Time-Related Changes of the Cardiovascular System during Maintenance Anesthesia with Sevoflurane and Isoflurane in Horses

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ABSTRACT. To clarify time-related changes in equine cardiovascular system during maintenance anesthesia (180 min, 1.2 minimum alveolar concentration) with sevoflurane (Sev-group) compared to isoflurane (Iso-group) as the basis for clinical use of Sev, horses were examined for the heart rate (HR), mean arterial pressure (MAP), cardiac index (CI), systemic vascular resistance (SVR) and pre-ejection period (PEP)/ejection time (ET) that is an index of the cardiac contractility. The HR was almost 30 beats/min in both groups without significant temporal change. MAP was significantly elevated with time but there was no significant difference between the groups. In the Sev-group, CI remained unchanged but the significant increase of CI with time was observed in the Iso-group. In the Sev-group SVR was significantly higher than that of the Iso-group and increased with time. No significant difference of PEP/ET was seen between the groups, but PEP/ET lowered with time in the Iso-group in association with prolonged ET. The results indicated that the time-dependent elevation of MAP in the Sev-group reflected increased SVR without increase of CI and that it reflected increased CI resulting from increased stroke volume in the Iso-group in association with lowered PEP/ET, that is, increased cardiac contractility.

KEY WORDS: cardiovascular system, equine, pulsed doppler echocardiography, sevoflurane.

FULL PAPER

Sevoflurane (Sev) is an excellent anesthetic with a very low blood/gas partition coefficient of 0.6, which realizes rapid induction and waking [20], and it is widely used in humane medicine [9]. The drug is being used in equine medicine and its minimum alveolar concentration (MAC) is known to be 2.31% [1]. Sev-anesthesia is considered to be more useful especially for orthopedic surgery than halothane or isoflurane (Iso)-anesthesia because it provides excellent recoveries in horses [5]. Halothane and Iso have been well examined for effects on the time-related changes of cardiovascular system in horses [6, 17]. If the surgeries are prolonged, it should be necessary for the anesthetists to know the time-related effects of cardiovascular system with anesthetics. But there are no data for the time-related changes during Sev-anesthesia in the equine cardiovascular system, except for dose-dependent decrease in the arterial pressure and cardiac index (CI) [2].

For non-invasive measuring of CI, the Pulsed Doppler echocardiography was reported to be useful to give data closely correlated with those of the dye dilution or thermodilution methods [12]. In humane medicine, pre-ejection period (PEP)/ejection time (ET), an index of the cardiac contractility, is known to be calculated from the wave shape of the aortic flow velocity and electrocardiogram (ECG) using the pulsed doppler echocardiography [3, 18, 19].

To search for time-related alterations in equine cardiovascular system during maintenance anesthesia with Sev, in the present study, indices of the cardiovascular system such as heart rates(HR), mean arterial pressure (MAP), CI and PEP/ET were temporally compared between horses anesthetized with Sev and those with Iso.

MATERIALS AND METHODS

Animals: Twelve healthy 3-year-old Thoroughbred male horses were divided into two groups of 6 animals each, which were anesthetized with either Sev (Sevofrane, Maruiishi Pharmaceutical, Osaka, Japan) or Iso (Forane, Dynabott Japan, Tokyo, Japan; MAC: 1.31%) [16]. The mean body weights ± standard deviation (S.D.) of the Sev- and Iso-groups were 466.0 ± 22.7 and 475.2 ± 27.7 kg, respectively. Six experiments were repeatedly conducted with each group in the order according to the table of random numbers. Animals were fasted for 12 hr before experiments while freely given water.

The use of animals for this study complied with the guidelines for the humane use of animals as outlined by The Japan Racing Association Animals For Research and The Animal Protection Guideline from the Prime Minister’s office.

Anesthesia: A face-mask was made of two double polyethylene pails 30 cm in diameter with a hole on the bottom, and the both openings were sealed with a thin rubber membrane. Animals were introduced into a padded squeeze door, and after setting the front space as narrow as possible using two wide ropes passing the breast and shoulder, the face-mask was fixed. A semi-closed anesthetic apparatus for large animal (Mera 350, Senkoika, Tokyo) and two specific vaporizers for anesthesia with a maximum power of 7% (Sev-group, PPV Σ, Penlon, Oxon, UK) or 5% (Iso-group, PPV Σ, Penlon), were connected in series with each
other. The dials of each vaporizer were set at 6 MAC (Sev-
group: 13.9%, Iso-group: 7.9%), and the flow rate of oxygen
was fixed at 15 L/min.
Continuing inhalation with the face-mask after falling-
down, the four limbs of animals were pulled up using a hoist
and the body was restrained on the padded surgical table in
lateral recumbency. Then after removing the face-mask, an
endotracheal tube was intubated and connected with an
anesthetic device for large animals (Mok 94, Silver Medical,
Tokyo) fitted with a time cycle ventilator (Compos-β EV,
Silver Medical). Intermittent positive pressure ventilation
(IPPV) was then started and regulated to maintain partial
arterial CO₂ pressures (PaCO₂) of 45 to 55 mmHg, using
the same vaporizer as in the induction. The flow rate of oxygen
and end-tidal anesthetic gas concentration was fixed at 6 L/
min and 1.3 to 1.5 MAC, respectively. When the ocular
reflex except corneal reflex disappeared, the end-tidal anes-
thetic gas concentration was changed into 1.2 MAC (S-
group: 2.70 to 2.80%, I-group: 1.55 to 1.60%) that was
maintained for 180 min thereafter. For avoiding gas con-
tamination two sets of the anesthesia system were provided.

Measurement of arterial and right atrial pressures and
gas analysis of arterial blood: MAP was measured with a
catheter (20G 5/4 inch) placed in the facial artery. Mean	right atrial pressure (MRAP) was measured with a Swan-
Gans catheter (93A-191-8F, Baxter, Tokyo) introduced into
the right atrium via the left jugular vein. These catheters
were connecting to pressure transducers (DX-312, Bigo
Spectramed, Tokyo). These pressure transducers were
placed at the level of the sternum.
All the data were obtained and recorded using an anesthe-
sia monitoring system (HP M1166A, Hewlett Packard, Ger-
many). Arterial blood was anaerobically sampled with a
heparinized syringe and was immediately analyzed by a
blood gas analyzer (288 Blood Gas system, CIBA-CORN-
ING, Tokyo).

Pulsed Doppler echocardiography: A stroke volume
(SV) was calculated using an ultrasound imaging system
(Logiq TM 500, Yokogawa, Tokyo) with a 2.5 MHz sector-
type probe. The left thoracic wall between the 5th and 6th
ribs was scanned by the sound to produce a B-mode image
of the aortic sinus, and the cut-surface area at a systolic stage
was calculated by measuring the inside diameter of the out-
flow passage of the left ventricle. The sampling point of the
aortic blood flow was immediately above the aortic valve in
the center of the ascending aorta [12]. Since blood flow
velocity given by the pulsed doppler echocardiography is
known to depend upon the doppler beam and blood flow
angles [18], the aortic blood flow were continuously imaged
at an incoming angle of 15° or less against the flow direction
of doppler. All the diagnostic images were recorded on a
super-VHS videotape, from which the typical and disting-
ushed the velocity waves of the aortic blood flow in suc-
cessive 5 strokes were selected. Then SV was calculated by
time-integration and multiplication by cut surface areas of
the cardiac outflow passage. From the waves of the aortic
blood flow velocity and of ECG (Base-apex lead), HR, PEP
(time between the start of the QRS complex and the start of
ejection) and ET (time between the start and the end of eje-
cion) were calculated. And then the cardiac output (CO), CI,
PEP/ET and SVR were calculated as follows:

\[
\text{CO (L/min)} = \text{SV (L)} \times \text{HR (beats/min)}
\]

\[
\text{CI (mL/min/kg)} = \frac{\text{CO}}{\text{Body weight (kg)}}
\]

\[
\text{PEP/ET} = \frac{\text{PEP (msec)}}{\text{ET (msec)}}
\]

\[
\text{SVR (dynes•sec/cm}^2) = \frac{60 \times [\text{MAP (mmHg)} - \text{MRAP (mmHg)}] \times 1332}{\text{CO (L/min)} \times 1000}
\]

Time stage of measurement and statistics: Each index
was measured and recorded at intervals of 15 min starting at
30 min (Base-line) after the end-tidal anesthetic gas concen-
tration changed into 1.2 MAC (Fig. 1). All the data were
analyzed for two-way ANOVA comparing between both the

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**Fig. 1.** Protocol for time-related studies of 1.2 minimum alveolar concentration (MAC) sevoflurane or isof-
lurane anesthesia in horses. A means the beginning of mask induction. B means the falling-down and
endo-tracheal intubation. C means continuing induction (1.3–1.5 MAC) with intermittent positive pres-
sure ventilation. D means the disappearance of the ocular reflex except corneal reflex and the beginning
of the maintenance anesthesia (1.2 MAC).
groups and the time stages. In cases with significant difference between time stages of measurement, the values at different time stages as well as Base-line data were examined by the paired t-test. In cases with significant difference between the groups, data of each anesthetic was examined by the non-paired t-test. The level of statistical significance was *P*<0.05 and all the data was expressed by means ± S.D.

**RESULTS**

**Induction:** Times required for falling down were 13.3 ± 2.3 and 15.4 ± 1.9 min in the Sev- and Iso-groups, respectively, and difference was not significant between the two groups. There was no significant difference in individual behaviors while hoisting, and the endotracheal tube was readily intubated. Times required for complete disappearance of the ocular reflex except corneal reflex were 18.2 ± 3.1 and 18.1 ± 2.2 min after falling down in the Sev- and Iso-groups, respectively, showing no significant difference.

**Ventilation:** The respiratory frequency, inspiration time, tidal volume and peak inspiration airway pressure are shown in Table 1. For keeping PaCO2 of 45 to 55 mmHg, the respiratory frequency, inspiration times and peak inspiration airway pressure were needed to change, while no significant difference was seen between the groups and among the time stages.

**Cardiovascular indices:** Changes in HR, MRAP, MAP, SV, CI and SVR with time are shown in Table 2. All the examined animals showed similar HR value of about 30 beats/min and neither change with time nor arrhythmia. Throughout the maintenance anesthetic period no significant difference in MRAP was seen between the groups as well as from the Base-line value. Also significant difference was not seen in MAP and SV between the groups during

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**Table 1.** Setting of intermittent positive pressure ventilation in maintenance anesthesia with sevoflurane (n=6) and isoflurane (n=6)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Base-line</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
<th>135</th>
<th>150</th>
<th>165</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory frequency (breaths/min)</td>
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<tr>
<td>Sev-group</td>
<td>8.3±0.5</td>
<td>8.3±0.5</td>
<td>8.3±0.5</td>
<td>8.3±0.5</td>
<td>8.3±0.5</td>
<td>8.7±0.5</td>
<td>8.7±0.8</td>
<td>8.8±0.8</td>
<td>8.8±0.4</td>
<td>9.0±0.9</td>
<td>8.8±0.8</td>
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<tr>
<td>Iso-group</td>
<td>8.3±0.5</td>
<td>8.3±0.5</td>
<td>8.3±0.5</td>
<td>8.7±0.8</td>
<td>8.3±0.5</td>
<td>8.3±0.5</td>
<td>8.7±0.5</td>
<td>9.0±0.6</td>
<td>9.0±0.6</td>
<td>9.0±0.6</td>
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<tr>
<td>Inspiratory time (sec)</td>
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<tr>
<td>Sev-group</td>
<td>1.2±0.1</td>
<td>1.2±0.1</td>
<td>1.2±0.1</td>
<td>1.3±0.1</td>
<td>1.3±0.2</td>
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<tr>
<td>Iso-group</td>
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<td>1.3±0.1</td>
<td>1.3±0.1</td>
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<td>Tidal volume (L)</td>
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<tr>
<td>Sev-group</td>
<td>5.5±0.2</td>
<td>5.5±0.4</td>
<td>5.4±0.5</td>
<td>5.6±0.2</td>
<td>5.5±0.4</td>
<td>5.6±0.2</td>
<td>5.5±0.3</td>
<td>5.5±0.2</td>
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<td>5.4±0.1</td>
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<tr>
<td>Iso-group</td>
<td>5.6±0.4</td>
<td>5.6±0.4</td>
<td>5.6±0.4</td>
<td>5.4±0.4</td>
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<td>5.5±0.7</td>
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<td>5.5±0.6</td>
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<td>Peak inspiratory airway pressure (cmH2O)</td>
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<tr>
<td>Sev-group</td>
<td>22.5±1.0</td>
<td>22.7±0.8</td>
<td>22.7±0.8</td>
<td>23.0±0.6</td>
<td>23.3±0.8</td>
<td>23.3±0.8</td>
<td>23.5±0.5</td>
<td>23.5±0.5</td>
<td>23.5±0.5</td>
<td>23.5±0.5</td>
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</tr>
<tr>
<td>Iso-group</td>
<td>22.3±1.4</td>
<td>22.0±1.4</td>
<td>22.0±1.4</td>
<td>22.7±1.7</td>
<td>22.2±1.9</td>
<td>22.5±1.8</td>
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<td>22.7±1.9</td>
<td>22.8±1.6</td>
<td>22.8±1.3</td>
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</tr>
</tbody>
</table>

Sev-group and Iso-group mean Sevoflurane group and Isoflurane group, respectively. Values are expressed as mean ± standard deviation. Significant differences (P<0.05) were not obtained time-related or between groups.

**Table 2.** Cardiovascular indices in maintenance anesthesia with sevoflurane (n=6) and isoflurane (n=6)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Base-line</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
<th>135</th>
<th>150</th>
<th>165</th>
<th>180</th>
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</thead>
<tbody>
<tr>
<td>Heart rate (beats/min)</td>
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<tr>
<td>Sev-group</td>
<td>30.7±3.6</td>
<td>30.5±3.6</td>
<td>30.2±3.3</td>
<td>30.8±2.5</td>
<td>29.7±3.1</td>
<td>29.7±4.8</td>
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<td>29.5±5.1</td>
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<tr>
<td>Iso-group</td>
<td>31.5±3.6</td>
<td>31.2±4.0</td>
<td>31.0±4.6</td>
<td>30.8±4.8</td>
<td>30.7±4.8</td>
<td>31.0±3.6</td>
<td>30.7±3.4</td>
<td>31.2±4.0</td>
<td>30.8±2.8</td>
<td>31.2±3.0</td>
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<tr>
<td>Mean right atrial pressure (mmHg)</td>
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<tr>
<td>Sev-group</td>
<td>8.5±3.0</td>
<td>9.3±3.4</td>
<td>9.7±3.9</td>
<td>9.5±3.3</td>
<td>9.3±2.9</td>
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<tr>
<td>Iso-group</td>
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<td>Mean arterial pressure (mmHg)</td>
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<tr>
<td>Sev-group</td>
<td>60.2±7.9</td>
<td>63.2±6.9</td>
<td>62.2±11.7</td>
<td>63.7±8.6</td>
<td>63.7±6.7</td>
<td>63.2±9.3</td>
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<td>67.2±8.8</td>
<td>68.7±8.4</td>
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<tr>
<td>Iso-group</td>
<td>53.8±7.8</td>
<td>60.3±5.9</td>
<td>63.7±6.0</td>
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<td>65.5±6.7</td>
<td>66.5±6.3</td>
<td>69.2±7.2</td>
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<td>68.0±7.7</td>
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<tr>
<td>Stroke volume (mL)</td>
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<tr>
<td>Sev-group</td>
<td>419±89</td>
<td>467±82</td>
<td>428±68</td>
<td>425±70</td>
<td>428±95</td>
<td>445±79</td>
<td>422±95</td>
<td>407±64</td>
<td>417±58</td>
<td>429±77</td>
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<tr>
<td>Iso-group</td>
<td>470±55</td>
<td>474±55</td>
<td>489±67</td>
<td>499±66</td>
<td>520±69</td>
<td>530±88</td>
<td>519±71</td>
<td>519±38</td>
<td>503±31</td>
<td>540±63</td>
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<tr>
<td>Cardiac index (mL/kg/min)</td>
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<tr>
<td>Sev-group</td>
<td>28.9±5.7</td>
<td>30.4±4.9</td>
<td>27.9±5.8</td>
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<td>28.3±6.7</td>
<td>26.7±7.0</td>
<td>25.6±4.7</td>
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<td>27.1±6.2</td>
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</tr>
<tr>
<td>Iso-group</td>
<td>31.2±5.3</td>
<td>31.2±5.2</td>
<td>31.8±5.9</td>
<td>32.4±6.7</td>
<td>33.8±7.6</td>
<td>33.2±8.8</td>
<td>33.8±7.3</td>
<td>34.1±6.2</td>
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<td>35.5±6.4</td>
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<td>Systemic vascular resistance (dyne·sec·cm−2)</td>
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<tr>
<td>Sev-group</td>
<td>329±98</td>
<td>315±76</td>
<td>341±101</td>
<td>358±81</td>
<td>360±97</td>
<td>362±133</td>
<td>401±127</td>
<td>408±198</td>
<td>394±119</td>
<td>401±138</td>
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<tr>
<td>Iso-group</td>
<td>257±65</td>
<td>301±57</td>
<td>296±44</td>
<td>285±41</td>
<td>269±45</td>
<td>279±51</td>
<td>291±43</td>
<td>304±55</td>
<td>306±36</td>
<td>286±48</td>
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</table>

* indicates a significant difference (P<0.05) from Base-line value using paired t-test. § indicates a significant difference (P<0.05) from Iso-group value using non-paired t-test.
anesthesia, although MAP of the Sev-group at 105 min or later and those of the Iso-group at 45, 60 and 105 min or later were significantly higher as compared to the Base-line values. The Sev-group showed a constant SV value, but the values of the Iso-group were significantly higher than the Base-line value at 75 to 180 min except at 150 min. CI remained almost constant in the Sev-group, being significantly higher than the Base-line value at 135, 165 and 180 min. At 135, 165 and 180 min the Iso-group showed significantly higher CI values as compared to the Sev-group. Throughout the maintenance anesthetic period SVR values were higher in the Sev-group than the Iso-group, and significant difference was obtained at 135, 165 and 150 min. In the Sev-group SVR increased with time, showing significant difference from the Base-line value at 120, 135 and 150 min. Also in the Iso-group SVR was significantly higher than the Base-line value at 135 and 150 min.

PEP/ET and its factors changed with time, as presented in Table 3. There was no significant difference in PEP between the groups through the duration of maintenance anesthesia. In the Sev-group PEP elevated with time, and the values were significantly higher than the Base-line at 45, 75, 90, 120 or later, while the values remained almost constant in the Iso-group. No significant difference of ET was observed between the groups throughout maintenance anesthetic period. In the Iso-group ET elevated with time, and the values were significantly higher than the Base-line at 120, 165 and 180 min, while the values remained almost constant in the Sev-group. The PEP/ET of the Sev-group increased with time, being significantly higher than the Base-line value at 45, 75, 90, 120 and 150 min or later. In the Iso-group, however, PEP/ET decreased with time, being significantly lower than the Base-line value at 165 and 180 min.

DISCUSSION

The inhibitory effect of Sev- and Iso-anesthesia on the cardiovascular system was reported to be equivalent in dogs [10], cats [7] and human beings [13]. In horses anesthetized with Sev, however, the authors experienced severer disoloration of the gingival visible mucosa without lowered MAP than in those given Iso, suggesting that the response of the equine cardiovascular system to anesthetic drugs might be specific. In this study, changes in indices of the cardiovascular system were investigated during Sev- or Iso-anesthesia in horses.

Surgical procedures usually require end-tidal anesthetic gas concentration of at least 1.2 MAC in horses [14], and the maintenance anesthesia for 150 min or less is generally required for either arthroscopic surgery or internal fixation. In this study the end-tidal Sev- and Iso-concentrations were kept at 1.2 MAC and the maintenance anesthetic period was fixed for 180 min. The horses were induced with Sev or Iso alone, via the face-mask without premedication to examine the effect of the anesthetic gases exclusively on cardiovascular system [2, 6, 15]. In order to examine the effect of the anesthetics during maintenance anesthetic period, time required for induction, the deepness of anesthesia as well as respiratory condition had to be controlled as similarly as possible between the groups. In this study, no significant difference between the groups was observed in time required for falling-down after putting the face-mask as well as in behaviors while hoisting onto the surgical table. The endotracheal tube was readily intubated and there was no significant difference between the two groups in time required for disappearance of the eye reflexes except corneal reflexes. The Base-line was set at 30 min after starting maintenance anesthesia with 1.2 MAC of the end-tidal anesthetic concentration to narrow the alveolar to arterial anesthesia in horses.

During maintenance anesthesia, ventilation was controlled to maintain PaCO₂ of 45 to 55 mmHg to prevent CO₂-induced sympathetic stimulations and to deliver the constant dose of anesthetic gases to the alveoli, inevitably resulting in lowered CI [8]. Effects of IPPV on the cardiovascular system were considered to be equivalent between the groups, as there was no difference in ventilation conditions.

In the two groups HR values were almost similar without any changes with time, suggesting that the chronotropic effects of Sev- and Iso-anesthesia were almost similar at 1.2 MAC.

Table 3. Cardiac contractility indices (by pulsed doppler echocardiography) in maintenance anesthesia with sevoflurane (n=6) and isoflurane (n=6)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Base-line</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
<th>135</th>
<th>150</th>
<th>165</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-ejection period (msec)</td>
<td>143±29</td>
<td>165±21*</td>
<td>180±26</td>
<td>193±35*</td>
<td>196±38*</td>
<td>193±37</td>
<td>205±37*</td>
<td>209±38*</td>
<td>208±38*</td>
<td>205±26*</td>
<td>205±47*</td>
</tr>
<tr>
<td>Iso-group</td>
<td>212±53</td>
<td>226±51</td>
<td>220±40</td>
<td>230±51</td>
<td>226±45</td>
<td>212±49</td>
<td>223±48</td>
<td>223±49</td>
<td>213±48</td>
<td>203±37</td>
<td>199±39</td>
</tr>
<tr>
<td>Ejection time (msec)</td>
<td>475±82</td>
<td>470±77</td>
<td>477±91</td>
<td>464±97</td>
<td>475±82</td>
<td>473±78</td>
<td>470±84</td>
<td>479±70</td>
<td>469±82</td>
<td>484±120</td>
<td>487±95</td>
</tr>
<tr>
<td>Iso-group</td>
<td>467±52</td>
<td>470±75</td>
<td>466±64</td>
<td>472±53</td>
<td>497±67</td>
<td>498±70</td>
<td>506±49*</td>
<td>486±59</td>
<td>482±50</td>
<td>514±66*</td>
<td>521±62*</td>
</tr>
<tr>
<td>Pre-ejection period/Ejection time (PEP/ET)</td>
<td>0.33±0.1</td>
<td>0.36±0.1*</td>
<td>0.40±0.1</td>
<td>0.44±0.2*</td>
<td>0.43±0.1*</td>
<td>0.42±0.1</td>
<td>0.46±0.2*</td>
<td>0.44±0.1</td>
<td>0.45±0.1*</td>
<td>0.45±0.1*</td>
<td>0.43±0.1*</td>
</tr>
<tr>
<td>Iso-group</td>
<td>0.48±0.2</td>
<td>0.51±0.2</td>
<td>0.49±0.2</td>
<td>0.51±0.2</td>
<td>0.47±0.2</td>
<td>0.45±0.2</td>
<td>0.47±0.2</td>
<td>0.42±0.2</td>
<td>0.44±0.1</td>
<td>0.37±0.1*</td>
<td>0.36±0.1*</td>
</tr>
</tbody>
</table>

* indicates a significant difference (P<0.05) from Base-line value using paired t-test. Significant differences (P<0.05) were not obtained between the groups.
The both groups showed similar MAP values increasing with time in this study. The MAP of the Iso-group elevated temporally was compatible with that previously reported in Iso-anesthesia in IPPV without premedication [6]. CI and SV increased also in this case. The reason for those cardiovascular improvements was considered to be accompanied by an increase in circulating catecholamine values caused by the compensation for the initial cardiovascular depression associated with inhalation anesthetic induction [6]. Also in our study, CI of the Iso-group was increased with time in parallel to SV, resulting in elevated MAP. In the Sev-group, however, both SV and CI remained constant, and the SVR values were higher than in the Iso-group through the whole maintenance anesthetic period, indicating that MAP elevated with time depended only on increased SVR. Between the two groups difference of SVR increased with time. Aida et al. [2] described that Sev-anesthesia resulted in a very weak vascular dilatation in horses since there was no dose-dependent decrease in SVR. Consequently, higher SVR and CI in the Sev-group might be due to weaker vascular dilatation than in the Iso-group.

The PEP values represent the sum of the electromechanical delay and the isovolumic contraction period. It is shortened depending on the decreased time of isovolumic contraction, which results from the increased contractility and/or lowered afterload [3, 19, 21]. ET values represent time between the opening and closing of the aortic valve, which is shortened when the cardiac contractility lowers [3]. Consequently PEP/ET is known to be inversely correlated with the cardiac contractility in cases with constant HR, cardiac preload and afterload [3, 12]. As MRAP represents changes at cardiac preload of horses without cardiopulmonary disease [4] and no significant difference in MRAP and HR was observed between the groups as well as from the Base-line values, the preload was considered to be equal between the both groups without any changes with time. From these results the PEP/ET might reflect the cardiac contractility and changes of the cardiac afterload in this study.

In human beings the Sev- or Iso-anesthesia (0.6 to 1.2 MAC) gives an equal value of PEP/ET, and the two drugs were reported to have almost the same grade of inhibitory effects on the cardiac contractility [13]. Also in this study, no significant difference in PEP/ET was seen between the two groups, indicating that the two anesthetic agents seemed to be equally effective on the cardiac contractility in horses, although changes of PEP/ET with time was different between the groups. Since the ET of the Sev-group remained constant, the PEP/ET changes might depend on the prolonged PEP. However, it is difficult to determine whether such prolongation of PEP resulted from lowered cardiac contractility or prolonged opening of the aortic valve due to increased cardiac afterload. On the other hand, the PEP/ET of the Iso-group that lowered with time might result from the prolonged ET, since PEP showed almost constant values. In addition, the decreased PEP/ET in spite of a slightly increased SVR suggested an increased cardiac contractility exceeding the increased cardiac afterload.

Since ET is known to be highly correlated with SV in human without cardiac disorders [21], the ET prolonged with time in the Iso-group was considered to reflect the increased SV in horses. Further studies are needed to examine the time-related change of pure cardiac contractility with these anesthetics.

In this study, no significant difference in the Base-line of each variables was seen between the groups, whereas each index, except for HR, MRAP and MAP, changed with time differently between the groups. In the Sev-group MAP was elevated with time reflecting only the increased SVR, being obviously different from the elevated MAP in the Iso-group associated with the increased CI. These results are compatible with discoloration of the visible gingival mucosa with time during clinical use of Sev.

It has been widely accepted that a MAP of at least 70 mmHg is necessary to maintain the adequate CI for preventing the horse from postanesthetic myopathy [11]. But if the surgeries in Sev-anesthesia are prolonged, for the present study, it should be difficult to maintain the adequate CI by monitoring MAP because of the spurious increase of MAP without increasing CI. Therefore the authors believe that Iso-anesthesia should be more suitable for the prolonged surgeries than Sev-anesthesia. On the other hand, Sev-anesthesia is suited for the orthopedic surgery because of the excellent recoveries [5]. It is needed for equine anesthetists to use both the two anesthetics properly according to their pharmacological and clinical features.

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REFERENCES


