Cardiac Output in Relation to Decompression Bubbles

Danica Grant[1], Josh Currens[1], Jayne Leypoldt[2], Dr. Virginie Papadopoulou[1,*], Dr. Frauke Tillmans[2,*]
[1]Joint Department of Biomedical Engineering, University of North Carolina at Chapel Hill
[2] Divers Alert Network
* Corresponding authors: papadopoulou@unc.edu; ftillmans@dan.org

Joint Department of BIOMEDICAL ENGINEERING | UNC CHAPEL HILL | NC STATE UNIVERSITY

INTRODUCTION

- When scuba diving, divers breathe in high pressure gasses, and as they descend pressure increases, causing inert gasses to dissolve into tissues. When divers ascend and decompress, bubbles called venous gas emboli (VGE) can be detected in the circulatory system [3].
- Decompression sickness (DCS) manifestations include skin itching, neurological symptoms, and death. DCS is caused by decompression bubbles. Increased amounts of VGE are associated with a higher risk of DCS, although this is not a one-to-one relationship [1].
- VGE can be seen in the heart chambers using echocardiography graded on the Eftedal-Brubakk scale. Variability in post-dive EB grades for divers doing identical dive profiles has been shown. However, the inter vs. intra-subject contributions are not known.
- It has been theorized that the amount of VGE detected in the heart is related to the cardiac output [4].

Objective: Investigate if cardiac output is associated with the VGE grades of the same diver after identical dive profiles as part of a larger study investigating if differences in VGE post-dive is due to inter or intra diver variability.

METHODS

$$Cardiac\ Output = Stroke\ Volume\ x\ Heart\ Rate \quad (1)$$

$$Stroke\ Volume = Left\ Ventricular\ Outflow\ Area\ x\ Time\ Velocity\ Integral \quad (2)$$

Collecting Data:

- Data for this project was obtained from a larger, longitudinal study (IRB: 029-21-21). 20 divers of various ages and sexes were observed, although one diver was pulled from the study early. A total of 820 scans were collected.
- VGE grades were assigned to each scan using the Eftedal-Brubakk scale. This scale ranges from 0 to 5 with 0 representing no bubbles seen, and 5 representing so many bubbles that individual bubbles cannot be identified [3]. A scan was taken before the dive, and every 20 minutes after the dive until bubbles were no longer detected.

1. Identified parasternal scans for collecting Left Ventricular Outflow Tract (LVOT) diameter measurements and pulse-wave images for Time-Velocity Integral (TVI) measurements.
2. Measured diameter and TVI using Vivid-Q system's tools.

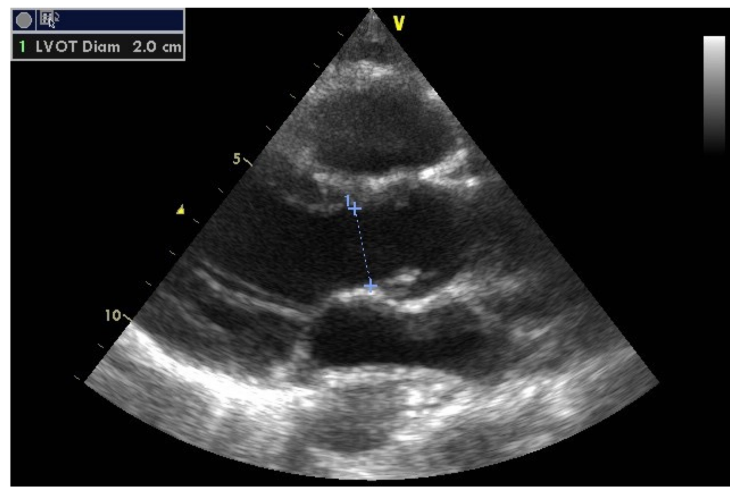


Figure 1. Parasternal scan of the heart. LVOT diameter is measured in centimeters during mid-systole, at the "between the hinge points of the aortic valve leaflets from inner edge-to-inner edge" [1].

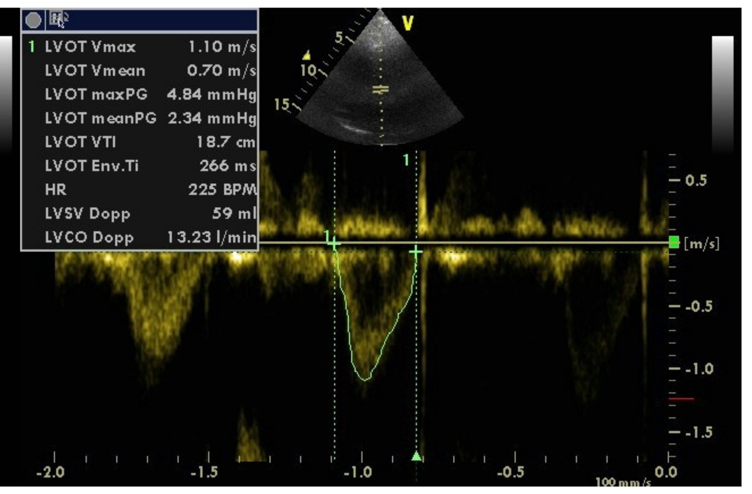


Figure 2. Pulse-wave diagram during the heart cycle. X-axis is time in seconds. Y-axis is the velocity of blood flow in m/s. TVI is calculated by taking the area under the curve during mid-systole (visualized by the peaks).

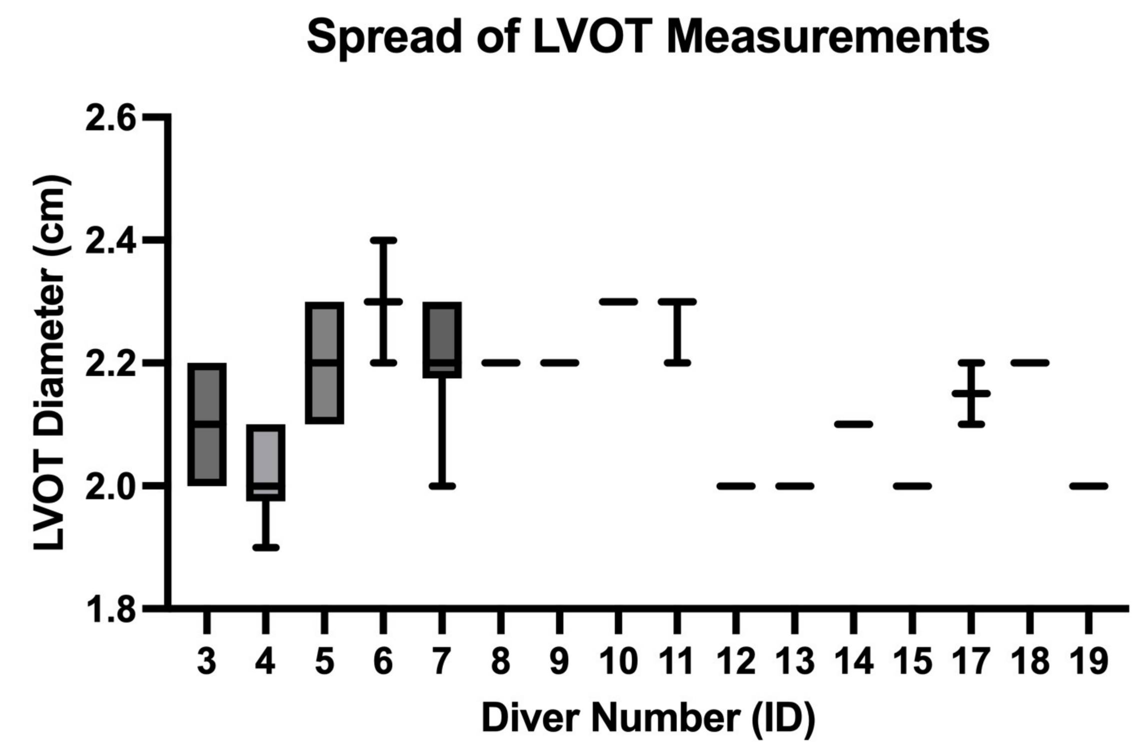
Calculations:

3. Calculated cardiac output (1) and verified results with external calculator [2].
4. Assessed cardiac output results with literature LVOT values and MATLAB code.
5. Correlation between cardiac output calculated using measured and literature LVOT values was determined using linear regression.
6. Compared cardiac output with existing echocardiography grades from larger VGE Variability Study.

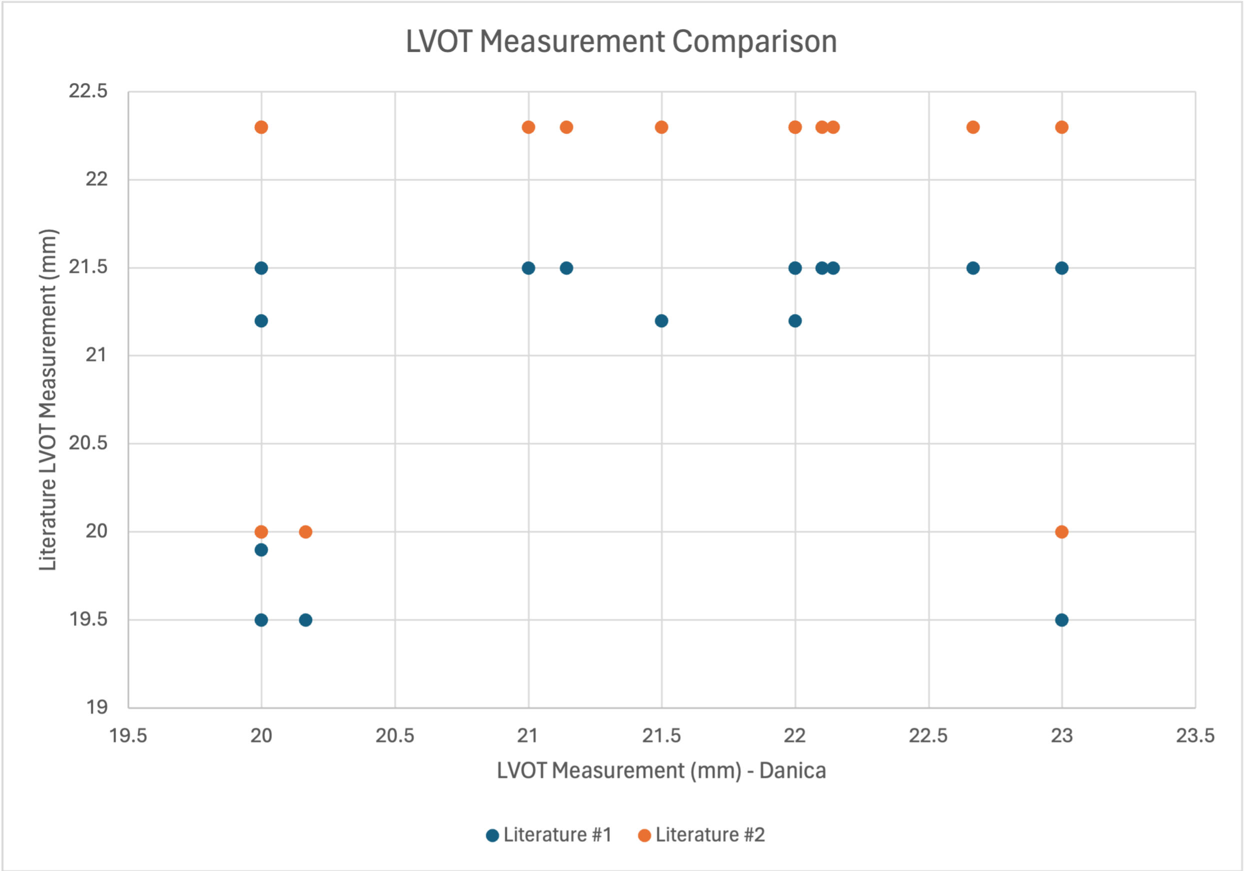
RESULTS

- 820 dive timepoints were reviewed and 72 LVOT diameters and TVIs were manually measured to calculate cardiac output.

(a)



(b)



(c)

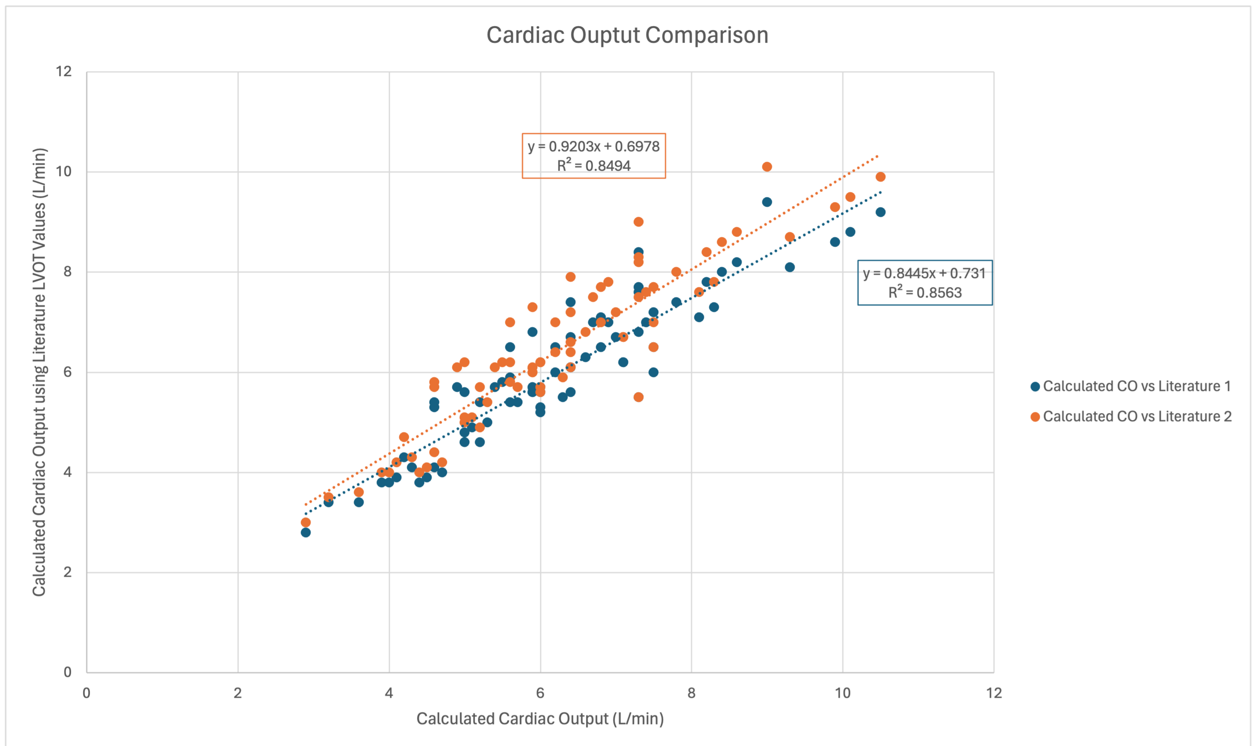
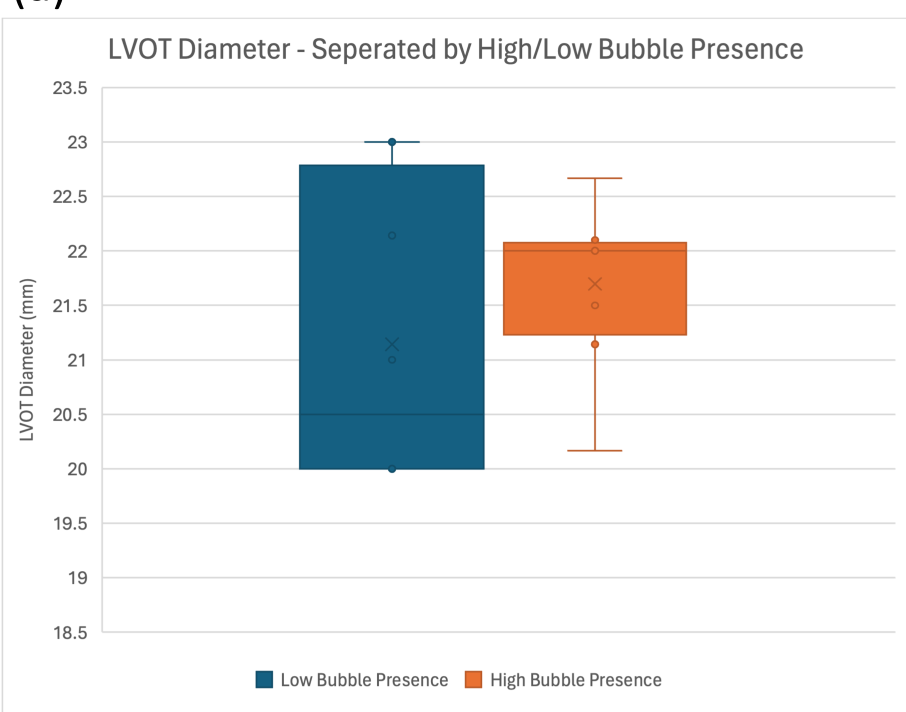


Figure 3. (a) The distribution of LVOT diameters for divers with a parasternal scan is shown. (b) LVOT diameter measurements are compared with the literature values based on sex and age (literature #1) [1] and sex (literature #2) [5]. (c) Cardiac output calculated from LVOT diameter measurements is compared to cardiac output calculated using literature LVOT diameter measurements.

RESULTS

(a)



(b)

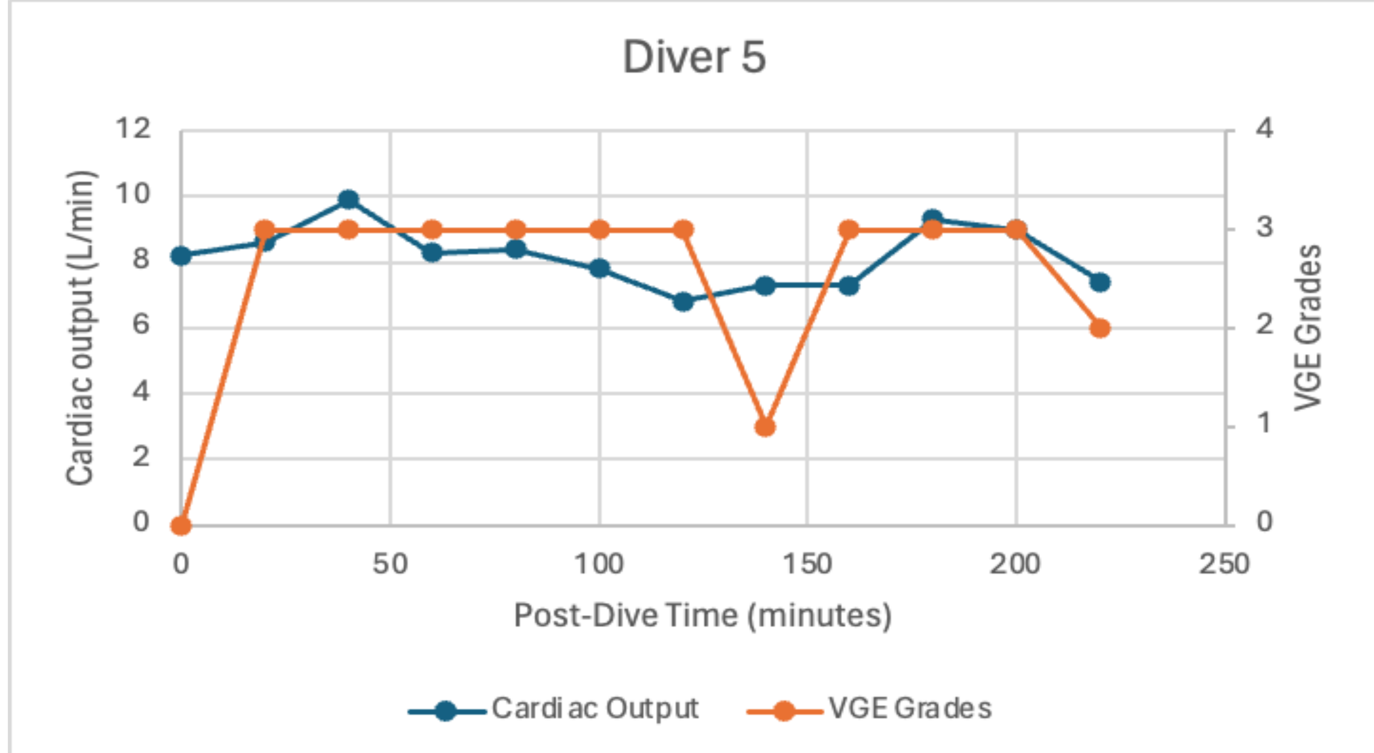


Figure 4. (a) 16 divers had a parasternal scan. The LVOT diameters among divers who had an EB grade of 3+ (high bubble presence) and those who did not (low bubble presence) is shown. LVOT values would eventually be correlated with cardiac output values I would calculate.
(b) The cardiac output and VGE grades for a complete dive. Scans were taken pre-dive (time 0 minutes) and for every 20 minutes post dive until bubbles were no longer detected.

CONCLUSION/FUTURE DEVELOPMENTS

- Analysis of LVOT diameter measurements shows that repeated measurements are precise, within a 2 mm range (diver #7 is an exception). For future purposes, it is acceptable to average the LVOT diameter measurements of divers who received multiple parasternal scans.
- 4 subjects did not have a parasternal scan. A literature value is necessary to calculate cardiac output. Based on data analysis (3b), the literature LVOT diameter values are not representative of actual measurements. However, further analysis (3c) seems to show that the resulting cardiac output is similar between the two methods.
- There is not a discernable trend between cardiac output and bubble presence. For our example dive (4b), there seems to be a weak, direct relationship between cardiac output and VGE grades. Keeping in mind that VGE grades are less continuous than cardiac output, generally an increase in cardiac output was followed by an increase in VGE grade (and vice versa). Regions of continuous/similar cardiac output values aligned with consistent VGE grades.
- This protocol would be useful for extending research to more recreational dives within the study for further analysis. Given more time, this pipeline can be extended to all 800+ scans of the larger, longitudinal study, to calculate cardiac output. With more calculations more conclusive results could be drawn about the relationship between cardiac output and decompression bubbles in recreational divers.

REFERENCES

[1] Hena N. Patel *et al.*. (2021). Normal Values of Aortic Root Size According to Age, Sex and Race: Results of the World Alliance of Societies of Echocardiography Study. Journal of the American Society of Echocardiography. Volume 35, Issue 3, Pages 267-274. 10.1016/j.echo.2021.09.011.
[2] Calculate by QxMD. (2021). Hemodynamics (Echo). Retrieved from https://qxmd.com/calculate/calculator_110/hemodynamics-echo
[3] Le Dq, Dayton PA, Tillmans F,, et al..(2021). Ultrasound in decompression research: fundamentals, considerations, and future technologies. UHM 2021, Volume 48 (1): 59-72.
[4] Fahlman A. (2017). Allometric scaling of decompression sickness risk in terrestrial mammals; cardiac output explains risk of decompression sickness. Scientific Reports. 7:40918. 10.1038/srep40918
[5] Kou, S *et al.*. (2014). Echocardiographic reference ranges for normal cardiac chamber size: results from the NORRE study. Eur Heart J Cardiovasc Imaging. 15(6): 680–690. 10.1093/ehjci/jet284