

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Compliance with ethical standards

Conflict of interest Douglas Meira dos Santos declares that he has no conflict of interest. Fabiano Politti declares that he has no conflict of interest. Ludmila Menezes Alves de Azevedo declares that she has no conflict of interest. Rita de Cássia das Neves Martins declares that she has no conflict of interest. Felipe Cunha Ricci declares that he has no conflict of interest. Kelly Sayuri Yun Masuda declares that he has no conflict of interest. Erika Maria Muramoto do Nascimento declares that he has no conflict of interest. Itana Lisane Spinato declares that she has no conflict of interest. Cid Andre Fidelis de Paula Gomes declares that he has no conflict of interest. Daniela Aparecida Biasotto-Gonzalez declares that she has no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance Resolution number 466/12 of the Brazilian National Board of Health and received approval from the ethics committee of Nove de Julho University (certificate number 12416319.9.0000.5511).

Informed consent Informed consent was obtained from all individual participants included in the study.

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