ABSTRACT

Arterial blood gas (ABG) sampling represents the gold standard for determining the patients’ acid-base and ventilatory status. However, it has many drawbacks. This study assessed the relationship and agreement between arterial and capillary measurements in adult intensive care unit (ICU) patients. ABG and capillary blood gas (CBG) samples were obtained from 49 adult and 51 elderly (total 100) patients with cardiopulmonary disorder, cerebrovascular accident, intoxication, multiple trauma, and metabolic coma. All samples, collected at the same time, were analyzed. The kendall’s tau rank correlation, unpaired t-test, paired-t test and Bland-Altman method which is used for measurement of agreement, were used for analysis. The median age was 65 years (min: 18, max: 90). There was a significant correlation between ABG and CBG values of pH, PCO₂, and HCO₃⁻ (P < 0.001). The agreement between measurements of pH, PCO₂, and HCO₃⁻ in ABG and CBG was good with mean differences of 0.0085, 3.049 mmHg, and 1.268 mmol/L, respectively. Despite a statistically significant correlation between arterial and capillary PO₂ (P < 0.001), the agreement between capillary and arterial measurements of PO₂ was poor (mean difference: 16.52, 95% CI: -23.74 to 56.79). Blood pressure and body temperature did not alter the correlations and agreement between measurements in elderly and adult groups and all together ICU patients. Capillary blood samplings provide an accurate assessment of pH, PCO₂, and HCO₃⁻ and can be used to reliably measure the acid-base and ventilatory status of patients in the presence of any limitation of or contraindication to ABG in ICU.

Keywords: Arterial blood gas, capillary blood gas, intensive care unit, body temperature, blood pressure

ÖZET

Arter kan gazı (ABG) örneklemesi hastaların asit-baz ve solunumsal durumunun belirlenmesi için altın standart olarak kabul edilir. Ancak bu işlem pek çok sakıncaları vardır. Bu çalışmada erişkin yoğun bakım unidadesındaki (ICU) hastalarda arteriyel ve kapiller kan gazı ölçümlerinin arasındaki ilişki ve uyum değerlendirildi. Kardiyopulmoner hastalık, serebrovasküler olay, zehirlenme, multipl trauma ve metabolik komalı 49 yetişkin ve 51 yaşlı (toplam 100) hastadan ABG ve kapiller kan gazı (CBG) örnekleri eşzamanlı olarak alındı ve analiz edildi. İstatistiksel incelemelerde Kendall's Tau rank korelasyonu, eşleştirilmemiş t-testi, Paired-t testi ve örnekler arasındaki uyumun analizi için Bland-Altman yöntemi kullanıldı. Hastaların ortanca yaş 65 olarak bulundu (min: 18, max: 90). ABG ve CBG örneklerinin pH, PCO₂ ve HCO₃⁻ değerleri arasında anlamlı bir ilişki saptandı (P < 0.001). ABG ve CBG'nin pH, PCO₂ ve HCO₃⁻ değerleri arasındaki uyum iyı idi ve farkların ortalaması sırasıyla PH için 0.0085, PCO₂ için 3.049 mmHg ve HCO₃⁻ için 1.288 mmol/L olarak bulundu. Arteriyel ve kapiller PO₂ arasında istatistiksel olarak anlamlı bir korelasyon olmasına rağmen (P < 0.001), bu ölçümlerin arasında uyum zayıf olarak bulundu (ortalama farklılık: 16.52, % 95 CI: -23.74 - 56.79). Kan basınç ve vücut ısı, yaşlı ve erişkin gruptarında da bütün hastalarda ölçümler arasındaki korelasyonları ve uyumu etkilemedi. Yoğun bakım unidadında ABG analizi için herhangi bir sınırlama ya da kontrindikasyon varlığında hastaların asit-baz ve solunumsal durumlarının güvenilir bir şekilde değerlendirilmesi için kapiller PH, PCO₂ ve HCO₃⁻ kullanılabilir.

Anahtar Kelimeler: Arteriyel kan gazı, kapiller kan gazı, yoğun bakım ünitesi, vücut ısı, kan basınç

1Department of Emergency Medicine Faculty of Medicine, Selcuk University, 2Department of Animal Science, Biometry Genetics Unit, Faculty of Agriculture, Selcuk University, 3Department of Anesthesiology and Intensive Care, Medicana Hospital, Konya/Turkey

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Iletişim Yazar: Ahmet AK
Department of Emergency Medicine Faculty of Medicine, Selcuk University, Konya/Turkey
E-mail: drahmetak@hotmail.com
Introduction

Blood gas analysis (BGA) is widely used to evaluate acid-base abnormalities and ventilatory status for patients at the emergency department and critically ill patients. Conventional BGA involves repeated arterial punctures or sampling from an indwelling arterial catheter. Both of these techniques can be distressing to the patients, and can cause complications such as local hematoma, arterial thrombosis or embolization with consequent ischemic injury to the digits especially when performed by inexperienced individuals. In addition, the conventional method of blood sampling for BGA may be hazardous in clinical situations such as coagulation disorders, patients on severe anticoagulant therapy, the presence of arterial graft and severe vascular disease. It may also not be feasible in patients with simple intoxication, for regular control in patients with obstructive lung disease, and in athletes (1-4).

Alternative noninvasive methods like using a pulse oximeter, capnography and transcutaneous oxygen and carbon dioxide monitoring have proven to be useful, (3,4) but they do not give information about pH and bicarbonate (HCO₃). Capillary blood gas (CBG) sampling may be a useful alternative to ABG sampling. It is easier to obtain, less painful, less invasive way of evaluating acid-base and ventilatory status in intensive care unit (ICU) patients (5-13). Over the years, researchers have searched for alternatives to ABG sampling. There are numerous studies comparing arterial and venous blood gas values that show a good correlation between arterial and venous samples in both humans and animals (14-17). There are also studies where capillary blood has been used as a substitute for arterial blood and it has been compared with arterial blood for blood gas and acid-base parameters (5,18,19). Capillary blood sample is widely adopted in pediatric practice (7-9,11) but it is used sparingly in adults (10,12).

This study aims to investigate the relationship and agreement between ABG and CBG values in patients with different blood pressure and body temperature in adult ICU.

Materials and Methods

After the approval of ethical committee of Selcuk University (# 2004-045), this prospective study was conducted in the intensive care unit of Emergency Medicine Department during two years. In our hospital, the reference ranges for ABG parameters are; pH, 7.34-7.46; PCO₃, 35-45 mmHg; PO₂, 76 - 100 mmHg; HCO₃, 21-26 mmol / L; and SO₂, 94 - 99%.

Patients. Sample size calculation was performed (20) and one hundred patients, selected randomly out of 1040 patients admitted to adult ICU, were enrolled in the study. Informed written consent was obtained prior to entry from the patients or their relatives. A mean arterial pressure (MAP) ranges between 80 mmHg - 100 mmHg (21) and body temperatures within a range of 36.2°C to 37.5°C (22) were accepted as normal in adult. Patients ≥ 65 years old were defined as elderly (23). The exclusion criteria involved rejection of the study protocol, the presence of known coagulopathy and anticoagulant therapy, the history of methemoglobinemia, the presence of an arterial graft, and severe peripheral vascular disease. In sixty six of the patients (66%) trachea was intubated and ventilated, other patients were received oxygen via a face mask when FiO₂ was being kept at 0.3 - 0.4 in appropriate flow.

Monitoring

Heart and respiratory rate, peripheral oxygen saturation, body temperature and MAP (noninvasively) of all the subjects were monitored (Criticare 508, Waukesha, WI). The demographic data and all the parameters were recorded on a specified proforma.

Blood gas analysis

The decision to take an arterial sample or to place an arterial catheter was always made by the physician of the intensive care unit. First, arterial catheter (preferably radial) was placed by the investigator physician. Following 90 minutes after the placement of the arterial catheter (22G), the blood sample was collected in pre-heparinized 2 ml syringes. CBG was obtained without warming and without using any vasodilator and local anesthetics. For capillary blood sampling, contralateral ring finger was punctured with a lancet and samples were taken in pre-heparinized capillary tube (SAFE-T-FILL, RAM Scientific, NY, USA). Two sides of the tubes were sealed with the first and third fingers of the investigator to avoid air bubbles. All samples were collected at the same time by two nurses under observation. One of the investigators was present at that moment and all samples were analyzed by the investigators. Samples were analyzed in a blood gas analyzer (Gem Premier 3000 Model 5700, Instrumentation Laboratory, SN 15767, Lexington, MA, USA), located in the ICU, within 3 minutes of extraction. PH, PO₂, PCO₂, and HCO₃ values were recorded.
**Statistical analysis**

Statistical analysis included Kendall’s tau correlations, paired and unpaired t-tests, and Mann-Whitney test. Bland-Altman plots24 and 95% limits of agreement were used to determine clinical utility of capillary gas. P < 0.05 was considered statistically significant. Prospectively, absolute differences between arterial and capillary pH of ≤ 0.05, PCO₂ of ≤ 6.5 mmHg, PO₂ of ≤ 6.5 mmHg, and HCO₃⁻ of ≤ 3.5 mmol / L were deemed acceptable for clinical decision making. Calculations of Kendall’s tau correlations were performed using Kendall library25 of R software.26 Rest of the statistical analyses were carried out using the R software.26

**Results**

A total of 100 ABG and CBG samples, of which 38% from males and 62% from females, were obtained. The median age in overall patients was 65 years (min = 18; max = 90 years) with adult and elderly median age being 48 years and 70 years, respectively. The diagnosis upon admission in ICU is given in Table 1.

The MAP (median) was 92.3 mmHg (min = 43 mmHg; max = 155 mmHg) in overall patients. Thirty five of the patients had a MAP between 80 mmHg to 100 mmHg (median = 89 mmHg), while twenty six of the patients (26%) had a MAP ≤ 80 mmHg (median = 67 mmHg), and 39 of the patients (39%) had a MAP ≥ 100 mmHg (median = 110 mmHg). The median MAP was 100 mmHg (min = 60 mmHg; max = 155 mmHg) in adults, while those values were 87.3 mmHg (min= 43 mmHg; max= 134.6 mmHg) in elderly group.

The median body temperature was 36.8°C (min= 35°C; max= 39.5°C) in overall patients. Fifty one of the patients had a body temperature between 36.2°C to 37.5°C (median = 35.8°C), while twenty five of the patients (25%) had a body temperature ≤ 36.2°C (median = 35.8°C), and 24 of the patients (24%) had a body temperature ≥ 37.5°C (median = 38°C). The median body temperatures were 37°C (min= 35°C; max= 39.5°C) in adult and 36.8°C (min= 35°C; max= 38.9°C) in elderly group.

ABG pH and CBG pH values were highly correlated (r = 0.915, p < 0.001). The relative average bias and 95% limits of agreement of the capillary pH were 0.0085±0.0338, 0.0075±0.0372, and 0.0092±0.0295 for overall, adult and elderly groups, respectively. In all groups mean capillary pH values were lower than mean arterial pH values. The absolute value of the difference between arterial and capillary pH was never >0.05 (Figure 1). The capillary pH found to be higher than the arterial pH in 20% of the patients. At maximum, the capillary pH was 0.03 higher than arterial pH. The CBG identified all 18 patients with arterial acidoses, defined as ApH < 7.35 (Table 2-A). The positive predictive value of a Cph < 7.35 for ApH < 7.35 was 90%. The negative predictive value of a Cph≥7.35 for ApH≥7.35 was 100%. APCO₂ and CPCO₂ values were highly correlated (r= 0.862, p<0.001). The relative average bias and 95% limits of agreement of the CPCO₂ were -3.01±5.38 mmHg, -2.88±4.94 mmHg, and -3.14±5.81 mmHg for overall, adult and elderly groups, respectively. In all groups mean CPCO₂ values were higher than mean APCO₂ values. In 88% (88 out of 100 patients) of cases, the differences between APCO₂ and CPCO₂ was ≤ 6.5 mmHg (Figure 2). The CPCO₂ found to be higher than the AP CO₂ in 7% of the patients. The maximum capillary underestimate of AP CO₂ was by 6 mmHg. The CBG identified all 18 patients with arterial hypercarbia, defined as APCO₂ >46 mmHg. The positive predictive value of a CPCO₂ >46 mmHg for AP CO₂ >46 mmHg was 85%. The negative predictive value of a CPCO₂ ≤ 46 mmHg for APCO₂ >46 mmHg was 100% (Table 2-B). Sensitivity (and 95% confidence interval; CI) and specificity (95% CI) were found to be 100% (82.4%-100%) and 96% (89.9%-98.7%), respectively.

There was a moderate correlation between APO₂ and CPO₂ (r = 0.633, p < 0.001). The relative average bias and 95% limits of agreement of the CPO₂ were 16.53±40.26 mmHg, 16.79±37.53 mmHg, and 16.27±43.16 mmHg for overall, adult and elderly groups, respectively. In all groups mean CPO₂ values were lower than mean APO₂ values.. In 63% of cases (63 of 100 patients), the difference between APO₂ and CPO₂ was ≤ 46 mmHg. Conversely, of 20 arterial samples with PO₂ >100 mmHg, and only two corresponding ABG had APO₂ <100 mmHg. In 3 CBG samples, the PO₂ <100 mmHg, and only two corresponding ABG had PO₂ >100 mmHg. Conversely, of 20 arterial samples with PO₂ >100 mmHg, and only two corresponding ABG had PO₂ >100 mmHg. Conversely, of 20 arterial samples with PO₂ >100 mmHg, and only two corresponding ABG had PO₂ >100 mmHg. Conversely, of 20 arterial samples with PO₂ >100 mmHg, and only two corresponding ABG had PO₂ >100 mmHg. Conversely, of 20 arterial samples with PO₂ >100 mmHg, and only two corresponding ABG had PO₂ >100 mmHg.

AHCO₃⁻ and CHCO₃⁻ values were highly correlated (r = 0.885, p<0.001). The relative average bias and 95% limits of agreement of the HCO₃⁻ were -1.19±2.62 mmol/L, -1.14±2.41 mmol/L, and -1.24±2.82 mmol/L for overall, adult and elderly groups, respectively. In all groups mean CHCO₃⁻ values were higher than mean AHCO₃⁻ values. In 92% of cases (92 of 100 patients), the difference between arterial and capillary HCO₃⁻ was < 3 mmol / L (Figure 4). Neither mean arterial pressure nor temperature altered the strength of relationship and agreement between ar-
terial and capillary pH, PCO$_2$, PO$_2$, HCO$_3$. Kendall’s tau correlation coefficients and 95% limits of agreement (Mean differences±1.96 SD) between ABG and CBG values did not change significantly for the subgroups of adult and elderly and all data together (Figures 1-4). Detailed information was given in Table 3.

**Discussion**

In the present study we demonstrated that CBG provided a clinically relevant prediction of arterial pH, PCO$_2$ and HCO$_3$ in the majority of ICU patients. The degree to which CBG underestimated arterial acidosis and hypercarbia was clinically insignificant.

The physiological status of critically ill patients must be followed very closely. ABG analysis is among the most frequently used procedures. This is accomplished through repeated arterial punctures or by having an indwelling arterial catheter in place. However, there are complications related to arterial puncture. The procedure itself is technically difficult. In addition, according to AARC clinical practice guideline; arterial sampling should be performed by trained health care personnel in order to evaluate ventilatory, acid base and oxygenation situations, to quantitate the patient’s response to therapeutic intervention and diagnostic evaluation and to monitorize severity and progression of disease process. Contraindications for ABG sampling according to AARC clinical practice guideline are the presence of negative Allen test, surgical shunt and infection or peripheral vascular disease involving the selected limb, the need for monitoring the femoral puncture site for an extended period because of femoral puncture should not be performed outside the hospital, medium to high dose anticoagulation therapy and coagulopathy. In addition, arterial puncture may not be useful in some clinical situations like the need of a few sampling, in healthy subjects like athletes and in situations when there is no need for monitoring continuously invasive blood pressure. The hazard and complications related with arterial puncture should not be forgotten. These are hematoma, arteriospasm, air or clotted blood emboli, anaphylaxis from local anesthetic, infection (of patient and health care personnel), hemorrhage, trauma to the vessel, arterial occlusion, vasovagal response and pain (3,4,12,15). The absence of a palpable pulse or inability to puncture the artery are also among the limitations of ABG sampling (4). Hence, there is a need for an alternative method to obtain blood gas values. CBG sampling is less invasive and may be a useful alternative to ABG sampling. If a blood gas value determined by capillary samples could be used to show patients’ acid-base status and guide their management with the same accuracy as arterial sampling, this would be preferable because of the ease of blood sample collection.

The literature is conflicting as to the accuracy of capillary blood to reflect arterial blood values. Arterialized capillary blood samples can reflect arterial blood if done properly according to some studies. In addition, many studies have shown good correlation between ABG and CBG samples (5-12). Begin et al. (6). conducted a com-

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**Table 2. A) Agreement of acidosis (pH < 7.35), diagnosed by ABG and CBG measurements, B) Agreement of hypercarbia (PCO$_2$ > 46 mmHg), diagnosed by ABG and CBG measurements.**

<table>
<thead>
<tr>
<th></th>
<th>ApH &lt; 7.35</th>
<th>ApH ≥ 7.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>CpH &lt; 7.35</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>CpH ≥ 7.35</td>
<td>0</td>
<td>81</td>
</tr>
<tr>
<td>CPCO$_2$ &gt; 46</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>CPCO$_2$ ≤ 46</td>
<td>0</td>
<td>80</td>
</tr>
</tbody>
</table>

ApH: Arterial pH  
CpH: Capillary pH  
PCO$_2$: Capillary partial pressure of carbon dioxide  
APCO$_2$: Arterial partial pressure of carbon dioxide  

A) The CBG identified all 18 patients with arterial acidosis. The positive predictive value of a CpH < 7.35 for ApH < 7.35 was 90%. The negative predictive value of a CpH ≥ 7.35 for ApH ≥ 7.35 was 100%.

B) The CBG identified all 18 patients with arterial hypercarbia. The positive predictive value of a CPCO$_2$ > 46 mmHg for APCO$_2$ > 46 mmHg was 85%. The negative predictive value of a CPCO$_2$ ≤ 46 mmHg for APCO$_2$ ≤ 46 mmHg was 100%.
parative study of blood gases and acid base parameters obtained simultaneously from arterial and finger capillary samples in 45 patients with acute respiratory distress without circulatory shock. Significant correlations were found between arterial and finger capillary samples of pH (r = 0.97), PCO$_2$ (r = 0.97) and PO$_2$ (r = 0.97). They concluded that capillary blood would be a valid substitute for arterial blood for blood gas and acid base parameters in patients with acute respiratory distress. McLain et al. (7) found high correlations for pH and PCO$_2$ in CBG and ABG in preterm infants, but the correlation for PO$_2$ was unsatisfactory. Another study (8) found high correlation between CBG and ABG even in the presence of hypothermia and hypoperfusion. In a pediatric intensive care, Yildizdas et al. (9) investigated the correlation between ABG, venous blood gas (VBG) and CBG and they found a significant correlation between pH, PCO$_2$, PO$_2$, BE and HCO$_3$ values except for a poor correlation with PO$_2$ in the presence of hypotension. They suggested that the capillary and venous blood gas measurements may be useful alternatives to arterial values for patients who do not require regular continuous blood pressure recordings and close monitoring of arterial PO$_2$. In their meta-analysis, Zavorsky et al. (27) evaluated (29) relevant studies and concluded that, blood samples from the fingertip or earlobe accurately reflected arterial PCO$_2$ and pH.

Although these studies found good relationships between ABG and CBG values, no analysis of the degree of agreement was reported. The finding that there is a high degree of correlation between ABG and CBG values are not surprising. It would be expected that there would be a relationship between them as they are part of the same physiological system. However, correlation does not necessarily imply agreement between the results which is the clinically relevant measure. Bland and Altman24 have stated that if the mean difference between two values is not clinically important (±1.96 SD), the two measurements could be used interchangeably. In our study “1.96 SD ranges” (around mean differences between arterial and capillary values) were as follow: ± 0.033 for pH, ± 5.38 mmHg for PCO$_2$, ± 2.616 mmol / L for HCO$_3$, and ± 40.26 mmHg for PO$_2$. These results are consistent with previous reports that suggested the use of CBG as a means of estimating the acid base and ventilatory status of patients but not the degree of oxygenation (5,10).

In our study, neither temperature nor blood pressure significantly altered correlation and agreement between ABG and CBG values. In a previous study (13) Honarmand and Safavi showed a good correlation in pH, PCO$_2$, BE, and HCO$_3$ between simultaneous samples of arterialized earlobe and arterial blood in normotensive and normothermic patients receiving mechanical ventilation. In another study (8) it was reported that results were not affected by temperature but hypotension affected the correlation between CBG and ABG in neonates. Several investigators stated that the poor correlation with hypotension should not discourage the use of CBG and that hypotension must first be reversed and then CBG could be expected to show a close correlation. It is noteworthy that we did not exclude any patients from our study. It is common to have patients with body temperature and blood pressure above or below normal values in ICU practice. In a study, Harrison et al. (11) stated that future comparisons of arterial and capillary samples in hypothermic, febrile, acidic and alkalotic patients would be pertinent. Therefore, in our study, we included the patients with different diagnosis.

In our study population, CBG provided a clinically useful estimate of APH and PCO$_2$ in 100% and 96% of samples, respectively. The CBG provided a sensitive screening tool for arterial acidosis and hypercarbia. Furthermore, CBG never provided a falsely reassuring estimate of arterial pH or PCO$_2$ (negative predictive values of pH ≥ 7.35 and PCO$_2$ ≤ 46 mmHg = 100%).

In a meta analysis on arterial versus capillary blood gases (12) authors stated that there were several methodological and technical differences between studies. They suggested that, proper care should include not squeezing or milking the puncture site, making sure that no air bubbles and ensuing that samples are minimally exposed to room air. In addition, in some previous studies, rubbing to warm the extremity or local anesthesia and vasodilator were used before capillary sampling while in some other previous studies (9,11) investigators stated that they were avoided from warming, local anesthetic, squeezing etc. Therefore, we avoided these applications too. Only one experienced staff team performed with the maximum care during capillary sampling. We did not warm the extremity and did not use any local anesthetic or vasodilator for capillary sampling. Warming is neither reliable from patient to patient and nor practical in ICU and we thought that these applications might affect the results.

In summary, we have shown a good relationship and agreement in pH, PCO$_2$, and HCO$_3$ but not PO$_2$, among ABG and CBG values even if body temperature and blood pressure were above or below normal values. The capillary samples did not underestimate arterial hypercarbia and acidosis.
The CBG can be used as an alternative to ABG in the presence of limitations or contraindications to ABG in ICU patients. The CBG may be more useful in situations like the need of a few sampling, in healthy subjects and when there is no need for monitoring continuously invasive blood pressure. We may speculate that, in clinical practice, it may preferably be combined with continuous pulse oximetry. Further studies in critically ill patients with different diagnosis and level of severity of respiratory and hemodynamic compromise should be performed to extend the usefulness of CBG.

### References


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### Table 3. Kendall’s tau correlation coefficients and 95% limits of agreement (Mean differences ± 1.96 SD) between ABG and CBG values for the subgroups and all data together.

<table>
<thead>
<tr>
<th>Sub-group</th>
<th></th>
<th>Correlations between Measurement</th>
<th>Agreement between measurement (Mean differences ± 1.96 SD)</th>
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<tr>
<td></td>
<td>n</td>
<td>PH</td>
<td>PCO₂</td>
</tr>
<tr>
<td>MAP &lt; 80 (mmHg)</td>
<td>8</td>
<td>.93**</td>
<td>.76*</td>
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<tr>
<td></td>
<td>18</td>
<td>.92**</td>
<td>.77**</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>.92**</td>
<td>.83**</td>
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<tr>
<td>MAP ≥ 80 (mmHg)</td>
<td>16</td>
<td>.94**</td>
<td>.75**</td>
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<td>.91**</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>.93**</td>
<td>.86**</td>
</tr>
<tr>
<td>BT ≤ 36.2 (0C)</td>
<td>8</td>
<td>.89**</td>
<td>.78**</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>.89**</td>
<td>.95**</td>
</tr>
<tr>
<td></td>
<td>25</td>
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<td>.88**</td>
</tr>
<tr>
<td>BT &gt; 36.2 (0C)</td>
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<td>.86**</td>
<td>.94**</td>
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<tr>
<td></td>
<td>30</td>
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<td>elderly</td>
<td>51</td>
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<td>.86**</td>
</tr>
<tr>
<td>In all cases</td>
<td>100</td>
<td>.92**</td>
<td>.86**</td>
</tr>
</tbody>
</table>

MAP: Mean arterial pressure, BT: Body temperature, PCO₂: Partial pressure of carbon dioxide, PO₂: Partial pressure of oxygen, HCO₃: Bicarbonate, * P < 0.05, ** P < 0.01.


