2023 45th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC) | 979-8-3503-2447-1/23/$31.00 ©2023 IEEE | DOI: 10.1109/EMBC40787.2023.10340601

A Pilot Observational Cohort Study to Investigate the Effect of Valsalva Maneuver on Internal Jugular Venous Diameter

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Abstract—**Valsalva maneuver (VM) is a technique widely used for acute elevation of blood pressure in humans. It has potential applications in cardiac health prediction and is also a diagnostic tool in cardiovascular, neurology and ENT screening. The jugular venous (JV) diameter increases during the VM procedure and hence it has been widely used to aid central venous catheterization in medical units. In this pilot study, we have quantified the variation in JV diameter response to VM across young and middle-aged populations. The study was conducted on a cohort of 16 males and 11 females, where the JV diameter in baseline, during and post VM intervention were acquired using a B-mode imaging system. The JV diameter measurements were within the ranges specified in earlier literature. The beat-to-beat variability in baseline diameter measurements was found to be between 8% to 20%. In younger population, the average maximum JV diameter during baseline was found to be 9.25 ± 2.61 mm and in middle-aged population it was 12.49 ± 2.65 mm. The average maximum JV diameter in young and middle-aged population during VM was 11.66 ± 2.74 mm and 16.73 ± 3.28 mm respectively. The study findings suggested a statistically significant variation ($p < 0.05$) between the JV diameter responses from young and middle-aged populations. The JV distensibility decreased significantly during VM in younger cohort (-35%) in comparison with the minimal changes observed in middle-aged population. The study demonstrates the variation in JV diameter and distensibility to VM in young and middle-aged populations.**

Clinical Relevance— **This pilot study reveals the variations in JV diameter in response to VM intervention in young and middle-aged groups which has potential utility in assessing age dependent changes in vasculature.**

I. Introduction

The internal jugular veins are the largest set of vessels in the neck region that return deoxygenated blood from the brain, skull, and superficial neck regions back to the heart [1]. The JV trail from the jugular foramen and are directly connected to the superior venacava. Hence the JV is considered as the reference access site for right atrial hemodynamic monitoring. The right atrial pressure estimation offers significant information regarding cardiac anomalies such as atrial fibrillation, tricuspid valve malfunctions, pericardial defects etc. [2]. The gold standard technique for right atrial pressure measurement is the invasive central venous catheterization [3], [4]. Valsalva maneuver is an intervention procedure to temporarily increase the JV diameter thereby facilitating improved venous access [4], [5]. The VM is a well-established medical tool to monitor the heart murmurs and the functioning of the heart [4]. It involves the forced expiration against the closed glottis resulting in elevated intra-thoracic and intra-abdominal pressures. A typical VM procedure has four phases were blowing air against closed glottis during the initial phase results in a temporary increase in aortic pressure resulting in a temporary increase in blood pressure (BP). The straining during VM results in a steady decrease in the BP. The BP further decreases as the subject relaxes at the end of the maneuver. This is followed by the recovery phase where the increased blood flow results in a slight increase in BP which gradually returns to the baseline ranges once the heart rate returns to normal [6], [7].

The intra-thoracic pressure changes during the VM results in the JV diameter variations [7]. Recent studies have indicated the ability of VM to evaluate valvular disorders [4]. The valvular malfunctions result in an increased pressure in the heart chambers. The intra-thoracic pressure dependent JV diameter response are explored recently to monitor the vascular health. While the prior studies focused on the usability analysis of JV diameter response to VM, to estimate the magnitude of diameter increase for cardiac catheterization applications [7], [8]. To our knowledge, no comparison study has been reported to demonstrate the variation in JV diameter response to VM among different age cohorts.

In this study, we have investigated the response of JV diameter in young and middle-aged populations to the VM stimulus. The JV diameter measurements were performed using a conventional B-mode ultrasound system. The JV diameter response and the JV distensibility, which is the ratio of change in the diameter to the minimum diameter were monitored. The study details and data collection strategy are elaborated in Section II followed by the comparative analysis on the JV variation to VM response discussed in Section III.

This research was partially supported by Science and Engineering Research Board (SERB), Department of Science and Technology (DST) and Indian Institute of Technology (IIT) Madras under the Institute of Eminence (IoE) funding from the Ministry of Human Resource Development (MHRD), Government of India

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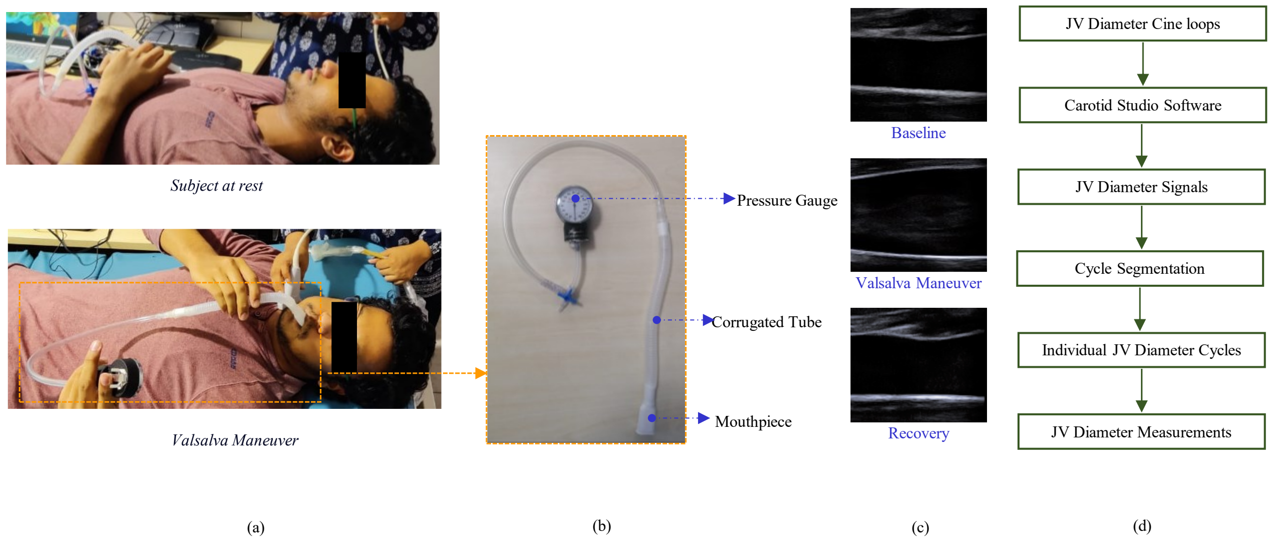

Fig.1 (a) Illustration of a subject performing VM (b) The Valsalva Maneuver setup (c) The JVP diameters in baseline, VM and recovery (d) JVP Diameter estimation algorithm.

II. Materials And Methods

A. Study Objectives

The in-vivo study objectives were:

1) To measure the JV diameter using B-mode imaging system and estimate its response to valsalva maneuver stimulus.
2) To compare the variation in JV diameter response across young and middle-aged population groups.
3) To evaluate the feasibility of measuring JV distensibility which is a direct indicator of vascular elasticity and further compare its variation in young and middle-aged cohorts.

B. Participants

The in vivo measurements were conducted on a cohort of 27 participants (16 males and 11 females). The participants were grouped as young (20 – 30) years and middle-aged (40 - 50) years in terms of the age distribution. The subject details are attached in Table I. The participants had no history of breathing disorders. Out of the 27 subjects, 25 were normotensive while the rest 2 were hypertensive. The in vivo study was conducted in par with the principles (approved by the Institutional Ethical Committee, IIT Madras, IEC/2021-01/JJ/07) compliant with the Helsinki Declaration of 1975, amended in 2013. Informed written consent was obtained from the participants prior to the measurement.

TABLE I: CHARACTERISTICS OF THE POPULATION

Parameters	Number/ Mean ± SD
No. of Participants (Male/Female)	27 (16/11)
Age (Years)	21 – 50
Height (cm)	166.94 ± 7.82
Weight (Kg)	66.58 ± 17.37
Baseline Brachial SBP (mmHg)	114.52 ± 12.32
Baseline Brachial DBP (mmHg)	71.11 ± 8.32
Baseline Heart rate (BPM)	74.05 ± 7.70
Recovery Brachial SBP (mmHg)	111.17 ± 9.04
Recovery Brachial DBP (mmHg)	69.47 ± 7.03
Recovery Heart rate (BPM)	74.70 ± 8.97

The experimental setup comprises of a mouthpiece through which the participants were asked to blow out during the valsalva maneuver. It comprises of a spirometer connected to a pressure gauge through a corrugated tube. The pressure gauge was used to monitor the pressure during VM. The VM experimental setup is indicated in Fig 1(b).

C. Measurement Protocol

The measurements were performed in controlled laboratory settings at a temperature (22 ± 2) °C. The participant was requested to rest in supine posture for about 5 minutes. The bed was elevated at an angle of 30° for optimum measurement. The anthropometric measurements and subject information were recorded prior to the measurement. The blood pressure measurements were obtained using the automatic BP monitor (SunTech®247™, SunTech Medical, USA).

The B-mode imaging measurements (Ultrasonix, Ultrasonix Medical Corporation, Canada) were acquired from the right internal JV 3 cm below the angle of the jaw. The participant was requested to tilt his head slightly to the left to prevent flattening of the JV. The ultrasound transducer probe (10 MHz) was positioned along the cross-section to locate the vessel and to ensure minimal applied hold on pressure. Further the probe is oriented until clear parallel vessel walls were obtained from the JV for reliable acquisition of JV diameter signals.

For the valsalva maneuver, the participant was instructed to take a deep breath and hold it by squeezing his nose while keeping his mouth closed. The subject was asked to bear down hard and breathe out through the mouthpiece maintaining a pressure of 30 - 40 mmHg for a duration of 15 s. Further, the participant was urged to relax and breathe normally. Following the valsalva maneuver, the blood pressure measurements were recorded. The JV diameter measurements during baseline was recorded for 30s followed by the VM intervention for 15 s. Further the post intervention recovery was observed for a period of 60 s. The JV diameter was recorded as cine loop videos in .avi format at a frame rate of 30 FPS. An illustration of the subject performing VM, and the diameter variation is represented in Figs. 1 (a) and (c) respectively.

D. *Data Processing*

The B-mode JV diameter cine loops were processed offline using Cardiovascular Suite (Quipu srl, Netherlands). The AVI cine loop file was loaded into the carotid studio software. The participant record was created by entering necessary information. The timing information on baseline, intervention and recovery were entered. A suitable tracking region of interests (ROI) was identified by manual inspection where the JV vessel walls were parallel to each other. Length calibration was performed by selecting the depth of the ultrasound scan. The software estimates the JV diameter by tracking the vessel wall motion and displays the diameter waveform on the screen. The diameter waveforms were further exported in .csv file format and were further processed in LabVIEW platform.

The JV diameter waveforms were processed offline to obtain JV diameter measurements. The developed correlation-based cycle segmentation algorithm processes the train of cycles and segments them into individual JV diameter cycles. The cycles were classified as baseline, valsalva maneuver and recovery diameter cycles. The mean diameter parameters (Dmax, Dmin) and distension (delD) were recorded.

E. *Statistical Analysis*

The measurements were recorded as mean ± standard deviation (SD) format. The box-and- whisker plots diagrams were plotted using mean and interquartile ranges to indicate the similarity and difference between the age groups. The ANOVA test was used to quantify the statistical significance between the groups. The beat-to-beat repeatability of JV diameter measurements were estimated as the ratio of SD to mean, expressed in percentage.

III. Results and Discussion

A. *Subject Demography*

The JV diameter response to valsalva maneuver was successfully evaluated in all the population. The descriptive characteristic information of the study population is indicated in Table 1.

B. *Reliability of Data Collection*

The B-mode diameter measurements were successfully acquired from all the population. The cine-loops were captured at a frame rate of 30 Hz offering a temporal resolution of 33 ms. The tracking resolution of the B-mode system was 56 µm, with a pixel to distance ratio of 17.81 pixels/mm. The beat-to-beat variability of JV baseline diameter measurements were between 8% and 20 %. The higher beat-to-beat variability even

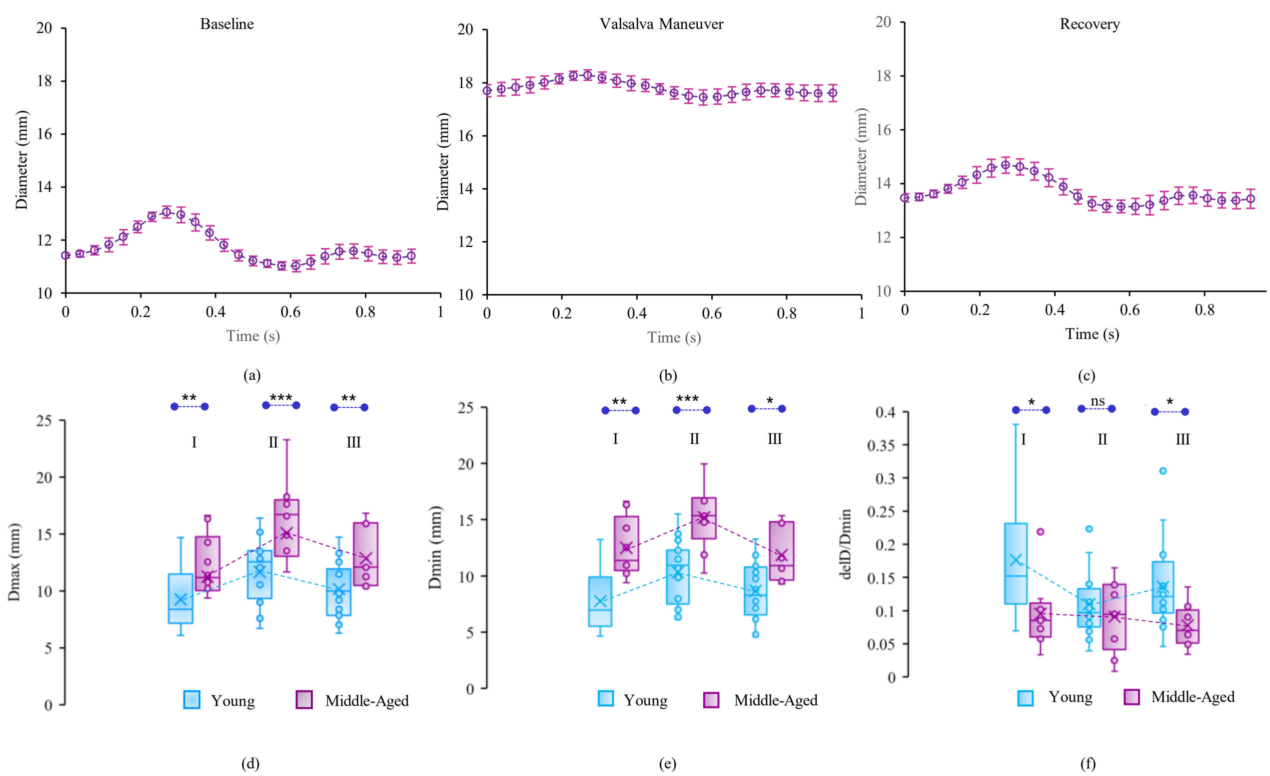

Fig 2. Beat-to-beat mean JV diameter during (a) baseline (b) valsalva maneuver (c) recovery. The variation of (d) Dmax (e) Dmin during baseline, VM and recovery in young and middle-aged population. (e) The variation of JV distensibility during baseline, VM and recovery in young and middle-aged population.

during baseline can be attributed due to the breathing artifacts. The visual feedback aided the operator to monitor the quality of JV vessel walls in real-time. Fig 2(a) - (c) depicts a sample JV diameter cycle during baseline, VM and recovery from a single subject (Male, Age = 24, BMI = 24.69). The marker points and error bars indicate mean and SD respectively from 10 consecutive JV diameter cycles.

C. Comparison of JV Response to Valsalva Maneuver

There is an increase in the JV diameter in response to VM among all age groups. The Box-and- Whisker comparison of the JV diameter during baseline (I), VM (II) and recovery (III) phases in young and middle-aged cohorts is depicted in Figs. 2 (d) and (e). It was observed that there was a statistically significant difference in Dmax and Dmin measurements across the two age groups ($p < 0.05$). The baseline JV diameter, Dmax and Dmin in young population were 9.25 ± 2.61 mm and 7.99 ± 2.66 mm respectively. In response to the VM stimulus the Dmax and Dmin increased to 11.66 ± 2.74 mm and 10.55 ± 2.69 mm. The baseline Dmax and Dmin in middle-aged population were 12.49 ± 2.65 mm and 11.51 ± 2.84 mm respectively. During VM, the Dmax and Dmin increased to 16.73 ± 3.28 mm and 15.19 ± 2.85 mm. The average JV diameter in middle- aged population was 36% higher than the younger population. Similarly, the increase in JV diameter from baseline to VM phase was higher in middle-aged cohort in comparison with the younger population measured as 36% and 27% respectively.

The variation in JV distensibility, the ratio of delD to Dmin is represented in Fig. 2 (f), wherein a significant difference in magnitudes of JV diameter was observed during the baseline and recovery phases, while the response during VM had a non-significant difference. The baseline distensibility in younger population 0.17 ± 0.09 decreased to 0.11 ± 0.05 during valsalva maneuver followed by an increase during recovery phase while, no significant variation was observed in middle-aged cohort, where the mean distensibility during baseline and VM phases were 0.09. The distensibility being a direct marker of the vessel elasticity, has significant clinical relevance and its variation in diverse age groups and diseased population would be investigated in future studies.

D. Limitations and Future Scope

The pilot study investigates the JV diameter and distensibility variations during VM. The pulse contour analysis of variation in JV pulse during VM can provide significant clinical information. The current ultrasound system had a limited frame rate, not all pulse contour features could be captured. Hence it is important to develop high frame-rate systems which can acquire high fidelity signals. Since the circulatory system is constituted by both arterial and venous systems, the responses in JV due to VM have potential associated implications in the arterial system. It is necessary to evaluate the changes in respiratory rate, ECG [10]– [12] and arterial parameters such as pulse wave velocity [13] stiffness and pulse pressure [14] in response to VM. Despite the limited sample size, the pilot study revealed the responses in JV diameter and distensibility in young and middle-aged cohorts. Further multicentric clinical trials are in progress to estimate the JV response variations to VM across diverse populations.

IV. CONCLUSION

In this pilot study, we have demonstrated the variation in JV diameter and distensibility in response to valsalva maneuver across young and middle-aged populations. The beat-to-beat variation in baseline JV diameter measurements were less than 20%. A significant bias ($p < 0.05$) was observed in the diameter variations in young and middle-aged populations. The diameter and distensibility parameters altered differently across the two age groups. The JV diameter response to VM was higher in middle -aged cohort, while the distensibility variations were minimal. The younger cohort had an evident decrease in distensibility during VM. The study findings suggest the applicability of VM procedure to evaluate age-related variations in JV diameter responses.

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