# Shortened Dental Arch and Cerebral Regional Blood Volume: An Experimental Pilot Study with Optical Topography

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ABSTRACT: A shortened dental arch without posterior occlusal support has been thought to maintain sufficient oral function. The mechanism of occlusal adaptation with a shortened dental arch is unclear. For a better understanding of the effects of molar teeth on brain function, the authors combined experimentally-shortened dental arches and a neuro-imaging technique. Regional cerebral blood volume was measured using near-infrared optical topography during maximum voluntary clenching tasks from 10 subjects on individually fabricated oral appliances, which can create experimentally complete and shortened dental arches. Results suggested that clenching on the complete dental arch showed a significantly higher brain blood volume than that on the shortened dental arch. Moreover, there were no differences between the two splints in the latency to the maximum oxyhemoglobin concentration. These findings suggest that occlusal status is closely related to brain blood flow and lack of occlusal molar support rapidly reduces cerebral blood volume in the maximum voluntary clenching condition.

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A shortened dental arch (SDA) without molar support has been thought to provide enough oral function by many researchers.[1-4] It is frequently seen as molars are often lost due to periodontal disease and dental caries. Naturally, biological systems have the ability to adapt to changing circumstances; this condition may lead to a new occlusal equilibrium.[1] However, reduced occlusal support may be considered a risk for occlusal instability as extensive and uncontrolled migration of the teeth might occur leading to collapse of the bite and further breakdown of dentition.[5-8] Although clinical studies show that SDA does not jeopardize occlusal instability, little is known about the adaptation mechanisms of occlusal equilibrium after loss of teeth. The authors' hypothesis is that the occlusal equilibrium may have a relationship with the central nervous system; therefore, it is important to find the link between occlusal status and brain condition. Cortical regulation of oral function is poorly understood because the application of brain-imaging methods such as functional magnetic resonance imaging (MRI) or positron emission tomography (PET) is difficult because of head motion or noises. Several brain imaging studies suggest that occlusal status is related to cerebral blood flow.[9-12] Improvement in occlusal condition with an implant prosthesis can increase cerebral blood volume.[13] For that reason, reduced dentition may have some effect on cerebral blood volume. In this study, the authors investigated functional brain imaging of experimentally-reduced dental arches during maximum voluntary clenching tasks using multi-channel near-infrared spectroscopy, a technique that permits measurement of cerebral hemoglobin oxygenation in response to brain activation through the intact skull without subject constraint.

The purpose of the present study was to investigate the difference in regional brain blood volume between a complete dental arch (CDA) and SDA with maximum voluntary clenching tasks.

## Materials and Methods

*Subjects*

Ten Japanese healthy participants [mean age, 28.3±3.1 (SD) years, seven males and three females who had individual normal occlusion] were evaluated in this study. Informed consent was obtained before the initiation of the experiments. The ethical committee of Kyoto University approved these experiments.

*Intra-Oral Appliance*

Stabilization splint-like mandibular oral appliances were fabricated for each patient with copolyester foil (two mm thick, 120 mm diameter, Erkodur, Erkodent, Germany). The occlusal surfaces were adjusted so that simultaneous and evenly distributed contact of teeth was obtained when the subjects closed their jaws. The appliances were then separated bilaterally between the first and the second premolars (**Figure 1**). The mean thickness of the appliances was 1.0±0.2 mm at the first molars.

*Near-Infrared Optical Topography*

A near-infrared optical topography was used, which is an effective method for examination of the cortical hemodynamic responses to stimuli lasting several seconds.[14-15] A Hitachi ETG-100 optical topography (Hitachi Medical, Tokyo, Japan) device was used to record brain activity and optical properties of brain tissue simultaneously from 24 channels and could estimate the changes in the concentration of oxyhemoglobin (oxy-Hb), deoxyhemoglobin (deoxy-Hb) and total hemoglobin (total-Hb) in response to stimulation with a 0.1 -s time resolution. The detailed experimental setting has been previously described.[13] The imaging of reflected light as a measure of neural activity has widespread use in the study of the functional architecture of the cortex.[16] **Figure 2** shows a schematic mechanism of the optical topography. The relative change in total-Hb was evaluated, which means blood volume, from an arbitrary zero baseline at the start of the measurement period on the basis of the Lambert-Beer law.[17] The exact optical path length of the light traveling through the brain tissue was not known; the unit of these values was molar concentration multiplied by length (mmolxmm). A pair of 3x3 arrays with five incident and four detection fibers was placed, and the probes of the optical topography were attached to the bi-lateral temporal area cortex.

*Experimental Task Procedure*

Subjects were allowed to assume the most comfortable posture, and the optical topography probes were mounted on a flexible cap over the right and left temporal areas of each subject's head. A CDA splint was set for each subject. All subjects were instructed to minimize head movements. During measurements, subjects alternated between 30 s of rest (off) and 10 s of a maximum voluntary clenching (on) task for a total of five times for 200 s. Each session consisted of 400 scans with a complete duration of 200 s. The scanner was in the acquisition mode for 40 s before each series to achieve a steady state. The subjects were requested to perform the task. After finishing the tasks, the molar region splint was removed, which was simulated experimentally by SDA. To avoid any effects related to muscle fatigue, breaks were given between the sessions. The same tasks were repeated for the SDA splint.

*Analysis*

The raw data from individual channels were digitally filtered at 0.02 Hz to remove the long-time baseline drift due to artifacts. By averaging the time series over epochs, the hemodynamic response of each channel was obtained. The mean values of maximum minus minimum concentration of oxy-Hb during the tasks in each channel were calculated. Thus, mean hemodynamic responses of each channel for the whole measured area were statistically compared between CDA and SDA. Additionally, two-dimensional spline interpolation were executed on the basis of the spatial arrangement of channels and spatiotemporal hemodynamic response as a series of images were obtained. The latency to maximum blood volume, after starting the clenching task, was measured with CDA and SDA, respectively. The data were recorded on a personal computer and analyzed with JMP for Windows (Software 5.1, SAS Institute Inc., Cary, NC, USA). Differences in the mean of continuous measurements were tested using a paired t-test. A p-value <0.05 was considered to indicate statistical significance.

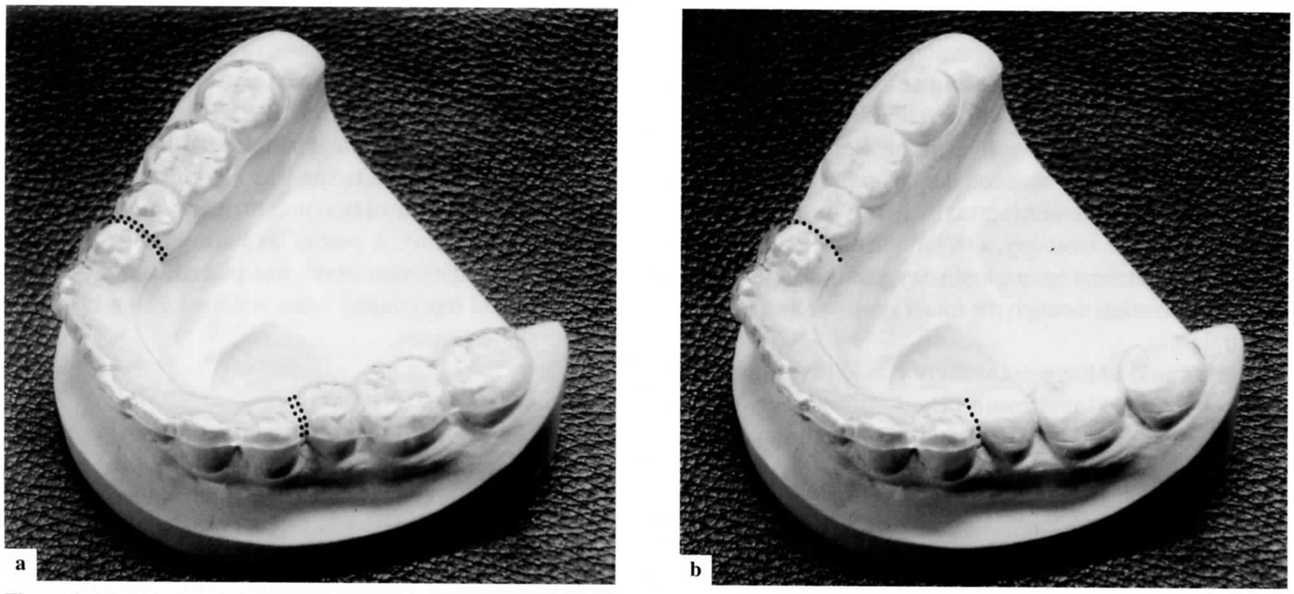


**Figure 1**
A full-arch mandibular oral appliance (**a**) separated the first and second premolars (dotted lines). A whole splint (**a**) was recognized as a complete dental arch (CDA) and a splint without bilateral posterior parts (**b**) was an experimentally shortened dental arch (SDA).

## Results

The authors obtained data from all subjects. An event-related increase in Hb volume was evident, and all subjects showed significant changes over the temporal cortex, which was consistent with the expected location of the masticatory cortex. **Figure 3a** displays typically measured mean signal changes of the task at 24 channels in the bilateral cortex of a subject. In response to the maximum voluntary clenching task, distinctive increases in total-Hb, oxy-Hb and deoxy-Hb with high contrast were observed in all subjects (**Figure 3b**, **c**). The degree of Hb concentration of 24 channels during tasks ranged widely. The mean oxy-Hb of cerebral blood volume of each channel in the whole measured area is shown in the **Table 1**. The mean oxy-Hb concentration was 0.482±0.087 (SEM)

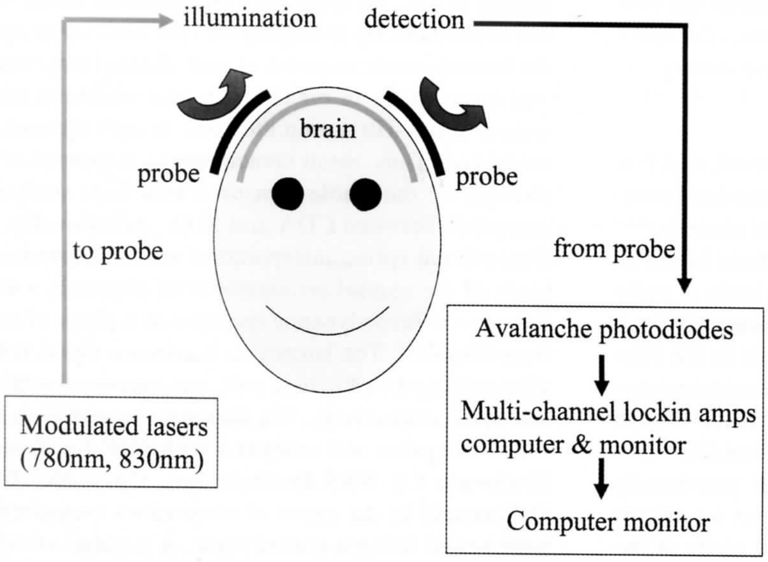


**Figure 2**
Optical topography consists of three parts. The light source generates a laser beam through optical fibers. The probe directs the modulated laser light onto the subject's head at the predetermined position and receives the reflection from the cranium. Reflected light goes to the photodiodes through the fibers. The third component is the controller, which converts optical signals into electrical signals. The probe consists of a soft plastic board on which the optical fibers are connected. The picture shows a pair of probe gears which measure both hemispheres simultaneously. The image represents the location of the optical topography probes attached to the bilateral temporal area.

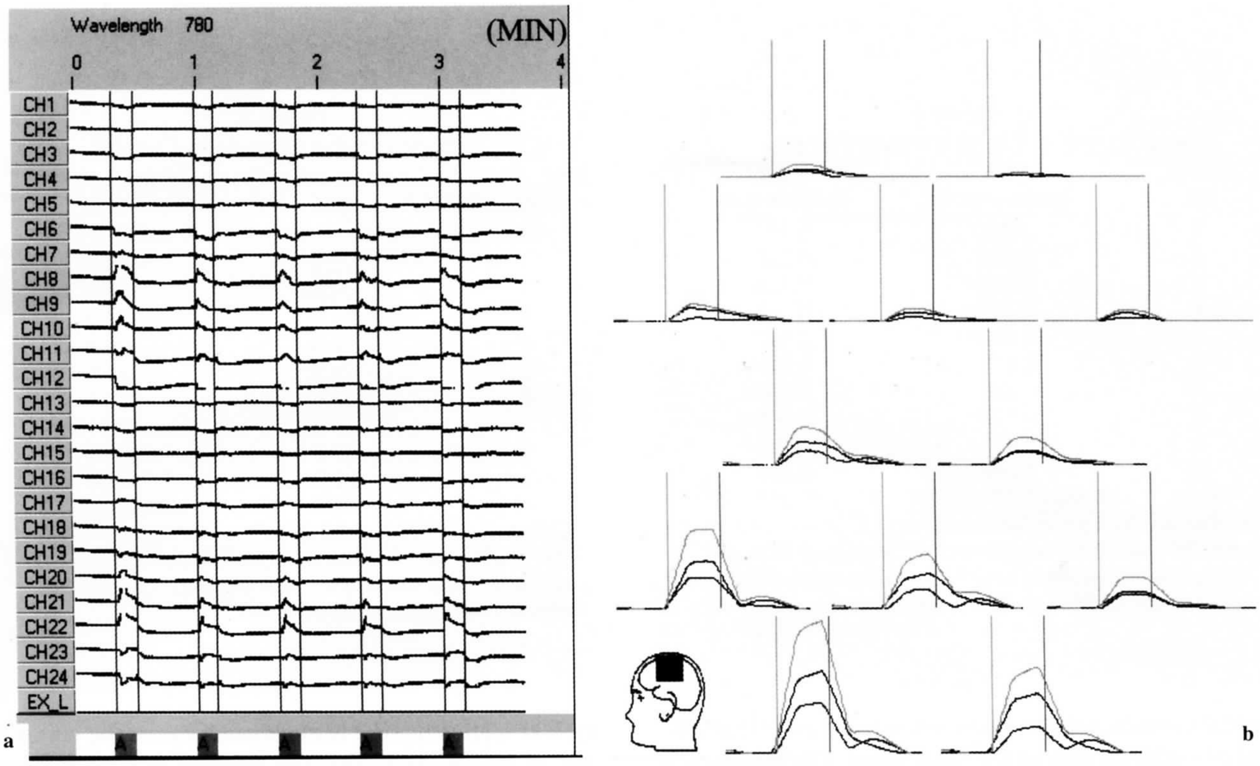


**Figure 3**
(**a,** above left) The graphic shows continuous hemoglobin concentration of the measured area with 24 channels during the tasks. Cerebral blood volume is clearly changing corresponding to the tasks. "A" means the 10 seconds of clenching task. (**b**, above right) The plot graph shows the average concentrations of the mean oxy-Hb (black line), deoxy-Hb (gray line) and total Hb (faint line) (mMol x mm) for successive 40 s windows of five clenching tasks for the left 12 channels over the bi-lateral cortex of a subject. The schematic illustration shows the left probe of the cerebral temporal cortex ( **c**, below) Typical signal change of one channel between CDA and SDA. The left vertical line indicates the start of the clenching task and the right vertical line shows the end of the task. The increase in Hb concentration is clear after starting the task for consecutive 10 s windows and the CDA splint showed a higher hemoglobin concentration than SDA.

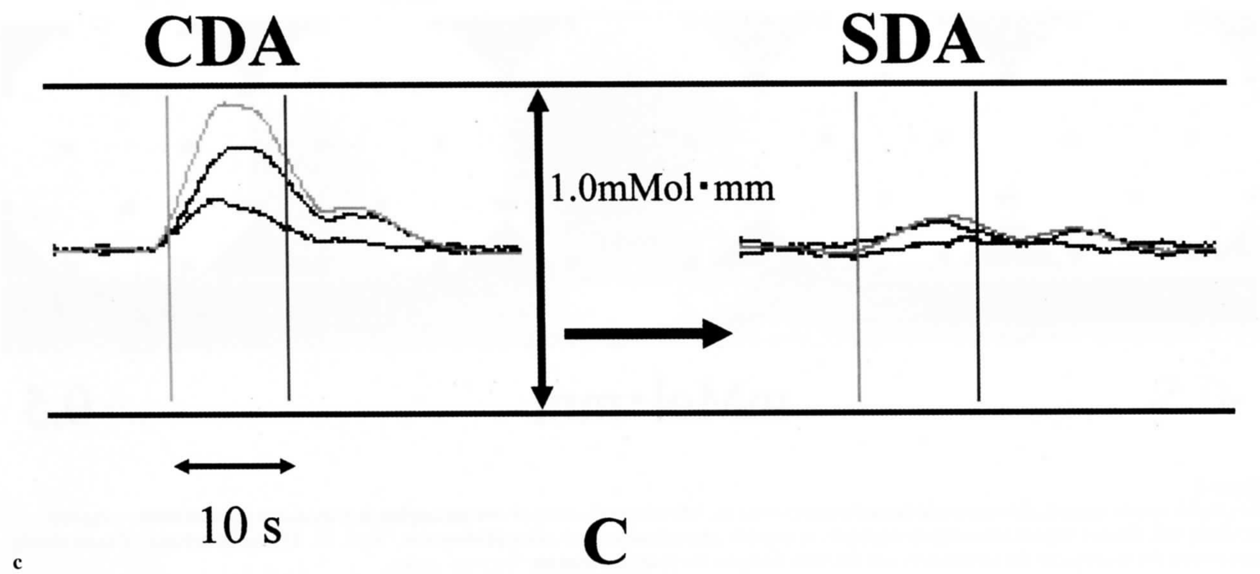

**Table 1**
Mean Cerebral Blood Volume Per Channel

| Subject No. | CDA (mMol x mm) | SDA (mMol x mm) |
|---|---|---|
| 1 | 0.726 | 0.197 |
| 2 | 0.247 | 0.295 |
| 3 | 0.663 | 0.325 |
| 4 | 0.230 | 0.155 |
| 5 | 0.589 | 0.347 |
| 6 | 0.271 | 0.247 |
| 7 | 0.433 | 0.356 |
| 8 | 0.165 | 0.145 |
| 9 | 0.451 | 0.205 |
| 10 | 1.040 | 0.880 |
| Mean | 0.482±0.087 (SEM) | 0.315±0.067 (SEM) |

Individual changes in measured oxy-Hb concentrations after the maximum voluntary clenching tasks CDA and SDA. The increases in oxy-Hb with CDA were significantly higher than for SDA (p<0.01: paired *t*-test).

**Table 2**
Latency to the Maximum Oxy-Hb Change After Each Task

| Subject No. | CDA (mMol x mm) | SDA (mMol x mm) |
|---|---|---|
| 1 | 20.9 | 21.2 |
| 2 | 21.5 | 25.0 |
| 3 | 21.4 | 25.0 |
| 4 | 19.9 | 20.3 |
| 5 | 20.9 | 22.5 |
| 6 | 21.8 | 21.1 |
| 7 | 20.3 | 20.1 |
| 8 | 20.2 | 20.5 |
| 9 | 20.3 | 22.2 |
| 10 | 20.4 | 19.7 |
| Mean | 20.8±0.20 (SEM) | 21.8±0.61 (SEM) |

The latency period to the maximum regional oxy-Hb concentration after starting the task showed no significant differences between CDA and SDA.

mMol x mm on the CDA splint, whereas it was 0.315±0.067 (SEM) mMol x mm on the SDA splint. The increases in oxy-Hb with CDA were significantly higher than for SDA (t=3.00, p<0.01; paired *t*-test). **Figure 4** presents typical spatiotemporal hemodynamics over the cortex in response to the task. The data revealed that the response to the task was vigorously detected as a localized increase in oxy-Hb concentration on the cortex. The latency to the

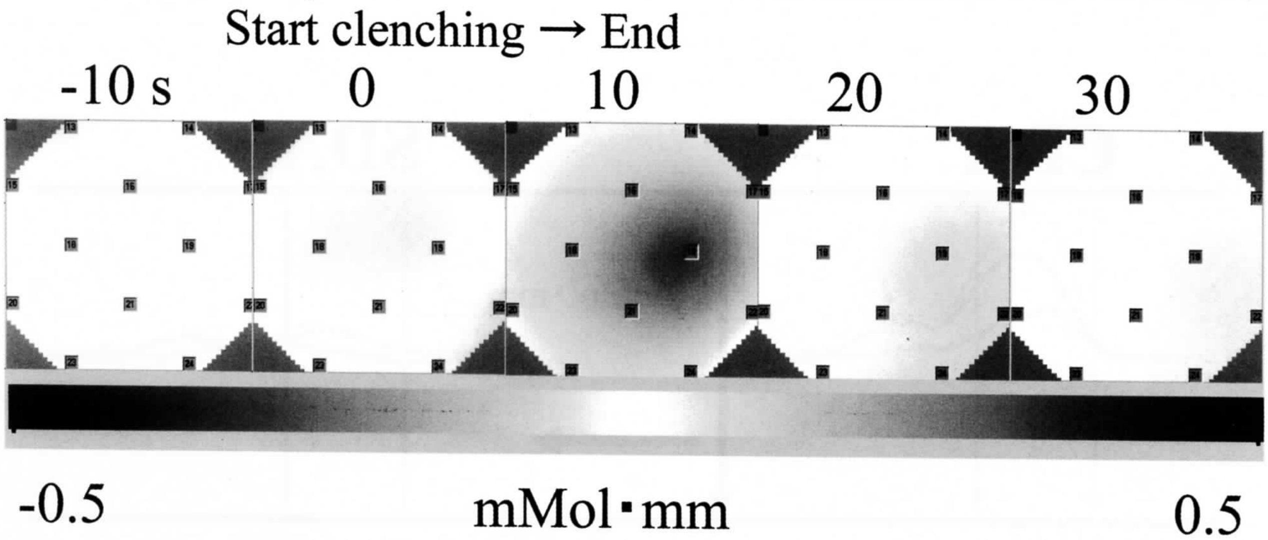


**Figure 4**
The graphic shows typical spatiotemporal hemodynamics over the left temporal cortex of one participant in response to the maximum voluntary clenching task. Darker shaded areas denote increases in oxy-Hb concentration. The series of images at -10, 0, 10, 20, and 30 seconds of tasks clearly demonstrate the response to the stimulation and the slow decay of the response over the temporal cortex.

maximum alteration from starting of the task is also shown in **Table 2**. The maximum latency of the oxy-Hb concentration was 10.8±0.20 (SEM) s after the task in CDA, while it was 11.8±0.61 (SEM) s in SDA. There were no statistically significant differences between these two conditions (t=1.99, p=0.961; paired *t*-test).

## Discussion

The study found that event-related increases in oxy-Hb were evident in localized areas of the temporal cortex and in the level of blood volume in maximum voluntary clenching tasks. The increase was significantly lower with SDA than with CDA. These results show that near-infrared optical topography is a method for investigating the cortical mechanisms of masticatory function.

The SDA concept has been controversial. Due to the reduced support, SDA may be susceptible to occlusal instability and may result in occlusal collapse. Moreover, it increases the risk of temporomandibular disorders and periodontal breakdown in the residual teeth, both of which are thought to be a consequence of excessive mechanical loading.[5-8] In the current study, the cerebral blood volume on the CDA was higher than that on the SDA with a voluntary clenching task in healthy subjects. The precentral cortex is important in controlling the strength of muscular contraction in monkeys.[18] Other studies suggested that occlusal muscle contraction is related to the periodontal afferents during cortically induced rhythmic jaw movements in a rabbit model.[19] A possible explanation for these results is that lack of molar support in SDA has fewer impulses from periodontal mechanoreceptors. Therefore, clenching on the SDA splint showed reduced cerebral blood volume immediately after removal of the molar part of the splint.

It has also been suggested that bite force in the CDA is the greatest in the most posterior tooth of the dental arch, and if the most posterior tooth is missing, the next anterior tooth will increase the occlusal force.[20] Excessive occlusal force may induce occlusal pain in the healthy occlusal status, so the negative feedback effect from the periodontal ligament might reduce occlusal force corresponding to the capacity of the new most posterior tooth. Consequently, when the most posterior tooth is missing, immediately occlusal adaptation will occur. In this study, the bite force was not measured simultaneously. Regional increases in brain neuronal activities are related to biting force.[10] It is uncertain whether there is a reduction in the increase in afferents from the periodontal mechanoreceptors. The most suitable region to detect information is 30 mm from the original illuminated points for optical topography. The effect of contamination by temporal muscle activity could not be excluded completely in this study.

Alternatively, there is a possibility that the clenching task induces direct hemodynamic effect to the circulation. The task might increase venous pressure and decrease blood flow to the heart. However, Hasegawa[21] reported that task-induced change in general circulation appeared to have less influence on cerebral blood flow than other factors, because heart rate increased significantly in the on-task and post-task periods of jaw movement with Doppler ultrasound examination during clenching, gum chewing and tapping.

Taken together, neuromuscular regulatory systems may control maximum clenching strength immediately after loss of occlusal support with a reduction in cerebral blood volume. However, there is no information on the detailed mechanism of this system in humans. This is a very early pilot study, and further research with controlled biting force and muscle activity with a higher number of subjects is needed to investigate the relationship between occlusal force and cerebral blood volume.

## References


1. Käyser AF: Shortened dental arches and oral function. *J Oral Rehabil* 1981; 8:457-462.
2. Witter DJ, Creugers NH, Kreulen CM, de Haan AF: Occlusal stability in shortened dental arches. *J Dent Res* 2001; 80:432-436.
3. Sarita PT, Kreulen CM, Witter D, Creugers NH: Signs and symptoms associated with TMD in adults with shortened dental arches. *Int J Prosthodont* 2003; 16:265-270.
4. Kanno T, Carlsson GE: A review of the shortened dental arch concept focusing on the work by the Kayser/Nijmegen group. *J Oral Rehabil* 2006; 33:850-862.
5. Luder HU: Factors affecting degeneration in human temporomandibular joints as assessed histologically. *Eur J Oral Sci* 2002; 110:106-113.
6. Tallents RH, Macher DJ, Kyrkanides S, Katzberg RW, Moss ME: Prevalence of missing posterior teeth and intraarticular temporomandibular disorders. *J Prosthet Dent* 2002; 87:45-50.
7. Wöstmann B, Budtz-Jøgensen E, Jepson N, Mushimoto E, Palmqvist S, Sofou A, Owall B: Indications for removable partial dentures: a literature review. *Int J Prosthodont* 2005; 18:139-145.
8. Nassani MZ, Devlin H, McCord JF, Kay EJ: The shortened dental arch—an assessment of patients' dental health state utility values. *Int Dent J* 2005; 55:307-312.
9. Onozuka M, Fujita M, Watanabe K, Hirano Y, Niwa M, Nishiyama K, Saito S: Age-related changes in brain regional activity during chewing: a functional magnetic resonance imaging study. *J Dent Res* 2003; 82:657-660.
10. Onozuka M, Fujita M, Watanabe K, Hirano Y, Niwa M, Nishiyama K, Saito S: Mapping brain region activity during chewing: a functional magnetic resonance imaging study. *J Dent Res* 2002; 81: 743-746.
11. Tamura T, Kanayama T, Yoshida S, Kawasaki T: Functional magnetic resonance imaging of human jaw movements. *J Oral Rehabil* 2003; 30:614-622.
12. Tamura T, Kanayama T, Yoshida S, Kawasaki T: Analysis of brain activity during clenching by fMRI. *J Oral Rehabil* 2002; 29:467-472.
13. Miyamoto I, Yoshida K, Tsuboi Y, Iizuka T: Rehabilitation with dental prosthesis can increase cerebral regional blood volume. *Clin Oral Implants Res* 2005; 16:723-727.
14. Maki A, Yamashita Y, Ito Y, Watanabe E, Mayanagi Y, Koizumi H: Spatial and temporal analysis of human motor activity using noninvasive NIR topography. *Med Phys* 1995; 22:1997-2005.
15. Taga G, Asakawa K, Maki A, Konishi Y, Koizumi H: Brain imaging in awake infants by near-infrared optical topography. *Proc Natl Acad Sci USA* 2003; 100:10722-10727.
16. Frostig RD, Lieke EE, Ts'o DY, Grinvald A: Cortical functional architecture

and local coupling between neuronal activity and the microcirculation revealed by in vivo highresolution optical imaging of intrinsic signals. *Proc Natl Acad Sci USA* 1990; 87:6082-6086.
17. Villringer A, Chance B: Noninvasive optical spectroscopy and imaging of human brain function. *Trends in Neurosciences* 1997; 20:435-442.
18. Hoffman DS, Luschei ES: Responses of monkey precentral cortical cells during a controlled jaw bite task. *J Neurophysiol* 1980; 44:333-348.
19. Hidaka O, Morimoto T, Masuda Y, Kato T, Matsuo R, Inoue T, Kobayashi M, Takada K: Regulation of masticatory force during cortically induced rhythmic jaw movements in the anesthetized rabbit. *J Neurophysiol* 1997; 77:3168-3179.
20. Hattori Y, Satoh C, Seki S, Watanabe Y, Ogino Y, Watanabe M: Occlusal and TMJ loads in subjects with experimentally shortened dental arches. *J Dent Res* 2003; 82:532-536.
21. Hasegawa Y, Ono T, Hori K, Nokubi T: Influence of human jaw movement on cerebral blood flow. *J Dent Res* 2007; 86: 64-68.

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