

Remote Monitoring and Automatic Analysis of Phonocardiographic Signals in Climbing of High Mountains

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Abstract

The climbing of high mountains, like the Himalayas, comes accompanied, as result of the deficit of oxygen, of certain changes of the hemodynamics, that can derive sometimes in High Altitude Pulmonary Edema (HAPE).

With the objective to analyze the cardiological effects of that hemodynamics changes, a satellite monitoring of phonocardiographic (PCG) signals and pulseoxymetric data of a mountain climber was made during the development of the climbing to the Broad Peak, of 8,047 meters, located in the mountain range of the Karakorum, in Pakistan.

Using an electronic estethoscope, signals were registered and sent to the hospital medical staff in Murcia by means of satellite phone, to be compared with basal registers. Different techniques for analysis in frequency and time domains were developed, mainly to detect and measure the first and second heart sounds and to observe possible modifications in the phonocardiographic patterns related to the altitude and pulseoxymetric data.

1. Introduction

At the present time a increasing interest in the adventure sports exists, particularly high altitude climbing and trekking, that count anywhere in the world with hundreds of thousands of fans.

Any altitude above 6,000 meters -approximately- is considered extreme. There is a serious risk of altitude related illnesses at these higher elevations. Mountaineers that ascend to those altitudes need to be sufficiently acclimatized. Ascent, without this substantial preparation, is exceedingly dangerous. However, above this altitude, it is not possible to become well acclimated to the altitude. Rather, human organism experiences a gradual decrease in physical conditioning and a progressive mental deterioration.

When the human body is exposed to hypoxia (oxygen reduced environments), it struggles to produce required

amounts of energy with less available oxygen. This struggle triggers the onset of a range of physiological adaptations geared towards enhancing the efficiency of the human body's respiratory and cardiovascular systems. For that reason, the diagnosis of possible inherent cardiopulmonary complications to this sport practice awakes nowadays a great attention, as much from the point of view of the public health like from an economic point of view. However, it presents great difficulties, since it requires an immediate medical attention in a hostile environment without hospitable means.

High mountain climbing has in the High Altitude Pulmonary Edema (HAPE), secondary to the pulmonary hypertension produced by the hypoxia, one of its main and more serious complications.

From the 50's, when for the first time mountains of more than 8,000 meters were reached, the number of stories in that the altitude related illnesses have a tragic end has been happened. Even nowadays, every year mortal victims take place for edemas between climbers and porters in the escalades to these high mountains. Not in vain, it is known as "Death Area" to these big altitudes.

Humans cannot survive more than some few days, sometimes hours, to that altitude.

Some studies [3, 4], some of them pioneers [7], they already aimed the existent relationship between the pulmonary arterial hypertension and an increase in the auscultated level of the second heart noise.

Within the techniques described for the pathophysiologic diagnosis of HAPE, studies have been made, that try to decipher the hemodynamics changes that take place, by means of echocardiographic analyses, although carried out at level of the sea inside hypobaric cameras. These studies reveal a significant, progressive and constant increase of the pressure gradient between right ventricle and right auricle from the level of the sea to a pressure equivalent to the 8,000 meters. We have not found, nevertheless, any bibliographical reference about the use of phonocardiogram in the study of the HAPE.

By means of portable computer, satellite phone and

the instrumentation that it is detailed later on, a clinical and phonocardiographic remote analysis of a mountaineer, during an escalade to the summit of the Broad Peak (8.047 meters) was carried out.

2. Methods

During the development of the expedition the phonocardiographic records were obtained using a measure chain as which is represented schematically in the figure 1.

By means of an independent sensor, specially designed for the occasion, or through the transducer that has the own Electronic Stethoscope (ES), the phonocardiographic signal is carried to the ES, which has an amplifier stage, with controlled variable gain, that besides making possible its audition, adapts the exit level from the signal to the recording instrument requirements. The used recording instrument varied in function of the altitude. In the Base Camp mainly a portable Computer (with an A/D card) it was used, while in Altitude Camps we used some of the following instruments (depending of the camp): PDA HP IPAQ POCKET PC H5450, Analogical Tape Recording or MP3 Recording.

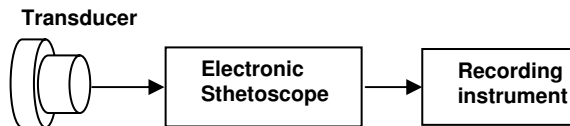


Figure 1. Simplified schema of measure chain.

The sounds registered during the climbing to Broad Peak have been analysed with a diagnosis application specifically developed for cardiovascular pathologies (ASEPTIC). This application processes the phonocardiogram (PCG) in all the stages from the acquisition to the final diagnosis. ASEPTIC is hierarchically organized in four levels, each one including several processing blocks. Some of these blocks are: signal conditioning, filtering, envelopes computation, events detection and identification, and pattern recognition.

Firstly, PCG is decimated to a sampling frequency of 4000 Hz, and then it is linearly scaled so its maximum absolute value is 1. The scaled signal is then band-pass filtered (Chebyshev IIR filter 3rd order, with cutting frequencies of 40 Hz and 800 Hz).

Two instantaneous magnitudes, amplitude (IA) and energy (IE) are computed from the filtered signal ($x(n)$), defined as:

$$y_{AI}(n) = |x(n)|$$

$$y_{EI}(n) = x(n)^2$$

The envelopes of the PCG, G_{IA} and G_{IE} , can then be computed using a moving average filter [5]:

$$G_j(m) = \frac{1}{P} \sum_{i=1}^P y_j(i) \cdot w(i)$$

where $m=1, \dots, M$, $j=\{AI, EI\}$, M is the number of samples in the envelopes, P is the number of samples in 60 ms (sampling frequency of 4000 Hz), and w is the Hanning window, used to smooth the envelopes. The overlap between windows has been 57 ms.

Then the envelopes are standardized (mean=0 and standard deviation=1), and the minimum value of each envelope is subtracted from the entire signal, in order to achieve envelopes with minimum values of zero.

Next step involves detection of cardiac events using the algorithm proposed in [6], which is based in the computation of relative maxima and minima from the amplitude envelope.

Some features are extracted from the envelopes in order to properly characterize the events and analyze their evolution. In this work, we have used a subset of 4 features: the mean of each event (grey areas in Figure 2) in the amplitude envelope ($meanA$), the maximum value of each event in the amplitude envelope ($maxA$), and the mean and maximum values of each event in the energy envelope ($meanE$ and $maxE$, respectively). Ratio of these features for S1 and S2 events ($S2/S1$ ratio) has been computed to represent the increase in the aortic and pulmonary components of S2 with respect to S1.

ASEPTIC also includes an efficient method that compresses the PCG [7], thus decreasing the bandwidth needed to transmit the signal. This is very useful in situations like this expedition, where communications were made with satellite telephone, in order to decrease transmission costs.

3. Results

Several PCG records were stored during the climbing. From this set, 10 records (R1 to R10), representing key situations, were selected and analyzed with ASEPTIC. Only S1 and S2 events were found in all the records.

R1 and R2 correspond to basal registers recorded at the beginning of the expedition, and R10 is also a basal register taken after descending the Broad Peak. R4, R5, R7 and R8 were recorded in altitudes above 4000 m, in good acclimatization conditions. Finally, R3, R6 and R9 were taken at higher altitudes after hard effort journeys, in bad acclimatization conditions. All registers were recorded at the apex position.

Figure 2 represents register R2, together with the amplitude and energy envelopes derived from the PCG, and the cardiac events (S1 and S2) detected. Since R2 is a

basal register, it can be seen how the amplitude (and, thus, the energy) of S1 is greater than that of S2, as corresponds to the intensity of the heart sounds.

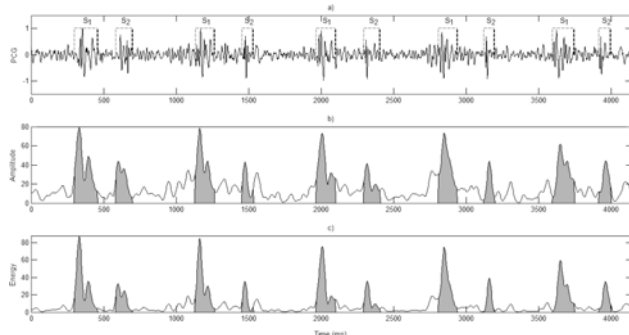


Figure 2. Example of detection of cardiac events for the basal record R2: a) PCG signal, b) amplitude envelope, c) energy envelope.

On the other hand, Figure 3 shows register R9, which was recorded in bad acclimatization conditions. It can be appreciated how the amplitude (and energy) of S2 is now greater than that of S1 (despite R9 was also recorded at the apex), showing an increasing of the intensity of S2 with respect to the basal record.

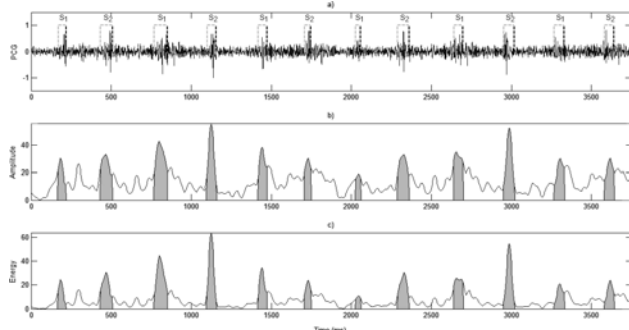


Figure 3. Example of detection of cardiac events for the high-altitude record R9: a) PCG signal, b) amplitude envelope, c) energy envelope.

Figure 4 represents *meanA*, *meanE*, *maxA* and *maxE* features for the set of 10 records. This figure show (for both, mean values (a) and maximum values (b)) three categories of records: 1) basal records (R1, R2 and R10), which have the lowest values for *meanA* and *meanE* features (and also for *maxA* and *maxE* features), 2) altitude records in good acclimatization conditions (R4, R5, R7 and R8), which have higher values than basal records, and 3) altitude records in bad acclimatization conditions (R3, R6 and R9), which have the highest values.

Also, it can be noted that amplitude values are always larger than energy values, except for R3, R6 and R9 records. For R3 and R6, the amplitude and energy values are practically the same, but for R9 (which is the record

taken in the worst acclimatization conditions), the relative position between the amplitude S2/S1 ratio and the energy S2/S1 ratio is inverted. Thus, a positive difference of *meanA* - *meanE* (and also *maxA* - *maxE*) means good acclimatization conditions, and as this difference decreases and becomes negative, this means worse acclimatization conditions.

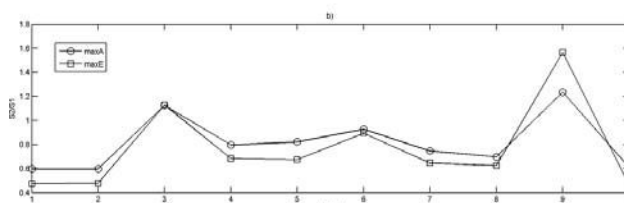
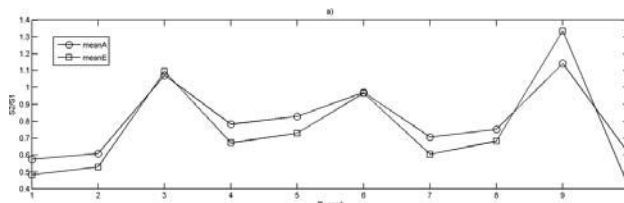


Figure 4. Variation of S2/S1 ratio extracted from the amplitude and energy envelopes: a) mean value, b) maximum value.

Table 1 indicates, for each record, the value of the S2/S1 ratio. Table also contains the altitude, expressed in meters, to which each phonocardiographic signal was acquired, as well the heart rhythm and the level of arterial saturation of oxygen in blood (SaO2). The last line shows the days of permanency in the mountain, which constitutes a fundamental fact to explain the acclimatization state to the height.

1. Figure 5 evidence the existent relationship among the values of the ratio S2/S1 and the level SaO2. The analysis of lineal regression among both groups of values shows the narrow relationship between both parameters, what is also deduced from the high value of the correlation index obtained, whose value is -0.92. The negative sign is consequence of the evolution in contrary senses of both parameters, that is to say, an increase of the ratio S2/S1 is translated in a decrease of the level of SaO2.

Table 1.

Record	Altitude (meters)	Ratio S2/S1	S _a O ₂ %	Heart Ryt.	Day
R1	45	0,8	97	56	0
R2	1200	0,81	96	60	10
R3	4060	0,9	83	77	14
R4	4920	0,83	88	68	21
R5	5700	0,9	81	80	27
R6	6200	0,96	75	82	28
R7	4920	0,77	90	64	29
R8	6250	0,88	83	75	34
R9	7050	1,29	-	-	35

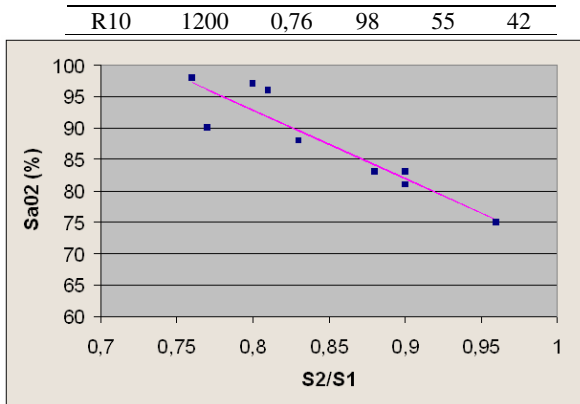


Figure 5. Ratio S2/S1 versus level of arterial saturation of oxygen in blood (SaO₂).

4. Discussion and conclusions

2. The automatic analysis to the records, by means of amplitude and energy envelopes, permits to detect the S1 and S2 cardiac events. This work shows the narrow relationship among the S2/S1 ratio and the SaO₂ level, whose high correlation index seems to confirm. The difference between the amplitude and energy features is a good indicator of the acclimatization degree too.

3. From a technological point of view, the connection through satellite with the medical centre has not only demonstrated to be feasible to transmit these signals, but rather it has been of great interest to monitoring the climber's general state and, specially, of its acclimatization degree.

In spite of the low speed of data transmission of the satellite-phones, the possibilities for the compression of the files of cardiac sounds, facilitates a reliable and quick transmission through electronic mail.

Acknowledgements

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