3-D BALLISTOCARDIOGRAPHY, A TOOL REVISITED FOR FOLLOWING ASTRONAUT CARDIOVASCULAR FUNCTION?

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ABSTRACT

A recording on a crew member of the D2-Spacelab mission constitutes, to our knowledge, the only 3-D acceleration data that includes respiratory movements. In a previous paper [1], the description of the Balistocardiogram (BCG) on three axes revealed that the information along the antero-posterior axis (which is inaccessible on earth) was of the same magnitude as the 2 other projections, and thus of crucial importance for the physiological interpretation. The present study analyses in details the 3-D displacement vector (DV).

1. INTRODUCTION

In the fifties, attempts were made to establish BCG as a mechanical equivalent of the electrocardiogram (ECG). After more than three decades, this field of research was almost abandoned. The analysis of a unique set of 3-D acceleration data collected in space [1] revealed that on earth, the 2-D BCG lacked key information and that may be one of the reasons of the difficulties to establish BCG as a non-invasive method for the determination of stroke volume (SV). In the past, the studies were focused on the analysis of the projection of the acceleration vector on a 2-D plane. In the present study we show that the analysis of DV provides rich and new information on the cardiac contraction.

2. SUBJECTS AND MEASUREMENTS

3-D BCG, ECG and respiratory movements were continuously recorded in microgravity (μG) during 15 min on a 42-yr-old male subject. A continuous 217 s period with 176 heartbeats, the longest uninterrupted period of the recording during which the astronauts was absolutely free of disturbing contacts, was selected.

3. METHODS

After removal of drift and respiratory components, displacement was computed by means of double integration of acceleration data (see Fig. 1). The 3 components of displacement were averaged beat by beat. A change of coordinates was applied so that the calculated DV represents the average displacement of the centre of mass of the astronaut's body moving parts during one cardiac cycle. DV in this representation is thus mainly due to the movement of circulating blood.

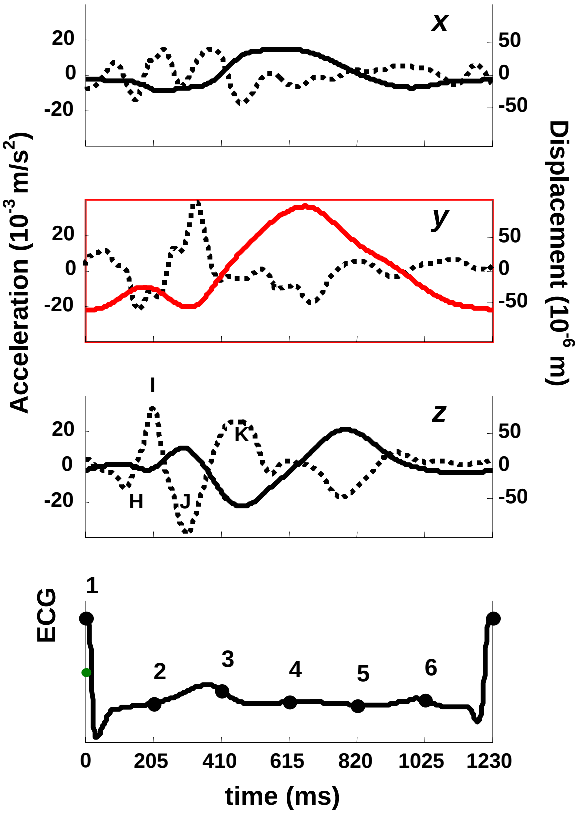

Fig. 1. The 3 projections of the BCG on the anatomical axes (left to right (***x***), antero-posterior (***y***), feet to head (***z***)) with the ECG and time stamps to allow identification of timing of events in the cardiac cycle.

The projections of the displacement vector on the 3 anatomical axes were used to construct a 3-D plot of DV (see Fig 2). As expected, after the drift removal procedure, at the end of the heart beat the curve returns to its point of origin, thus in agreement with Newton's second law of motion. To show the influence of respiration, DV was computed for heart beats occurring at the lung's functional residual capacity (FRC) and at the end of inspiration, FRC + tidal volume (FRC+TV). The curve described by the tip of DV was further characterized through the computation of scalar parameters independent of the frame of reference:

- ds the magnitude of displacement vector:

$$ds = \sqrt{dx^2 + dy^2 + dz^2} \qquad (1)$$

- the curvature of the curve:

$$\frac{1}{\rho^2} = \frac{|\dot{r} \times \ddot{r}|}{ds^6} \tag{2}$$

- and its torsion

$$\frac{1}{\tau} = \frac{|\dot{r} \cdot \ddot{r} \cdot \dddot{r}|}{|\dot{r} \times \ddot{r}|^2} \tag{3}$$

where ρ and τ are the radius of curvature and torsion.

4. RESULTS

The 3-D representation of displacement revealed that it is mostly confined within a plane close to the sagittal plane (see Fig. 2).

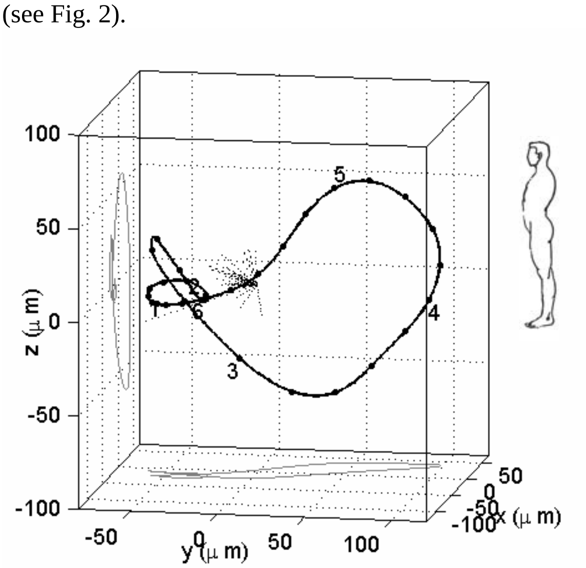

Fig. 2. The displacement of the centre of mass of moving parts represented in 3-D with projections on xy and xz planes.

The tilt angles of this plane were measured (19.9° in azimuth and 15.8° in elevation). The diastolic part of DV was particularly simple and evolved up to 98 % in that plane. The systolic part of DV was more curved and tortuous and very sensitive to respiration. Curvature and torsion (see Fig. 3) were stable during the diastole whereas they peaked sharply during contraction of the heart cavities.

5. DISCUSSION

Unexpectedly, the sharp systolic peaks in curvature and torsion occurred at different times, when the heartbeat occurred at the end of expiration as opposed to the end of inspiration (see ***a*** and ***b*** peaks on fig. 3.B.). Thus, they cannot be related to known features (I-J-K waves) of the 2-D BCG, which in the past were thought to be linked to the ventricular ejection. This suggests that the classical physiological interpretation of the 2-D BCG is misleading. The fact that the displacement takes place in a plane is likely due to the high symmetry of the cardiovascular tree in respect to the sagittal plane.

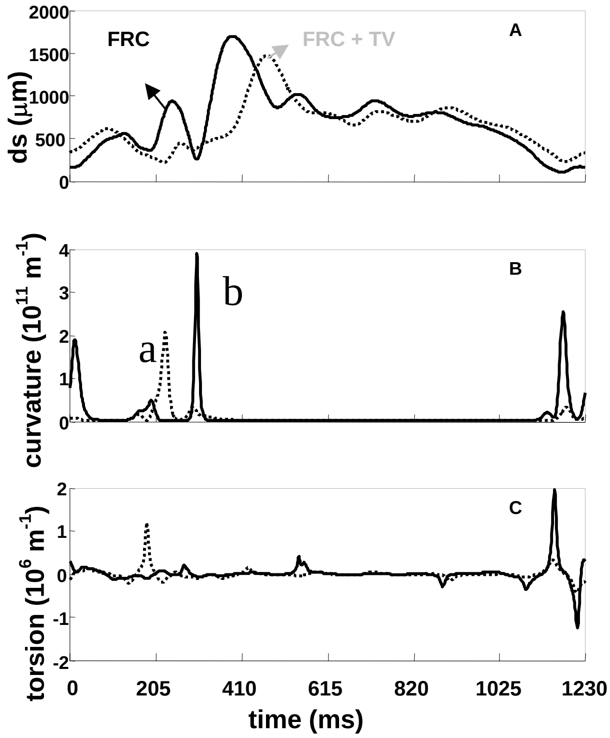

Fig. 3. (A) Magnitude of the displacement vector, (B) curvature and (C) torsion of DV vs time in the cardiac cycle (see Fig 1.).

6. CONCLUSION

The collection of scalar parameters (ds, curvature, torsion) may be the basis for normative tables which can provide new non-invasive information about beat-to-beat SV changes. Furthermore, it is likely that situations that change cardiac contraction, e.g. valvuloplasty and unilateral exclusion of large vascular beds leave their footprint on the loop. On earth, 3-D force measurements could advantageously replace accelerometers and allow practical use of the presently disregarded BCG.

7. ACKNOWLEDGMENTS

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8. REFERENCES

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