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Original Research

Comparison of Two Isoflurane Delivery Systems for Maintaining Anesthesia in Horses: End-Tidal Closed-Loop Target-Controlled Versus Out-Of-Circuit Vaporizer

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ABSTRACT

The purpose of this study was to compare two different isoflurane (Iso) delivery systems: (1) end-tidal closed-loop target-controlled infusion (ETCLo-TCI) system and (2) out-of-circuit vaporizer (VOC)—in horses undergoing surgery. Twenty-four horses undergoing scheduled surgery were enrolled in this study. Anesthesia was maintained using Iso delivered either by a calibrated TEC 4 VOC (group V, n = 14) or an ETCLo-TCI system (group I, n = 10). Data were collected within the first hour of anesthesia on the consumption of Iso, the number of anesthetist drug delivery adjustments (modifing the vaporizer setting or the FE'Iso target in the software), the number of fresh gas flow changes, and the time taken to reach the first FE'Iso target (1.5%) after induction. The median consumption of Iso and the median consumption of Iso per kilogram of body weight during the first hour of anesthesia were significantly lower in group I compared with group V (20.5 [9.3–31.4] vs. 29.1 [21.5–43.0]) mL ($P = .003$) and 0.042 (0.028–0.052) versus 0.062 (0.037–0.094) mL kg$-^{1}$ ($P = .009$). The median number of anesthetist drug delivery adjustments was significantly lower in group I compared with group V (1.5 [0–3] vs. 4 [3–9]; $P = .0002$). No significant difference was found in FGF changes and in the time taken by both systems to reach the end-tidal target.

1. Introduction

Quantitative anesthesia is the delivery of the exact amount of anesthetic required to maintain the desired depth of anesthesia in the anesthetized subject [1]. This technique has been shown to have some advantages over qualitative anesthesia, such as easy and efficient monitoring of the uptake of anesthetic vapors, a substantial reduction in pollution, reduced costs, and continuous measurement of O_2 uptake and CO_2 production [1]. Despite its reported advantages, quantitative anesthesia using the low gas flow technique has been unpopular because there is a conflict between reducing the gap between the desired and actual drug concentration and minimizing agent consumption by decreasing the fresh gas flow (FGF), particularly when using conventional anesthesia machines [2]. This conflict is resolved when the volatile anesthetic agent is administered by injecting it directly into the respiratory circle system [3]. However, although satisfactory results were obtained when quantitative anesthesia was attempted by manual injection of a volatile liquid anesthetic into a closed breathing circuit according to the square root of the time, there was a failure to predict the volatile anesthetic uptake and cardiovascular depression [4–8].

Various experimental and commercial anesthesia delivery systems using closed-circuit technology together with in-circle agent delivery have been described in the

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literature, with each study attempting to identify the criteria that could be used to achieve agent control and delivery [3,9,10]. These computerized delivery systems should aim to allow the anesthetist to obtain a particular concentration of anesthetic by simply entering a value into the computer controlling the system. Target-controlled inhalational anesthesia is a method of producing anesthesia based on controlled infusion by using an inhalational anesthetic delivery system, where the system automatically adjusts the anesthetic agent concentration to achieve the desired target levels set by the user. Such a system has been found to reduce anesthetic consumption, as well as the average time required to achieve the desired FE' of the volatile agent and the number of drug delivery adjustments required to maintain anesthesia [11].

A low-budget electronic prototype of an isoflurane (Iso) delivery system, an end-tidal closed-loop target-controlled infusion (ETCLo-TCI), was tested on horses undergoing various surgical procedures [12]. The anesthetist had only to input the desired FE'Iso (ETtarget***) into the anesthetic delivery system and set the FGF manually. Isoflurane was directly injected into the breathing system by a closed-loop system, comprising a laptop computer (with dedicated software), a computer-controlled syringe driver (loaded with liquid Iso) connected to the inspiratory arm of a large-animal circle breathing system, and a respiratory gas monitor providing Iso end-tidal concentrations (FE'Iso) every 20 seconds to the computer (Fig. 1). This system works by administering an initial loading dose, based on Lowe's equation [13], which is simply calculated by considering the total volume of the breathing system and the ventilator bellows, the functional residual capacity, and the target FE'Iso and roughly estimating the cardiac output (CO). The delivery system then injects Iso every minute to maintain the target FE'Iso. This system proved to be sufficiently accurate and easy to use [12].

The aim of this study was to assess during the first hour of inhalational anesthesia whether the ETCLo-TCI system provides some advantages over a out-of-circuit vaporizer (VOC), in terms of the amount of Iso consumed, the number of drug delivery adjustments required, and the time needed to reach the targeted FE'Iso in horses undergoing surgery.

2. Materials and Methods

The institutional Ethics Committee of the University of Padua discussed and approved the study procedure (Protocol number 69,012; 2009; Tit III; Cl. 11; Fasc. 10).

Owners were informed about the ongoing nature of the study and signed the anesthesia consent form. The estimated sample size to detect a difference in the primary endpoint (Iso consumption in 1 hour of anesthesia) with a power of 80% and an alpha error of 5% in a two-independent group study design was calculated using commercially available software (Statistica, Statsoft IT). The effect size calculation was obtained assuming a hypothesized mean difference of 8 mL, with a standard deviation (SD) of 6.5 mL. The calculated minimum sample size was 10 subjects for each group. Horses recruited for this study were undergoing Iso-maintained general anesthesia for scheduled surgical procedures. Only horses positioned in dorsal recumbency were enrolled for this study.

2.1. Anesthetic Technique

Horses were randomly assigned to group I or V. Subjects assigned to the former group were maintained in anesthesia using the ETCLo-TCI system, whereas those assigned to group V were anesthetized with an Iso VOC (TEC 4; Ohmeda, Finland). It was noted on the anesthesia record if the subject being anesthetized was the first case of the day. The health of the horses was determined by their history and a physical examination. The physical status of the horse

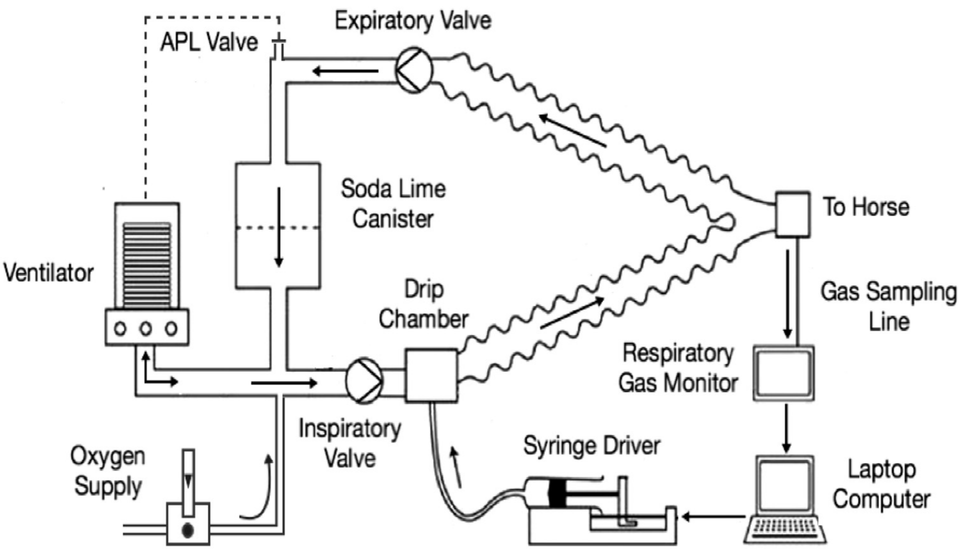

Fig. 1. The end-tidal closed-loop target-controlled infusion device (ETCLo-TCI) system. In this system, isoflurane is directly injected into the breathing system by a closed-loop system, which comprises a laptop computer (with dedicated software), a computer-controlled syringe driver (loaded with liquid isoflurane) connected to the inspiratory arm of a large-animal circle breathing system, and a respiratory gas monitor. APL, adjustable pressure-limiting.