ELASTIC AND HYDROSTATIC PROPERTIES OF THREE DIFFERENT REBREATHER BELLOW DESIGNS

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Background

The European norm for rebreathers (EN1414-3:2003) allows for a hydrostatic pressure difference of +2.0 to -2.0 kPa (-2.5 face-down, horizontal) relative to the suprasternal notch ('B', Figure 1). Warkander, Clark and Lundgren (1) suggest the limits for hydrostatic imbalance to be 1.5 to -1.0 kPa for the horizontal face-down position and 1.0 to -1.0 kPa for the vertical head-up position centered around the lung centroid ('C', Figure 1). Converting the limits proposed by Warkander et al to the suprasternal notch reference point generates the limits +0.8 to -1.7 kPa for the horizontal face-down and 2.4 to 0.4 kPa for vertical head-up position. Further, the authors suggest to limit the elastance to 0.7 kPa/l which makes 1.75 kPa allowed at 2.5 l tidal volume. Different breathing bellow designs were tested to investigate how well they conform to the standard and proposed limits.

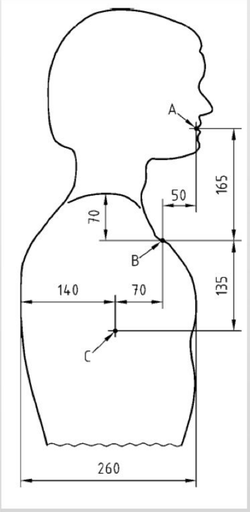

Figure 1: The distances in mm between anatomical landmarks according to the European rebreather norm EN1414-3:2003

Methods

The tests were carried out in accordance with the testing method for hydrostatic imbalance in EN1414-3:2003. With the apparatus lowered in to water at a depth sufficient to preclude surface effects (e.g. 1 m). The breathing simulator was set at 25 bpm and the tidal volume at 2.5 l. The apparatuses were tested in all the directions indicated in figure 2. The hydrostatic imbalance is the pressure difference between the suprasternal notch and the end of exhalation (no flow) pressure in the mouthpiece. The difference in pressures between end exhalation and the end inhalation is taken as the elastance of the system

Rebreathers under test:-

EOD Stealth (Divex Ltd), is an electronically controlled closed-circuit apparatus, with a split over the shoulder breathing bag design.

Viper+ (Carlton Technologies Inc.), is a self-mixing active flow semi-closed apparatus, with a split over the shoulder breathing bag design, were the relief valve is activated at the end of exhalation.

CRABE (Aqualung - La Spirotechniquel.C.I), is a demand controlled, passive dosage, semi-closed apparatus. The apparatus is back mounted, of a cylindrical inner bellow, within an outer bellow design, that moves outwards from the diver. The relief valve is activated during the whole inhalation.

DCSC (Interspiro AB), is a demand controlled active dosage semi-closed apparatus, with a back mounted hinged bellow with weights to counteract hydrostatic imbalance. Tested with and without the 8 kg bellow weights.

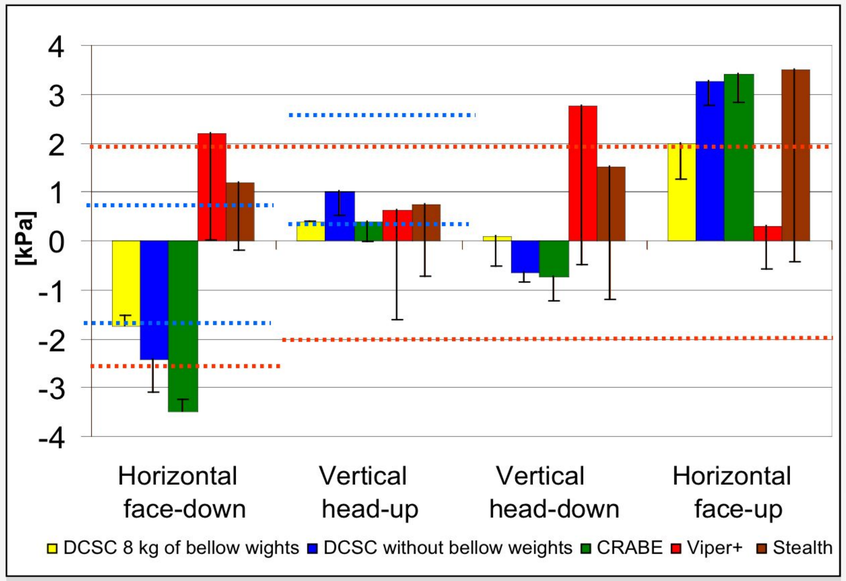

Figure 2: Hydrostatic imbalance (end exhalation "no flow") relative to the suprasternal notch in three different bellow and rebreather designs. The black line in each pressure bar is the elastance and it shows the end inhalation pressure difference as well. The dotted red lines show the allowable limits of the European rebreather standard EN1414-3:2003. The blue dotted lines show the limits proposed by Warkander et al(1).

Results

In the horizontal face down position the hydrostatic imbalance of the four systems tested was -1.75 kPa for the DCSC with weights, -2.44 kPa for the DCSC without weights, the CRABE was -3.50 kPa the Viper+ had a hydrostatic imbalance of 2.22 kPa and the Stealth had a pressure of 1.20 kPa. The elastance were respectively -0.22, -0.66, -0.25, 2.20 and 1.14 kPa. In the vertical head up position they were 0.38, 1.00, 0.40, 0.63 and 0.75 kPa. with the elastic property of -0.03, 0.5, 0.42, 2.25 and 1.50 kPa.

Discussion

Of the tested systems the only one complying with the standard was the DCSC, probably because the bellow weights are designed to counter act the imbalance. Interestingly, the bellow is not fully balanced out by the weights even though one can see a marked increase in hydrostatic imbalance when the weights are removed. One other interesting effect of the bellow weights is that it appears to also reduce the elastance, which could well be due to increased inertia in the system working against elastic acceleration.

The unweighted back mounted CRABE bellow seems to generate substantial hydrostatic imbalances in the horizontal position, simply because of the distance between the reference point at the chest and the bellow on the back. The large area of the bellow keeps the elastance low.

The two systems with front mounted, split breathing bags seem to follow the same pattern. It was noted that the semi closed unit (Viper+) emits gas on each end exhalation, causing an increased pressure in the system due to the position of the release valve. This is normally not the case for a closed system like the Stealth, making the geometric design of the counter lung more important for the hydrostatic imbalance than the position of the release valve. The markedly increased value for the Stealth in the horizontal face-up position comes from a free flow situation generated by the ADV (automatic diluent valve) and the position of the relief valve.

Conclusion

Testing of these bellow types found in existing and widely used diving systems show that only one, the DCSC, conform to the European norm, and none to the limits proposed by Warkander, Clark and Lundgren(1).

References

(1) Warkander DE, Clarke JR and Lundgren CEG. Undersea and hyperbaric medicine 2001:28(suppl)(Abstract)151.

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