Int J Clin Exp Med 2018;11(6):5894-5902
www.ijcem.com /ISSN:1940-5901/IJCEM0064716

Original Article

Preliminary research on activating cerebral cortex with premature contact on tooth

Chun-Hua Yu[1,2,3], Wei-Jun Tang[4], Fu-Qiang Zhang[1,2,3]

[1]Department of Prosthodontics, Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai, China; [2]Shanghai Key Laboratory of Stomatology and Shanghai Research Institute of Stomatology, Shanghai, China; [3]National Clinical Research Center of Stomatology, Shanghai, China; [4]Department of Radiography, Hua Shan Hospital, Fu Dan University, Shanghai, China

Received August 30, 2017; Accepted March 28, 2018; Epub June 15, 2018; Published June 30, 2018

Abstract: Functional magnetic resonance imaging (fMRI) has been used to show a relationship between the occlusal function and brain activity among several kinds of modalities. The aim of this fMRI study was to investigate the clenching-induced regional activation within the brain correlated with both the presence and location of a premature contact on the teeth during clenching. Fifteen volunteers participated in this research. An experimental premature contact was created using composite resin and applied to every subject. The blood-oxygenation-level-dependent (BOLD) signals were recorded using fMRI on each subject. Recordings were made on each of subjects during each of the following: (1) Normally voluntary clenching, (2) Clenching with premature contact on lower first molar, and (3) Clenching with premature contact on lower canine. Statistical difference was then examined between each of the three groups. In the voluntary clenching group, the sensory cortex, motor cortex, pre-motor cortex, pre-frontal cortex, Broca's area, supramarginal gyrus, cingulate gyrus, cerebellum and insula were activated. A significant reduction in activated areas was found in the clenching groups with premature contacts. The discrepancy of BOLD signals was also found in prefrontal cortex, supramarginal gyrus, cerebellum and insula between the clenching with premature contact on first molar and canine. Both the presence and location of a premature occlusal contact could reduce the number of activated areas in the brain as seen using fMRI.

Keywords: Tooth clenching, functional magnetic resonance imaging, premature contact, brain activation, human

Introduction

In the early 1980s, several experiments on animals had been carried out to show a relationship between the occlusal function and brain activity through several kinds of modalities (e.g. electroencephalograph, electrophysiology, and lobotomy) [1-3]. After the advent of functional magnetic resonance imaging (fMRI), more evidence have been revealed regarding experiments on human subjects. Tamura et al [4, 5] found the activated areas in sensory cortex, motor cortex and premotor cortex during clenching, gum chewing, and teeth tapping. Onozuka et al [6] further conducted an experiment with fMRI and concluded that the intensity of blood-oxygenation-level-dependent (BOLD) signals were affected by occlusal force. In 2011, Markus et al [7] placed custom-made splints in human subjects to examine the brain regional BOLD signals under malocclusion. Significant differences were found between normal and malocclusion in the amygdala and prefrontal areas. They also recognized the increasing BOLD signal in the prefrontal area as the simulated malocclusion became more severe. fMRI is a non-invasive technique with high spatial and temporary resolution [8]. For this reason, it has become increasingly popular for cognitive research as a tool for occlusion that processes sensory and motor signals in the brain. In this study, fMRI was used to test two malocclusion models with premature contact located on either an anterior or posterior tooth. Clenching under normal occlusion was included as a control. We compared all results in order to investigate how the location of malocclusion affects the brain cortex activities.

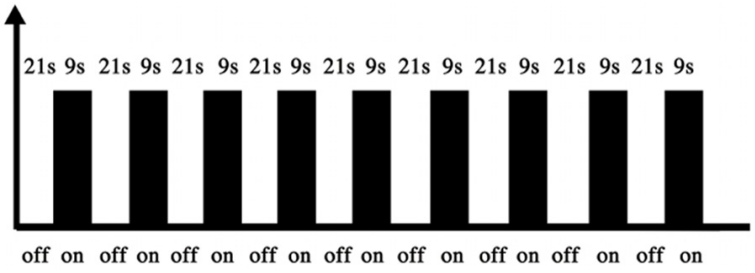

Figure 1. Sketchy map of block design. "Off" denotes in rest. "On" denotes in task, means 21 seconds for rest, clenching 9 seconds for task, and going alternately. Every circle is 30 seconds. Whole test involves nine circles; duration of total test is 270 seconds.

Table 1. The activated region in the brain during clenching in normal or with premature contact

	Normal Contact	Premature Contact on the first molar	Premature Contact on the canine
Primary sensory cortex (Right)	A	A	N
Primary sensory cortex (Left)	A	A	A
Primary motor cortex (Right)	A	A	A
Primary motor cortex (Left)	A	A	A
Premotor cortex (Right)	A	A	N
Premotor cortex (Left)	A	A	A
Prefrontal cortex	A	A	N
Broca's area (Right)	A	A	A
Broca's area (Left)	A	A	N
Insula	A	A	N
Supramarginal gyrus	A	A	N
Cerebellum (Right)	A	A	N
Cerebellum (Left)	A	N	N
Cingulate gyrus	A	N	N

'A' means activated; 'N' means none.

Material and methods

Subjects

Fifteen healthy volunteers were involved in this research (8 males and 7 females, aged 23 to 33, mean age is 27.87). All subjects were right-handed, with class I occlusion relationship in the absence of history of somatic, psychological disorders and temporomandibular dysfunction (TMD). Subjects with missing teeth, unilateral chewing, or noncooperation were excluded. Explanation of aims and method of study were provided to every subject before written informed consent was approved by the Committee for Research Ethics of Ninth People's Hospital affiliated to Jiao Tong University, Shanghai, China.

Artificial intervention

After each subject's examination, impressions of maxillary and mandibular dentition were made and poured into plaster models that were mounted to an articulator (Handy, SHOFU, JAPAN). Light-cured composite (Filtek 2250, 3 M ESPE, U.S.A) was used to make premature contact on the tip of the lower right canine and mesial cusp of lower first molar. The contact was then trimmed so that the composite premature contact was 1 mm high and verified using a caliper.

fMRI scanning

The experiment utilized block design. Testing consisted of nine cycles of 9-sec voluntary maximum clenching following a 21-sec resting period (**Figure 1**). The total task lasted four minute and thirty seconds. Every subject performed three tasks including normal clenching, clenching with premature composite contact on the canine, and clenching with a premature composite contact on the first molar. Between each task, the subject was instructed to wait at least 30 minutes before performing the next one in order to avoid any influence from the previous task. Three dimensional anatomy images and functional images were achieved with a Signa VH/i 3.0T system (GE, Waukesha, U.S.A.). The functional images composed of echo-planar image volumes sensitive to BOLD contrast in the axial orientation (TE = 45 ms, TR = 3000 ms). The volume included the entire brain with a 64*64 matrix and continuous slices of 5 mm thickness.

Statistical analysis

All of the images were manipulated by SPM2 on Matlab 7.0.1 (The MathWorks, Torrance, U.S.A.). Head motion was corrected by realigning with the first phase image and functional images were matched with anatomical images

Table 2. Result of localization of activated regions in the brain under normal clenching

Number of Voxels	Max. coordinates			T	p
7	0	-68	-34	4.3	<0.001
62	24	-64	-30	6.55	<0.001
5	-10	-64	-22	4.25	<0.001
5	-16	-66	-20	5.52	<0.001
6	20	-50	-14	4.7	<0.001
7	-22	-82	-8	5.87	<0.001
6	44	8	-4	4.12	<0.001
53	46	28	-6	6.53	<0.001
6	42	16	-6	5.35	<0.001
758	-54	-8	44	8.81	<0.001
543	48	-6	18	7.08	<0.001
9	48	8	2	4.63	<0.001
5	40	14	6	4.52	<0.001
63	-54	26	20	5.6	<0.001
20	-16	-66	8	4.39	<0.001
7	-36	26	8	5.33	<0.001
7	42	26	12	5.99	<0.001
9	42	40	10	4.86	<0.001
5	24	-62	8	4.61	<0.001
7	-46	24	12	5.2	<0.001
5	-6	-70	12	5.64	<0.001
6	-32	-6	14	4.73	<0.001
13	-52	-30	24	4.87	<0.001
7	34	-4	18	5.48	<0.001
8	42	34	20	4.77	<0.001
11	50	-34	22	4.83	<0.001
5	42	-20	22	4.52	<0.001
7	52	20	22	5.39	<0.001
5	-46	36	20	4.45	<0.001
6	-54	-44	26	4.77	<0.001
6	-60	-18	24	3.44	<0.001
154	58	-22	32	7.07	<0.001
9	38	30	30	5.38	<0.001
10	48	-20	32	5.38	<0.001
6	40	-16	32	5.11	<0.001
6	58	-40	36	4.85	<0.001
99	44	-40	62	6.05	<0.001
8	10	-80	36	4.71	<0.001
7	40	-52	38	5.97	<0.001
46	-62	-32	42	6.39	<0.001
7	48	-28	38	4.09	<0.001
37	42	-10	46	5.68	<0.001
7	-60	-40	38	5.15	<0.001
5	-38	4	42	4.48	<0.001
5	10	10	36	4.85	<0.001
5	-44	12	36	3.5	<0.001
11	-34	-16	42	5.45	<0.001
6	56	-14	44	5.23	<0.001
6	-14	-14	44	5.5	<0.001
14	42	-48	48	4.92	<0.001
6	-28	-44	48	4.85	<0.001
9	36	-18	54	4.91	<0.001
7	36	-50	50	4.99	<0.001
13	-56	-34	54	5.3	<0.001
7	-40	-50	52	4.85	<0.001
5	0	-14	54	4.63	<0.001
6	6	-10	54	4.91	<0.001
5	-46	-34	62	4.38	<0.001

p<0.001 not corrected, cluster>5 voxel.

by Coregister. Both images were normalized to the MNI template and spatially smoothed by a 7 mm Gaussian kernel. Data were statistically analyzed through a general linear model approach and compared by t-test with a random effects model. A value of $p<0.001$ was considered a statistically significant threshold to define the activated region. For each region of the brain, ANOVA and Tukey's HSD were utilized to compare the BOLD signal changes associated with clenching under two differently premature occlusal conditions. Statistical significance was established at p<0.01, cluster>5 voxels.

Results

All of the activated regions in the brain during clenching in normal or with premature contact were listed in the form (**Table 1**). Statistical analysis showed that clenching under normal occlusal situations in intercuspal position increased the BOLD signals extensively in sensory cortex, motor cortex, premotor cortex, prefrontal cortex, Broca's area, supramarginal gyrus, cingulate gyrus, cerebellum and insula (**Table 2**; **Figure 2A**). When comparing normal clenching to clenching with premature contact, the clenching on composite premature contact activated significantly less regions of the brain (**Tables 3**, **4**; **Figure 2B**, **2C**). When comparing the activated area during clenching on first molar premature contact and clenching on canine premature contact, the former activated prefrontal cortex, supramarginal gyrus, cerebellum and insula whereas the latter did not. In the sensory and motor cortex, the former's

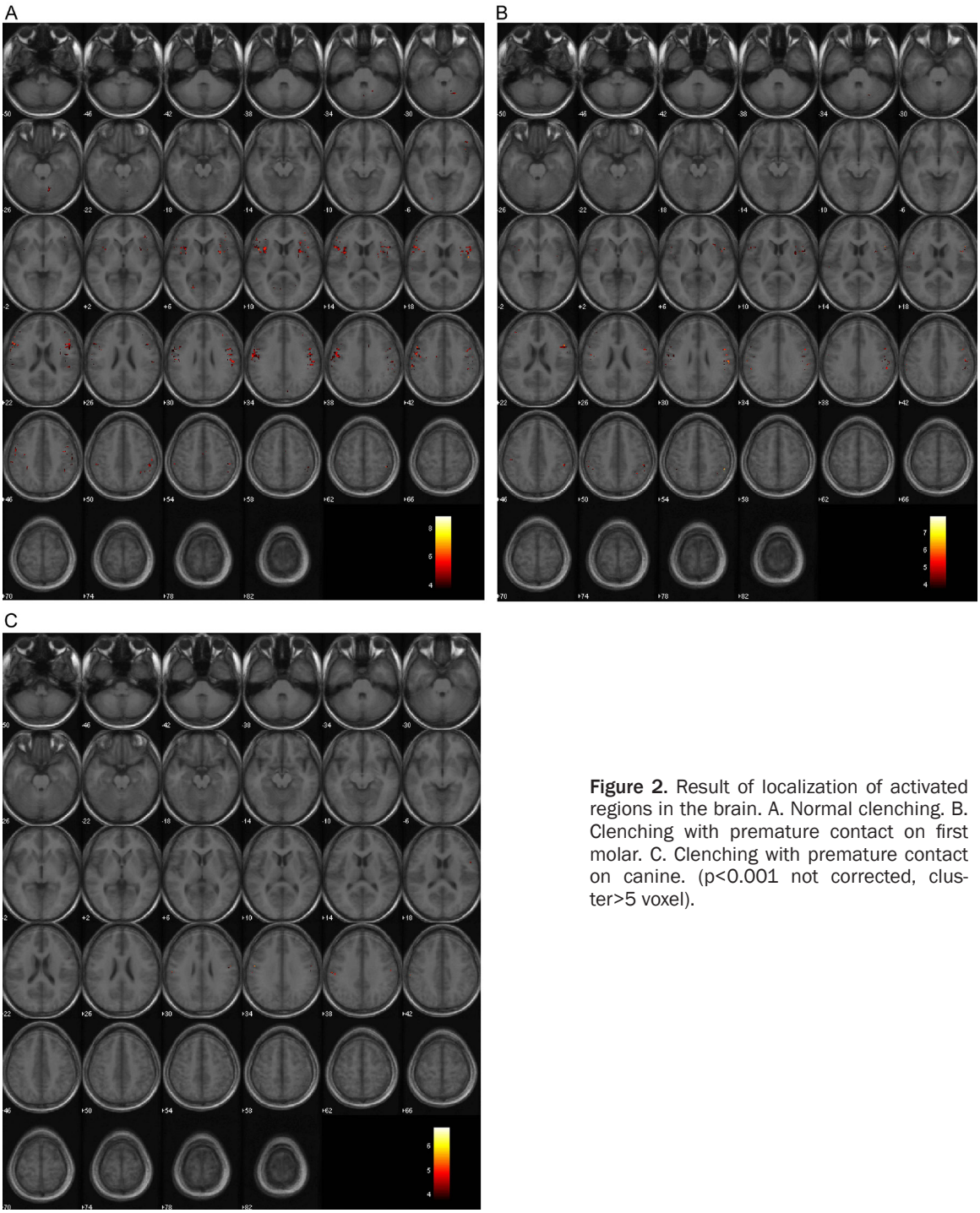

Figure 2. Result of localization of activated regions in the brain. A. Normal clenching. B. Clenching with premature contact on first molar. C. Clenching with premature contact on canine. ($p<0.001$ not corrected, cluster>5 voxel).

BOLD signals also increased significantly higher than the latter (**Table 5**; **Figure 3**).

Discussion

In normal occlusion individuals, clenching generally increased BOLD signals in several regions of the brain including sensory cortex, motor cortex, premotor cortex, prefrontal cortex, Broca's area, supramarginal gyrus, cingulate gyrus, cerebellum and insula. These results are similar to results found in previous similar studies [4, 7, 9-11]. The sensory and motor cortices are basic regions involved in all movement and the premotor cortex functions mainly in motional control and integration. During mandibu-

Table 3. Result of localization of activated regions in the brain under clenching with premature contact on first molar

Number of Voxels	Max. coordinates			T	p
9	20	-68	-32	5.87	<0.001
6	-42	10	-4	4.6	<0.001
53	38	10	-4	5.47	<0.001
13	-36	6	-2	5.35	<0.001
6	38	-4	-2	4.62	<0.001
205	52	10	6	7.92	<0.001
26	36	14	10	5.24	<0.001
6	-44	-8	8	5.75	<0.001
20	-60	10	14	4.88	<0.001
18	-52	12	8	5.33	<0.001
25	-32	14	12	4.85	<0.001
5	42	4	8	4.67	<0.001
8	-56	-26	16	4.6	<0.001
81	-56	-8	14	5.22	<0.001
6	-48	2	16	4.88	<0.001
5	60	-8	24	4.29	<0.001
22	-54	4	32	5.28	<0.001
8	-42	34	24	5.08	<0.001
7	-64	-34	26	5	<0.001
7	50	-28	28	6.17	<0.001
122	56	-20	32	6.69	<0.001
10	-54	-18	26	4.55	<0.001
5	-64	-18	30	4.71	<0.001
21	56	-10	28	5.92	<0.001
80	52	-44	54	7.29	<0.001
5	-62	-28	30	4.34	<0.001
12	-60	-20	34	7.84	<0.001
5	-56	0	32	4.91	<0.001
8	-52	-36	34	5.35	<0.001
9	-64	-22	38	5	<0.001
10	-62	-38	44	5.44	<0.001
5	40	-38	48	0.72	<0.001
7	-50	-26	48	5.04	<0.001
12	-58	-38	50	5.41	<0.001
9	38	-52	52	5.87	<0.001
6	-48	-46	52	4.6	<0.001
5	-58	-32	50	4.44	<0.001
6	-42	-46	52	4.77	<0.001

p<0.001 not corrected, cluster>5 voxel.

lar movement, the premotor cortex plays an important role in preparation [12]. Takeda et al [13] showed that the activity in the premotor area might be related to bite force control. Broca's area is considered to be involved in

Table 4. Result of localization of activated regions in the brain under clenching with premature contact on canine

Number of Voxels	Max. coordinates			T	p
10	56	6	18	3.61	<0.001
41	-58	-22	40	6.77	<0.001
9	56	-10	30	3.74	<0.001
8	-52	-10	34	4.08	<0.001
10	56	-18	38	3.6	<0.001

p<0.001 not corrected, cluster>5 voxel.

Table 5. Result of localization of the regions with significantly higher BOLD signals during clenching on first molar premature contact compare to clenching on canine premature contact

Number of Voxels	Max. coordinates			T	p
237	-66	-24	12	5.24	<0.001
192	-58	-14	8	4.54	<0.001
97	-18	-98	-6	4.88	<0.001
35	50	38	34	4.48	<0.001
79	10	-98	8	4.47	<0.001
29	8	18	56	4.47	<0.001
29	-10	-100	6	4.22	<0.001
22	20	-94	20	4.21	<0.001
27	26	-68	20	4.14	<0.001
19	-10	-20	24	4.08	<0.001
27	30	-64	40	4.07	<0.001
22	-50	-42	8	4.03	<0.001
33	34	44	-2	3.99	<0.001
16	10	40	22	3.95	<0.001
8	52	-48	40	3.83	<0.001
6	68	-26	-20	3.81	<0.001
6	-40	-58	38	3.78	<0.001
6	-40	-68	-18	3.78	<0.001
6	-46	-66	-12	3.76	<0.001
6	22	-96	-6	3.73	<0.001
7	22	24	6	3.69	<0.001

p<0.01 not corrected, cluster>5voxel.

speech production, facial neuron control and language processing. Furthermore, recent research have also shown the Broca's area plays an essential role in mouth movement including clenching [10, 14, 15]. Both cerebellum and insula are activated during normal clenching movement because of their function in motor control and balance.

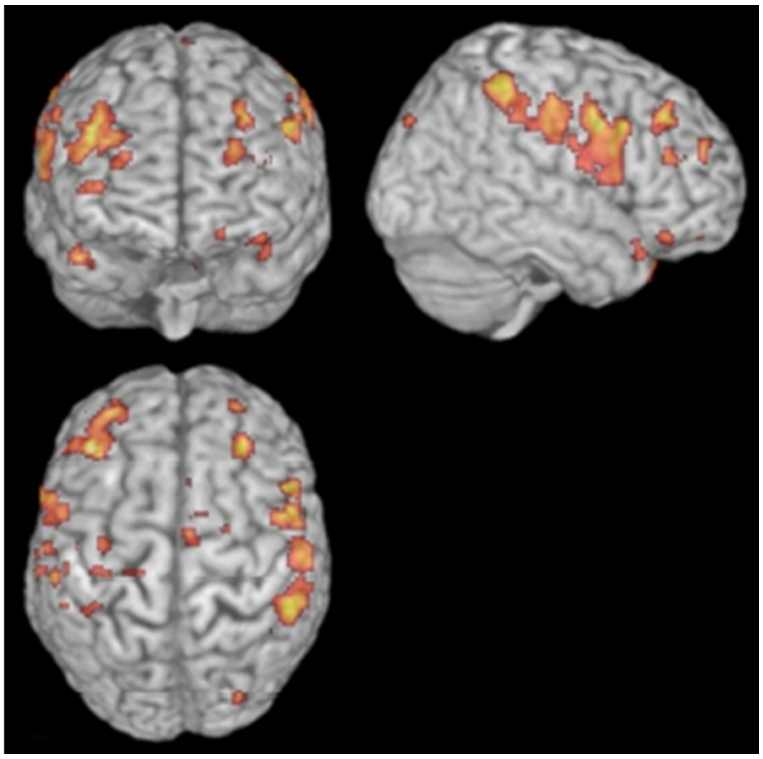

Figure 3. Differences in BOLD signals between clenching with premature contact on first molar and on canine. 3D figure of localization of the regions with significantly higher BOLD signals during clenching on first molar premature contact compare to clenching on canine premature contact. ($p<0.01$ not corrected, cluster>5voxel).

In this research, we also tried to understand the changes of activated regions when clenching on a premature contact. As a result, we found that the number of activated regions in the brain decreased significantly when compared to those in normal clenching. As we know, the adult human brain is a complex network optimized for both segregated and distributed information processing. To perform cognitive tasks, different areas of the brain must "cooperate", thereby forming complex networks of interactions also known as brain functional networks [16]. Activation and inhibition compose the elements of this cooperation. Therefore, if the premature contact was suddenly introduced to the tooth, the previous balance between the activation and inhibition would not proceed. The information of the immediate increase of tooth loading was conducted to the brain through proprioceptors in the periodontal membrane. The receptors related to mandibular position in the temporomandibular joint and craniofacial muscles were also responsible for transmitting the information of the positional changes to the brain. All of the negative information ultimately led to the less activated regions in the brain. No relevant research explaining the mechanism of this change has been found. However the paper published by Rugh et al [17] likely described the similar phenomena occurring to patients with bruxism. The researchers delivered the bite-high crown onto subjects' teeth to create the premature contact. After 1 to 4 days, all of the subjects performed less intensity of bruxism. As time progressed, the symptoms of bruxism relapsed to the same severity as before. The authors considered that the premature contact of teeth during bruxism movement prompted the peripheral receptors to send the abnormal information to brain. The balance of central nervous system network was broken and some regions were changed into reduced activation in response to abnormal occlusal situation. These sudden changes resulted in relieving the symptoms of bruxism in order to avoid the further damage to teeth and orofacial muscles. As observed in the research by Rugh et al, our experiment forced the healthy volunteers into an abrupt change in occlusal contact. Therefore the results, which were achieved by means of fMRI, confirmed the explanation given by Rugh et al to a certain extent.

Additionally, the discrepancies in activated regions between two kinds of premature contact situations (premature contact on canine versus premature contact on first molar) were achieved in this research. Activation or lack of activation in the prefrontal cortex, supramarginal gyrus and cerebellum are the major differences observed. The function of prefrontal cortex is still debated. Most research [18-26] have shown that prefrontal cortex is involved in various higher cognitive functions such as movement, planning and execution, monitoring, sensory processing, learning and memory, emo-

tions and affections, reward and attention. Some recent reports have described the relation between mastication and prefrontal cortex. A pilot research conducted by Narita et al [27] examined chewing-related prefrontal cortex activation while wearing partial denture prostheses and concluded that the denture stimulates both masticatory muscle and prefrontal cortex activation. Takada and Miyamoto [28] also reported the prefrontal cortex was activated significantly stronger during gum chewing than sham chewing. Both of these results demonstrated that the bite force was associated with the activity of prefrontal cortex. Higher bite force may activate prefrontal cortex more significantly. Due to the discrepancies in structure and axial alignment of the teeth, anterior teeth handle less bite force than posterior teeth. Thus, when the premature contact was applied to the anterior teeth, a more protective reflex is achieved through proprioceptive receptor in the periodontium. This prominent bite force difference might be responsible for the divergence in activation of the prefrontal cortex. Unfortunately, the bite force test under premature condition was not involved in this experiment and will be explored in further research. Supramarginal gyrus and insula were recognized as somatosensory area and associate with speech jaw movement [29] and oral stereognosis [30]. In addition, these areas played a role in emotional processing [31, 32]. Currently, no relevant report shows the relation between premature contact location and activated alteration of these two areas. We consider the BOLD signal distinction was mostly influenced by the unpleasant emotion induced by the premature contact.

Some studies [33, 34] showed that the location of premature contact affected jaw function and movement. Both studies concluded that the more posteriorly the premature contact was, the more seriously the jaw was affected. Additionally, Greven et al [7] conducted an experiment to describe the amount of jaw displacement correlated with brain activity. They discovered that feeling of discomfort in all subjects tended to increase as the mandibular position moved backwards and that it significantly improved the BOLD signals in prefrontal area, which the author concluded that it may be interpreted as a scale of unpleasantness. The findings partly coincided with the result achieved in this research, but we considered the supramarginal gyrus and insula also to be involved in this unpleasantly emotional processing. For activation of cerebellum, Onozuka et al [6] conducted research to demonstrate that it was positively correlated with the masticatory force. Thus the discrepancy of activated cerebellum in this research was mainly due to this similar reason which explains the discrepancy in prefrontal area that we observed.

Conclusions

This study was designed to discover if the activation changes in different brain locations correlated with the presence of experimental premature contact on the teeth. We have found that there is a reduction of activated areas in the brain in subjects with experimental premature contacts when compared to the normal voluntary clenching group. With the removal of premature contact from first molar to canine, significantly less activation was found in prefrontal cortex, supramarginal gyrus, cerebellum and insula. However, due to the small sample size and unclear mechanism underlying the clenching-induced regional activation within the brain at this time, further research is still required to discover the possibility of objectively accessing the severity of malocclusion by focusing on brain activity.

Acknowledgements

Supported by Shanghai Leading Academic Discipline Project: S30206-sms02, T0202.

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Fu-Qiang Zhang, Department of Prosthodontics, Shanghai Ninth People's Hospital, Shanghai Jiao Tong University, School of Medicine, Shanghai Key Laboratory of Stomatology, 639 Zhizaoju Road, Shanghai 200011, China. Tel: 86-21-53315207; Fax: 86-21-63136856; E-mail: dr_fqzhang@163.com

References

[1] Budtz-Jorgensen E. Occlusal dysfunction and stress. An experimental study in macaque monkeys. J Oral Rehabil 1981; 8: 1-9.

[2] Yoshihara T, Matsumoto Y, Ogura T. Occlusal disharmony affects plasma corticosterone and

hypothalamic noradrenaline release in rats. J Dent Res 2001; 80: 2089-2092.
[3] Onozuka M, Watanabe K, Fujita M, Tonosaki K, Saito S. Evidence for involvement of glucocorticoid response in the hippocampal changes in aged molarless SAMP8 mice. Behav Brain Res 2002; 131: 125-129.
[4] Tamura T, Kanayama T, Yoshida S, Kawasaki T. Analysis of brain activity during clenching by fMRI. J Oral Rehabil 2002; 29: 467-472.
[5] Tamura T, Kanayama T, Yoshida S, Kawasaki T. Functional magnetic resonance imaging of human jaw movements. J Oral Rehabil 2003; 30: 614-622.
[6] 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.
[7] Greven M, Otsuka T, Zutz L, Weber B, Elger C, Sato S. The amount of TMJ displacement correlates with brain activity. Cranio 2011; 29: 291-296.
[8] Bandettini PA, Jesmanowicz A, Wong EC, Hyde JS. Processing strategies for time-course data sets in functional MRI of the human brain. Magn Reson Med 1993; 30: 161-173.
[9] Ishikawa T. Brain regions activated during the mandibular movement tasks in functional magnetic resonance imaging. Kokubyo Gakkai Zasshi 2002; 69: 39-48.
[10] Wang YW, Ma XC, Jin Z, Zhang L. Brain activities during maximum voluntary clenching with and without soft splint in patients with hemimasticatory spasms by functional magnetic resonance imaging. Zhong Hua Kou Qiang Yi Xue Za Zhi 2006; 41: 37-40.
[11] Zhang QS, Liu HC, Jin Z, Chen Y, Li K. Neuronal activities related to right-sided mastication detected with functional magnetic resonance imaging. Zhong Hua Kou Qiang Yi Xue Za Zhi 2005; 40: 356-358.
[12] Yoshino K, Kawagishi S, Takatsuki Y, Amano N. Functional properties of the primary motor cortex and ventral premotor cortex in the monkey during a visually guided jaw-movement task with a delay period. Brain Res 2000; 852: 414-423.
[13] Takeda T, Shibusawa M, Sudal O, Nakajima K, Ishigami K, Sakatani K. Activity in the premotor area related to bite force control–a functional near-infrared spectroscopy study. Adv Exp Med Biol 2010; 662: 479-484.
[14] Zhao YP, Ma XC, Jin Z, Li K, Liu G, Zeng YW. Cerebral activation during unilateral clenching in patients with temporomandibular joint synovitis and biting pain: an functional magnetic resonance imaging study. Chin Med J 2011; 124: 2136-2143.
[15] Jiang H, Liu H, Liu G, Jin Z, Liu X. The effects of chewing-side preference on human brain activity during tooth clenching: an fMRI study. J Oral Rehabil 2010; 37: 877-883.
[16] Kuchaiev O, Wang PT, Nenadic Z, Przulj N. Structure of brain functional networks. Conf Proc IEEE Eng Med Bio Soc 2009; 2009: 4166-4170.
[17] Rugh JD, Barghi N, Drago CJ. Experimental occlusal discrepancies and nocturnal bruxism. The J Prosthet Dent 1984; 51: 548-553.
[18] Jenkins IH, Jahanshahi M, Jueptner M, Passingham RE, Brooks DJ. Self-initiated versus externally triggered movements. II. The effect of movement predictability on regional cerebral blood flow. Brain 2000; 123: 1216-1228.
[19] Lewis PA, Wing AM, Pope PA, Praamstra P, Miall RC. Brain activity correlates differentially with increasing temporal complexity of rhythms during initialisation, synchronisation, and continuation phases of paced finger tapping. Neuropsychologia 2004; 42: 1301-1312.
[20] Coghill RC, Gilron I, Iadarola MJ. Hemispheric lateralization of somatosensory processing. J Neurophysiol 2001; 85: 2602-2612.
[21] Stoeckel MC, Weder B, Binkofski F, Buccino G, Shah NJ, Seitz RJ. A fronto-parietal circuit for tactile object discrimination: an event-related fMRI study. NeuroImage 2003; 19: 1103-1114.
[22] Harada T, Saito DN, Kashikura K, Sato T, Yonekura Y, Honda M, Sadato N. Asymmetrical neural substrates of tactile discrimination in humans: a functional magnetic resonance imaging study. J Neurosci 2004; 24: 7524-7530.
[23] Goldberg RF, Perfetti CA, Fiez JA, Schneider W. Selective retrieval of abstract semantic knowledge in left prefrontal cortex. J Neurosci 2007; 27: 3790-3798.
[24] Fallon S, Shearman E, Sershen H, Lajtha A. Food reward-induced neurotransmitter changes in cognitive brain regions. Neurochem Res 2007; 32: 1772-1782.
[25] Toichi M, Findling RL, Kubota Y, Calabrese JR, Wiznitzer M, McNamara NK, Yamamoto K. Hemodynamic differences in the activation of the prefrontal cortex: attention vs. higher cognitive processing. Neuropsychologia 2004; 42: 698-706.
[26] Okamoto M, Matsunami M, Dan H, Kohata T, Kohyama K, Dan I. Prefrontal activity during taste encoding: an fNIRS study. NeuroImage 2006, 31: 796-806.
[27] Narita N, Kamiya K, Yamamura K, Kawasaki S, Matsumoto T, Tanaka N. Chewing-related prefrontal cortex activation while wearing partial denture prosthesis: pilot study. J Prosthodont Res 2009; 53: 126-135.

[28] Takada T, Miyamoto T. A fronto-parietal network for chewing of gum: a study on human subjects with functional magnetic resonance imaging. Neurosci Lett 2004; 360: 137-140.
[29] Golfinopoulos E, Tourville JA, Bohland JW, Ghosh SS, Nieto-Castanon A, Guenther FH. fMRI investigation of unexpected somatosensory feedback perturbation during speech. NeuroImage 2011; 55: 1324-1338.
[30] Fujii R, Takahashi T, Toyomura A, Miyamoto T, Ueno T, Yokoyama A. Comparison of cerebral activation involved in oral and manual stereognosis. J Clin Neurosci 2011; 18: 1520-1523.
[31] van der Heiden L, Scherpiet S, Konicar L, Birbaumer N, Veit R. Inter-individual differences in successful perspective taking during pain perception mediates emotional responsiveness in self and others: an fMRI study. NeuroImage 2013; 65: 387-394.
[32] Cheon BK, Im DM, Harada T, Kim JS, Mathur VA, Scimeca JM, Parrish TB, Park H, Chiao JY. Cultural modulation of the neural correlates of emotional pain perception: the role of other-focusedness. Neuropsychologia 2013; 51: 1177-1186.
[33] Koibuchi H. Effects of positions of experimental premature contacts on jaw unction. Kokubyo Gakkai Zasshi 1990; 57: 165-186.
[34] Cheng HJ, Chen YQ, Geng Y, Zhang FQ. The effect of the position of artificial premature on mandible moving track during opening movement. Shanghai Kou Qiang Yi Xue 2006; 15: 356-359.