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ORIGINAL ARTICLE

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New evidence from magnetic resonance imaging of brain changes after climbs at extreme altitude

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Abstract The aim of the present study was to look for anatomical changes in climbers' brains, using magnetic resonance imaging (MRI), after extremely high-altitude climbs and to relate them to possible associated risk factors. Clinical history, neurological examinations and MRI were carried out on a group of nine climbers before and after climbing to over 7500 m without the use of supplementary oxygen. None of the subjects showed any neurological dysfunctions. In five climbers MRI abnormalities (high signal areas, cortical atrophy) were observed before the expedition. After the descent, two of them showed new high intensity signal areas recorded by MRI. Both subjects suffered severe neurological symptoms during the climb. The present study suggested that the brain changes observed by MRI could be related to the severity of clinical events at high altitude. However, we do not know the exact meaning of such MRI findings or the reason for their location, predominantly in posterior regions of the brain. The new evidence that a high percentage of climbers show MRI brain abnormalities, and especially the appearance of changes after the ascent, reinforces the possibility of a potential neurological risk in high-altitude climbing.

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Introduction

It has been suggested that high-altitude hypoxia may be the cause of acute and subacute neurological disorders (Cavaletti et al. 1987; Hornbein et al. 1989; Ryn 1988; West 1986). The study of isolated cases of acute mountain sickness by means of imaging techniques has occasionally been reported to have revealed alterations in certain brain structures (Fukushima et al. 1988; Shiota et al. 1990). However, it has not been until recently that structural brain changes have been detected by magnetic resonance imaging (MRI) performed on a wide range of climbers who had ascended to extremely high altitude without supplementary oxygen (Garrido et al. 1993). As we had not previously observed any correlation between the aforementioned anatomical brain abnormalities and the total time of hypoxia or other related factors, we carried out a further study both before and after an extremely high-altitude climb with the following aims:

1. To assess by MRI any brain changes produced by a single climb
2. To detect typical subacute MRI changes
3. To study the possible relationship between certain risk factors associated with the appearance of such disorders.

Our previous study (Garrido et al. 1993) was a tranversal study, and not a longitudinal one (as is the one reported here), in which the individuals were studied some time after performing several ascents to high altitude. In the present work we have studied climbers before and shortly after a climb to extremely high altitude and, in addition, we have tried to correlate the alterations observed by MRI with possible risk factors.

Methods

Subjects

Medical histories, clinical neurological examinations and MRI brain scans were obtained from nine elite climbers (seven men, two women) before and after a climb of over 7500 m without the use of supplementary oxygen. The climbers formed part of Himalayan expeditions to Makalu (8463 m), Lhotse Shar (8383 m), Cho Oyu (8201 m) and Xixa Pangma (8046 m) where they reached altitudes ranging from 7800 m to 8463 m [mean height 8156 (SD 216) m]. The average interval of time between the highest altitude reached and the second control was 33 (9 SD) days, and the time between the controls performed before and after the expedition was 104 (16 SD) days. The average age of the group was 34 (6 SD) years, their body mass 67 (11 SD) kg, and their height 171 (9 SD) cm. All the subjects were born and had spent most of their lives at sea level and none of them had had neurological or psychiatric histories or head injuries such as contusions.

The medical history was specially designed and conducted by a doctor, a member of our group, who had had experience in Himalayan expeditions and had worked closely with the climbers. The questionnaire included information concerning drug habits, fitness level, metabolic disorders, and was especially aimed at detecting biological, motivational, emotional, perceptual, cognitive and neuromotor dysfunctions or abnormalities during the acclimatization period, when climbing at extreme altitude, and on return to sea level. We also obtained their climbing histories and collected and calculated the total times spent at altitudes over 7000 m and 8000 m, with or without supplementary oxygen, during the whole of their climbing careers. Each subject was assigned a number between 1 and 9. For comparison purposes, we have considered the characteristics of a group of 21 subjects who had never been exposed to high altitudes.

Procedure

The MRI system used was a 1.5 T superconducting magnet (Signa, General Electric, Milwaukee, USA). A head quadrature polarized coil was installed. Full cranial MRI scans in sagittal, axial and coronal planes with slice thickness equal 4 mm, and gap thickness equal 1 mm in Proton density, T1 and T2 weighted images were obtained. Sagittal plane [spin-echo (SE), echo time (TE) equal to 20 mseg, repetition time (TR) equal to 575 mseg], axial and coronal plane [variable echo (VE), TE equal to 40–100, TR equal to 2000]. Two radiologists, who were unaware of the results of the medical histories and the neurological examinations, independently examined all the scans, reporting any abnormalities for the following anatomical zones: centrum semiovale, periventricular areas, brain stem, basal ganglia, internal capsula, thalamus, cerebellum, hemispheric brain sulci and ventricles.

Results

Medical history

Five of the nine climbers (nos. 1, 6, 7, 8, 9) had previously climbed over 7000 m, two of them (nos. 1, 8) on several occasions. None had ever used supplementary oxygen during their ascents. Two of the nine subjects were smokers, and four regularly performed physical exercise (3 or more days a week). None of them had a history of alcoholism or of other neurotoxic drugs.

During the expedition under study, seven climbers (78%) had typical slight clinical symptoms during the initial days at high altitude, such as headache, insomn asthenia or anorexia; four (44%) suffered moderate severe psycho-neurological symptoms during the pe od spent at extremely high altitude such as ataxia, a nesia, aphasia, hallucinations and/or behavioural dis ders. Four (44%) also presented slight postexpediti symptoms (lack of concentration, absent-mindedne asthenia). Of the four climbers who showed more se ous neurological disorders (nos. 1, 4, 7, 8), two of the were particularly noteworthy: climber no. 1 usually e perienced defective or poor acclimatization with seve headaches and general discomfort during the early da at over 5000 m. He had also suffered a severe episo of acute mountain sickness at 5200 m 8 years befo which had forced him to abandon the base camp. Al 5 years before, he had experienced certain psycho-ne rological deterioration during 1 night spent at 8600 after the descent from the summit of Mount Evere Finally, he had suffered temporary aphasia after pr longed over-exertion above 8000 m 13 months befo Climber no. 4 presented an amnesia disorder during t last expedition and a prolonged period of hallucinati between 7300 m and 8000 m. Furthermore, his fell climbers noted that his behaviour was unusual duri the time spent at over 5000 m (irritability, aggressiv ness and antagonism towards the group). He also e perienced persistent insomnia.

Neurological examination and cranial MRI

In all cases the physical and neurological exploratio performed before the expedition were normal, and th had not changed after the climb. The encephalic M were normal in all the control subjects.

In Table 1 we give the results of the MRI, perform on the climbers before and after high-altitude climb In five of nine individuals (56%), MRI carried out b fore leaving on the expedition, showed the presence high intensity signal areas (nos. 1, 2, 3, 4, 5). In one them (no. 5) a moderate degree of parietal-posteri cortical atrophy was also observed.

In two subjects with previous MRI abnormaliti new brain changes were detected as high-intensity si nal areas in the posterior lobes, which had not origin ly shown up. In climber no. 1, who previously showed lesion on the left posterior horn, a new abnormal hig intensity signal area appeared in the white matter the right occipital lobe (Fig. 1). In climber no. 4, wh had lesions in the right posterior horn, a new abnorm high signal area appeared on the posterior contralate horn. Table 2 shows the relationship between the M changes detected before the expedition and some vari bles (sex, age, drug habits, regular physical training a previous climbs of over 7000 m). These variables we also compared, as was the appearance of new abn malities in the two subjects who presented pre-p changes in the cranial MRI (Table 3).

Table 1 Magnetic resonance imaging (*MRI*) findings in elite climbers ($n=9$) before and after a high altitude climb without oxygen. Note that subjects have been assigned a number to identify the changes before and after the climb

MRI Findings ($n=9$)	Before climb	After climb	Changes pre-post
	Subject no.	Subject no.	Subject no.
HIGH SIGNAL AREAS	$n=4$ (♂)	$n=4$ (♂)	$n=2$ (♂)
Symmetrical bilateral — Posterior horns	2	2,4	4
Asymmetrical —			
Right posterior horn	4	4	
Left posterior horn	1,3	1,3	
Right occipital lobe		1	1
CORTICAL ATROPHY + HIGH SIGNAL AREAS	$n=1$ (♂)	$n=1$ (♂)	
Symmetrical bilateral — posterior horns	5	5	
NORMAL	$n=4$ (2♂, 2♀) 6, 7, 8, 9	$n=4$ (2♂, 2♀) 6, 7, 8, 9	

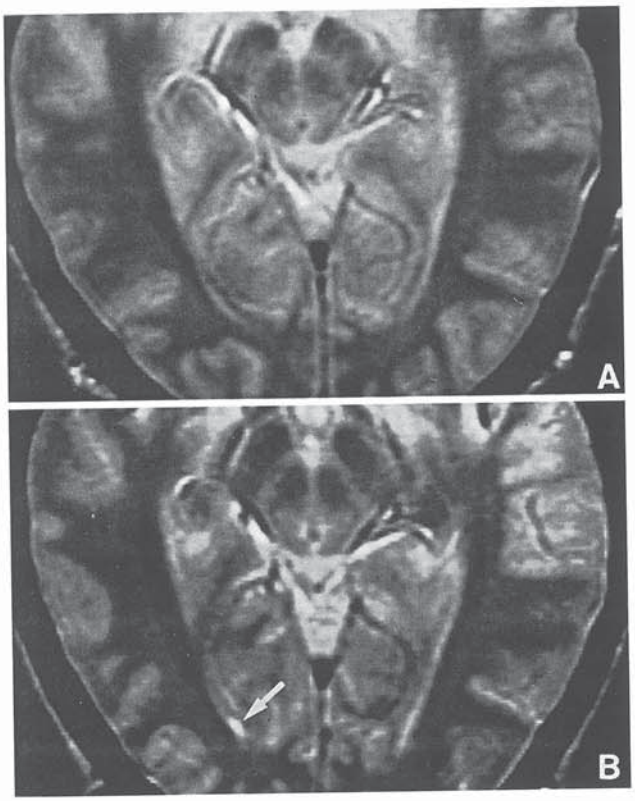

Fig. 1 Same subject pre-post (**A–B**) proton density weighted images in axial slice at the level of the posterior horns of the lateral ventricles. The *arrow* shows a lesion located in the white matter of the occipital lobe that appeared after the climb

Table 2 Comparison between pre-magnetic resonance imaging findings and some related variables

	With changes ($n=5$)	Normal ($n=4$)
Sex	5 (♂)	2 (♂), 2 (♀)
Age (years)	33 (SD 9)	34 (SD 3)
Smokers	1	1
Regular physical training	3	1
Previous climbs over 7000 m	1	4

Discussion

The MRI carried out before the expedition showed a high incidence of abnormalities in the subjects studied (56%), in agreement with our recent study (Garrido et al. 1993). This could, probably, be explained by the fact that they had been previously exposed to very high altitude; in this respect, it is noteworthy that none of the individuals in the control group showed any abnormalities on MRI. Such findings confirm the neurological risk to which climbers are exposed under conditions of relative hypoxia, and are in agreement with studies concerning the wide range and severity of neurological dysfunctions that have occurred at extreme high altitude (Clarke 1988; Jason et al. 1989; Ryn 1988; Song et al. 1986; Townes et al. 1984), even a long time after climbing (Regard et al. 1989; Townes et al. 1984; West 1986).

Table 3 Correlation of associated variables between the magnetic resonance imaging groups with and without changes after climbs

	Without changes ($n=7$)	With changes ($n=2$)
Sex	2 (♀), 5 (♂)	2 (♂)
Age (years)	34 (SD 7)	34 (SD 1)
Smokers	2	0
Regular physical training	3	1
Highest altitude reached (m)	8118 (SD 228)	8292 (SD 129)
Time over 7000 m (h)	79 (SD 74)	85 (SD 49)
Time over 8000 m (h)	10 (SD 17)	12 (SD 11)
Severe neurological symptoms	2	2

Only two of the nine climbers showed brain changes in the postclimb MRI, which would suggest that simple exposure to environmental hypobaric hypoxia is not always a sufficient condition to cause detectable anatomical brain changes by MRI. Other factors should also be taken into consideration, such as genetic variables, dehydration (both difficult to assess), fast climbs (not the case with this group) and/or unsatisfactory acclimatization. However, the acclimatization methods (approach and progression towards the summit) are usually carried out following well-defined standards.

As for the presence of further possible related risk factors in our study, we would emphasize the following: comparing the group of four climbers with previously normal MRI to the group of five climbers presenting abnormal images, we observed that the latter consisted entirely of men. Far from being conclusive, due to the small number of climbers studied, this finding is in keeping with our other recently report (Garrido et al. 1993), in which 50% of the men presented brain lesions, as opposed to 25% of the women. These results would suggest that women could be less susceptible to brain changes showing up by MRI. We also observed that in the group with normal MRI only one subject (25%) regularly performed physical training as opposed to three (60%) with MRI lesions. It may be suggested that a greater habit of, and tolerance, to intense physical training, could cause the climbers to force themselves to the limit in such situations to perform faster climbs, thus diminishing the possibility of correct adaptation to high altitudes.

It is worth noting that four of the five (80%) who had already presented MRI changes had climbed over 8000 m for the first time during the period of this study. The highest altitudes they had reached during other expeditions ranged from 5500 m to 6800 m. Assuming that such alterations were produced exclusively by hypobaric hypoxia, it could be suggested that climbing to lower altitudes induces brain MRI changes in those subjects with greater susceptibility to them. This would be in keeping with the high incidence of pathology which has often been shown to occur at nonextreme high altitude (Clarke 1988; Dickinson et al. 1983; Fukushima et al. 1988; Shiota et al. 1990; Song et al. 1986).

It is worth pointing out that the only two subjects who exhibited the brain changes shown up on MRI were the climbers who presented the most significant symptoms. Climber no. 1 regularly had difficulty in acclimatizing and showed a varied history of severe neurological symptoms at high altitude. In spite of this, he had taken part in seven expeditions above 8000 m and had reached four of the world's highest summits; he never used supplementary oxygen. Climber no. 4 presented total amnesia during one phase of the ascent, as well as a prolonged period of hallucination, behavioural disorders and persistent insomnia. The latter could be the result of the frequent instances of awakening caused by phases of prolonged apnoea which he suffered during Cheyne-Stokes breathing rhythm at high altitude. This fact could also illustrate the importanc or role it has been suggested is played by arterial oxy gen desaturation (Anholm et al. 1992; Normand et al 1990), a physiopathological mechanism that has bee questioned in some studies (Masuyama et al. 1989). I both climbers such symptoms could be interpreted a an indication of an already critical neurological condi tion because of which it would be reasonable to discou rage them from climbing at high altitudes without sup plementary oxygen.

In the current study there does not seem to be a re lationship between the appearance of MRI changes an the maximal altitude reached, the length of the sta over 7000 m and 8000 m, tobacco consumption or age as we have indicated in our previous study (Garrido e al. 1993).

We still do not know the exact pathological signifi cance of such MRI brain findings. However, because o their similar appearances and particular location, the are similar to the alteration known as leuko-araiosis defined by Hachinski et al. (1987) as a neuroradiologi cal image with MRI signal change in the deep whit periventricular matter. This abnormality is commonl found in elderly people, and is probably related to atro phy due to cortical-subcortical lesions; however, w must emphasize the fact that the mean age of this grou was only 34 years. The frequent incidence of suc images appearing in the posterior periventricular re gion is of particular importance and could be related t the predominance of parietal-posterior atrophy.

In conclusion, the present study confirmed th marked prevalence of neuroradiological brain abnor malities detected by MRI in high-altitude climbers. I addition, new brain changes were found after a singl climb over 7500 m without the use of supplementar oxygen. The appearance of severe neurological symp toms during the climb would seem to bear a relation ship to the subsequent appearance of subacute MR brain changes. It appears that exposure to nonextrem altitudes may also produce MRI brain changes. The ex act meaning of such brain changes by MRI are no clear, such as their etiology, their pathophysiologica mechanisms and their possible functional consequence at both mid- and long-term. However, the suggestio that there is a potential risk of permanent brain dam age during extremely high-altitude climbs has bee reinforced.

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