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Comparison of Water Manometry to 2 Commercial Electronic Pressure Monitors for Central Venous Pressure Measurement in Horses

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Background: Central venous pressure (CVP) customarily has been measured in veterinary patients with water manometry. However, many institutions are now using stallside electronic monitors in both anesthesia and intensive care units for many aspects of patient monitoring.

Hypothesis: Electronic stall side monitoring devices will agree with water manometry for measurement of CVP in horses.

Animals: Ten healthy adult horses from the university research herd.

Methods: Central venous catheters were placed routinely, and measurements were obtained in triplicate with each of the 3 methods every 12 hours for 3 days. Data were analyzed by a Lin concordance correlation coefficient and modified Bland-Altman limits of agreement, with all devices compared pairwise.

Results: Compared with water manometry, agreement (bias) of the Passport was $-1.94\,cmH_2O$ (95% limits of agreement, -8.54 to $4.66\,cmH_2O$) and of the Medtronic was $-1.83\,cmH_2O$ (95% limits of agreement, -8.60 to $4.94\,cmH_2O$). When compared with the Passport, agreement of the data obtained with the Medtronic was $0.27\,cmH_2O$ (95% limits of agreement, -4.39 to $4.93\,cmH_2O$).

Conclusions and Clinical Importance: These data show that both electronic monitors systematically provide measurements that are approximately $2\,cmH_2O$ lower than water manometry, but differences between the 2 electronic devices are small enough ($< 0.5\,cmH_2O$) to be considered clinically unimportant. This discrepancy should be taken into account when interpreting data obtained with these monitoring devices.

Key words: Continuous monitoring; Hydration; Pressure transducer.

Central venous pressure (CVP) customarily has been measured with water manometry in horses.[1–3] However, most human hospitals[4] and now many veterinary institutions are using bedside or stall side electronic monitors in both anesthesia and intensive care units for many aspects of patient monitoring. In horses, CVP is measured in order to estimate vascular volume and facilitate estimation of hydration and volume status. In the euvolemic horse, CVP typically is between 7 and $12\,cmH_2O$,[1,2,5] and has been shown to be inversely related to degree of hypovolemia in both blood loss and dehydration models,[1,6] as well as to changes in vascular status induced by inhalant anesthesia and body position.[2] Monitoring CVP by electronic pressure monitors could provide a less labor intensive method to obtain clinically relevant and continuous readings, and has been shown to remove human error in the measurement and monitoring of blood pressure in humans.[7] Electronic pressure monitors use piezoresistive technology to convert direct mechanical pressure from the circulation into a measurable electrical signal,[8] and may give more accurate and repeatable measurements, save time with more instantaneous readings and remove some interreader variation.[7] However, before implementation in horses, these devices, which are designed and validated for 50 kg humans, should be demonstrated to be comparable to the most commonly used technique, water manometry. The aim of this study was to evaluate the agreement of CVP values obtained with water manometry and 2 commercially available bedside monitoring devices, the Datascope Passport LT and Medtronic Lifepak 12. We hypothesized that 2 commercially available pressure monitoring systems would provide readings that were comparable to water manometry and prove to be a clinically acceptable way of monitoring CVP in the standing adult horse.

Abbreviations:

CVP	central venous pressure
MEMS	microelectromechanical systems

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Methods and Materials

This experimental study was designed to investigate the agreement of traditional handheld water manometry and stall side electronic pressure monitors in the measurement of CVP in adult horses. Ten healthy adult horses maintained in the university teaching herd were used for this study. They were between the ages of 7 and 14 years and weighed 450–700 kg (Thoroughbreds, Standardbreds, and Warmbloods). During these experiments, the horses were kept in stalls, allowed access ad lib to hay and water, and fed grain twice daily. All procedures were approved by the Institutional Animal Care and Use Committee at the University of Pennsylvania.

A 16 G single lumen central venous catheter[a] was placed in the right jugular vein at the junction of the proximal 3rd and middle 3rd of the neck using standard techniques. The placement within the cranial vena cava was confirmed by small oscillatory movements of the indicator ball of the water manomenter,[b] which were associated with respiration. An indicator line was clipped over the point of the right shoulder as a reference point for the zero level of manometer and transducer.

CVP measurements were obtained by 3 different methods. For the 1st reading, a hand-held water manometer was positioned with the zero mark at the point of the shoulder. It was connected to the CVP catheter extension set with a 3-way stop-cock, and filled to $>20\,cmH_2O$ using a $60\,cm^3$ syringe filled with sterile saline. The stop-cock then was opened to the horse, creating a solid column of saline between the cranial vena cava to the meniscus in the manometer, which was open to the atmosphere. The reading was taken when the indicator ball was no longer dropping but moving synchronously with the animal's respiration. The Datascope Passport LT[c] (Passport) was connected to the central venous catheter via an electronic transducer[d] placed affixed at the point of the shoulder using adhesive tape. The transducer was affixed to the skin over the designated spot with adhesive tape. Three measurements were recorded with the horse's head in neutral position (muzzle level with the point of the shoulder), and measurement sets were taken every 12 hours over the course of 3 days). The Medtronic Lifepak 12[e] (Medtronic) then was attached to the transducer, which remained affixed to the point of the shoulder, and measurements were repeated in a similar fashion. The same saline-filled medical tubing was used for both electronic monitoring systems. Measurement sets were taken every 12 hours over the course of 3 days.

Statistical Anaylsis

Data were analyzed by use of the Lin concordance correlation coefficient, which compares 2 techniques measuring the same variable without the inherent bias of establishing a gold standard. The concordance correlation coefficient (ρ) indicates the overall agreement between the 2 measurements, across all paired observations, by the 2 methods, with a value of 1 indicating perfect concordance. However, Lin's concordance correlation analysis does not accommodate the use of repeated measures. To account for this, each animal was randomly sampled once and that dataset was used to derive an estimate of ρ. This process then was repeated until the average concordance based on all the random samples ceased to change with increases in the sample size. The data from the resultant concordance postprocessing file were averaged to yield estimates of the final concordance correlation coefficients and their errors. Two hundred runs were required to produce consistent estimates of the concordance.

The bias (mean difference between 2 methods) and limits of agreement of test methods were analyzed by the method described by Bland and Altman[9] that has been modified for use with multiple observations per individual. The bias represents the systematic departure between the 2 measurement methods. The upper and lower LOA were calculated as bias $\pm$ 2 times the SD and define the range in which 95% of the differences between 2 techniques lie. The relative difference between each electronic meter (EM) and the water manometer (H_2O) was calculated as $(EM-H_2O/H_2O) \times 100\%$.

Values of $P \leq .05$ were considered significant. All analyses were performed with a commercially available statistical software package.[f]

Results

All measurements were obtained at each time point, and 3 readings were successfully taken in immediate succession using each method. No measuring period was longer than 10 minutes. Mean values were calculated for each triplicate measurement for each device at each time point, and these values used to generate Bland-Altman plots. Compared with water manometry, the bias of the Passport device was $2.43\,cmH_2O$, with the 95% limits of agreement between -3.55 and $8.42\,cmH_2O$ (Fig 1) with a ρ of 0.641 ± 0.14. Measurements obtained with the Medtronic monitor had a bias of $2.17\,cmH_2O$ compared with water manometry, and 95% limits of agreement of -4.07 to $8.43\,cmH_2O$ (Fig 2), with a ρ of 0.65 ± 0.13. When compared with the Passport, the Medtronic demonstrated a bias of $-0.23\,cmH_2O$ and 95% limits of agreement from -5.02 to $4.55\,cmH_2O$ (Fig 3), with a ρ of 0.86 ± 0.08.

Discussion

This study found that 2 commercially available stall side electronic monitors, the Datascope Passport LT and the Medtronic Lifepak 12, obtained CVP readings that were systematically approximately $2\,cmH_2O$ lower higher than readings obtained using water manometry in adult horses and showed poor agreement based on the calculated ρ values. However, readings between the 2 electronic monitors are within $0.23\,cmH_2O$ agreement with each other. It is likely that this difference is clinically unimportant, but it does not imply that, because of their close agreement, the electronic measurements are more accurate. In fact, we hypothesize that it is unlikely that the electronic readings are more accurate than the most commonly used method current gold standard of water manometry. The vented manometer used is a simple system of a column of fluid between the cranial vena cava or right atrium that is open to the atmosphere, and, without a power source or electrical components that must be calibrated by the factory, it thus intrinsically has fewer sources for error or inaccuracy. A possible source of this discrepancy could be related to differences in the length

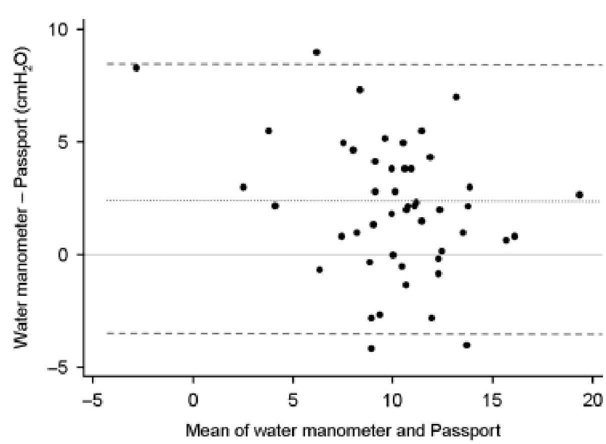

Fig 1. A modified Bland-Altman plot of agreement on central venous pressure (CVP) taken obtained with a Datascope Passport LT device versus water manometry. The *x*-axis shows the mean of the 2 measurements and the *y*-axis shows the difference between the CVP values measured by the Passport and the water manometer. The solid line denotes mean difference (bias: $2.43\,cmH_2O$), whereas the dotted lines show the upper and lower limits of agreement (-3.55 to $8.42\,cmH_2O$).

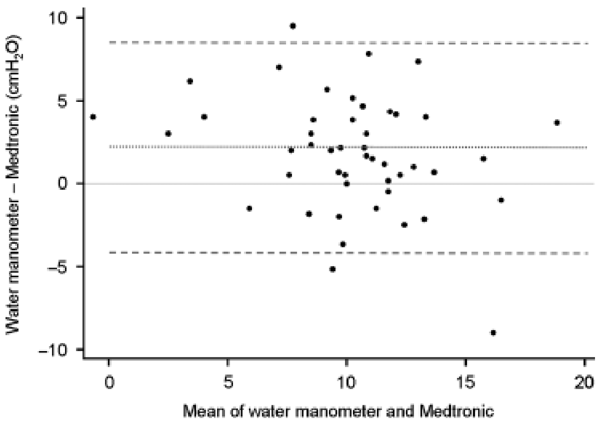

Fig 2. A modified Bland-Altman plot of agreement on central venous pressure (CVP) taken obtained with the Medtronic Lifepak 12 device versus water manometry. The x-axis shows the mean of the 2 measurements and the y-axis shows the difference between the CVP values measured by the Medtronic and the water manometer. The solid line denotes mean difference (bias: 2.17 cmH_2O), whereas the dotted lines show the upper and lower limits of agreement (−4.07 to 8.43 cmH_2O).

of the tubing used to connect the measuring devices to the catheter, which was slightly longer (~10 cm) for the water manometer than the tubing used with the electronic devices. Variation in resistance associated with this difference in length may have contributed slightly to the incongruity between the devices. The accuracy of the water manometer could be established and compared with the electronic devices with the use of a digital pressure calibrators commonly used by the manufacturers and servicing companies in the development and maintenance of these devices, although this technique would not identify any error that was created by factors specific to the clinical application of this device in the adult horse.

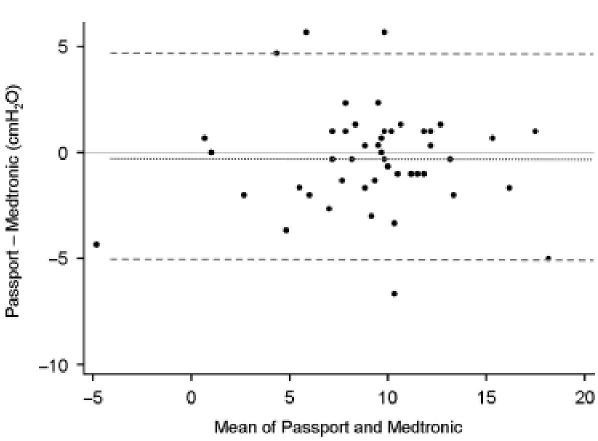

Fig 3. A modified Bland-Altman plot of agreement on central venous pressure (CVP) obtained taken with the Medtronic Lifepak 12 versus readings taken with the Datascope Passport LT device. The x-axis shows the mean of the 2 measurements and the y-axis shows the difference between the CVP values measured by the Medtronic and the Passport. The solid line denotes mean difference (bias: −0.23 cmH_2O), whereas the dotted lines show the upper and lower limits of agreement (−5.02 to 4.55 cmH_2O).

Both electronic monitors evaluated in this study use the piezoelectric effect to measure pressure. Piezoresistive sensors are silicon devices used for a variety of applications including automotive and biomechanical manufacturing as well as medical diagnostics and monitoring. When compression or strain is applied to piezoresistive materials, it results in quantifiable changes to the electrical resistance of the material. These microelectromechanical systems (MEMS) make use of micromachining to produce smaller sensors that have higher sensitivity and lower production costs. Piezoresistive diaphragms usually contain thin slices of silicon implanted between 2 protective surfaces,[10] which can be connected to a Wheatstone bridge that detects changes in resistance and reports the change as a change in pressure.[11] In medical applications, micromachined piezoresistive devices with silicon diaphragms convert the mechanical pressure from an intravascular catheter into an electrical output that allows continuous monitoring of pressures systems with high sensitivity.

The accuracy of the Passport is stated by the manufacturer as ±1 mmHg (1.36 cmH_2O) or 2% of the reading, whichever is greater. The Medtronic reports accuracy as ±2 mmHg (2.72 cmH_2O) or 2% of the reading (whichever is greater). With these reported accuracies, the 2 cmH_2O difference seen in this study could be accounted for by the inherent variation in the machines. It is also possible that the disagreement between the electronic readings and water manometry is because of the transducer that was used. One single-use transducer was used for all readings. It is not uncommon in clinical veterinary practice to reuse these costly pieces of equipment for several cases. These disposable transducers have been shown to be even more accurate than the requirements of the American National Standards Institute.[12] However, changes in the transducer over time could have led to poor repeatability, which would widen the limits of agreement despite manufacturer claims of over 500 hours of operating life.[13] Although the bias was not clinically relevant in either comparison (2.43 and 2.17 cmH_2O), the limits of agreement (−3.55 to 8.42 and −4.07 to 8.43 cmH_2O) could be considered clinically relevant, and the ρ values calculated (0.64 and 0.65) indicate poor correlation. The wide limits of agreement in this study are probably associated with the relatively small sample size, which is a limitation of this experiment, but also may be because of poor repeatability or measurement error associated with transducer fatigue or other systematic failure.

In conclusion, the small bias seen between water manometry the gold standard and the 2 machines electronic monitors evaluated in this study can be considered a minimally important difference, and this method may be an alternative to the current standard method. Because there is a consistent trend toward lower readings, re-establishing reference ranges using the electronic methods could prevent any misinterpretation of readings based on current "standard values." As with most measuring techniques, it is important to be consistent with which technique is used when the results are being compared. This holds true for repeated measures in clinical cases as well as comparison of values in a research setting. Although accuracy compared with the gold standard mercury manometer was not evaluated in this study, we have shown that all 3 methods deliver results within the established ranges and can be used successfully in clinical and research settings provided the same technique is used consistently throughout each case or trial. Further investigations should include comparison of the 2 devices with the use of a standardized pressure calibrator as well as the feasibility of these machines for continuous monitoring of CVP in the standing adult horse.

Footnotes

[a] PICC Peripherally Inserted Central Catheter Set, Arrow International, Reading, PA
[b] Central Venous Pressure Manometer, Smiths Medical ASD Inc, Dublin, OH
[c] Datascope Passport LT, MAQUET Cardiovascular, Wayne, NJ
[d] Transpac IV, Hospira, Lake Forest, IL
[e] Medtronic Lifepak 12, Medtronic Physio-Control Inc, Redmond, WA
[f] Stata 10.0, StataCorp, College Station, TX

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Conflict of interest: none.

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References

1. Magdesian KG, Fielding CL, Rhodes DM, Ruby RE. Changes in central venous pressure and blood lactate concentration in response to acute blood loss in horses. J Am Vet Med Assoc 2006;229:1458–1462.
2. Klein L, Sherman J. Effects of preanesthetic medication, anesthesia, and position of recumbency on central venous pressure in horses. J Am Vet Med Assoc 1977;170:216–219.
3. Wilsterman S, Hackett ES, Rao S, Hackett TB. A technique for central venous pressure measurement in normal horses. J Vet Emerg Crit Care (San Antonio) 2009;19:241–246.
4. Scales K. Central venous pressure monitoring in clinical practice. Nurs Stand 2010;24:49–55; quiz 56.
5. Hall LW, Trim CM. Positive end-expiratory pressure in anaesthetized spontaneously breathing horses. Br J Anaesth 1975; 47:819–824.
6. Norton JL, Boston R, Underwood C, et al. Repeatability, reproducibility and effect of head position on central venous pressure measurement in standing adult horses. Proceedings of the ACVIM Forum & Canadian VMA Convention, Montreal, Canada, June 3–6, 2009.
7. Gupta P, Mittal L, Rizzo RA, et al. In-use comparison of blood pressure measurements from an automated blood pressure instrument with those from a mercury sphygmomanometer. Biomed Instrum Technol 2009;43:158–163.
8. Wagner B. Principles of development and design of microsystems. Endosc Surg Allied Technol 1995;3:204–209.
9. Bland JM, Altman DG. A note on the use of the intraclass correlation coefficient in the evaluation of agreement between two methods of measurement. Comput Biol Med 1990;20:337–340.
10. Madou MJ. MEMS fabrication. In: Gad-el-Hak M, ed. The MEMS Handbook. Boca Raton, FL: CRC Press; 2002: 16–16.
11. Barlian AA, Park WT, Mallon JR, et al. Review: Semiconductor piezoresistance for microsystems. Proc IEEE Inst Electr Electron Eng 2009;97:513–552.
12. Gardner RM. Accuracy and reliability of disposable pressure transducers coupled with modern pressure monitors. Crit Care Med 1996;24:879–882.
13. Bailey RH, Bauer JH, Yanos J. Accuracy of disposable blood pressure transducers used in the critical care setting. Crit Care Med 1995;23:187–192.