Original articles

The effect of pre-dive exercise timing, intensity and mode on post-decompression venous gas emboli

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Abstract

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Introduction: The effect of pre-dive exercise on post-decompression venous gas emboli (VGE) remains contentious. The aim of our study was to investigate the effect of timing, intensity and mode of exercise before diving on post-decompression VGE production.

Methods: Fifteen male volunteers performed three identical 100 min chamber dives to 18 metres' sea water. Two of the three dives were conducted with prior exercise at 24 or 2 h; a dive without prior exercise formed the control. Moderate-intensity impact exercise consisted of jogging on the spot for one minute followed by ten star jumps, repeated for a total of 40 min at 70% of maximum heart rate. Post-dive Doppler monitoring began within 2 min of surfacing and was carried out for at least 180 min. VGE were assessed using the Kisman-Masurel (KM) code and the Kisman Integrated Severity Score (KISS).

Results: The median peak KM grade for each condition following the dives was not significantly different. Pre-dive exercise at 2 h resulted in a significant reduction in the mean KISS compared to the control (11.3 versus 17.2, $P < 0.04$, Wilcoxon sign-ranked test). Moderate-intensity jogging/star jump exercise used in this series of dives resulted in significantly lower mean KISS (11.3 versus 21.8, $P < 0.04$) and median KM grade over 180 min ($P < 0.006$, Mann Whitney U test) compared to high-intensity cycling exercise used in our previous study.

Conclusions: This study suggests that moderate-intensity impact exercise reduces VGE production when conducted 2 h prior to diving.

Key words

Doppler, diving, exercise, bubbles, decompression illness

Introduction

The effect of pre-dive exercise on post-decompression venous gas emboli (VGE) remains contentious. It was thought for many years that exercise before, during, or after diving, was an additional risk factor for decompression sickness (DCS).[1] However, a number of studies conducted by two main groups over the last few years have shown that this may not be the case and that exercise prior to diving may actually help to reduce bubble formation and the incidence of DCS. There are, however, differences in the results of these studies with respect to the timing, intensity and mode of the exercise conducted.[2–10]

Wisloff et al. demonstrated that a single bout of high-intensity aerobic exercise performed by rats on a treadmill 20 h before a chamber dive reduced VGE formation and gave protection from lethal DCS.[2] Scheduling appeared to be important, protection occurring only if the interval between exercise and the subsequent dive was 10–20 h. Dujic et al. then demonstrated in man, that a single bout of high-intensity exercise (treadmill running) 24 h before performing a chamber dive to a depth of 18 metres' sea water (msw) significantly reduced the amount of VGE in the pulmonary artery compared to no exercise.[3]

Further studies in rats found the same high-intensity treadmill exercise starting 2 h before a dive either increased or had no effect on VGE formation and eliminated the protection afforded by exercise 20 h prior to diving.[4–6] Contrary to this, a study in military divers found that medium-intensity running starting 2 h before a chamber dive to 30 msw decreased VGE formation.[7] This was repeated using high-intensity running at a controlled heart rate, which resulted in the same outcome.[8] The same dive profile was then performed in open-water, with medium- or high-intensity cycling 2 h prior to diving; both intensities reduced bubble grades.[9] Furthermore, Castagna et al. have recently found that 45 min of treadmill exercise starting just one hour before an open-water dive also reduced bubble grades.[10]

These apparent contradictions in the effect of pre-dive exercise timing led to our study. Our previous series of dives were preceded by exercise which mimicked the high intensity and duration used by Dujic et al., but substituted treadmill running with low-impact cycling.[3,11] The exercise was performed at 24 h or 2 h before a chamber dive to 18 msw, but showed no benefit in reducing VGE compared to the no-exercise controls. As a continuation of our study, the present series of dives examined the effect of reducing the intensity and increasing the impact of the exercise on VGE production following identical dive profiles.

Methods

The study was approved by the UK Ministry of Defence Research Ethics Committee and conducted in accordance with the principles of the Declaration of Helsinki.[12]

SUBJECTS

Fifteen male volunteers, aged 22–53 (mean 36.5) years, participated in the study. They comprised Royal Navy (RN) divers and QinetiQ staff with mixed wet- and dry-diving experience, all of whom had passed their dive medical, involving a fitness test. The purpose of, and procedures and risks associated with the study were explained and the volunteers gave their written consent. Each subject's height and weight were measured and their body mass index (BMI) calculated. Their percentage body fat was measured by bioelectrical impedance analysis using a Bodystat 1500™.

HYPERBARIC EXPOSURES

The study was carried out at the QinetiQ Hyperbaric Medicine Unit, Royal Hospital Haslar, Gosport, UK, a Category 1 facility containing an RN Type A recompression chamber. The chamber air dives were to 18 msw with a bottom time of 100 min. Decompression stops were at 6 msw for 5 min and 3 msw for 15 min, with an ascent rate of 15 msw min^{-1} in accordance with RN Table 11-Mod.[13] Each subject conducted three dives; two were conducted with exercise bouts at 24 or 2 h pre-dive and a dive with no prior exercise formed the control. The order in which the exercise or control dives were conducted was randomly allocated and each dive commenced at exactly the same time each day (1300 h) to avoid any influence of circadian effects. No flying or diving was permitted for at least seven days before commencing the trial and there were at least seven days between the experimental dives. Alcohol and caffeine were prohibited from the evening of the preceding day, but the subjects were free to eat breakfast and lunch on the day of their chamber dives.

This series of chamber dives formed a continuation of our study examining the effect of pre-dive exercise on VGE formation. The same dive profile, period between dives and timing and duration of pre-dive exercise were used throughout. The only difference was in the mode and intensity of exercise conducted: medium-intensity impact exercise (described below) compared to previous high-intensity cycling.

EXERCISE REGIMEN

The exercise regimen for this series of chamber dives consisted of jogging on the spot for 1 min followed by 10 star jumps, repeated for a total of 40 min. No exercise was permitted for 48 h before a dive or exercise bout. Participants were fitted with a Polar™ heart rate monitor and after a brief warm-up period they were asked to aim at 70% of their theoretical maximum heart rate (220 - age (in years) beats min^{-1}) for the exercise period.

DOPPLER MONITORING

Pre-cordial Doppler monitoring of VGE was carried out using a continuous-wave Doppler Bubble Monitor (Techno Scientific Inc., TSIDBM 9008) with the subject standing at rest. Pre-dive baseline monitoring was carried out shortly before the dives. Post-dive monitoring began within 2 min of surfacing and was carried out every 5 min for the first 30 min and every 15 min thereafter, up to 180 min. Subjects were asked not to depart before their Doppler VGE score was declining and so, on a few occasions, monitoring was continued beyond 180 min, but only data collected up to 180 min were used in the analysis. Subjects remained at rest for the whole of the monitoring period. VGE were scored using the Kisman-Masurel (KM) code and the Kisman Integrated Severity Score (KISS) was then calculated to give a linearised measure of VGE.[14,15] Doppler technicians were blinded to the order of the exercise and control dives and were assigned to the monitoring of the same subject for each of their three dives. The Doppler technicians each had several years of experience of audio Doppler monitoring and undertook regular quality assurance assessments. Monitoring sessions were recorded so that they could be re-analysed at a later time if required, using an Archos 605 portable media player, which directly encoded the audio signal to Waveform Audio File Format sampled at 44,100 Hz.

STATISTICAL ANALYSIS

Subject variables are presented as mean and standard deviation (SD). Individual peak Doppler KM grades for

Table 1
Subject demographics

Subject	Age (years)	BMI (kg m^{-2})	Body fat (%)
1	47	28.7	19.1
2	41	26.3	23.2
3	49	25.4	18.7
4	53	25.1	21.1
5	37	25.1	21.1
6	36	28.1	19.4
7	32	24.8	16.5
8	36	28.1	19.4
9	33	24.7	16.4
10	30	25.0	16.4
11	32	27.5	21.1
12	25	25.3	18.5
13	22	24.7	12.6
14	39	26.2	16.1
15	35	29.3	23.6
Mean (SD)	36.5 (8.5)	26.3 (1.6)	18.8 (3.0)

Table 2
Doppler bubble detection

Doppler bubble detection	Control (no exercise)	Exercise at 24 h	Exercise at 2 h
Median peak KM grade (Range)	3 (0–3-)	2 (0–4-)	2 (0–3+)
Time to median peak KM grade (min)	90	82.5	90
Mean KISS (over 180 min period)	17.2	13.1	11.3

Figure 1
KISS for control dives versus pre-dive exercise at 2 h (bars represent mean value); *P* < 0.04

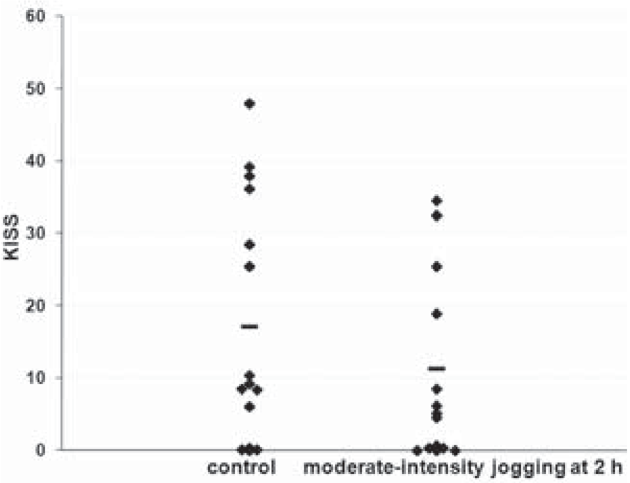
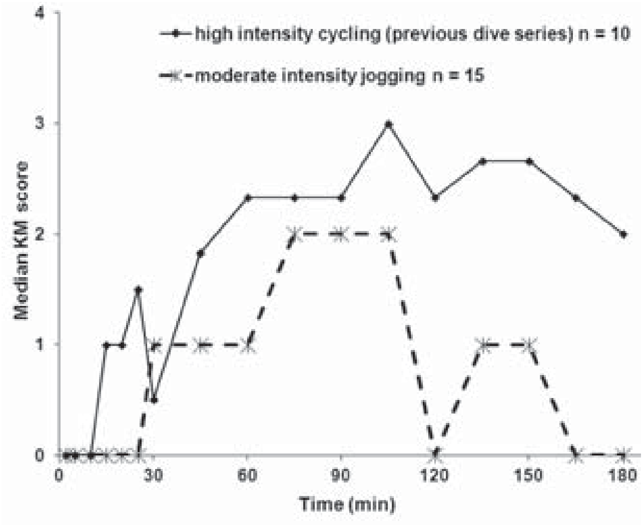


Figure 2
Median KM grades up to 180 min for moderate-intensity jogging versus high-intensity cycling performed 2 h prior to the dive; *P* < 0.006



control and pre-dive exercise dives were compared using the Freidman test. The KISS for pre-dive exercise at 24 or 2 h was compared to the control using the Wilcoxon sign-ranked test. For comparison with our previous series of dives, differences in subject variables were tested using an unpaired t-test. Median KM grades and KISS over the Doppler monitoring period were compared using a Mann Whitney U test. Differences were considered significant if $P < 0.05$.

Results

No DCS occurred in any of the subjects following the dives. Details of individual subject age, BMI and percentage body fat are shown in Table 1.

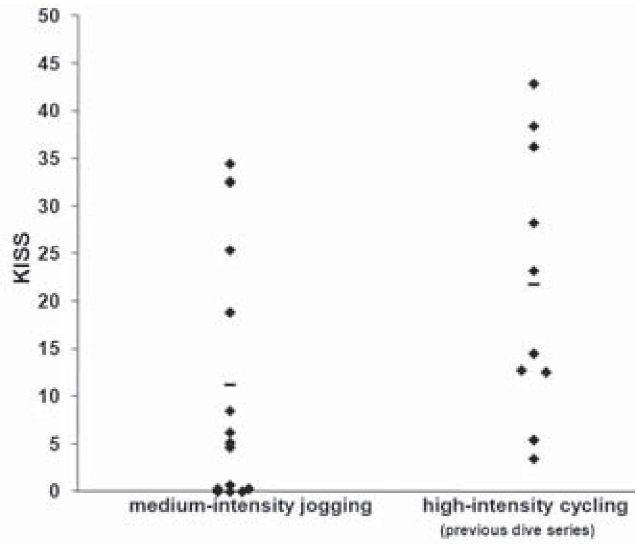
Details of the Doppler measurement of VGE are shown in Table 2. The median peak KM grade decreased from 3 for the control dives to 2 for those dives with pre-dive exercise at either 2 or 24 h, but this decrease was non-significant. The time to reach the median peak KM grade was similar for all dives. The mean KISS up to 180 min post-dive was lower with pre-dive exercise, but was only significantly different from the control when exercise was conducted at 2 h prior to diving (11.3 versus 17.2, $P < 0.04$, Wilcoxon sign-ranked test). The individual KISS following the control dives and pre-dive exercise at 2 h are shown in Figure 1.

This series of dives was a continuation of our study examining the effect of pre-dive exercise on VGE production. There was no significant difference in the median KM grades over the Doppler monitoring period for this and our previous series of control dives. This allowed the effect of the different mode and intensity of pre-dive exercise to be compared. Changing from the high-intensity, low-impact cycling used previously to moderate-intensity impact exercise resulted in a reduction in median KM bubble grades over the monitoring period when conducted at 2 h ($P < 0.006$, Mann Whitney U Test, Figure 2), but not 24 h, prior to diving. Similarly, the KISS was only different between the exercise conditions when performed 2 h prior to the dive (11.3 versus 21.8, $P < 0.04$, Mann Whitney U Test, Figure 3). There were no significant differences in subject variables.

Discussion

Recent studies have demonstrated that prior exercise can reduce the number of VGE and the incidence of DCS following a pressure exposure.[2,3,7–10] The peak Doppler bubble grade is often used for comparing the decompression stress between dives. However, some studies have used limited Doppler monitoring, with measurements at four time

Figure 3
KISS for moderate-intensity jogging versus high-intensity cycling performed 2 h prior to the dive (bars represent mean value); *P* < 0.04



points in some and as few as only two in others, making it difficult (or impossible) to know whether a peak had been reached. Furthermore, the duration of the monitoring has been as short as 60 min, which may have missed VGE produced in those with a long latency of bubble evolution. Indeed, following our present dives the maximum latency to VGE detection was 120 min.

We monitored VGE for at least 180 min, from first appearance until a peak was reached and then until bubbles either declined or disappeared, totalling a minimum of 17 measurements for each subject for each dive. No significant difference was demonstrated between the peak KM grades for the control dives and those with prior exercise at either 24 or 2 h. However, a single peak Doppler grade gives no information as to the grades over the whole of the monitoring period. The KISS integrates VGE over time, providing a more complete picture of bubble activity and gas load than a single peak KM grade.[15] We found no significant difference between the KISS for control dives and those with pre-dive exercise at 24 h. However, the KISS was significantly reduced when exercise was conducted 2 h prior to the dive.

The benefit of this pre-dive exercise at 2 h, but not at 24 h, led us to question whether the results of our previous series of dives could be explained in terms of the intensity/mode of exercise. The only difference we found was a significant reduction in bubbles in changing from the previous high-intensity cycling to moderate-intensity jogging when conducted 2 h prior to a pressure exposure. This suggests that exercise mode/intensity does indeed have an effect if conducted this close to a dive.

The majority of published results on the effect of pre-dive exercise on post-decompression VGE have come from two main groups, showing benefit at either 24 h or 2 h before diving. It is important that independent studies are conducted so that confidence in the results of such studies is robust. Moreover, if there is a common mechanism involved it will not be influenced by factors that may be peculiar to a particular research group. Our previous dive series used the same exercise intensity and duration as that used by Dujic et al. 24 h before diving, but changed the exercise mode from running to cycling and examined its effect at 24 h or 2 h prior to diving.[3,11] This did not result in a reduction in VGE and in our present dive series there was no benefit from medium-intensity jogging on the spot (which can be considered as similar in impact to treadmill running) when conducted 24 h prior to diving. Thus, it may be that only the combination of high-intensity and running (impact) exercise is effective in reducing VGE when conducted 24 h prior to a dive, as reported by Dujic et al.[3]

For pre-dive exercise conducted at 2 h, both medium- and high-intensity running and cycling have been reported to reduce VGE.[7–9] However, in contrast, our previous dive series showed that high-intensity cycling at this time did not reduce VGE formation and others have found no benefit from high-intensity running this close to a dive.[2–6] The results of our present dive series confirm the earlier results of Blatteau et al. by demonstrating that moderate-intensity jogging on the spot 2 h prior to diving reduces VGE formation.[7] An interesting recent finding is that a period of whole-body vibration 1 h before diving decreased VGE formation.[16] Vibration may have a similar action to impact exercise and this may account for the beneficial effect we observed with higher-impact exercise such as jogging and jumping, while we observed no such benefit for low-impact cycling.

When conducting a series of investigations it is desirable to have a level of confidence in the reproducibility of VGE production following control dives. In our study, there was no significant difference in the level of VGE between our present and previous series of control dives. However, reproducibility has been highlighted by others as being problematical. Studies in rats weighing less than 300 g produced few bubbles on some occasions, but many on others (median Doppler grade 0 versus grade 4).[4,5,17] Similarly in man, control dive profiles which had been chosen to reproducibly produce significant Doppler grades resulted in very low bubble grades (median peak grade 0) in a study which had previously resulted in a median peak grade of 3.[3,18] This lack of reproducibility in VGE following control dives leads to the suspicion that dives with prior exercise may also produce differing results on different occasions. Thus, variability in VGE in studies with relatively small subject numbers may be responsible for some of the differences between studies.

Gas bubbles produced following a pressure exposure are thought to grow from micronuclei present in tissues and crevices on blood vessel walls. Muscle activity can induce micronuclei, and microbubbles have recently been demonstrated in the leg muscles of human subjects after exercise on a cycle ergometer, which decayed over time following cessation of exercise.[19] The half-life of intravascular exercise-induced micronuclei was in the order of one hour in another study.[20] Some forms of exercise may act to dislodge micronuclei from the vessel surface and increased blood flow during exercise may cause 'wash-out' of bubble micronuclei from the endothelial cell surface. Removal of such micronuclei before a pressure exposure would have obvious benefits in terms of VGE production, but the net effect will be the difference between their formation and elimination. For exercise close to a dive, the effect may be different depending on the duration of the dive.

If there is a simple common mechanism for the effect of exercise before diving per se it would seem reasonable that studies would agree on timing and exercise mode and intensity. The exact mechanism(s) of any protection afforded by exercise is unknown at present, but is likely to be multi-factorial.[2,21–23] To have a major impact on diving 'safety', reductions in Doppler grades that represent a substantial reduction in gas load must be demonstrated, as high numbers of VGE are associated with an increased risk of DCS.[24,25] The protective effect may be too small or too variable to allow more stressful dives to be carried out with improved safety. Some apparent disparities between studies in the timing and intensity/mode of exercise can be explained, but others remain unresolved. Perhaps commonality should be sought in developing an approach for larger scale trials using consistent dive profiles and full Doppler monitoring, which may then lead to a consensus on the benefit of exercise before diving.

Conclusion

This study suggests that moderate-intensity impact exercise reduces VGE production when conducted 2 h prior to diving.

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Conflict of interest: none

References

1 Vann RD, Thalmann ED. Decompression physiology and practice. In: Bennett PB, Elliott DH, editors. *Bennett and Elliott's physiology and medicine of diving*, 4th ed. London: Saunders; 1993. p. 376-432.

2 Wisloff U, Richardson RS, Brubakk AO. Exercise and nitric oxide prevents bubble formation: a novel approach to the prevention of decompression sickness? *J Physiol*. 2004;555:825-9.

3 Dujic Z, Duplancic D, Marinovic-Terzic I, Bakovic D, Ivancev V, Valic Z, et al. Aerobic exercise before diving reduces venous gas bubble formation in humans. *J Physiol.* 2004;555:637-42.

4 Jorgensen A, Brubakk AO, Berge V, Laset A (sic), Wisloff U. The effect of predive exercise on bubble formation in the rat [abstract]. *Undersea Hyperb Med*. 2004;31:341-2.

5 Berge VJ, Jorgensen A, Loset A, Wisloff U, Brubakk AO. Exercise ending 30 min pre-dive has no effect on bubble formation in the rat. *Aviat Space Environ Med*. 2005;76:326-8.

6 Loset A Jr, Møllerløkken A, Berge V, Wisloff U, Brubakk AO. Post-dive bubble formation in rats: effects of exercise 24 h ahead repeated 30 min before the dive. *Aviat Space Environ Med*. 2006;77:905-8.

7 Blatteau JE, Gempp E, Galland FM, Pontier JM, Sainty JM, Robinet C. Aerobic exercise 2 hours before a dive to 30 msw decreases bubble formation after decompression. *Aviat Space Environ Med*. 2005;76:666-9.

8 Blatteau J-E, Boussuges A, Gempp E, Pontier JM, Castagna O, Robinet C, et al. Haemodynamic changes induced by submaximal exercise before a dive and its consequences on bubble formation. *Br J Sports Med.* 2007;41:375-9.

9 Pontier JM, Blatteau JE. Protective effect of a 2-hours pre-dive exercise on bubble formation: part of exercise intensity. *European Journal of Underwater and Hyperbaric Medicine*. 2007;8:28.

10 Castagna O, Brisswalter J, Vallee N, Blatteau JE. Endurance exercise immediately before sea diving reduces bubble formation in scuba divers. *Eur J Appl Physiol*. 2010;111:1047-54.

11 Gennser M, Blogg SL, Jurd KM. Pre-dive exercise and post-dive evolution of venous gas emboli. *Aviat Space Environ Med*. 2011 (Forthcoming).

12 World Medical Association Declaration of Helsinki. *Ethical principles for medical research involving human subjects.* 52nd World Medical Association General Assembly, Edinburgh, Scotland, October 2000.

13 *UK Military Diving Manual*. Ministry of Defence, BRd 2806, Volumes 1 to 4, December 2010.

14 Kisman K, Masurel G. *Method for evaluating circulating bubbles detected by means of the Doppler ultrasonic method using the 'K.M. code'*. (English translation of 283 CERTSM 1983), Toulon: Centre d'Etudes et de Recherches Techniques Sous-Marines; 1983.

15 Jankowski LW, Nishi RY, Eaton DJ, Griffin AP. Exercise during decompression reduces the amount of venous gas emboli. *Undersea Hyperb Med*. 1997;24:59-65.

16 Germonpre P, Pontier P, Gempp E, Blatteau JE, Deneweth S, Lafere P, et al. Pre-dive vibration effect on bubble formation after a 30–m dive requiring a decompression stop. *Aviat Space Environ Med*. 2009;80:1044-8.

17 Wisloff U, Richardson RS, Brubakk AO. NOS inhibition

increases bubble formation and reduces survival in sedentary but not exercised rats. *J Physiol*. 2003;546:577-82.
18 Brubakk AO, Duplancic D, Valic Z, Palada I, Obad A, Bakovic D, et al. A single air dive reduces arterial endothelial function in man. *J Physiol*. 2005;566:901-6.
19 Wilbur JC, Philips SD, Donoghue TG, Alvarenga DL, Knaus DA, Magari PJ, Buckey JC. Signals consistent with microbubbles detected in legs of normal human subjects after exercise. *J Appl Physiol*. 2010;108: 240-4.
20 Dervay J P, Powell MR, Butler B, Fife C. The effect of exercise and rest duration on the generation of venous gas emboli at altitude. *Aviat Space Environ Med*. 2002;73:22-7.
21 Dujic Z, Palada I, Valic Z, Duplancic D, Obad A, Wisloff U, et al. Exogenous nitric oxide and bubble formation in divers. *Med Sci Sports Exer*c. 2006;38:1432-5.
22 Gempp E, Blatteau JE, Pontier JM, Balestra C, Louge P. Preventative effect of pre-dive hydration on bubble formation in divers. *Br J Sports Med*. 2009;43:224-8.
23 Blatteau JE, Gempp E, Balestra C, Mets T, Germonpre P. Predive sauna and venous gas bubbles upon decompression from 400 kPa. *Aviat Space Environ Med*. 2008;79:1100-5.
24 Sawatzsky KD. *The relationship between intravascular Doppler-detected gas bubbles and decompression sickness after bounce diving in humans* [dissertation]. Toronto:York University; 1991.
25 Nishi RY, Kisman KE, Eatock BC. Assessment of decompression profiles and divers by Doppler ultrasonic monitoring. In: Bachrach AJ, Matzen MM, editors. *Underwater Physiology VII*: Proceedings Seventh Symposium on Underwater Physiology. Bethesda, MD: Undersea Medical Society; 1981. p. 717-27.

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