Real Time Measurement of Surgical Blood Loss in Suction Tubing Using Computer Vision and Machine Learning

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Introduction: Accurate assessment of blood loss can lead to timely recognition and management of hemorrhage and help guide perioperative blood management. However, visual estimation of blood loss is inaccurate [1] and weighing sponges and volumetrically assessing canisters is labor-intensive and potentially confounded by the presence of non-sanguineous fluids such as irrigation, amniotic fluid, and ascites [2]. Artificial intelligence-based technology has been developed to photometrically monitor blood loss from digital images of suction canisters and sponges [3-5]. The use of the technology improves hemorrhage recognition and has been associated with reduced unnecessary transfusion [6-8]. A limitation of this approach is its incompatibility with closed suction canister systems, where optical resolution of fluids is challenging. To address this problem, we developed a novel device that directly measures hemoglobin (Hb) mass flow (g/min) through suction tubing in real time. Sanguineous fluids evacuated using suction can significantly vary in flow profile based on suction strength and mode of use. Whereas standard flow/volume sensors (e.g., ultrasound) are known to function erroneously when turbulence or air are present, the proposed device overcomes these limitations by also employing a high-speed camera to digitally image the flow path. Computer vision and machine learning algorithms are then used to photometrically assess Hb mass loss in different flow regimes. In this study, we characterize the accuracy of the new device with an *in vitro* model under laminar and turbulent flow conditions.

Methods: Reconstituted expired whole blood was diluted with normal saline to various Hb concentration (0.5 to 12.0 g/dl) and hemolysis levels (0% to 50%). The experimental apparatus consisted of two canisters (source and sink) and a vacuum pump. A suction wand connected at one end of the suction tubing was employed to evacuate blood from the source canister at each concentration/hemolysis level under -67 mm Hg vacuum pressure, while two synchronized Bluetooth weighing scales continuously tracked the weight changes of source and sink canisters. The reference estimate of Hb mass flow was computed by multiplying the measured weight change with the density of blood and the known Hb concentration. The novel measurement device was attached to the suction line and simultaneously used to measure hemoglobin mass flowing through the experimental apparatus. The accuracy of the new device was compared with the reference determination under both continuous/laminar flow turbulent flow conditions. We performed Pearson correlations and Bland-Altman analysis for quantitative comparison of the two measurement methods.

Results: Seventy-four minutes of data was recorded across laminar flow (11 experiments) and turbulent flow (8 experiments) conditions. Time-series measurements were divided into 1-minute, non-overlapping segments to obtain 74 independent measurements of Hb mass flow for statistical comparison. The Pearson correlation (r) between the device measures and reference standard was 0.90 (n=74) across all flow regimes; r = 0.89 (n = 34) for turbulent flow, r = 0.93 (n=40) for laminar flow *(Fig 1a)*. The device exhibited a mean percent error of -14.1% across all measures; -6.6% for laminar flow, -20.5% for turbulent flow. Bland-Altman Analysis revealed a bias of -1.32 g/min [95% CI, -1.760 to -0.872 g/min] and narrow limits of agreement: upper LOA = 2.5 g/min [1.7 to 3.3 g/min], lower LOA = -5.1 g/min [-5.9 to -4.4 g/min] *(Fig 1b)*.

Conclusions: The novel device for measuring blood loss in suction tubing overcomes the limitations of closed suction systems and standard volumetric sensors and performs

measurements with high accuracy, in the presence of both laminar and turbulent flow. This real time approach may improve recognition of bleeding and enhance perioperative blood management.

Figure 1 (a) Association between novel device and reference standard; each data point represents 1-minute, non-overlapping measures. **(b)** Bland-Altman plot of agreement between device measures and ground truth. **(c)** Example time-series plot of blood loss measurement in turbulent flow conditions (0% hemolysis, 2 g/dl) using new method, compared to reference standard.
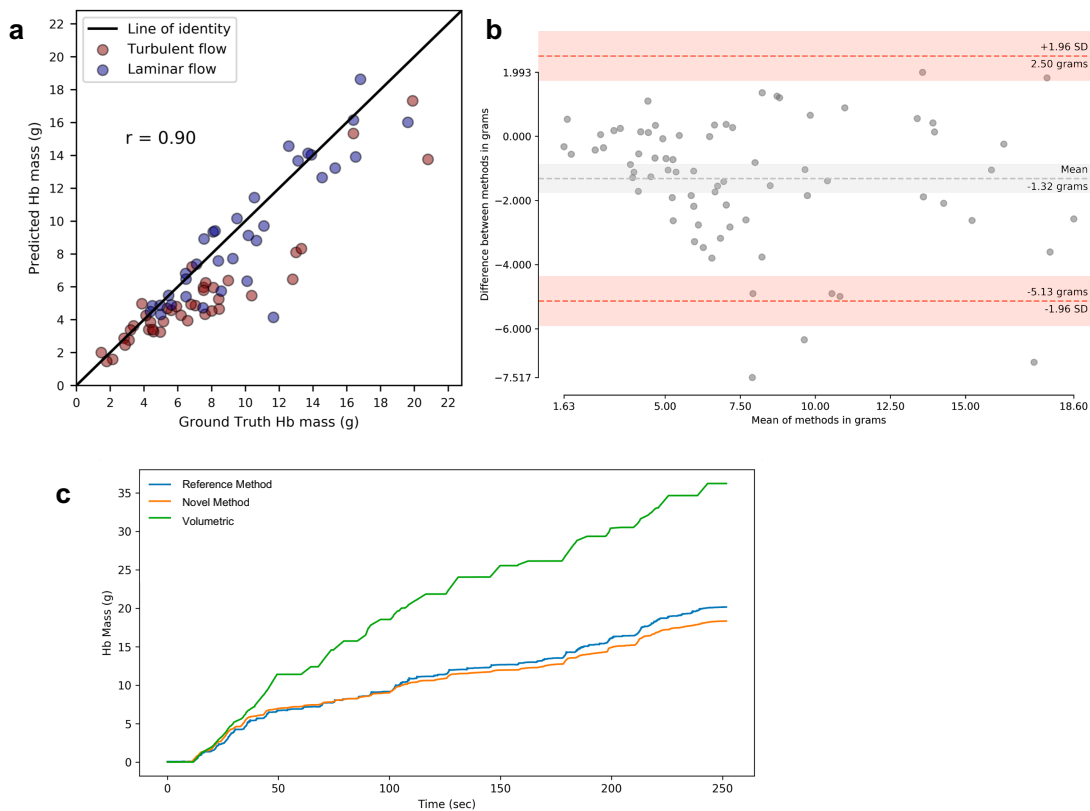
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