The effect of the physiological rest position of the mandible on cerebral blood flow and physical balance: an observational study

Tammarie Heit, Carol Derkson, Jordan Bierkos & Maher Saqqur

To cite this article: Tammarie Heit, Carol Derkson, Jordan Bierkos & Maher Saqqur (2015) The effect of the physiological rest position of the mandible on cerebral blood flow and physical balance: an observational study, CRANIO®, 33:3, 195-205

To link to this article: http://dx.doi.org/10.1179/0886963414Z.00000000063
The effect of the physiological rest position of the mandible on cerebral blood flow and physical balance: an observational study

Tammarie Heit, Carol Derkson, Jordan Bierkos, Maher Saqqur

Department of Medicine (Neurology), University of Alberta, Canada

Aims: There has been much published evidence that balance can improve by changing the mandible’s position relative to the maxilla as it comes together with the teeth (or oral device) as the endpoint. To help with the complexity of this topic, a definitions table* (in Appendix) has been included at the end of the manuscript for reference as needed. The aim of the current study is to evaluate whether the physiologic rest position of the jaw* (oral device overtop of the teeth as endpoint where the muscles of mastication are optimized) can have an effect on cerebral blood flow and physical balance using measurable data relative to the person’s natural, or habitual bite (teeth as endpoint) in both healthy and diseased volunteers.

Methodology: Seven healthy male professional football athletes and two females with multiple sclerosis were included in this observational study, which tested the subjects in both jaw positions. Cerebral blood flow was measured non-invasively by ultrasound over the temporal region of the skull using mean flow velocity (MFV)* and pulsatility index (PI)* of the right and left middle cerebral arteries while the subject clenched the teeth together in both jaw positions. The MFV is the average speed of the blood flow in a given region of a blood vessel. The PI measures cerebral intravascular resistance. Physiologic balance of the whole body was also tested while the subjects were in both jaw positions using the y-excursion balance test* and by videotape.

Results: (i) Cerebral blood flow. On the natural teeth, the MFV dropped from baseline to clenching position (mean drop $2.6\pm 7.7$ cm/second, whereas, the MFV was slightly enhanced with the physiologic rest position (PRP) [mean enhancement is $0.82\pm 3.7$ cm/second ($P = 0.07$)]. At baseline on natural teeth, the PI dropped slightly from baseline to clenching (mean drop $0.015\pm 0.19$). Whereas with PRP, the PI dropped by mean of $0.059\pm 0.072$ ($P = 0.15$). (ii) Balance. The mean balance measurement while using the PRP was $119.54\pm 12.56$ cm ($P = 0.001$), whereas the mean balance measurement on natural teeth was $110.72\pm 9.47$ cm. Balance improved subjectively in both MS patients on videotape.

Conclusion: The physiologic rest position of the mandible might have an effect on balance by showing a trend (demonstrating a tendency) in enhancing cerebral blood flow as measured by transcranial Doppler. Further studies are needed to confirm this study’s finding.

Keywords: TMJ, Migraine, Headache, Balance, Multiple sclerosis, Cerebral blood flow, Transcranial Doppler

The Physiologic Rest Position of the Mandible

The human teeth can be considered the ‘top block’ of the entire posture of the individual by being the dominant entity and endpoint of the posture, as they interdigitate together during all functions of the jaw, including talking, eating, swallowing and resting. They have a highly sensitive proprioceptive feedback system that feeds directly into the center of the brain.1–11 Abnormal teeth and jaw position might lead to many neurological phenomena experienced by humans today.12 The goal of obtaining the physiologic rest position bite registration is to optimize the normal physiology of the human and allow for ‘de-accommodation’. The stomatognathic triad consists of teeth, jaw joints and muscles.13 The teeth dominate, and the muscles and jaw joints accommodate in function. The physiologic rest bite changes the dominant force of the teeth, as the focus becomes the physiological stability of the muscles, which can be measured using electromyographic studies and jaw tracking to determine a more...
optimal endpoint of the teeth. Simply put, the bite is built where the muscles have some say and the teeth support optimal muscle function.14

There has been much anecdotal evidence and case series indicating clinical improvement when the jaw is permitted to function from the physiological rest position.15 The physiological rest position of the jaw can be measured and replicated using K-7 data (EMG and jaw tracking measurements; Myotronics, Kent, WA, USA). The anecdotal evidence ranges from better balance and strength in healthy people, professional athletes and teams,16 to the elimination of headaches in balance and strength in healthy people, professional athletes and teams,16 to the elimination of headaches in migraine patients, to subjective improvement in multiple sclerosis patients,17 improvement in Parkinson’s disease symptoms, ADHD, and reduction in chronic pain, TMD and other craniomandibular disorders when a neuromuscular orthotic is worn full time.

The mechanism of action of different jaw positions is not well understood. There is a suggested vascular mechanism in an fMRI study.17 Another study suggests the bite affects cerebral regional blood volume using optical topography.18 The malpositioned bite has been thought to affect the vertebral alignment with subsequent neurological effects.19 Another more physical mechanism is when the bite posteriorizes the jaw and narrows the airway, which affects the oxygenation of the brain.20

Transcranial Doppler ultrasound (TCD) has the ability to provide non-invasive continuous monitoring of cerebral blood flow (CBF) in real time.21 It provides a dynamic real time tool for quantitative measurements of arterial flow velocity changes that reflect changes in CBF during different – lower jaw positions, if obtained at a constant angle of insonation (the angle of the Doppler to the middle cerebral artery) and during short-term monitoring of positional changes.22

The current study’s aim is to evaluate whether the physiologic rest position (PRP) can have an effect on CBF and physical balance in healthy and diseased volunteers, using measurable data relative to the person’s natural bite.

It has long been thought that the bite affects the brain. This study is meant to connect the bite (dentistry) to the brain (neurology) and measure it in a double blind study.

Materials and Methods

Subjects tested

Seven professional Canadian football players (healthy subjects) were randomly selected. The exclusion criterion was the inability to achieve high quality data on CBF measurement. As an example, one athlete was omitted from this study, as the authors were unable to assess CBF through a large volume of hair.

The two females with multiple sclerosis were included in this observational study because loss of balance is one of the hallmark symptoms, and improvement of same is significant in a diseased state as well as a healthy state.

Three mouth guards in different jaw positions were fabricated for each athlete. Written consents were obtained, and the athletes were told they were going to be tested using three different mouth guards. The balance of each athlete was tested while biting into each different mouth guard using the y-exursion balance test.23 The subject, the person taking the measurements and the recorder were all blinded as to which mouth guard was in situ. The blood flow in the brain was then measured with the transcranial Doppler while the jaw was at rest (baseline) with no mouth guard, while biting on natural teeth, at rest (baseline) with the PRP mouth guard in situ, and while biting on the PRP mouth guard.

Further observation of subjects in a diseased state was also observed by including two ambulatory female adults with multiple sclerosis who had a PRP device on their lower teeth full time. The blood flow in the brain was measured with and without the orthotic, and their change in balance was documented on videotape. The difference between systemic balance recorded on videotape between biting on the natural teeth and biting in the physiologic rest position of the jaw was too difficult to measure using data, but it can be observed. Prior to videotaping, the subject was told, ‘we would like to videotape you walking’, and all subsequent instructions were delivered during the taping.12

Method of capturing the physiologic rest position of the mandible

The protocol for capturing the physiological rest position of the jaw was described by Robert Jankelson in the test series Neuromuscular Dental Diagnosis and Treatment.24 To start, the baseline data of the patient’s presenting bite, jaw position and posture is documented using photography and K-7 data (Myotronics; Kent, WA, USA) (Fig. 1).

The patient’s muscles of mastication are then relaxed using ultra low frequency, transcutaneous electrical neural stimulation (ULF-TENS) for a minimum of 45 minutes on the fifth, seventh and eleventh cranial nerves that are accessed through the coronoid notch and the posterior triangle called the ‘Prabu’ point. The ‘Prabu Point’ is in the upper portion of the middle 1/3 of the posterior cervical triangle, just posterior to the sternocleidomastoid muscle (SCM). Cranial nerve XI innervates SCM and trapezius, and if stimulated with ULF-TENS, these muscles and their associated muscles...
can be relaxed simultaneously without risk of direct stimulation of the carotid sinus nerve (CSN).25

Panel D shows improved EMGs of the muscles of mastication in the rest position following ULF-TENs with activation of the temporalis muscles bilaterally when the patient was asked to lightly touch their teeth together (light CO) to help the clinician find the physiologic rest position. Lower EMGs indicate more stable musculature.

Following relaxation of the jaw and neck muscles, K-7 data is obtained and used to find the most relaxed position of the jaw where the muscles coordinate together, documented in a single point in space (Fig. 2).

The physiological rest jaw position is captured using K-7 data. The bite position is reproducible on both the individual and K-7 for documentation and is transferable to a laboratory articulator where the oral mandibular device (the orthotic) is fabricated with the full anatomy of occlusion. The orthotic thus positions the jaw in physiological rest position, determined by measurable data and repeatable on the patient using the measurable K-7 data.

Clinical measurement
Alginate impressions were obtained of the upper and lower arches of the teeth, poured in dental stone, and reproduced for three oral devices in the form of athletic mouth guards that fit on the upper teeth.

First device
The PRP registration was taken following K-7 protocol to determine the physiological rest position
while sitting upright in a chair as previously described. This bite was used to create teeth marks in the upper mouth guard that the lower teeth could fit into, and reflected the PRP of the athlete.

**Second device**
No bite. A mouth guard was fabricated that had a smooth occlusal (biting) surface where there were no teeth marks for the lower teeth to fit into. The lower jaw had no endpoint for the lower teeth to fit into.

**Third device**
The patient’s natural bite position was indented into the mouth guard.

The master technician of a certified dental laboratory was instructed to make three mouth guards with the following prescription:

1. make one mouth guard with no occlusion (no bite marks in the receiving surface for the mandible). Color code yellow

2. make one mouth guard using the physiologic rest position bite registration by first mounting the upper cast in HIP (using the hamular notches and incisive papilla for skeletal landmarks for mounting on the stratus articulator, then using the bite registration to relate the upper jaw to the lower jaw (Ivoclar-Vivadent; Liechtenstein). Color code red (Fig. 3)

3. Make one mouth guard with the patient’s natural bite position. Color code blue.

Only the author and lab technician, who were not involved in collecting or observing data, knew the color codes. The athletes and the volunteers gathering the statistics were not aware which mouth guard was in situ. The order of the mouth guards trialed was randomly determined by individual draw of colored paperclips from a hat.

**Balance measurement**
The Y-exursion balance test was used to determine balance. The athlete was required to balance on one foot while extending the other foot as far as possible in three directions without losing balance. Six practice stretches (two in each direction) were completed before
trailing the mouth guards. The right and left legs were tested in three directions with three marks mathematically averaged out. The standard requirements for a successful stretch were instructed and adjudicated by the volunteers who were trained in performance of the star excursion balance test. Color markers were used to mark the tapes that coordinated with the particular mouth guard used by the athlete. It was unknown to the athlete or volunteer which color code corresponded to which mouth guard (Fig. 4).

Data was gathered and results obtained for balance on the right foot, left foot and average of the two in four scenarios in random order: 1. No mouth guard; 2. No bite mouth guard; 3. Centric Occlusion; 4. Physiologic Rest Position Bite.

Balance measurements for the two female subjects with multiple sclerosis were subjective and recorded by visual analogue scale and by videotape with and without a neuromuscular orthotic in situ on the lower teeth.

Transcranial Doppler ultrasound (TCD)
The transcranial Doppler is a non-invasive device that can measure blood flow using ultrasound by placing the Doppler against the temporal region of the skull so it can detect the velocity of blood flow in the middle cerebral artery.

Transcranial PMD 100 mol/l (Spencer Technologies, Inc.; Seattle, WA, USA) was used in all TCD studies. This technology collects (1) 2-MHz spectral single-gate TCD information at a specific depth when placed against the temporal region bilaterally of the skull to detect the activity of the middle cerebral artery and (2) power M-mode information from 33 sample volumes placed at 2-mm intervals from 24 to 88 mm depth of insonation (exposure to ultrasound). The PMD display was configured with red or blue colors for directionality, and with brightness of colors to reflect Doppler signal intensity. A 2-MHz pulsed-wave transducer was used to generate simultaneous M-mode and spectral TCD displays. The transcranial PMD equipment uses an emitting transducer surface 13 mm in diameter and effectively measures CBF that can be observed clinically. The study was performed by a registered nurse trained and experienced in acquiring TCD data (Fig. 5).

The pulse repetition scale settings were 5 kHz, gain of 40 dB, and minimum dynamic range of 80 dB. Algorithms for signal intensity measurement utilized power (in decibels) of the Fourier transform coefficients; acquisition and processing parameters included a 6-mm axial sample volume length, 128 points Hanning window data taper, 128 points fast Fourier transform (16 ms), 50% fast Fourier transform overlap, 2-MHz carrier frequency, 200-Hz high-pass filter (7 cm/second), and 1 minute recording time.

An appropriate window over the temporal bone of the subject was identified prior to the procedure with a standard handheld technique. Probe fixation using a Marc 500 head frame (Spencer Technologies) was used for monitoring. Bilateral proximal middle cerebral artery (MCA) segment was insonated (measured with ultrasound). The insonation depth for spectrogram recording was between 45 and 65 mm for the unilateral MCA. Doppler waveforms were analyzed post-procedure in a blind fashion to the physiologic rest position of the jaw.

The baseline TCD blood flow velocity measurement of the bilateral MCA was obtained with the teeth apart and lower jaw at rest. Then a TCD measurement was obtained following 10 seconds of clenching on the natural occlusion. The same TCD measurement was re-obtained with the PRP mouth guard in situ at rest and 10 seconds after clenching. The TCD velocity measurements were read and recorded off line by an expert neurosonologist who was blind to the study’s stage.

The TCD blood flow velocity is a result of the Doppler shift that was generated by the movement of the blood. A special formula was used to convert the Doppler shift effect into flow velocity measurement. The peak systolic velocity (PSV), end diastolic velocity (EDV), mean flow velocity (MFV) \( \left[ \frac{\text{PSV} + \text{EDV}}{2} \right] \) and pulsatility index (PI) \( \left( \frac{\text{PSV} - \text{EDV}}{\text{MFV}} \right) \) in the bilateral middle cerebral arteries were measured at each time point (at rest, at clenching on natural teeth, at rest with PRP, and at clenching with PRP).

The relative change in flow velocities was calculated as:

\[
\left( \frac{\text{aMFV}_{\text{during procedure}} - \text{MFV}_{\text{baseline}}}{\text{MFV}_{\text{baseline}}} \right) \times 100\%
\]
Data analysis
The TCD MCA flow velocities measurements that were recorded are: PSV, EDV, MFV and PI at each time point of the MAST procedure. The velocities measurements from the transcranial Doppler were recorded separately for each vessel at different points of the procedure. The data was analyzed using SPSS (version 19). All data is expressed as mean±standard deviation. ANOVA and nonparametric tests (Mann–Whitney U test) were used for all statistical analysis. Asterisks denote a significance value of (P<0.05).

Results
Seven healthy male volunteers were included in the current study with mean age 28.5±2.7 years. Two more patients were female, average age 38, and had multiple sclerosis.
Table 1 summarized the MFV, PI and Y-excursion balance results both on natural teeth and in physiologic rest position of the jaw. Patient ID A5 is missing data because there was too much hair for the transcranial Doppler to get clear data of the middle cerebral artery. Y-Excursion balance testing was not done on MS patients.

| Patient ID | Natural teeth | | | Physiologic rest position | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Baseline (B) MFV | Clenching (C) MFV | Change MFV from B to C | Baseline (B) MFV | Clenching (C) MFV | Change MFV from B to C | Y excursion balance test (cm) | Baseline (B) PI | Clenching (C) PI | Change PI from B to C |
| A1-R | 54 | 48 | -6 | 0.73 | 0.86 | 0.12 | 109.07 | 53 | 50 | -3 |
| A1-L | 60 | 60 | 0 | 0.76 | 0.79 | 0.03 | 108.87 | 59 | 59 | 0 |
| A2-R | 64 | 62 | -2 | 0.79 | 0.80 | 0.01 | 95.67 | 61 | 65 | 4 |
| A2-L | 73 | 67 | -6 | 0.81 | 0.78 | 0.03 | 94.97 | 66 | 70 | 4 |
| A3-R | 55 | 66 | 11 | 0.68 | 0.64 | -0.04 | 114.53 | 57 | 58 | 1 |
| A3-L | 60 | 76 | 16 | 0.74 | 0.47 | -0.27 | 121.70 | 63 | 69 | 6 |
| A4-R | 55 | 43 | -12 | 0.77 | 0.70 | -0.07 | 118.97 | 56 | 55 | -1 |
| A4-L | 67 | 60 | -7 | 0.61 | 0.70 | 0.09 | 119.93 | 67 | 71 | 4 |
| A5-R | 54 | 48 | -6 | 0.73 | 0.86 | 0.12 | 109.07 | 53 | 50 | -3 |
| A5-L | 60 | 60 | 0 | 0.76 | 0.79 | 0.03 | 108.87 | 59 | 59 | 0 |
| A6-R | 55 | 58 | 3 | 0.87 | 0.95 | 0.08 | 109.27 | 50 | 49 | -1 |
| A6-L | 76 | 75 | -1 | 0.75 | 0.74 | -0.01 | 106.17 | 78 | 72 | -6 |
| A7-R | 61 | 56 | -5 | 0.83 | 0.68 | -0.15 | 122.80 | 57 | 58 | 1 |
| A7-L | 58 | 54 | -4 | 0.74 | 0.78 | 0.04 | 128.07 | 52 | 51 | -1 |
| MS1-R | 62 | 49 | -13 | 0.84 | 0.87 | 0.03 | 128.07 | 60 | 55 | -5 |
| MS1-L | 62 | 51 | -11 | 0.84 | 0.74 | -0.10 | 128.07 | 59 | 58 | -1 |
| MS2-R | 69 | 67 | -2 | 0.73 | 0.74 | 0.01 | 71 | 76 | 5 |
| MS2-L | 64 | 61 | -3 | 0.74 | 0.76 | 0.02 | 71 | 76 | 5 |
| Mean | 62.2 | 59.6 | -2.6 | 0.76 | 0.75 | 0.015 | 110.72 | 61.8 | 62.7 | 0.82 |
| Deviation (±) | 6.5 | 9.3 | 7.7 | 0.06 | 0.02 | 0.19 | 9.47 | 8.2 | 9.47 | 3.7 |

Note: A= healthy athlete. 
MS= Multiple sclerosis. 
R= Right Middle Cerebral Artery (RMCA)/Right foot for Y-Excursion test. 
L= Left Middle Cerebral Artery (LMCA)/Left foot for Y-Excursion test.
TCD flow findings
The average MFV at baseline without clenching, with clenching, PRP at baseline, PRP with clenching are: 62.18±6.5, 59.56±9.3, 61.8±8.2 and 62.7±9.47 (P=0.7), respectively.

The mean PI at baseline, clenching, baseline PRP and PRP with clenching are: 0.764±0.06 and 0.749±0.02, 0.78±0.09, 0.74±0.12 (P=0.3).

At baseline on natural teeth, the MFV dropped from baseline to clenching position. The mean drop in MFV is -2.6±7.7. In the case of the PRP, however, the MFV was slightly enhanced from baseline to clenching position. The mean enhancement in MFV in PRP from baseline to clenching is 0.82±3.7 (P=0.07).

At baseline on natural teeth, the PI slightly dropped from baseline to clenching position. The mean drop in PI is 0.015±0.19. Whereas with PRP, the PI did drop by mean of 0.059±0.072 (P=0.15) (see Fig. 6 as an example) (Table 1).

Balance findings
Improvement in balance was measured in centimeters from baseline with and without the physiologic rest device along with the other two oral devices. The mean balance while using the PRP was 119.54±12.56 cm, whereas the mean balance on natural teeth was 110.72±9.47 cm. The improvement in balance in the physiologic rest position of the jaw was measured at 8.82±11.62 cm. The P value was 0.001, meaning this data was statistically significant.

The two subjects with multiple sclerosis both reported subjective improvements in balance, which was recorded on videotape. These balance measurements were observational, and therefore anecdotal and not measurable.

Discussion
The current study revealed that the physiologic rest position of the mandible might have an effect on CBF (measured by MFV) by decreasing the intravascular resistance (measured by PI) and slightly enhancing the CBF measured by cerebral blood velocity on TCD. It should be noted that the enhancement of the MFV measurements was not statistically significant, but there was a trend of improvement and the small number of this study’s sample could explain that. These findings translated into clinical meaning by measurement of balance testing in a sample of healthy and diseased subjects. A larger study is needed to confirm these clinical findings.

The laws of optimal anatomy prepare the body for optimal physiology. Anatomy is defined as ‘the branch of biology concerned with the study of body structure of various organisms including humans’ in Gray’s Anatomy.28 Conversely, compromised anatomy produces compromised physiology in a biofeedback loop of the organism adapting to its environment.29 Evidence of compromised physiology of the stomatognathic system is found in compromised anatomy, such as abfractions and wear of the teeth, tori and malocclusion.30 The lower jaw postures from the head by an intricate sling of muscles. The teeth are the endpoint for the jaw position, which affects the position of the jaw as related to the skull (temporomandibular joints), the skull related to the spine (C1–C2), and so forth, affecting the entire posture of the individual.2,3,6,11,19,31–39

When the balance is changed (accommodation), many nerves and blood vessels that pass through small orifices and within sheaths of muscles can be compressed, and their function is compromised.40 There are four parasympathetic ganglia: the ciliary, the sphenopalatine, the submandibular and the otic ganglia. All these ganglia will receive preganglionic parasympathetic fibers from cranial nerves. Two of the four parasympathetic ganglia receive preganglionic parasympathetic fibers from the facial (VII) nerve. The facial nerve passes through the posterior space of the temporomandibular joint (greater petrosal nerve) and can be compressed in temporomandibular joint disorders.

All postganglionic fibers of the parasympathetic ganglia get to their end organs by following the trigeminal (V) nerve. The trigeminal nerve has multiple branches and highways throughout the head.41 The trigeminal (V) and facial (VII) cranial nerves are directly stimulated by TENs without teeth contact to allow the full function of the nerve and muscle anatomy to perform in optimal posture. The PRP supports this more optimal posture and allows more optimal physiology to occur.

This more optimal anatomy (posture) could lead to more optimal physiology and decrease intracranial pressure and enhance blood flow as one mechanism.

The second mechanism is the proprioceptive one
The facial nerve has all three components of nerve function: motor, sensory and parasympathetic. A branch of the facial nerve, the greater petrosal nerve, is responsible for parasympathetic innervations to several glands and sinuses, including the sphenopalatine ganglion via the tympanic plexus.

The trigeminal nerve has two sensory and one sensory/motor branch with the third division, which has a proprioceptive component from muscle spindles that go directly to the brain.
Balance is a measurement of the body’s ability to detect and respond to the environment in the ultimate neuromuscular feedback loop.\textsuperscript{11}

The connection between the sphenopalatine ganglion stimulation of the parasympathetic nervous system and blood flow in the brain has been made.\textsuperscript{42,43}

Perhaps the sphenopalatine ganglion is allowed its optimal stimulation naturally by enhanced body posture in the case of this study, which only changed the jaw position.

The physiologic jaw position provides a more eloquent and complete restoration of the lower jaw posture in six dimensions to allow for the best anatomical relationships within the system of posture. It addresses the jaw position vertically, antero-posteriorly, laterally, pitch of the mandible, yaw of the mandible and roll of the mandible in functional movement, with respect to the cranial base to using the teeth as the endpoint.\textsuperscript{44}

It could be that the sophisticated, proprioceptive feedback loop to the sphenopalatine ganglion, etc. is optimized in the physiological rest position, which provides for a cascade of more efficient physiology manifestations within the anatomical complex.

This may explain the myriad of subjective and objective reports clinically from dentists using the neuromuscular orthotic.

The current study’s limitation is, first, a small sample size. A large sample size might have shown more significant results. Second, TCD measures blood flow velocities and not the actual cerebral perfusion flow in the brain tissues. However, the intracranial flow velocity can reflect CBF, and the velocity changes can be proportional to changes in CBF tissue as long as the following factors are taken into consideration during the TCD monitoring: the angle of insonation (the angle between the ultrasonic probe and the insonated vessel) remains constant, the perfusion territory remains the same, and the effect of only one stimulus is observed.\textsuperscript{45} In the current study, the authors tried to account for these factors in all cases during the TCD-monitoring.

In conclusion, the PRP of the jaw might have an effect on balance by enhancing CBF as measured by transcranial Doppler. Further studies are needed to confirm this study’s findings.

Disclaimer statements

Contributors TH, CG and JB performed the study. TH and MS drafted and approved the manuscript. Rob Heuvelink from Aurum Ceramics supplied the mouthguards.

Funding None.

Conflicts of interest None.

Ethics approval None.

Appendix

*Definitions table*

EMGs (electromyography): a method to record action potential from human muscle fibers in healthy and diseased patients using surface or needle electrodes.

PRP (physiologic rest position): the position of the mandible relative to the maxilla while in optimal sitting posture following relaxation of the muscles of mastication using TENs. It is maintained with use of an orthotic placed on the lower teeth, which is fabricated using biomedical instrumentation that evaluates EMGs of the muscles of mastication, tracking of the jaw during function and sonography of the jaw joints.

TENS (transcutaneous electrical neural stimulation): low frequency stimulation of the afferent nerve that produces involuntary muscle contraction every 1.5 seconds. The purpose is to establish equilibrium of the muscle fibers at their resting length.

MVF (mean flow velocity): the average speed (cm/second) of the blood that flows through a specified area of a blood vessel; in this case, the middle cerebral artery. It is detected by use of the transcranial Doppler (ultrasound).

PI (pulsatility index): measurement of the cerebral intravascular resistance of the middle cerebral artery, which is influenced by many mechanisms, including the autonomic nervous system. It is calculated as PSV-EDV/MVF.

PSV (peak systolic velocity): the highest velocity of the blood flow through the middle cerebral artery, as measured by the transcranial Doppler (produced by contraction of the heart).

EDV (end diastolic velocity): the lowest velocity of the blood flow through the middle cerebral artery, as measured by the transcranial Doppler (produced by the relaxation of the heart).

Prabu Point: The ‘Prabu Point’ is in the upper portion of the middle 1/3 of the posterior cervical triangle, just posterior to the sternocleidomastoid muscle (SCM). Cranial nerve XI innervates SCM and trapezius, and if stimulated with ULF-TENS, these muscles and their associated muscles can be relaxed simultaneously without risk of direct stimulation of the carotid sinus nerve (CSN). Electric stimulation of the CSN activates the carotid baroreflex resulting in a dangerous drop in blood pressure and heart rate.\textsuperscript{25}
K-7 data: Data obtained using biomedical instrumentation from Myotronics (Kent, WA, USA), which includes the tracking of the mandible in function in six dimensions (antero-posterior, vertical, lateral, pitch, yaw and roll). It also includes sonography of the temporomandibular jaw joints and electromyography. The data is used to assist in diagnosis and treatment of craniofacial disorders.

Y-excision balance test: a clinical evaluation of balance while standing and performing specified movements on each leg, which can be measured. The y-excision balance test is a thoroughly researched and easy way to test functional symmetry of the lower quarter of the human body. It is used to test athletes as a predictor of lower extremity injury as well as pre-participation and return to sport decision making.

TCD (transcranial Doppler): a medical ultrasound device that can accurately measure the pulsatile flow of blood through the middle cerebral arteries, from Spenser Technologies Inc. (Seattle, WA, USA). It is used clinically to aid in diagnosis and treatment results of stroke patients.

Angle of insonation: the angle at which the Doppler of the TCD device is held while obtaining ultrasound data from the middle cerebral artery via the temporal region of the skull. This is the angle where the best waveform is obtained for recording of clinically significant data used to determine blood flow velocity.

Insonated: the exposure (of the middle cerebral artery) by ultrasound.

Depth of insonation: the depth of the ultrasound measurement into a tissue.

References
7 Gerwer JW. Orthodontic course manual. LVI Neuromuscular Functional Orthodontics. 2007;11(11).


