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# Validation of a mobile clinical pathology laboratory for canine hematology and biochemistry

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## Abstract

**Background** In clinical diagnosis and research, it is often essential to carry out laboratory tests that provide reliable results rapidly. However, in some circumstances, these tests are not available at the patient's location, leading to a delay before analysis that increases turnaround time and can cause pre-analytical errors. To this end, a new mobile laboratory van containing one hematology and one biochemistry benchtop analyzers was developed, and a validation study was performed under field conditions (i.e., after trips of varying distances) with canine specimens and quality control materials.

**Results** Linearity was considered acceptable for all variables. Coefficient of variation was < 5% for biochemical variables and most hematological ones (0.0–8.11%) and imprecision was in line with the recommendations for all variables except for neutrophil count in the short-term imprecision. Observed total error for albumin with the quality control material was higher than allowable total error, secondary to a high bias. The comparison with the same model of analyzer showed significant bias for nearly all variables but observed total error remained lower than acceptable total error for all variables except for lymphocyte and reticulocyte counts.

**Conclusion** Both analyzers exhibited acceptable performance in the mobile laboratory operating conditions, making them suitable for future use in the field.

**Keywords** Benchtop analyzer, Biochemistry, Canine, Hematology, Laboratory van, Mobile laboratory, On-field, POCA, Validation study

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## Background

Routine clinical pathology in veterinary medicine relies either on reference laboratories that offer a wide variety of tests with a high analytical performance and ensure the quality of the results, or on benchtop analyzers that usually offer a more limited range of tests but with acceptable analytical performance and the ability to obtain rapid results. However, in some circumstances, laboratory tests remain not easily accessible and the specimens may need to be transported before being analyzed. The time needed for transport increases the turnaround time (TAT), and can deteriorate the specimens leading to pre-analytical errors. In response, several small portable analyzers called point-of-care analyzers (POCAs) have been developed and allow clinicians to perform some laboratory tests almost anywhere directly at the patient's location, and in various species including wildlife [1]. However, POCAs generally offer a limited number of variables, usually have poorer analytical performance than traditional methods, and are rarely fully validated under real-life conditions.


**Fig. 1** Exterior (**A**) and interior (**B**) of the mobile laboratory van. The van is a fully operational laboratory equipped with many of the instruments and machines used in a conventional small-scale laboratory. These include a centrifuge, a refrigerator (+4 °C), two freezers (-20 °C and −80 °C), a microbiological safety cabinet, a light microscope, an rapid stain kit, a tube agitator (Blood Tube Rocker 8-Tube, IDEXX Laboratories), one hematology analyzer (ProCyte Dx, IDEXX Laboratories), one biochemistry analyzer (Catalyst One, IDEXX Laboratories) both connected to the IDEXX VetLab Station (IVLS), one blood gas analyzer (VetStat, IDEXX Laboratories) and all the equipment needed for blood sampling including needles, syringes and blood collection tubes

It would therefore be useful to be able to perform a wide panel of routine validated analyses directly at the patient's location for diagnosis and clinical research, especially in animals that are not easily transported to a clinic (e.g., horses and other livestock on farms or at exhibitions or competitions, pets of individuals experiencing homelessness, wildlife, laboratory animals, etc.). To meet this need, we have developed a mobile laboratory installed in a van, including all the equipment required for collecting, preparing and storing specimens, to carry out hematological, biochemical and cytological analyses (Fig. 1). We chose two already validated veterinary benchtop analyzers (ProCyte Dx and Catalyst One [IDEXX Laboratories, Westbrooks, USA] for hematology and biochemistry, respectively) based on their relatively small size, ease of use, ability to measure a wide panel of variables routinely used in veterinary medicine and validated in canine and other species [2–4]. The use of non-POCA analyzers outside a conventional laboratory setting has been successfully described in human clinical pathology. Examples include RT-PCR assays of SARS-CoV-2 [5–9], Ebola [10–13] and arbovirus [14] detection, and the use of a flow cytometry device previously modified to withstand space travel on the International Space Station [15]. In veterinary medicine, use of a benchtop biochemistry device transported in a 4-wheel-drive vehicle has also been described [16].

The use of a laboratory van in the field introduces several challenges for the analyzers, such as possible effects of exposure to vibrations during travel, gasoline vapors, and varying temperatures and humidity levels, all of which may alter the functionality of the analyzers, thus rendering them useless in the field. Therefore, before putting our mobile laboratory into service, a validation procedure under field conditions and in line with the American Society of Veterinary Clinical Pathology (ASVCP) recommendations for method validation [17] is necessary.

This study aimed to assess the analytical performance of the analyzers in the laboratory van after trips of varying distances. It focused on linearity, short- and long-term imprecision and comparison of the results with the same analyzers and reagents used under conventional in-clinic settings. We hypothesized that there was a strong likelihood that analytical performance would be impacted, probably to a greater degree for hematology than for biochemistry.

## Results

Results of all biochemical variables are fully reported in text, tables and figures. Due to the number of variables in hematology, we have chosen to report only the results of the following variables: red blood cell count (RBC), hemoglobin concentration (HGB), hematocrit (HCT), mean corpuscular volume (MCV), white blood cell count (WBC), impedance platelet count (PLT), and Reticulocyte count (RET); with detailed results for the rest as supplementary material.

### Linearity of the van analyzers

In hematology, linearity was visually good to excellent for all variables and linear fitting r ($R^2$) was > 0.999 for all variables except monocyte count (Mono) ($R^2$=0.989) (Figure S1). Maximum differences from linear fit was ≤ 4.8% for RBC, HCT, HGB, WBC, neutrophil count (Neutro), PLT and plateletcrit (PCT), and between 5.4% and 7.7% for RET, Mono, and eosinophil (Eosino) and lymphocyte (Lympho) counts.

In biochemistry, linearity was visually good for glucose, total calcium and albumin, but quite poor for alanine amino transferase (ALT) and alkaline phosphatase (ALP). $R^2$ was > 0.990 for all variables. Maximum differences from linear fit ranged from 2.6% for total calcium to 20.1% for glucose (Figure S2).

### Imprecision – Bias– TEobs of the van analyzers

Results for short- and long-term imprecision are shown in Table 1 and S2 for hematology and Table 2 for biochemistry. Results for the in-clinic analyzers are shown in Table S3.

### Short-term imprecision

With a fresh canine blood specimen, coefficient of variation (CV) was < 5% for most variables (between 0.33% and 4.48%) except for Eosino (6.93%) and reticulocyte percentage (RET%) (5.49%). Standard deviation (SD) was < 0.25*$TE_a$ ($TE_a$, allowable total error) for all variables except mean corpuscular hemoglobin (MCH), red cell distribution width (RDW), reticulocyte hemoglobin (RET-HGB), platelet distribution width (PDW), mean platelet volume (MPV) and PCT for which $TE_a$ was not available in literature [18]. Neutro was the

**Table 1** Imprecision of selected hematological variables with the Van analyzer, using QCM and a canine specimen

| Variable | Unit | QCM1 | | | | | QCM2 | | | | Canine Blood | | | $TE_a$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Target | ST | LT | | | Target | LT | | | ST | | | |
| | | | CV % | CV % | Bias % | $TE_{obs}$% | | CV % | Bias % | $TE_{obs}$% | Mean | CV% | | |
| RBC | $10^{12}$/L | 2.30 | 1.98 | 2.50 | 0.47 | 5.46 | 4.40 | 1.06 | 0.15 | 2.26 | 7.21 | 0.56 | | 10 |
| HGB | g/L | 59 | 0.00 | 1.10 | -2.05 | 4.26 | 129 | 0.59 | -2.25 | 3.42 | 156 | 0.79 | | 10 |
| HCT | L/L | 0.180 | 0.86 | 1.49 | -0.43 | 3.41 | 0.380 | 0.75 | 1.21 | 2.71 | 0.465 | 0.74 | | 10 |
| MCV | fL | 79 | 0.34 | 1.46 | -2.05 | 3.92 | 87 | 0.92 | 1.26 | 3.10 | 64.5 | 0.33 | | 7 |
| WBC | $10^9$/L | 3.00 | 2.18 | 3.13 | -0.88 | 7.13 | 7.30 | 1.91 | -1.63 | 5.46 | 8.89 | 3.14 | | 15 |
| PLT | $10^9$/L | 56 | 4.14 | 8.11 | 0.22 | 16.44 | 230 | 2.44 | 1.27 | 6.15 | 264 | 3.62 | | 25 |
| RET | $10^9$/L | 165.7 | 2.70 | 2.58 | -6.67 | 11.83 | 120.9 | 6.01 | -3.85 | 15.87 | 11.8 | 4.48 | | 20 |

Legends: $TE_a$ and $TE_{obs}$ were calculated and reported following Nabity et al. [18]

Abbreviations: CV, coefficient of variation, $CV\% = \frac{SD}{Mean} * 100$; HCT, hematocrit; HGB, hemoglobin concentration; LT, long term imprecision; MCV, mean corpuscular volume; PLT, platelet count; QCM, quality control material; RBC, red blood cell count; RET, reticulocyte count; SD, standard deviation; ST, short term imprecision; $TE_a$, allowable total error; $TE_{obs}$, observed total error; WBC, white blood cell count

only variable with a previously published $TE_a$ and SD > 0.25*$TE_a$ (SD = 0.25 and $TE_a$ = 0.92*$10^9$/L). With the quality control material (QCM), CV was < 5% (between 0.00% and 4.14%) for all variables tested (RBC, HCT, HGB, MCV, MCH, mean corpuscular hemoglobin concentration (MCHC), RDW, %RET, RET, WBC, PLT) and SD was < 0.25*$TE_a$ for all variables with a previously published $TE_a$.

In biochemistry, CVs were < 5% for all variables (between 0.98% and 3.12%) with the canine plasma and the QCM (between 0.59% and 1.86) and SD was < 0.25*$TE_a$ for all variables.

#### Long-term imprecision

In hematology, for the van analyzer, CV was < 5% for all variables tested (between 0.84% and 3.13%) except PLT (8.11%) with QCM level 1 (QCM1), and for all variables tested (between 0.49% and 2.44%) except the reticulocyte indices (6.01% for RET and 6.30% for RET%) with QCM level 2 (QCM2). SD was < 0.33*$TE_a$ and observed total error ($TE_{obs}$) was lower than $TE_a$ for all variables with QCM1 and QCM2. For the in-clinic analyzer, CV was < 5% for all variables tested except PLT, RET and RET% (8.25%, 5.17% and 5.52%, respectively) with QCM1 and for all variables except reticulocyte indices (5.94% for RET and 5.74% for RET%) with QCM2. The in-clinic analyzer's CV was higher than the van analyzer's CV for all variables available with the QCMs except RBC, HCT, MCV, MCH, MCHC and RDW with QCM1 and MCV, RET and RET% with QCM2. SD was < 0.33*$TE_a$ and $TE_{obs}$ was less than $TE_a$ for all variables with QCM1 and QCM2.

In biochemistry, for the van analyzer, CV was < 5% for all variables with the pooled canine plasma and QCM (between 1.00% and 4.90%, and between 1.58% and 3.17% respectively) and SD was < 0.33*$TE_a$ for all variables. $TE_{obs}$ was lower than $TE_a$ for all variables except for albumin with QCM (15.87% > 15%) and the latter quality goal index (QGI) was 4.95. For the in-clinic analyzer, CV was < 5% for all variables except ALT and ALP (6.64% and 6.42%, respectively) and CV was higher than the van analyzer (long-term imprecision CVs with both QCM and plasma) for all variables except for total calcium. SD was > 0.33*$TE_a$ only for ALP (SD = 5.76 and $TE_a$ = 17.3 U/L) and $TE_{obs}$ was less than $TE_a$ for all variables.

#### Comparison of results by Van and in-clinic analyzers

##### *Comparison between hematology analyzers*

Comparisons between the two analyzers are reported in Table 3, S4 and S5, and Fig. 2 and S3. Spearman's correlation coefficient (r) was ≥ 0.910 for all variables except MCH ($r$ = 0.899) and RET-HGB ($r$ = 0.771).

Passing-Bablok regression equation slopes and intercepts were close to 1 and 0, respectively, but a proportional bias was observed for most variables (Table 3 and S4). Positive proportional biases were observed for RET%, RET, RET-HGB, WBC, Neutro, Mono, Eosino, PLT and PCT.

$TE_{obs}$ was less than $TE_a$ for all variables except Lympho and RET (16.83% > 15% and 22.76% > 20%, respectively) for which QGI were 1.78 and 2.04, respectively.

The observed difference between paired analysis was lower than $TE_a$ for all erythrocyte variables, and for WBC, Neutro and PLT. One and three differences were higher than TEa for Mono and Eosino, respectively, and had very low values (mean value 0.26 for Mono and range for mean value 0.01–0.8 for Eosino). Nine differences were higher than TEa for Lympho, and included values distributed over the entire reference interval (range for mean value 0.06–4.30).

Some pairs of results were classified differently with respect to the manufacturer's RI (one result within and one result outside) and had a difference higher than analytical variability: in one case (out of 45) for HCT, PLT and PCT; two cases each (out of 43) for Lympho and Eosino; three cases each for HGB and MCH (out of 45) and PDW (out of 34); four cases (out of 45) for RET; seven cases (out of 43) for Mono; eight cases (out of 45) for MPV and nine cases (out of 45) for RET-HGB. No reference interval is available for RET%.

#### Comparison between biochemistry analyzers

Comparisons between the two analyzers are reported in Table 4 and S6 and Fig. 3. Spearman's correlation coefficient (r) was ≥ 0.971 for all variables.

Passing-Bablok regression equation slopes and intercepts were close to 1 and 0, respectively, for most variables (Table 4). No significant proportional bias was observed, however, there was a slight constant positive bias for glucose and a slight constant negative bias for total calcium.

$TE_{obs}$ was less than $TE_a$ for all variables. The observed difference between paired analysis was lower than $TE_a$ for albumin, total calcium and ALT. Only one difference was higher than $TE_a$ for ALP and glucose, and both were low values (mean 28.5U/L and 1mmol/L, respectively).

One pair of results for total calcium was classified differently with respect to the manufacturer's RI (one result within and one result outside) and had a difference higher than analytical variability.

## Discussion

Analytical performance assessed with canine specimens and QCMs, and method comparison with the same model of analyzers assessed with fresh canine specimens in a conventional in-clinic setting showed that the van is a suitable environment for practical use of the hematology and biochemistry analyzers tested in this study,

**Table 2** Imprecision of biochemical variables with the Van analyzer, using QCM and a canine specimen

| Variable | Unit | QCM | | | | | Canine plasma | | | | $TE_a$ % | QGI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Target | ST | LT | | | ST | | LT | | | |
| | | | CV % | CV % | Bias % | $TE_{obs}$ % | Mean | CV % | Mean | CV % | | |
| Glucose | mmol/L | 4.67 | 0.85 | 1.58 | -0.95 | 4.12 | 6.96 | 1.84 | 6.82 | 1.00 | 10[a], 20[b,c] | |
| Total Ca | mmol/L | 2.175 | 0.59 | 1.92 | -3.22 | 7.06 | 2.34 | 1.97 | 2.39 | 1.66 | 10 | |
| Albumin | g/L | 32 | 1.85 | 1.68 | -12.50 | **15.87** | 28.10 | 3.12 | 29.20 | 1.44 | 15 | 4.95 |
| ALT | U/L | 88.5 | 1.55 | 3.17 | -4.52 | 10.86 | 96.70 | 0.98 | 87.70 | 4.90 | 25 | |
| ALP | U/L | 86.5 | 1.86 | 3.06 | -11.21 | 17.33 | 262.5 | 0.99 | 239.80 | 3.71 | 25 | |

Legends: Bolded results are the ones for which $TE_{obs} > TE_a$, and CV for which SD > 0.25*$TE_a$ and SD > 0.33*$TE_a$ for ST and LT, respectively. $TE_a$ and $TE_{obs}$ were calculated and reported following Harr et al. [19]. QGI was calculated when $TE_{obs} > TE_a$

[a] $TE_a$ for concentration below the reference interval; [b] $TE_a$ for concentration within the reference interval; [c] $TE_a$ for concentration above the reference interval

Abbreviations: ALP, alkaline phosphatase; ALT, alanine aminotransferase; Ca, calcium; CV, coefficient of variation, $CV\% = \frac{SD}{Mean} * 100$; LT, long term imprecision; QCM, quality control material; QGI, quality goal index $= \frac{Bias}{1.5 * CV}$; SD, standard deviation; ST, short term imprecision; $TE_a$, allowable total error; $TE_{obs}$, observed total error

without significant clinical implications, according to the ASVCP recommendations.

According to ASVCP guidelines [17], a method validation study is required when a new instrument or method is introduced into a laboratory and may include some or all of the following, depending on the situation: reportable range/linearity study, short-term and long-term imprecision studies, comparison of methods, interference study, recovery study, reference interval determination, detection limit study and quality control (QC) validation. Our situation is unique, as we have brought analyzers that have previously been validated and are commonly used throughout the world into a new environment highly likely to impact their analytical performance. Indeed, while both analyzers are benchtop analyzers that are considered quite robust, they still have quite strict manufacturer-recommended operating conditions for best function, including temperature, humidity levels and altitude, while avoiding vibrations, exposure to gas or chemicals and direct sources of sunlight, heat, cold and humidity. Moreover, unlike POCAs, these analyzers were not designed to be transported on a regular basis, and when they must be, the manufacturer recommends packing them carefully to minimize shocks, and carrying out specific procedures (e.g., cleaning and draining fluid circuits) before transport, which are incompatible with everyday use. However, these recommendations apply when the analyzers are transported individually in a box and therefore potentially subjected to rotational movements around different axes (back and forth, sideways, etc.), and when they are not used for long periods of time, leading to a risk of crystallization of the fluids in the circuits for the ProCyte Dx. In our case, the situation is different, as the analyzers are secured within a moving frame of reference, but are always maintained in their normal operating position. Additionally, the analyzers were switched off during trips and the shutdown procedure is preceded by a partial draining of the fluid circuits, limiting the risk of crystallization. Although every precaution was taken to reduce the effects of the mobile setting on the analyzers (e.g., secured to minimize vibrations, temperature maintained within the range recommended by the manufacturer during use), there was still a strong likelihood that analytical performance would be impacted. Thus, a complete validation method study was indicated, but for economic reasons we had to opt for a partial validation focusing on the assessment of analytical performance to determine if the hematology and biochemistry in-clinic analyzers met analytical requirements in the van environment. A second validation phase is therefore required, including recovery, reference interval determination or transference, and QC validation.

Linearity was acceptable for all hematological and biochemical variables. Correlation coefficient $R^2$ for

**Table 3** Comparison of selected hematological variables between the van and the in-clinic analyzers

| Variable (Units) | | Median (min to max) | | Spearman's *r* | Passing-Bablok Van = a*Clin + b | |
|---|---|---|---|---|---|---|
| | | Van | Clin | | a | b |
| RBC ($10^{12}$/L) | *n* = 45 | 6.22 (2.89 to 8.78) | 6.14 (2.86 to 8.71) | 0.996 (0.993–0.998) | 1.01 (1.00–1.02) | -0.02 (-0.10–0.04) |
| HGB (g/L) | *n* = 45 | 140 (64 to 205) | 144 (64 to 212) | 0.997 (0.994–0.998) | 0.96 (0.94–0.98) | 1 (-2–4) |
| HCT (L/L) | *n* = 45 | 0.418 (0.211 to 0.595) | 0.425 (0.216 to 0.612) | 0.995 (0.992–0.998) | 0.98 (0.96–1.00) | -0.007 (-0.007–0.007) |
| MCV (fL) | *n* = 45 | 65.9 (57.0 to 81.5) | 67.8 (58.9 to 84.6) | 0.989 (0.979–0.994) | 0.94 (0.90–0.98) | 2.4 (-0.5–5.4) |
| RET ($10^9$/L) | *n* = 45 | 62.6 (3.8 to 284.6) | 55.6 (3.7 to 229.1) | 0.987 (0.976–0.993) | 1.25 (1.18–1.30) | -2.2 (-6.4–0.3) |
| WBC ($10^9$/L) | *n* = 44 | 10.52 (1.53 to 38.63) | 10.07 (1.38 to 37.90) | 0.999 (0.998–0.999) | 1.04 (1.01–1.06) | 0.03 (-0.11–0.21) |
| PLT ($10^9$/L) | *n* = 45 | 215 (23 to 568) | 193 (27 to 561) | 0.988 (0.979–0.994) | 1.05 (1.01–1.12) | -5.10 (-14.28–4.28) |

Legends: 95% CI of Spearman's correlation coefficient r and Passing-Bablok equation coefficients between brackets. Bolded results do not contain 1 for slope (a) or 0 for intercept (b) in the 95% CI of the Passing-Bablok equation

Abbreviations: CI, confidence interval; Clin, in-clinic analyzer; HCT, hematocrit; HGB, hemoglobin concentration; max, maximum; MCV, mean corpuscular volume; min, minimum; PLT, platelet count; RBC, red blood cell count; RET, reticulocyte count; WBC, white blood cell count

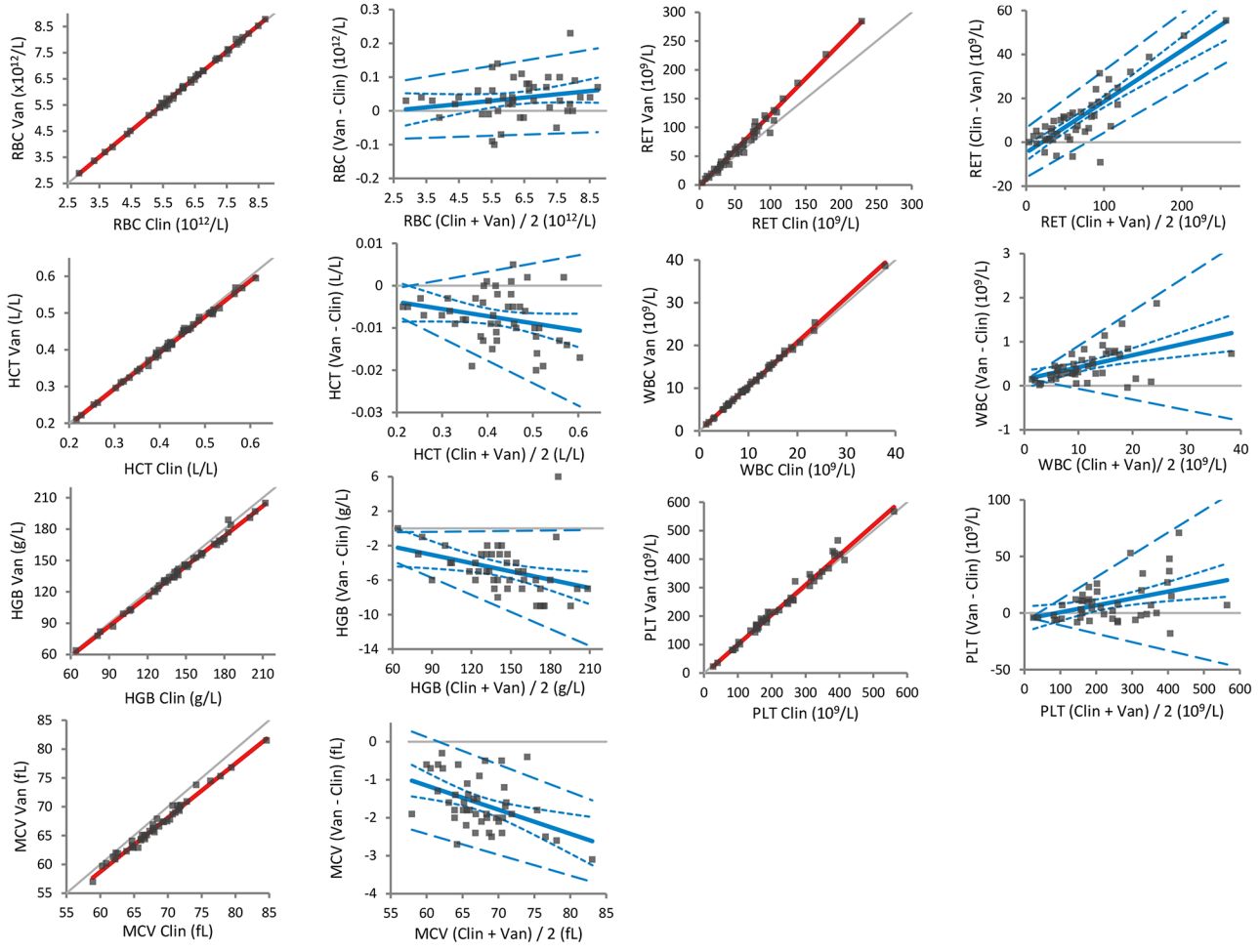


**Fig. 2** Passing-Bablok and Bland-Altman plots for selected hematological variables. On the Passing-Bablok plots (left), the thin gray line is identity line (y = x); the red line is the regression curve. On the Bland-Altman plots (right), the blue lines are the regression curve (solid line) with 95% CI (dotted lines) and 95%LoA (dashed lines).Abbreviations: CI, confidence interval; clin, in-clinic analyzer; HCT, hematocrit; HGB, hemoglobin concentration; LoA, limit of agreement; MCV, mean corpuscular volume; PLT platelet count; RBC, red blood cell count; RET, reticulocyte count

hematological variables were similar or higher when compared to the literature [4]. Overall, short- and long-term imprecision studies revealed good analytical performance for both analyzers, with most variables performing in line with recommendations. In hematology, imprecision was considered acceptable for all variables. Short-term SD for normal values for Neutro was higher than recommended when compared to the $TE_a$ [18] but deviation was mild and considered clinically acceptable; long-term SD could not be assessed as results for Neutro

**Table 4** Comparison of biochemical variables between the van and the in-clinic analyzers

| Variable (Units) | | Median (min to max) | | Spearman's *r* | Passing-Bablok equation Van = a*Clin + b | |
|---|---|---|---|---|---|---|
| | | Van | Clin | | a | b |
| Glucose (mmol/L) | *n* = 42 | 5.25 (1.00 to 13.28) | 5.22 (0.89 to 13.22) | 0.992 (0.985–0.996) | 1.00 (0.98–1.00) | 0.06 (0.06–0.15) |
| Total Ca (mmol/L) | *n* = 42 | 2.33 (1.90 to 2.70) | 2.43 (1.95 to 2.80) | 0.971 (0.947–0.985) | 1.00 (1.00–1.00) | -0.10 (-0.10–0.08) |
| Albumin (g/L) | *n* = 42 | 29.0 (21.0 to 41.0) | 29.0 (20.0 to 38.0) | 0.983 (0.968–0.991) | 1.00 (1.00–1.00) | 1.00 (0.00–1.00) |
| ALT (U/L) | *n* = 40 | 70 (29 to 797) | 70 (23 to 734) | 0.993 (0.986–0.996) | 1.00 (0.96–1.03) | 2.66 (-0.41–5.19) |
| ALP (U/L) | *n* = 39 | 74 (22 to 1087) | 72 (20 to 1169) | 0.998 (0.996–0.999) | 0.99 (0.94–1.01) | 1.81 (-0.71–4.47) |

*Legends*: 95% CI of Spearman's correlation coefficient r and Passing-Bablok equation coefficients between brackets. Bolded results do not contain 1 for slope (a) or 0 for intercept (b) in the 95% CI of the Passing-Bablok equation

*Abbreviations*: ALP, alkaline phosphatase; ALT, alanine aminotransferase; Ca, calcium; CI, confidence interval; Clin, in-clinic analyzer; max, maximum; min, minimum

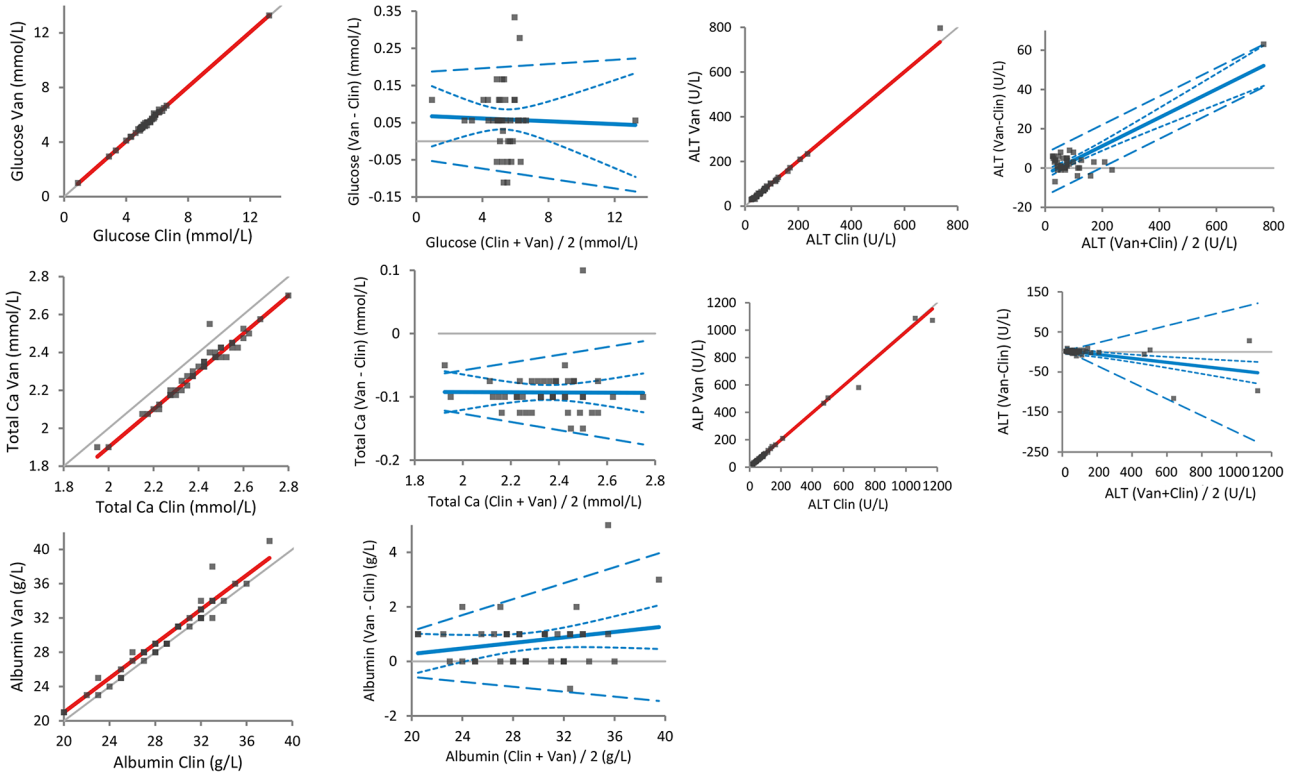


**Fig. 3** Passing-Bablok and Bland-Altman plots for biochemical variables. On the Passing-Bablok plots (left), the thin gray line is identity line (y = x); the red line is the regression curve. On Bland-Altman plots (right), the blue lines are the regression curve (solid line) with 95% CI (dotted lines) and 95%LoA (dashed lines).Abbreviations: ALP, alkaline phosphatase; ALT, alanine amino transferase; Ca, calcium; CI, confidence interval; Clin, in-clinic; LoA, limit of agreement

were not reported with QCMs. When compared to the validation study performed by *Goldmann et al.* [4] on the ProCyte Dx, short-term imprecision was similar for all hematological variables and better for most. For example, CVs for PLT were lower than expected (13.8% in literature [4]) but were calculated for normal values with fresh blood and low values with QCM1 in our study, *versus* high values with fresh blood in the literature. Similarly, CVs for reticulocyte counts were lower than expected (22% in literature [4]) but were calculated for low and slightly increased values in our study *versus* very high values with fresh blood in the literature. Long term imprecision was similar to the in-clinic analyzer for all hematological variables and better for some of them. In biochemistry, short- and long-term imprecision was in line with published recommendations [19] for all variables, and for a similar range of values was comparable to values found in the literature with the Catalyst One using QCM [2, 20]. When compared to the in-clinic analyzer, long-term imprecision for the van analyzer was similar for all variables, with CVs lower for all variables except for total calcium. $TE_{obs}$ was lower than $TE_a$ for all variables except for albumin, which was due to a high bias according to the QGI calculations. However, performance was considered acceptable as deviation from $TE_a$ was very mild and mostly secondary to bias. Similarly,

*Boes et al.* [2] found $TE_{obs}$ higher than $TE_a$ for albumin with two levels (low and high values) of QCM, secondary to a high bias (QGI = 17 and 16 for low and high values respectively); $TE_{obs}$ was also higher than $TE_a$ with both levels of QCM for ALP, and with one level of QCM (low values) for glucose and ALT in their study.

For the method comparison, we chose to perform and report Passing-Bablok regression analysis for all variables, despite ASVCP recommendations, in order to standardize the figures and facilitate reading and comprehension. However, linear regression statistics were also performed when indicated, and despite slightly different numerical results, led to similar interpretations. The method comparison between van and in-clinic analyzers revealed significant bias for almost every variable analyzed in both hematology and biochemistry. However, when compared to the in-clinic analyzer, $TE_{obs}$ was less than $TE_a$ for all variables except for RET and Lympho, and for both it was due to a high bias according to QGI calculations. Thus, the van's hematology and biochemistry analyzers were judged to be interchangeable with the in-clinic's ones without significant clinical implications, except for RET and Lympho. The observed difference between pairwise analyses were less than $TE_a$ for all biochemical and hematological variables, with the exception of the leukocyte differential count (Mono, Eosino and Lympho). Given that these differences concerned low to very low values for Eosino and Mono, and that eosinopenia and monocytopenia have limited clinical significance [21], observed differences were judged clinically acceptable. Regarding Lympho, the 9 paired results for which the difference was greater than $TE_a$ were distributed over values ranging from 0.05 to 4.84, but all were associated with abnormal scattergrams and 5/9 cases had no flag; 3/9 had flags on both analyzers; 1/9 had a flag only on the in-clinic analyzer, indicating difficulty in correctly identifying lymphocytes. Such differences have already been noted by *Goldmann et al.* [4] who showed that agreement improved between the ProCyte Dx and the reference analyzer for all leukocyte populations when specimens with abnormal dot plots were excluded. Some results were discordant regarding classification based on the reference intervals used in this study. However, facility-specific reference intervals not having been previously determined for the in-clinic analyzers, the reference intervals used in this study were therefore those provided by the manufacturer, which is not optimal.

Since the van analyzers were compared to the same models, almost perfect correlation could be expected in the method comparison. The observation of bias could be interpreted as an effect of the van environment which, to the authors' knowledge, represents a unique environment for these benchtop analyzers. However, bias has been demonstrated between commercial laboratory analyzers of the same model used under similar conditions [22]. In this study, it is impossible to choose between these two hypotheses, as the correlation between our analyzers was not evaluated prior to van commissioning.

There are some limitations to this study. For economic reasons, linearity was assessed with only 2 replicates rather than 3 to 4 replicates as recommended by the ASVCP, and only on normal to low values for most variables. This was due to the fact that assays were carried out after the van had completed a journey, with fresh blood or plasma, to approximate the real conditions of the van's future use. Given the limited number of van journeys and the fact that all variables analyzed were grouped together on the commercial reagent plates used, we were obliged to carry out the linearity study for all variables at once, which meant that we were unable to assess the linearity of the various variables at high concentrations. Similarly, only 10 replicates of one and two levels of concentration were carried out for biochemistry and hematology, respectively, for both short- and long-term imprecision assays while the ASVCP recommends 20 replicates of two to three levels of concentration. Moreover, the long-term imprecision for hematology was assessed using different lots of QCM, introducing a source of error. For the method comparison, results were not interpreted immediately, therefore, specimens with large unexplained differences could not be retested as recommended by the ASVCP, and had to be excluded.

Biochemical variables were limited to the ones recommended by the manufacturer for internal quality control. This allowed testing of each light-emitting diode (LED) and wavelength used for analysis of a routine biochemistry panel with this analyzer, while limiting the cost of the study. It was hypothesized that if a drop in performance occurred in one or more variables of a complete biochemistry panel, it would be related to the LED involved in the measurement or the pipetting system, and would therefore be identified with the variables investigated in this study. As the other variables available on this analyzer and measured in routine biochemical assessments have shown acceptable performance with QCM and specimens from various species, we can assume that they are also acceptable in our case [2, 20]. Electrolytes are measured with a different LED and were not investigated in this study, so it is not possible to confirm or assume that the analytical requirements are met for these variables.

Another limitation of this study may be that all the factors likely to interfere with the analyzers' performance were studied together under conditions similar to those for which the van will be used in the future, but the specific effect of each of them on analytical performance was not investigated. For example, it is reasonable to assume that the length and type of road (e.g. presence of speed

bumps, potholes, hills, frequent turns, gravel, etc.) may have an effect on the amount of vibrations to which the analyzers are exposed and therefore have an effect on their analytical performance, but this has not been investigated in this study and could be verified by further studies focusing on this point. Moreover, it seems reasonable that the delay between the end of the trip and the analysis may have an impact on analytical performance. Indeed, a delay of several hours, as was the case in our study after some long journeys (> 12 h), allows the analyzers to have a rest period that could be beneficial. Conversely, a short delay also exposes the analyzers to the presence of gasoline vapors, which could interfere with measurements (NB: the manufacturer recommends that smokers wear gloves, as cigarette residues can interfere with biochemical measurements). It would be interesting to test if analytical performances would be similar with a shorter delay after a long trip. Finally, in our region, the analyzers could have been exposed to temperatures below and over the limits indicated by the manufacturer, but if this were to affect analyzer operation, the analyzers would display an error message and be nonfunctional when turned on. In addition, the van is equipped with air-conditioning to heat or cool the laboratory area and maintain the correct temperature for analyzer use, and was used in this study to maintain an acceptable temperature prior to analyzer start-up and specimen analysis. Reagents were kept at recommended temperatures. Recommendations are also given by the manufacturer on maximum altitude and humidity levels tolerated but the van was not exposed to significant changes in altitude in this study, and while humidity levels were not measured, they were presumed to be acceptable given the wide range tolerated by the analyzers (up to 85%). Future routine use of the van may allow us find conditions altering analytical performance but a systematic preliminary testing would be long and expensive and likely of limited use.

## Conclusion

This study showed that the benchtop hematology and biochemistry analyzers tested can be used in the laboratory van under field conditions for canine specimens, enabling hematology and biochemistry analyses to be carried out directly at the patient's location in all road-accessible locations. This could facilitate experimental studies and access to care for certain patients while eliminating the delay before analysis, which can have a major impact, particularly in the case of hematological analysis. Moreover, although each analyzer is unique in the combination of its method/technology, components, software, etc., and is therefore more or less sensitive to factors that may cause it to malfunction, this study showed that benchtop analyzers can potentially be used in a laboratory van, provided they have been handled in the best possible conditions. Obviously, such analyzers would still have to be validated under the van operating conditions before they can be used in practice. Finally, although this study focused on the validation of the van's analyzers in dogs, given that no effect of the van utilization was apparent on the analyzer's performance with either canine specimens or QCM, it is likely that this mobile laboratory can be used in other species for which the analyzers have been validated.

## Methods

### Analyzers

Four analyzers were used: the van analyzers (ProCyte Dx and Catalyst One) and the reference analyzers (ProCyte Dx and Catalyst One) from the in-clinic laboratory of the emergency unit of the National Veterinary School of Toulouse's teaching hospital. According to the manufacturer, the analyzers must be used indoors in a properly ventilated room, between 15 and 30 °C, within 30–85% or 15–75% humidity for the ProCyte Dx and the Catalyst One, respectively. The analyzers must not be installed where gases can accumulate or chemicals are stored, and must be protected from dust, vibrations and direct sources of sunlight, heat, cold or humidity.

Van and in-clinic analyzers were used according to the manufacturer's instructions, using settings for "quality control material" or "dog" and latest software version (ProCyte Dx software 00–35_61; Catalyst One version 2.19). QC assays were carried out throughout the study on all analyzers, more frequently than recommended by the manufacturer. In hematology, the manufacturer's QCM (e-CHECK, IDEXX Laboratories, Westbrooks, USA) was analyzed every weekday alternating between QCM1 and QCM2. In biochemistry, the manufacturer's QCM (VetTrol control plus diluent, IDEXX Laboratories) was analyzed with commercial QC clips once a week.

### Variables

The following variables were analyzed in hematology: RBC, HGB, HCT, MCV, MCH, MCHC, RDW, WBC, leukocyte differential count including Neutro, Lympho, Eosino and Mono, PLT, MPV, PCT, PDW, RET, RET%, RET-HGB. Basophil count was excluded from the study because it has not been validated and appears unreliable in dogs with the ProCyte Dx and other analyzers using similar technologies [4, 23]. With QC mode, results were only available for RBC, HCT, HGB, MCV, MCH, MCHC, RDW, RET, RET%, WBC and PLT.

In biochemistry, the following variables were analyzed with the QC clip: albumin, ALP, ALT, total calcium, glucose and ammonium. These variables were chosen because it allowed testing of almost every LED and wavelength used by the analyzer, while limiting the cost

of the study. Briefly, the analyzer uses 7 LEDs emitting at different wavelengths, each used for several variables' measurements. Glucose, total calcium, albumin, ALT, ALP and ammonium are measured with LEDs emitting at 560 nm, 680 nm, 650 nm, 365 nm, 405 nm and 588 nm respectively. A seventh LED emitting at 470 nm is used to measure electrolytes but was not assessed in this study. Ammonium was excluded from the statistical analysis because the study design did not comply with the pre-analytical requirements for its measurement [24]. All reagents used for hematological and biochemical analyses were purchased from the manufacturer.

### Specimens

Experiments were performed on two levels of manufacturer's QCM (QCM1 and QCM2) and fresh canine K3-EDTA blood specimens (VacuMed 4mL, FL medical, Padova, Italia) for the ProCyte Dx and one level of manufacturer's QCM and canine Li-heparin plasma specimens (BD Vacutainer 4mL, Becton Dickinson, Franklin lakes, USA) for the Catalyst One. QCMs were purchased from the manufacturer and canine specimens were not, as they were left over from hematologic and biochemical diagnostic work-up or routine health screens at the Laboratoire Central de Biologie Médicale (Central Laboratory of Clinical Pathology, Labo Central) of the National Veterinary School of Toulouse between December 2022 and July 2023. As the patients were presented to many different services (internal medicine, surgery, emergency, intensive care, oncology and general medicine), specimens were obtained from privately owned dogs of different breeds, weights, ages and with different diseases or conditions, thus covering a wide range of results.

Prior to hematology analysis, blood specimens and QCMs were kept at room temperature (24℃), placed on an agitator (Blood Tube Rocker 8-Tube, IDEXX Laboratories) for 20 min, and then gently inverted to ensure complete homogenization. Specimens with visible clots were excluded.

Prior to biochemistry analysis, tubes were centrifuged (1250 g; 5 min) within 20 min of sampling. Plasma was removed and placed in an Eppendorf tube (Safe-Lock tubes 1.5mL, Eppendorf, Hamburg, Germany). Fresh plasma was kept at room temperature (24 °C) for less than 2 h before analysis with the two biochemistry analyzers. Some validation studies required a larger volume of plasma. For this purpose, a pooled plasma sample was prepared, using varying volumes of leftover plasma from five healthy dogs (based on clinical examination and unremarkable biochemistry and hematology panels). One milliliter aliquots of the pooled plasma were prepared and stored frozen (-20 °C) for a maximum duration of 6 months, then thawed for 1 h at room temperature and analyzed within 2 h after careful homogenization.

### Van settings

The van is a fully equipped small-scale laboratory, including the hematology and biochemistry analyzers evaluated in this study. It was developed with the help of a company (TIB, Tollerie Industrielle de Brezolles, Brezolles, France) specializing in the fitting out of emergency medical transport vehicles (fire engines, ambulances, etc.). The analyzers were secured with the company's help to minimize shock and vibrations. After the analyzers were successfully installed and secured, they were checked by technicians from IDEXX.

For the study, the van was driven varying distances between December 2022 and July 2023. After each trip, it returned to the veterinary school prior to analyzing samples through the day, as canine hematology and biochemistry requests were submitted to the Labo Central, when adequate sample volumes were provided to allow analysis using both the in-clinic analyzers and the van analyzers. All tests were run within 24 h of the end of the trip. While analyzing samples, the van was stationary and plugged into an electric car charging socket located adjacent to the Labo Central.

Trip length was considered short if < 50 km, medium if 50–100 km and long if > 100 km, respectively. Detailed trip lengths are given in Table S1 and all travels were on paved roads. Briefly, the short-term replication study was performed after a long trip, linearity was performed after a long trip, and long-term replication and comparison studies were assessed over several days after trips of varying distances. The linearity study was carried out first, after a 3-day trip of nearly 1500 km which was the first trip after the installation of the analyzers in the van. In total, the van travelled 4739kms over the course of the study. Analyzers were turned off during the trips, and turned on after the van was stationary. If necessary, an electric-powered heating and air-conditioning unit was used to bring the laboratory compartment to recommended operating temperatures prior to turning the analyzers on.

### Method validation/verification study

#### *Linearity*

Linearity was only tested on variables expressed as concentrations or counts, and not as indexes or percentages, and was evaluated by analyzing two repeats of a 5-point (0%, 25%, 50%, 75% and 100%) serial dilution of a canine specimen. For hematology, a fresh canine K3-EDTA blood specimen with sufficient remaining volume was diluted with the analyzer's system diluent (IDEXX Laboratories). For biochemistry, 2.5mL from the pooled canine plasma was diluted with sodium chloride 0.9% solution (Laboratoires AGUETTANT, Lyon, France). Results from diluted specimens for which concentration was below the linear range or the limit of quantification

(according to the manufacturer) were excluded from the linearity study.

#### *Imprecision*

Short-term imprecision was evaluated from 10 consecutive repeats of a randomly selected canine EDTA blood specimen analyzed within two hours of sampling and one level of QCM (QCM1) for hematology, and from 10 consecutive repeats of one aliquot from the pooled canine plasma and the QCM for biochemistry.

Long-term imprecision was evaluated using 10 repeats (2 repeats per day for 5 days) of two levels of QCM (QCM1 and QCM2) from 3 different lots for the hematology analyzer and 10 repeats (2 repeats per day for 5 days with more than 2 h of delay between analyses) of the pooled canine plasma (1 aliquot per day) and one lot of QCM (VetTrol, IDEXX laboratories) for the biochemistry analyzer. Long-term imprecision was also assessed for the in-clinic analyzers used for the comparison study, using results from QC events over the period of the van's repeated trips (December 2022 to July 2023) and 4 and 2 lots of QCM were used for hematology and biochemistry, respectively.

### Comparison of results by Van and in-clinic analyzers

The study was performed on canine specimens presented to the Labo Central and analyzed with both analyzers (in-clinic and van) in random order, within 2 h after blood collection and with a delay of less than 30 min between the two measurements. Specimens were selected to ensure at least 25% presented abnormal results.

In hematology, forty-five results were analyzed, with the following results excluded from the comparison: two leukocyte differential counts because of errors associated with abnormal scattergrams (one on both analyzers and the other only on the in-clinic analyzer); one WBC and one RDW because of unexplained marked difference between results. In addition, eleven specimens were excluded from PDW comparison because results were not provided by one or both analyzers.

In biochemistry, forty-four specimens were analyzed and two specimens were excluded because of unexplained marked difference between results for all variables. Moreover, two specimens for ALP and ALT were excluded from statistical analysis because one or more results were not provided by one or both of the analyzers and one more specimen was excluded from ALP analysis because results were higher than the limit of quantification of the analyzer.

### Statistical analysis

Statistical analyses were performed with Excel (Microsoft, Redmond, USA) and Analyse-It (Analyse-It for Microsoft Excel 6.15.4, build 8349.332216, Redmond, USA). The level of significance was set at $p < 0.05$.

Linearity was tested visually, with regression analysis, and correlation coefficients were calculated. Analysis of data from the short- and long-term replication studies included calculation of the mean, SD, CV and $TE_{obs}$. SD was compared with the ASVCP recommendations ($0.25*TE_a$ and $0.33*TE_a$ for short- and long-term replication, respectively [17]), when $TE_a$ was available in the literature [18, 19]. Bias was calculated from the QCM analysis using manufacturer's data as Bias% = ([measured - target] values/target values)∗100, and observed total error was then calculated as $TE_{obs}$ = Bias% + 2∗CV [17] using the long-term imprecision CV. When $TE_{obs}$ was higher than the $TE_a$, the QGI was calculated as QGI = Bias%/(1.5∗CV). As long-term imprecision was assessed using different lots of QCM, results were standardized for comparison: for QC results obtained with a lot X, a correction factor ($target_{lot1}/target_{lotX}$) was applied. Long-term imprecision for the in-clinic analyzers was assessed from QC events performed over the entire study with standardization of the results between lots.

The comparison of van and in-clinic results was based on Spearman's correlation, Passing-Bablok regression analysis and Bland-Altman analysis. $TE_{obs}$ was calculated as described above, using mean bias in percent from the Bland-Altman analysis of relative difference. The CVs used to calculate $TE_{obs}$ were the CV obtained from the pooled canine plasma during the long-term replication study for biochemistry. For hematology, we used the mean of CVs obtained from the long-term replication study with the 2 levels of QCM when these were available, and otherwise, the CV obtained from the short-term replication study with fresh blood. The possible clinical relevance of differences between the van and in-clinic analyzers was tested by counting discrepancies between the results as within or outside the manufacturer's reference interval for each variable and testing if the difference was higher than the analytical variability (i.e., > 2.77*CVa) [25]. Confidence interval of the upper and lower limits of the reference interval could not be used because they were not provided by the manufacturer.

**Abbreviations**

| | |
|---|---|
| ALP | Alkaline phosphatase |
| ALT | Alanine amino transferase |
| ASVCP | American Society of Veterinary Clinical Pathology |
| CI | Confidence interval |
| CV | Coefficient of variation |
| Eosino | Eosinophil count |
| HCT | Hematocrit |
| HGB | Hemoglobin concentration |
| LED | light-emitting diode |
| LT | Long term imprecision |
| Lympho | Lymphocyte count |
| MCH | Mean corpuscular hemoglobin |

| | |
|---|---|
| MCHC | Mean corpuscular hemoglobin concentration |
| MCV | Mean corpuscular volume |
| Mono | Monocyte count |
| MPV | Mean platelet volume |
| Neutro | Neutrophil count |
| PCT | Plateletcrit |
| PDW | Platelet distribution width |
| PLT | Impedance platelet count |
| POCA | Point of care analyzer |
| QC | Quality control |
| QCM | Quality control material |
| RBC | Red blood cell count |
| RDW | Red cell distribution width |
| RET | Reticulocyte count |
| RET% | Reticulocyte percentage |
| RET-HGB | Reticulocyte hemoglobin |
| SD | Standard deviation |
| ST | Short term imprecision |
| TAT | Turnaround time |
| $TE_{obs}$ | Observed total error |
| $TE_a$ | Allowable total error |
| WBC | White blood cell count |

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12917-025-04601-6.

Supplementary Material 1 Fig. S1: Linearity of relevant hematological variables with the van analyzer Squares represent results from duplicate analyses and blue crosses represent the mean of duplicates. Red lines represent linear fit and dashed blue lines represent the identity line (x = y). Results of diluted specimens for which concentration was below the linear range or the limit of quantification (according to the manufacturer) were excluded. Abbreviations: HCT, hematocrit; HGB, hemoglobin concentration; PCT, plateletcrit; PLT, platelet count; RBC, red blood cell count; RET, reticulocyte count; WBC, white blood cell count.

Supplementary Material 2 Fig. S2: Linearity of biochemical variables with the van analyzer Squares represent results from duplicate analyses and blue crosses represent the mean of duplicates. Red lines represent linear fit and dashed blue lines represent the identity line (x = y). Results of diluted specimens for which concentration was below the linear range or the limit of quantification (according to the manufacturer) were excluded. Abbreviations: ALP, alkaline phosphatase; ALT, alanine amino transferase; Ca, calcium.

Supplementary Material 3 Fig. S3: Passing-Bablok and Bland-Altman plots for hematological variables On the Passing-Bablok plots, the thin gray line is identity line (y = x); the red line is the regression curve. On the Bland-Altman plots, the blue lines are the regression curve with 95% CI (dotted lines) and 95%LoA (dashed lines). Abbreviations: CI, confidence interval; Clin, in-clinic analyzer; Eosino, eosinophil count; HCT, hematocrit; HGB, hemoglobin concentration; LoA, limit of agreement; lympho, lymphocyte count; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; MCV, mean corpuscular volume; Mono, monocyte count; MPV, mean platelet volume; Neutro, neutrophil count; PCT, plateletcrit; PDW, platelet distribution width; PLT platelet count; RBC, red blood cell count; RDW, red cell distribution width; RET, reticulocyte count; RET-HGB, reticulocyte hemoglobin; WBC, white blood cell count.

Supplementary Material 4 Table S1: Schedule of trips and studies. Resting time is the time between the end of the trip and running the analyses. d1 to d5 are the five days of LT study. Abbreviations: Comp, comparison; d, day; Lin, linearity; LT, Long-term imprecision; Pool, pooled plasma from 5 healthy dogs; QCM, quality control material; ST, Short-term imprecision.

Supplementary Material 5 Table S2: Imprecision of hematological variables with the van analyzer, using QCM and a canine specimen. Bolded results are the ones for which $TE_{obs} > TE_a$, and CV for which $SD > 0.25*TE_a$ and $SD > 0.33*TE_a$ for ST and LT, respectively. $TE_a$ and $TE_{obs}$ were calculated and reported following Nabity et al. [18]. [a] $TE_a$ for concentration lower than below the reference interval; [b] $TE_a$ for concentration within the reference interval; [c] $TE_a$ for concentration above the reference interval. Abbreviations: CV, coefficient of variation, $CV\% = \frac{SD}{Mean} * 100$; HCT, hematocrit; HGB, hemoglobin concentration; LT, long term imprecision; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; MCV, mean corpuscular volume; MPV, mean platelet volume; PCT, plateletcrit; PDW, platelet distribution width; PLT, platelet count; QCM, quality control material; RBC, red blood cell count; RDW, red cell distribution width; RET, reticulocyte count; RET-Hgb, reticulocyte hemoglobin; SD, standard deviation; ST, short term imprecision; $TE_a$, allowable total error; $TE_{obs}$, observed total error; WBC, white blood cell count.

Supplementary Material 6 Table S3: Long-term imprecision of biochemistry and hematology in-clinic analyzers calculated from QC checks. Bolded results are the ones with $TE_{obs} > TE_a$ and CV for which $SD > 0.33*TE_a$. $TE_a$ and $TE_{obs}$ were reported and calculated following Nabity et al. and Harr et al. [18, 19]. Abbreviations: ALP, alkaline phosphatase; ALT, alanine aminotransferase; Ca, calcium; CV, coefficient of variation, $CV\% = \frac{SD}{Mean} * 100$; HCT, hematocrit; HGB, hemoglobin concentration; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; MCV, mean corpuscular volume; PLT, platelet count; QC, quality control; QCM, quality control material; RBC, red blood cell count; RET, reticulocyte count; RET-Hgb, reticulocyte hemoglobin; SD, standard deviation; $TE_a$, allowable total error; $TE_{obs}$, observed total error; WBC, white blood cell count.

Supplementary Material 7 Table S4: Comparison of hematological variables between the van and the in-clinic analyzers. 95% CI of Spearman's correlation coefficient r and Passing-Bablok equation coefficients are between brackets. Bolded results do not contain 1 for slope (a) or 0 for intercept (b) in the 95% CI of Passing-Bablok equation. Abbreviations: CI, confidence interval; Clin, in-clinic analyzer; Eosino, eosinophil count; HCT, hematocrit; HGB, hemoglobin concentration; Lympho, lymphocyte count; max, maximum; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; MCV, mean corpuscular volume; min, minimum; MPV, mean platelet volume; Mono, monocyte count; Neutro, neutrophil count; PCT, plateletcrit; PDW, platelet distribution width; PLT, platelet count; RBC, red blood cell count; RET, reticulocyte count, RET-HGB, reticulocyte hemoglobin; WBC, white blood cell count.

Supplementary Material 8 Table S5: Bland-Altman results of hematological variables between the van and the in-clinic analyzers. Bolded results are the ones with $TE_{obs} > TE_a$ or the ones for which 95% CI do not contain 0 for mean bias (%) and slope of mean bias linear regression. $TE_a$ and $TE_{obs}$ were calculated and reported following Nabity et al. [18] using the mean of long term imprecision CVs obtained with QCM1 and QCM2 except for the ones with an asterisk for which the short term imprecision CV with fresh canine blood was used. 95% CI of mean bias and Bland-Altman equation coefficients are between brackets. [a] $TE_a$ for concentration below the reference interval; [b] $TE_a$ for concentration within the reference interval; [c] $TE_a$ for concentration above the reference interval. Abbreviations: CI, confidence interval; Clin, in-clinic analyzer; Eosino, eosinophil count; HCT, hematocrit; HGB, hemoglobin concentration; Lympho, lymphocyte count; Max, maximum; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; MCV, mean corpuscular volume; Min, minimum; MPV, mean platelet volume; Mono, monocyte count; Neutro, neutrophil count; PCT, plateletcrit; PDW, platelet distribution width; PLT, platelet count; RBC, red blood cell count; RET, reticulocyte count; RET-HGB, reticulocyte hemoglobin; $TE_a$, allowable total error; $TE_{obs}$, observed total error; WBC, white blood cell count.

Supplementary Material 9 Table S6: Bland-Altman results of biochemical variables between the van and the in-clinic analyzers. Bolded results are the ones with $TE_{obs} > TE_a$ or the ones for which 95% CI do not contain 0 for mean bias (%) and slope of mean bias linear regression. $TE_a$ and $TE_{obs}$ were calculated and reported following Harr et al. [19] using the LT CVs obtained with canine plasma. 95% CI of mean bias and Bland-Altman equation coefficients are between brackets. [a] $TE_a$ for concentration below the reference interval; [b] $TE_a$ for concentration within and above the reference interval; Abbreviations: ALP, alkaline phosphatase; ALT, alanine aminotransferase; Ca, calcium; CI, confidence interval; Clin, in-clinic analyzer; LT, long term imprecision; $TE_a$, allowable total error; $TE_{obs}$, observed total error.Comité d'éthique en expérimentation animale SCIENCE ET SANTE

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**Author contributions**
All authors participated in the general design and conception of the study. CT drove the van for the short and medium trips. AP, ML and CT carried out the analysis of specimens on all analyzers. AP collected the results and created the dataset. TC performed the statistical analysis. TC and CT drafted the manuscript. TC, CT, EL, NBA, and FG revised the manuscript and gave final approval of the version to be published. All authors read and approved the final manuscript.

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**Data availability**
Data is provided within the manuscript or supplementary information files.

## Declarations

**Ethics approval and consent to participate**
This study was approved by the "Science et Santé animale" Ethics Committee (N° SSA_2023_023). Comité d'éthique en expérimentation animale SCIENCE ET SANTE ANIMALES N°115 Ecole Nationale Vétérinaire 23 chemin des Capelles BP 87614 31076 TOULOUSE cedex 3, France. Informed consent was obtained from owners for the use of blood specimen from their dogs.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

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