Journal of Medical Imaging and Health Informatics
Vol. 10, 718–723, 2020

Effects of Mindful Breathing on Rapid Hypoxia Preacclimatization Training

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Rapid exposure at high altitude is likely to cause Acute Mountain Sickness (AMS) of different levels. This paper designs a “quick acclimatization” method to make the volunteers adapt to 3,600 meters (m) after 2-day training and 3,900 m after 3-day training. Especially, we investigate the effects of mindful breathing on rapid hypoxia preacclimatization training. 8 young male volunteers were randomly divided into one treatment group and one control group. Peripheral Saturation of Oxygen (SpO_2), Heart Rate (HR) and Respiratory Rate (RR) were recorded from the beginning to the end. We find that: (1) Hypoxic Preacclimatization Training Scheme (HPTS): at 3600 m, the increment of SpO_2 was 3.18% after 2-day training ($P < 0.01$); at 3900 m, 8 volunteers got obviously higher SpO_2 (2.65%, $P < 0.05$) and lower HR (−5.31 bpm, $P < 0.05$) after 3-day training. (2) Mindful Breathing Training Scheme (MBTS): at 3,600 m, the treatment group obtained better SpO_2 level (2.21%) with obviously lower HR (−7.1 bpm) and unobvious higher RR (2.85 br/min) than control group after 2-day training; at 3900 m, the treatment group did not show a significant difference after 3-day training. Besides, the treatment group exhibited a comprehensive better performance over the control group at night, which obtained a higher SpO_2 with lower HR and lower RR. In the comparison of different altitudes, the two groups had similar RR while the treatment group had a higher SpO_2 ($P < 0.05$) and a lower HR ($P < 0.001$). In the dynamic comparison during mindful breathing training, SpO_2 occurred remarkable differences: $P < 0.05$ every 15 minutes started from the 45th minute. We conclude that HPTS successfully helped volunteers adapt to the setting altitude in a short time. MBTS can induce significant phenomenon of sustained gain effect. It can effectively increase the acclimatization speed to quickly return to lower HR and RR and obtain higher SpO_2. MBTS can enable beginners without any experience of mindfulness and breathing training to initially stimulate the trend of “energy-saving” acclimatization in 2–3 days.

Keywords: Hypoxic Training, Mindful Breathing, “Saving Energy” Acclimatization, High Altitude.

1. INTRODUCTION

With the progress of science and technology, the convenience of transportation, the development of economy and the acceleration of the pace of life, more and more people need to reach the plateau quickly due to economic, religious, military, entertainment and other factors [1]. For example, one commercial corporation located in the U.K. once held 93 mountaineering campaigns and expeditionary activities in 12 months. The participants were organized to climb Mount Kilimanjaro, which was 5,895 m above sea level [2]. European Alps attracted 120 million travelers each year [3]. In China, one-sixth of the territory area is a plateau section. The magnificent landscape and the special minority culture in western China make the mysterious snowy plateau become a holy land of travelers from all over the country. With the promotion of the Belt and Road Initiative, there is an increasing number of people come to the plateau section for working or visiting. Also, hypoxia environment in the plateau section could benefit the treatment and the recovery of various disease [4, 5]. The demand of keeping healthy and curing disease with the help of hypoxia arises worldwide. Affected by the collision between India plate and Asia, the jam of Bayan Har block on the Qinghai-Tibet Plateau makes it one of the most active fault zones. From 1950 to 2003, there were 30 earthquakes of magnitude 7.0 or above in this region. From 2003 to now, there have been more than 10 earthquakes of different magnitude [6, 7]. Thus, acclimatizing to hypobaric hypoxia in a short time plays a very important role in economic effectiveness, rescue activities and national defense strategy.

Severe environmental conditions of high altitude include hypoxia, low pressure, decreased temperature, low humidity,

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 2156-7018/2020/10/718/006 doi:10.1166/jmihi.2020.2923

large temperature difference, and increased ultraviolet radiation [1]. Due to the special nature ecological environment at high altitude, failure to acclimatizing will commonly result in Acute Mountain Sickness (AMS), even worse, High Altitude Cerebral Edema (HACE) or High Altitude Pulmonary Edema (HAPE). AMS/HACE and HAPE would cause death in high altitude [8]. The incidence of AMS changes from 50%–80%, with a symptom like headache, dizzy, nausea and vomiting, anorectic, exertion and somnipathy [8, 9]. HAPE commonly appears in 2–4 days after people enter the high altitude while AMS usually comes as a complication. Major symptoms of HAPE include cyanosis, chest distress, cough and dyspnea. More seriously, some patients will have pink frothy sputum [10]. Most death at high altitude is caused by the HAPE [3]. HACE is the terminal stage of AMS [11]. From AMS to HAPE, the length is 24–36 hours or several hours [12]. If treatment fails, death can be caused within hours [8].

Most general public have to face the severe health-threatening challenge when they try to enter the high altitude quickly. Basically speaking, it will take normal people 5–7 days to adapt the altitudes of 3,000 m above sea level, and 5–12 days to adapt the altitudes of 4,000 m above sea level [13]. But in most cases, there is no that long time for people to adapt. For example, a total of over 20,000 rescuers involved in the mountain rescue of Yushu Earthquake in 2010. But 83% of the lowland rescuers were identified AMS in the earthquake area. This is mainly due to they rarely had time to adapt to the high-altitude environment. Finally, the rescuers needed to be rescued and the rescue in Yushu Earthquake was affected seriously. What was worse, some of the rescuers lost their lives during the rescue [7, 13, 14]. It was a sad lesson in the rescue history. Thus, effective acclimatization is the key to solve this problem.

As for measures to promote acclimatization, the scientific and effective Hypoxic Preacclimatization (HPC) training program is the first choice, and other measures include sleep, medicine, diet, nutrition, as well as early prevention and treatment of AMS [7, 15]. Some researchers showed that breathing training could benefit high altitude acclimatization. But the related research was not sufficient. Slow deep breathing can increase the body tidal volume, improve ventilation efficiency for oxygen, reduce breath consumption, release dyspnea, improve ventilation, and raise blood oxygenation [16–18]. The research of Han [19] and Ojashwi [16] both showed that the slow deep breathing raised oxyhemoglobin saturation irrespective of altitude. Bilo's research verified slow deep breathing could improve blood oxygenation capacity, improve ventilatory efficiency and decrease metabolic rate [20]. Breathing exercise was an important component of Yoga technology [21]. According to Bernardi, Yoga breathing could affect the balance between excitements (sympathetic) and control (parasympathetic), maintain a better blood oxygenation without increasing minute ventilation (VE) and increase exercise tolerance by reducing the activation of sympathetic [22, 23]. Some researchers had presented hypoxia stress could increase sympathetic nervous activity which would furtherly cause AMS [24]. Thus, breathing training could prevent AMS to some extent. Himashree's experiment also showed that breathing training, including yoga training, could effectively increase blood oxygenation and improve the work efficiency at high altitude [25]. Also, it's worth noticing that Berardi's another research had identified that trainees could get better physiological index after long-time breathing training. Their physiological index was even better than Sherpa's (whose index was improved by a long-term evolution) in Mount Everest. Trainees got similar blood oxygenation as Sherpa did, with lower HR, lower RR and less increased hematology. The training method is an efficient adaption by actively increasing human performance. Berardi named it as "saving energy" acclimatization strategy [26]. However, all of the studies were not universal because the researchers did not focus on exploring intervention efficacy of breathing training on a completed hypoxia acclimatization process and all the trainees had some basic breathing training experience usually before research.

The purpose of our research was to develop an efficient preacclimatization strategy to meet the increasing needs of rapidly entering high altitude. In the scheme, the volunteers could adapt to 3,600 m after 2-day training and 3,900 m after 3-day training. Also, this experiment tested the effect of mindfulness breathing on hypoxic acclimatization.

2. METHODS

Subjects: We recruited 8 male nonsmoking volunteers, aged between 18 and 22. The BMI index of these volunteers ranges from 17.96 to 32.37 and the mean value is 23.38. The height of these volunteers ranges from 1.60 m to 1.75 m and the mean value is 1.69 m. And the weight of these volunteers ranges from 50 kg to 98 kg and the mean value is 67 kg. They were permanently lowland residents with no respiratory or cardiopulmonary diseases, and they had no exposure to the altitude greater than 1,000 m for at least 6 months immediately preceding the study. They were used to siesta. All volunteers were not allowed to take sedative-hypnotic medicine or medicine which would work on autonomic nervous system or cardiopulmonary. Smoking, drinking, coffee or tea were forbidden. Using cell phone during the sleep was not allowed. All the volunteers had no mindfulness or breathing training experience before.

Volunteers were randomly sent by a security company according to the above requirements in two times. In the first time, four volunteers composed the treatment group. And four volunteers made up the control group in the second time. Experiments were implemented within two weeks. All the volunteers were trained under the guideline (Fig. 1). The treatment group had two more

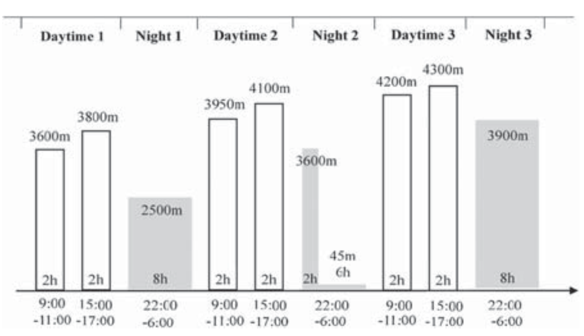

Fig. 1. Hypoxic preacclimatization training scheme. The bar chart showed the height, duration, and starting and ending times of hypoxic exposure. Colorless represented day training, gray for night sleep.

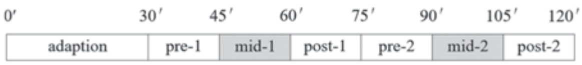

Fig. 2. Hypoxic preacclimatization training under the mindful breathing. This figure presented the division of training segments and their corresponding duration in one training session. The gray segment represented two mindfulness breathing exercises.

mindful breathing training during the HPTS training (Fig. 2). The control group did not implement mindful breathing training.

2.1. Hypoxic Preacclimatization Training Scheme

The volunteers got 3-day training in a normobaric hypoxia cabin. They took 2 hours' hypoxic training each morning and afternoon. Simulated altitude increased from 3,600 m to 4,300 m. During the training, the volunteers were in resting state to avoid snoozing and they will take a nap at noon. At night, they were required to sleep in the hypoxic environment, and the altitude is 2,500 m, 3,600 m and 3,900 m, respectively. In order to speeded-up self-repairing after the stress, volunteers only stayed in the hypoxic environment in the first 2 hours on Night 2. To test the effect of the acclimatization, contrast experiments were set up to compare SpO_2, HR and RR before and after training at a target altitude of 3,600 m and 3,900 m, respectively. The training height of the first 2-hour hypoxia training was 3,600 m, in which the training result of the first half hour was regarded as the baseline of 3,600 m before training. The cabin height raised to 3900 m in the last 15 minutes, as the baseline of 3,900 m before training. According to the training target, volunteers were tested on the third and fourth morning to obtain the hypoxia experiment data at 3,600 m and 3,900 m, respectively. Our scheme made various efforts to improve the efficiency of acclimatization, including turn one day into two by napping, sleeping in hypoxia environment, distributing training load. Finally, our experiment tried to validate the effects of mindful breathing on the acclimatization.

2.2. Mindful Breathing Training Scheme in the Treatment Group

2 hours training was cut into 7 periods as shown in Figure 2. In the adaption period, volunteers calmed down and lay in bed for 30 minutes. Then, they took the mindful breathing for two separated 15 minutes. Data was recorded for comparison before and after the 15-minutes mindful breathing. Though the control group would skip this part, their training was also cut into the same 7 parts as the treatment group for comparison purpose.

Collection of indicators and devices: (1) SpO_2 was measured by pulse oximetries (Prine-100H, Creative Co. Ltd., Shenzhen, China), (2) HR and RR were recorded by dynamic ECG recorders (SensEcho-5A, Health Regulation Co. Ltd., Beijing, China). 9 to 11 o'clock in the morning, 15 to 17 o'clock in the afternoon and 22 to 6 o'clock during night is the recording time, as shown in Figure 1.

3. RESULTS

3.1. Baseline Comparison

On the first half day (3,600 m), the average physiological indicator of the first-half hour training was set as the baseline before training. There is no significant difference between the baselines in two groups, $P(SpO_2/HR/RR) = 0.99/0.42/0.64$ (two-tailed), thus the two groups are comparable.

3.2. Comparison Between Before and After Trainings at 3,600 m and 3,900 m

Ungrouped comparison: At 3,600 m, 8 volunteers demonstrated a distinct improvement of SpO_2 after 2-day training ($P < 0.01$, one-tailed, the same below). At 3900 m, 8 volunteers obtained higher SpO_2 ($P < 0.05$) and lower HR ($P < 0.05$) after 3-day training.

Comparison between groups (3,600 m): SpO_2 in the treatment group and the control group increased by 4.28% ($P < 0.05$) and 2.09% ($P = 0.107$), respectively (Table I). HR of the treatment group increased 4.57 bpm while the control group increased 7.41 bpm. RR of the treatment group increased 2.5/min and the control group increased 1.27/min. So, after 2-day training, the treatment group achieved higher SpO_2 level (2.21%) with significantly lower HR (−7.1 bpm) and slightly higher RR (2.85 br/min). However, the comparison between groups was not statistically significant.

Comparison between groups (3,900 m): SpO_2 in the treatment group and the control group increased by 1.25% ($P = 0.322$) and 4.05% ($P < 0.05$), respectively (Table I). At the same time, HR of both groups began to show regression (HR in the treatment group and the control group decreased 6.13 bpm and 4.49 bpm, respectively) and indicated a good trend towards acclimatization. However, in the comparison between groups, the treatment group only had a slight advantage. Its SpO_2 was 1.67% higher than the control group, and the decrease of HR was slightly larger. There was no statistically significant difference between groups.

3.3. Comparison of SpO_2, HR and RR During Night Sleep

The only difference was that the treatment group implemented mindful breathing exercise in the daytime. Compared to the control group, the treatment group obtained a better SpO_2 (4.76% higher in average) with lower HR (9.61 bpm lower in average) and lower RR (3.26/min lower in average). As time went on, the differences of HR and RR between the two groups tended to be larger and larger. For Night 1, first part of Night 2 (3,600 m)/second part of Night 2 (45 m), Night 3, the HR differences of two group were 3.27, 12.12/10.13, 12.9 bpm, respectively. The RR differences of the two groups were 2.87, 3.01/3.54, 3.59 per minute, respectively. Data analysis result during night sleep was more objective and persuaded because the long time data was steadier, and volunteers were undisturbed in most time. This result was more true and objective to reflect the differences of training effect between the two groups. However, due to the small sample size and large individual differences, there was no significant difference between the two groups, except the HR in the first period of Night 2 and Night 3 ($P < 0.05$).

Table I. Comparison between two groups before and after training.

		3,600 m		3,900 m	
Index	Time	Group T	Group C	Group T	Group C
SpO_2 (%)	Before	84.32	84.29	87.37	82.9
	After	88.59	86.38	88.62	86.95
HR (bpm)	Before	79.61	83.87	86.71	83.03
	After	84.18	91.28	80.58	78.54
RR (br/min)	Before	17.52	16.51	17.84	18.38
	After	20.03	17.78	21.07	16

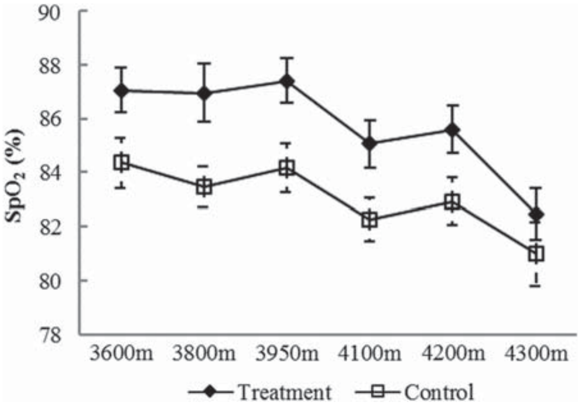

Fig. 3. SpO_2 at various altitude.

3.4. Comparison of Training Heights Between the Two Groups

SpO_2: As could be seen from Figure 3, the SpO_2 level of the treatment group was significantly higher than that of the control group during each training ($P < 0.05$), and the average difference of 6 times was 2.71%.

HR: Figure 4 showed a slight and steady drop of HR while the altitude increased constantly in the treatment group after the first day's training. On the contrary, the control group raised rapidly in fluctuations. The difference between the two groups increased from 3.54 bpm at 3,600 m to 22.71 bpm at 4,300 m. The average difference was 10.39 bpm ($P < 0.001$).

RR: There was no significant difference in the comparison between groups, which showed an upward trend with the increase in height.

In summary, the treatment group gained a significant higher SpO_2 with an obvious lower HR. The RR had no significant difference.

3.5. Dynamic Comparison of SpO_2 During Training Between the Two Groups

The 2-hour hypoxic exercise could be divided into 7 parts by the 2-separate mindful breathing (Fig. 5). The SpO_2 of the treatment group sharply went up as the mindful breathing started. And the increment increased as well. After the first mindfulness training, the SpO_2 kept going up for 30 minutes. On the contrary, there was a gradual decline in the control group. The SpO_2 of the control group kept decline until the second mindfulness breathing training began to rebound. Therefore, from the first mindfulness breathing training, there was a significant difference in SpO_2 between the two groups: $P < 0.05$ every 15 minutes started from the 45th minute of training. Comparing post-2 (in the end) with the adaption period (at the beginning), the treatment group obtained $P < 0.001$ while the control group got $P = 0.247$. From the comparison, we could find that the mindful breathing provided a noticeable intervention.

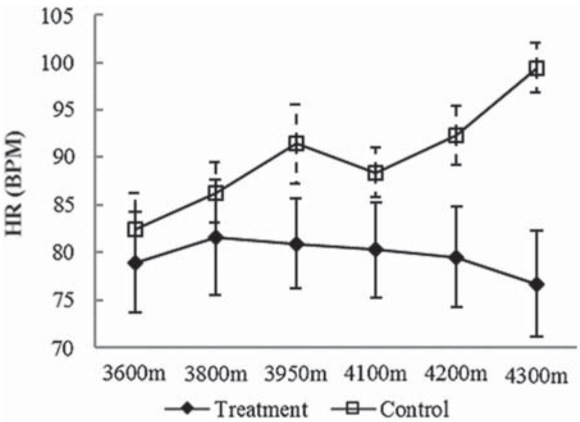

Fig. 4. HR at various altitude.

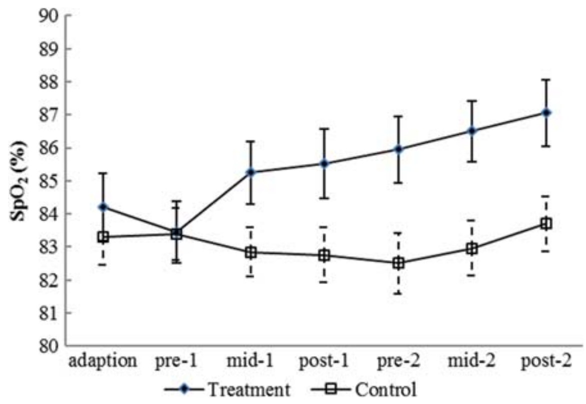

Fig. 5. SpO_2 at different period.

4. DISCUSSION

4.1. Hypoxic Preacclimatization Training Scheme

According to the comparison of before and after training at 3,600 m and 3,900 m, the volunteers had no obvious adverse reactions after 2–3 days' training and their SpO_2 grew up steadily. Especially, considering that the HR of two groups at 3,900 m began to regress, we could see the volunteers were gradually adapted to the environment and the acclimatization was in the benign direction. In addition, Figure 3 showed that the volunteers could get a higher SpO_2 in the morning than the previous afternoon after a night's sleep even though the altitude increases. This result approved that this training scheme was not beyond the scope of benign stress, thus it was safe and efficient.

4.2. Effects of Mindful Breathing on Hypoxia Preacclimatization Training

According to the experimental results, the treatment group didn't exhibit a significant improvement at 3,900 m after training. This was mainly because the baseline at 3,900 m was achieved by rising to 3900 m in the last 15 minutes of the 3600 m training on the first morning. At that time, the treatment group had already completed two mindful breathing training. As shown in Figure 5, mindful breathing had an obviously long-lasting effect. The SpO_2 of the treatment group was up to 87.37% before training, and 4.47% higher than that in the control group. Moreover, in the post-training detection, the treatment group got a 1.67% higher SpO_2 than the control group. Thus, it was also a proof that mindful breathing significantly promoted the acclimatization.

Figure 5 showed that mindful breathing could sharply and constantly increase the SpO_2. Inter-group comparison at different heights showed treatment group gained a better SpO_2 with a similar RR, and a quick regression and obviously lower HR. Data from the night experiment showed the treatment group obtained a better SpO_2 with lower HR and lower RR, and the difference between the two groups kept on increasing.

Therefore, only from SpO_2, HR and HH, mindful breathing could effectively balance the sympathetic and parasympathetic in hypoxia environment, make HR and RR stay at a low stress level, consume less energy, and prevent AMS more effectively. Though this training only lasted 2–3 days and the volunteers had no mindfulness experience or breathing training experience, the "saving energy" acclimatization as Bernardi said did work to some extent. In summary, mindfulness breathing had a good effect on the process of hypoxic acclimatization, and it could promote acclimatization more safely and efficiently.

4.3. Sustained Gain Effect After Mindful Breathing

Bilo's research had shown that if slow breathing exercise was stopped in hypoxia environment, the improvement of SpO_2 would lose after 5 minutes' spontaneous breathing. And there was no significant difference from baseline after 30 minutes [20]. However, in our experiment, the SpO_2 kept increasing in the following at least 30 minutes (interval period between the two-mindful breathing exercises) instead of decreasing after the termination of the mindful breathing exercise. It is an unexpected phenomenon.

This may be the result of mindful effect and cardiopulmonary coupling effect induced by breathing training. Mindfulness has been shown to have a wide range of mind-body conditioning effects [27–29]. Stress can make the anterior cingulate gyrus [30], autonomic nervous system [31] and cortisol secretion dysfunctional [32]. However, mindfulness can effectively maintain homeostasis, make relevant functions stable and better adapt to the environment [33, 34]. At the same time, breathing training can reduce respiratory frequency, reduce chemical reflex sensitivity, maintain higher pressure reflex sensitivity and parasympathetic activity, improve ventilation efficiency, enhance cardiopulmonary coupling, realize energy saving and increase ventilation reserve [22, 35]. Therefore, the combination of mindfulness and breathing exercises can induce the coordination and ordering of multiple systems, and enhance the homeostasis and the organization efficiency, which is the possible reasons of "Sustained gain effect" in this experiment.

Besides, we only found Doctor Tressoldi had reported the similar delayed effect in conscious science filed. According to Doctor Tressoldi, the dedicated mind could remotely increase the number of photons in photomultiplier. Moreover, the phenomenon did not disappear in a moment when the mental entanglement ended [36]. Doctor Tressoldi retrieved only one related research about this phenomenon—delayed effect of meditation. Meditation experiment proved that meditation had a long-last effect on the 2-hexanol gas concentration of cucumber slices ten days after this experiment had terminated [37]. Caswell's research showed that human consciousness could enhance biological photons [38]. Energy Medicine is an important component of NIH complementary and alternative medicine (CAM) [39]. Energy Medicine is an emerging field [40], which is focused on studying the interaction between spirit and physical fitness. Diseases can be healed and health can be maintained in a best status with the subtle energy [41]. Not only can it provide Nonpharmacological self-treatment, but also improve various efficiency on physical function, artistic expression, kung fu, meditation, etc. [42].

Therefore, mindful breathing training could maintain energy and boost the photons, and it might induce cardiorespiratory coupling and psychosomatic coupling. This was a reasonable explanation for the long-last effect of mindful breathing training. It also made the volunteers fundamentally active "energy-saving" hypoxia acclimatization and adapt well to the high altitude after 2–3 days' training.

5. CONCLUSION

The proposed HPTS can basically meet rapid growth in demand for entering high-altitude at a rapid pace. The volunteers could adapt to 3,600 m after 2-day training and 3,900 m after 3-day training. But more tests are needed because the tested subjects are not universal. MBTS can induce significant phenomenon of sustained gain effect. It can effectively increase the acclimatization speed to quickly return to lower HR and RR and obtain higher SpO_2. MBTS can enable beginners without any experience of mindfulness and breathing training to initially stimulate the trend of "energy-saving" acclimatization in 2–3 days.

Acknowledgment: This work was supported by the National Natural Science Foundation of China (81871444) and the Innovation Special Zone Project of Military Commission Science and Technology.

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Received: 17 July 2019. Revised/Accepted: 10 September 2019.