









Association of S⁽⁺⁾ ketamine, dexmedetomidine and butorphanol for chemical restraint in scarlet macaws (*Ara macao*)

Associação cetamina S⁽⁺⁾, dexmedetomidina e butorfanol na contenção química de araracangas (*Ara macao*)

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ABSTRACT

The present study aimed at assessing the effects of combining 20 mg/kg S⁽⁺⁾ ketamine with 25 µg/kg dexmedetomidine and 0.4 mg/kg butorphanol on the physiological parameters and anesthetic recovery time and score of eight captive scarlet macaw (*Ara macao*) specimens. These specimens were captured at the Marabá Zoobotanic Foundation (Fundação Zoobotânica de Marabá), Pará, using butterfly and mist nets, and subsequently subjected to the proposed protocol. The following physiological parameters were evaluated: heart rate (HR), respiratory rate (RR), saturation of peripheral oxygen (SpO₂), body temperature (BT), and non-invasive blood pressure 5 min after drug administration (M0) and every 10 min thereafter (M1-M5), with a total of 55 min of analysis of anesthetic effects. Glycemia was measured 5 min after drug administration and every 30 min thereafter. Anesthetic induction and recovery times were also determined. Among the parameters evaluated in this study, both HR and BT significantly decreased throughout the anesthetic period, with the lowest levels at 55 min after drug administration (M5). In contrast, RR did not significantly differ, and all animals remained stable, maintaining an RR close to a mean of 20 ± 8 cpm. Throughout the anesthetic period, SpO₂ was 92 ± 5%, with no significant difference. The birds remained under spontaneous ventilation and without oxygen supplementation. Systolic, diastolic, and mean blood pressures remained stable, with no significant differences in any of these measurements. At M0 and M3, the glycemia decreased slightly, albeit with no significant difference justifying an adverse effect or even hypoglycemia. The anesthetic induction time, from M0 to decubitus, was 2.4 ± 0.7 min. The anesthetic recovery time, from M0 to effortless bipedal position and adequate phalangeal flexion, was 99.3 ± 32.4 min. The sedation was assessed as intense, and the anesthetic recovery was rated excellent in 62.5% and good in 37.5% of the animals.

Keywords: Anesthesia. Bird. Dissociative. Opioid. α-2 agonist.

RESUMO

O presente estudo objetivou avaliar os efeitos do uso da cetamina S⁽⁺⁾ 20 mg/kg associada à dexmedetomidina 25 µg/kg e butorfanol 0,4 mg/kg sobre os parâmetros fisiológicos, tempo e qualidade da recuperação anestésica de araracangas (*Ara macao*). Foram utilizados oito espécimes de *Ara macao* cativas da Fundação Zoobotânica de Marabá, Pará. A captura foi realizada com o uso de puçá e rede de contenção e em seguida as aves foram submetidas ao protocolo proposto. Foram avaliados: frequência cardíaca, frequência respiratória, saturação parcial da oxihemoglobina (SpO₂), temperatura corporal e pressão arterial não-invasiva a partir de 5 minutos após a aplicação dos fármacos (M0) e a cada 10 minutos seguintes (M1, M2, M3, M4 e M5), totalizando 55 minutos de contemplação dos efeitos anestésicos. A glicemia foi avaliada aos 5 minutos da aplicação dos fármacos e repetida após 30 minutos. Também foi determinado o tempo de indução e de recuperação. Dentre os parâmetros avaliados, a frequência cardíaca e a temperatura demonstraram queda estatisticamente significativa ao longo do período anestésico, ambas com os menores valores registrados aos 55 minutos após a aplicação dos fármacos (M5). A frequência respiratória não apresentou diferença estatística e todos os animais se mantiveram estáveis e com a frequência próxima a média de 20±8mpm. A saturação da oxihemoglobina (SpO₂) ao longo do período anestésico foi de 92±5%, não houve diferença estatisticamente relevante, as aves permaneceram sob ventilação espontânea e sem suplementação de oxigênio. As pressões arteriais sistólica, diastólica e média, mantiveram-se estáveis e não houve diferença estatística para nenhuma dessas medidas. A glicemia, mensurada em M0 e M3 demonstrou queda discreta, sem diferença significativa capaz de justificar um efeito adverso ou mesmo hipoglicemia. O tempo de indução, desde aplicação dos anestésicos até o decúbito, foi de 2,4±0,7 minutos. O tempo de recuperação, compreendido desde a aplicação dos fármacos (M0) até a constatação da posição bipedal sem esforço e adequada flexão das falanges, foi de 99,3±32,4 minutos. A qualidade de sedação foi considerada intensa e a recuperação anestésica foi classificada como ótima para 62,5% e boa para 37,5% dos animais.

Palavras-chave: Anestesia. Ave. Dissociativo. Opióide. α-2 agonista.

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Introduction

Scarlet macaw (*Ara macao*), the third largest species of the genus *Ara*, which includes macaws and mini-macaws, is a unique species of the Brazilian fauna. This parrot belongs to the Psittacidae family, and its distribution ranges from Mexico through the Amazon rainforest to the north of Mato Grosso, southeastern Pará, Maranhão, and Bolivia (Sick, 1997). Each specimen is approximately 90-cm long and weighs approximately 1 kg. The plumage is mostly scarlet red; the wing feathers are red, yellow, and blue; and the tail feathers are red with blue ends. In addition, the face has bare and whitish skin (Sick, 1997).

Although this species is tolerant to habitat alterations and is widespread across vast swaths of suitable habitats and thus categorized as a least-concern species (International Union for Conservation of Nature and Natural Resources, 2016), anthropogenic activities have displaced thousands of scarlet macaw specimens from their habitats. Furthermore, the scarlet macaw is highly affected by animal trafficking, which has contributed to the population decline of this species (Soares-Filho et al., 2006).

Anesthetic procedures (sedation, tranquilization, chemical restraint, and general and/ or local anesthesia) are essential to the veterinary routine in the clinical, surgical, and emergency care of numerous species of wild animals (McCormick & Ridgway, 2018; Smith et al., 2018). In birds, anesthetic procedures are challenging because bird species have numerous anatomical and physiological specificities (Gunkel & Lafortune, 2005). Moreover, due to the high metabolic rate of birds, anesthetics are metabolized quickly (Benez, 2001), often requiring increased doses to achieve the intended therapeutic effect.

Chemical restraint in birds can be performed using injectable anesthetics, whose main advantages include their low cost, minimal need for specific equipment and ease of administration (Ludders, 2017).

Among the anesthetics used in clinical routine, racemic ketamine is commonly used in veterinary medicine for wild animals because this drug is accessible and easily applied and has a wide safety margin. However, its isolated use should be avoided, which is why ketamine is normally combined with drugs of the α -2 agonist class, which has shown promise in the most diverse anesthetic procedures (Muir III et al., 2013). Also commercially available, its dextro-enantiomer S(+) ketamine has a higher analgesic potential than the racemic mixture (Ferraro et al., 2018).

Dexmedetomidine is an α -2 agonist drug that remains mostly underused in veterinary medicine. It is considered a prototype of super-selective α -2 adrenergic agonists and, therefore, is more specific to α -2 adrenergic receptors and has a stronger effect on wakefulness, promoting hemodynamic control under stress, analgesia, muscle relaxation, and sedation, with less respiratory depression than other drugs of the same group, even at high doses. In addition, this drug enables patients to be easily awakened after procedures using reversal agents (Bagatini et al., 2002; Villela & Nascimento Júnior, 2003).

Butorphanol is one of the most indicated opioids for birds, mainly because this drug has few effects on the cardiopulmonary system and body temperature (BT), with a good analgesic and sedative potential (Miller & Fowler, 2012; Thomas & Lerche, 2017).

Combining drugs from different anesthetic classes aims at promoting balanced anesthesia towards reducing the dose of anesthetics, mitigating adverse drug effects, and strengthening analgesic effects, thus improving the quality and safety of anesthetic procedures (Gunkel & Lafortune, 2005). This combination of small doses of different drugs improves positive effects (rapid induction, deep sedation, and more agile and calm recovery) and attenuates negative effects, such as longer recovery times and agitation during induction and immobilization (Henrique et al., 2019).

Chemical restraint has become essential in wildlife conservation programs for enabling veterinarians to perform the most diverse procedures in an increasingly safe manner. Therefore, the surest way to assess the safety and efficacy of a given protocol on a species is by measuring physiological parameters, anesthetic times, and anesthetic recovery in a group of animals. Furthermore, new and safer drugs with reversal agents have recently been launched on the market, but studies on their use in bird medicine and surgery remain scarce.

In addition to being original, the present study aimed to evaluate the effects of S(+) ketamine combined with dexmedetomidine and butorphanol on the physiological parameters, and anesthetic recovery time and quality in scarlet macaws (*Ara macao*).

Materials and Methods

Eight captive scarlet macaws (*A. macao*) of the Marabá Zoobotanic Foundation (Fundação Zoobotânica de Marabá), Pará, Brazil, were studied in this trial. The health status of the animals was evaluated using their medical records to exclude specimens that previously or, during the experiment, presented with suggestive signs of morbidity. Once deemed fit, the animals were included in the pre-anesthetic preparation for the trial.

Prior to anesthesia, all animals were subjected to a 5-h fast, with access to water ad libitum. The experiment was performed in the morning. The animals were captured using butterfly and mist nets and then weighed on a digital scale and anesthetized using the following protocol: 20 mg/kg S(+) ketamine, 25 µg/kg dexmedetomidine, and 0.4 mg/kg butorphanol, combined in a single 1-mL syringe and injected into the pectoral muscle. Birds weighed an average of 1.13 ± 0.20 kg. The volume of all doses was adjusted to 1 mL, and the drugs were diluted in 0.9% saline solution.

The latency period, from drug administration to decubitus, was timed as the animals were taken to a covered and silent place, suitable for observing anesthetic effects. The first measurement (M0) was taken 5 min after administering the anesthetic protocol. The other measurements (M1–M5) were performed every 10 min, totaling 55 min of anesthetic monitoring.

At each time point (M0–M5), the following parameters were measured:

- Heart rate (HR), assessed by calculating the time between two consecutive R-R intervals in the electrocardiographic tracing, recorded in a patient monitor (Deltalife DL900), reading in the second derivative (DII);
- Respiratory rate (RR), assessed by visual observation of the rib cage movements and expressed as breaths/minute;
- Saturation of peripheral oxygen (SpO₂), measured by placing the sensor on the wing of the animal and reading the patient monitor (Deltalife DL900), expressed as %;
- Systolic (SBP) and diastolic blood pressures (DBP) were measured non-invasively using an electronic sphygmomanometer (CONTEC08A-Vet) and expressed as mmHg. For this purpose, the cuff was placed on the pelvic limb;
- Mean blood pressure (MBP) was calculated from the SBP and DBP values, according to the following formula: $MBP = (2DBP + SBP)/3$ (pressure in mmHg).
- Body Temperature (BT) (T °C), measured using a specific sensor placed on the cloaca and whose value, in degrees Celsius, was read on a patient monitor (Deltalife DL900).

Because glycemia (in mmol/L) does not oscillate as quickly as the other parameters, this parameter was evaluated 5 min after anesthetic application (M0) and repeated only at 35 min (M3). To perform the test, a drop of blood was collected from the wing of the animal and placed in a blood glucose meter (Accu-chek® Active) to read the corresponding value.

After the end of the anesthetic monitoring, the scarlet macaws were taken to a quiet and covered area to recover without external interference. Anesthetic recovery was assessed by a trained researcher, using the anesthetic recovery table by Donaldson et al. (2000) and anesthetic recovery tables adapted by Mendonça (2019) and Benarrós (2022) to create a descriptive method for avian anesthetic recovery (Table 1).

Table 1 – Anesthetic recovery stages and respective scores evaluated in each stage; anesthetic recovery was assessed immediately after the anesthetic monitoring period (M5).

| Anesthetic Recovery Stages | | Evaluated Scores |
|----------------------------|--|---|
| Stage I | Behavior at the end of anesthetic monitoring | Calm (1), active (3), slightly excited (5), excited (7), very excited (8), uncontrollable (10) |
| Stage II | Behavior from the first voluntary movement | Calm with occasional effort (1), nervous (3), struggling (5) |
| Stage III | Transition from lateral to sternal decubitus | Calm (1), agitated (5), struggling and falling (10) |
| Stage IV | Attempts to get up | Absolute number of attempts at sternal decubitus |
| Stage V | Sternal stage | Short pause (1), inexistent (3), prolonged (6), multiple attempts (7), struggling (10) |
| Stage VI | Bipedal position | Calm (1), unsteady (3), leaning against the walls (6), struggling (10) |
| Stage VII | Strength and endurance | Near the maximum (1), intermediate (3), falling before getting up (6), and repeated attempts and weakness (10) |
| Stage VIII | Phalangeal flexion | Moving normally (1), wobbling (3), maintaining reflexes (5), hesitating to use the limbs (8), repeatedly falling (10) |

In total, eight anesthetic recovery stages were evaluated. The scores (in parentheses) were given according to the bird's behavior at each stage.

Eight recovery stages were scored based on a scale. The scores were assessed and noted by a trained researcher, then summed and deemed as: “excellent” when the scores ranged from 7 to 23 points; “good”, from 24 to 38 points; “fair”, from 39 to 53 points, and “poor” when the scores were higher than 54 points. That is, animals with lower scores were considered to have a smoother recovery, whereas those with more agitated recoveries and greater movement had higher scores. The animals were evaluated from the final monitoring period (M5) until they were able to remain in a bipedal position effortlessly and with adequate phalangeal flexion. Once recovered from anesthesia, the birds were returned to their enclosure with normal access to water and food.

The data were subjected to statistical tests to assess whether the values had equal variances. Using GraphPad Prism 7.0 statistics software, the quantitative variables were subjected to the Shapiro–Wilk test for normality. The data were compared between birds using Welch’s t-test. Paired data (variations over time) were compared by repeated measured analysis of variance, followed by Tukey’s range test when $p < 0.05$. The anesthetic recovery scores were subjected to descriptive analysis.

Results and Discussion

The entire trial, from animal capture to drug administration to anesthetic recovery and return to the enclosure, ran uneventfully. The protocol provided safe anesthesia, with a fast latency period; good muscle relaxation; and adequate anesthetic level for procedures lasting up to 1 h, without requiring drug reapplication for anesthetic maintenance. The anesthetic recovery occurred smoothly and without irregularities.

The mean and standard deviation of the physiological parameters HR, RR, SpO₂, BT (°C), SBP, MBP, DBP, and glycemia are outlined in Table 2.

HR

HR significantly decreased throughout the anesthesia, and the lowest values were recorded at M5. The mean values continuously decreased, albeit with no significant differences according to Tukey’s range test ($p < 0.05$) between M0, M1, and M2. However, HR considerably varied between M2 and M3; thus, the values observed in M3, M4, and M5 were significantly lower than those observed in M0, M1, and M2.

Butorphanol may slightly decrease cardiovascular activity by lowering HR, blood pressure, and cardiac output (Souza et al., 2007). The decrease observed during anesthetic monitoring may also be explained by the dexmedetomidine effect on presynaptic receptors of peripheral nerve endings, which reduces noradrenaline release, thereby causing bradycardia (Alves et al., 2000).

When used alone, ketamine increases HR and blood pressure due to a combination of inhibitory effects on the parasympathetic nervous system with sympathomimetic stimulatory effects on the heart. The combination of ketamine with dexmedetomidine creates mutually compensatory mechanisms, with dexmedetomidine preventing the tachycardia caused by ketamine and ketamine controlling the bradycardia induced by the α -2 agonist. This balance between the cardiovascular effects of the two drugs is one of the reasons why ketamine has been combined with an α -2 agonist in several species over the years (Baumgartner et al., 2010).

RR

RR decreased in the first three time points (M0–M2) and then slightly increased in M3, subsequently decreasing again in M4 and M5. Despite the slight RR oscillation, observed during anesthetic monitoring, all animals remained stable regarding this parameter, with no significant difference in RR between time points according to Tukey’s range test ($p < 0.05$).

Table 2 – Mean \pm standard deviation of the physiological parameters of scarlet macaws (*Ara macao*) at 5, 15, 25, 35, 45, and 55 min (M0, M1, M2, M3, M4, and M5, respectively) after sedation with dexmedetomidine (25 μ g/kg) and butorphanol (0.4 mg/kg), combined with S(+) ketamine (20 mg/kg).

| Parameters | Time Points | | | | | |
|----------------------|-----------------------------|------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| | M0 | M1 | M2 | M3 | M4 | M5 |
| HR (bpm) | 166 \pm 42 ^a | 152 \pm 33 ^a | 142 \pm 26 ^a | 130 \pm 27 ^b | 126 \pm 23 ^b | 119 \pm 17 ^b |
| RR (cpm) | 26 \pm 11 | 19 \pm 8 | 17 \pm 5 | 22 \pm 10 | 18 \pm 5 | 17 \pm 5 |
| SpO ₂ (%) | 93 \pm 3 | 89 \pm 5 | 91 \pm 6 | 93 \pm 3 | 93 \pm 3 | 93 \pm 5 |
| BT (°C) | 41.3 \pm 0.5 ^a | 40.8 \pm 0.8 ^{ab} | 40.3 \pm 0.5 ^b | 39.6 \pm 0.6 ^c | 39.1 \pm 0.5 ^d | 38.7 \pm 0.5 ^e |
| SBP (mmHg) | 148 \pm 25 | 132 \pm 23 | 129 \pm 16 | 133 \pm 19 | 140 \pm 15 | 136 \pm 19 |
| MBP (mmHg) | 107 \pm 22 | 100 \pm 22 | 98 \pm 20 | 100 \pm 18 | 103 \pm 15 | 95 \pm 16 |
| DBP (mmHg) | 86 \pm 21 | 84 \pm 26 | 83 \pm 24 | 82 \pm 20 | 85 \pm 18 | 74 \pm 17 |
| Glycemia (mmol/L) | 147 \pm 21 | NA | NA | 137 \pm 28 | NA | NA |

NA: Not assessed; different lowercase letters on the same row indicate a significant difference ($p < 0.05$) between times (M0–M5).

Dexmedetomidine does not cause significant respiratory depression, even when used in high doses, and is able to reduce respiratory depression induced by opioids (Bagatini et al., 2002). When combined with ketamine, dexmedetomidine may cause cardiorespiratory depression, albeit milder than when combining ketamine with other α -2 agonists, such as romifidine and xylazine (Fantoni & Cortopassi, 2002).

Studies on ketamine effects on the parameters of birds have shown that respiratory depression is a major disadvantage of this drug (Guimarães & Moraes, 2000). While S(+) ketamine is a stronger anesthetic than racemic ketamine, S(+) ketamine causes less respiratory depression (Trevisan et al., 2016). Butorphanol presumably does not produce dose-dependent respiratory depression in birds (Paul-Murphy, 2013).

SpO₂

SpO₂ did not significantly differ between time points during anesthesia either, according to Tukey's range test ($p < 0.05$). The scarlet macaws, which remained under spontaneous ventilation and without oxygen supplementation, had a 92% mean SpO₂ throughout the monitoring period. Between M0 and M1, SpO₂ decreased, but its values increased again in M2, remaining stable in the following periods (M3-M5).

α -2 agonist drugs can decrease the partial pressure of oxygen or increase the partial pressure of carbon dioxide, mainly in the first minutes after administration, as observed in the first time point of anesthesia (Leppänen et al., 2006). The initial decrease in SpO₂ may also be related to the slight decrease in RR, observed in the first time point, to the decrease in respiratory amplitude, or even to an erroneous pulse oximetry measurement caused by peripheral vasoconstriction, which commonly occurs when administering α -2 adrenergic agonists (Mendonça, 2019).

Though noninvasive pulse oximetry is vastly used in mammals as a method of estimating SpO₂, in a study using pulse oximetry in pigeons and macaws, Schmitt et al., (1998) encounter poor accuracy when recording oxygen saturation and high incidence of motion artifact. The same study also revealed different photometric behavior between avian and mammals hemoglobin, resulting in an underestimation of the actual oxygen saturation value in birds. However, pulse oximetry may be used to indicate SpO₂ tendencies in avian species (Klaphake et al., 2006; Schmitt et al., 1998).

BT

BT was the parameter with the most significant variations throughout the anesthesia according to the Tukey test ($p < 0.05$). The birds had their limbs covered with aluminum foil to reduce temperature drops, but even with a considerably high ambient temperature (approximately 32°C) at the anesthetic monitoring site, the BT of scarlet macaws clearly decreased in every time point of the anesthetic monitoring from 41.3 ± 0.5 °C in M0 to 38.7 ± 0.5 °C in M5. In the initial time points (M0 and M1), the mean BT decreased, albeit nonsignificantly, as well as between M1 and M2. From M2 to M5, however, BT significantly decreased between each measurement.

The accelerated decline in BT is due to the drop in basal metabolism, which is primarily responsible for thermoregulation, and to exposure to the colder environment (Nascimento et al., 2021). The agonistic action of dexmedetomidine on the central α -2 receptor reduces vasoconstriction/ shivering thresholds and physiological responses for increasing BT (Cruz et al., 2022). Butorphanol has a weak effect on BT (Miller & Fowler, 2012; Thomas & Lerche, 2017), but drug interactions of this opioid cannot be ruled out.

The ketamine-induced decrease in BT has been reported in birds (Kaya et al., 2019; Ludders, 2017; Trevisan et al., 2016), but S(+) ketamine may have a weaker hypothermic effect than the racemic mixture of ketamine because S(+) ketamine has a higher anesthetic potential, requiring lower doses to reach the intended effect. Other studies with similar anesthetic combinations in birds have shown a decrease in cloacal temperature (Atalan et al., 2002; Lumeij & Deenik, 2003; Monteiro, 2012).

Blood pressure

The average SBP was 136 ± 20 mmHg, peaking at the initial time point of the anesthesia (M0), decreasing in the next two time points (M1 and M2), increasing in M3 and M4, and decreasing again in M5. The limited oscillation of SBP demonstrates that this parameter remained stable throughout the anesthesia.

The average MBP was 100 ± 18 mmHg and fluctuated little throughout the anesthetic period, thus demonstrating the stability of this parameter throughout anesthetic monitoring. The highest MBP value was recorded in M0, subsequently MBP following a curve similar to that of SBP, slightly decreasing in M1 and M2, increasing in M3 and M4, and decreasing again in M5.

The average DBP was 82 ± 20 mmHg. The means remained virtually unchanged in the first five time points (M0-M4), with the lowest value at 74 mmHg in M5. Despite the visible decrease in DBP in the last 10 min of monitoring, this parameter was considered stable throughout the experiment, similarly to other blood pressure-related parameters (SBP and MBP).

No significant difference was found in any blood pressure parameter (SBP, MBP, and DBP) according to Tukey's range test ($p < 0.05$). The oscillations in systolic, mean, and DBP observed during the monitoring period may be related to the three drugs (dexmedetomidine, ketamine S(+), and butorphanol) used for anesthesia. The combination of these drugs may have caused the oscillation of blood pressure in scarlet macaws, due to the mutually compensatory effects of these anesthetics, without causing hypotension or hypertension.

Butorphanol causes mild hypotension by promoting peripheral vascular muscle relaxation, decreasing DBP and, therefore, MBP (Trim, 1983). When administered intramuscularly, α -2 adrenergic drugs may lower the blood pressure by activating α -2 adrenergic receptors in the vasomotor center in the central nervous system, which potentiates parasympathetic nervous activity, thereby decreasing both blood pressure and vasodilation (Bagatini et al., 2002). However, dexmedetomidine also acts on postsynaptic α -2 adrenergic receptors in the vascular endothelium, causing peripheral vasoconstriction and possible transient hypertension (Alves et al., 2000). Therefore, the action of dexmedetomidine on vascular endothelial receptors apparently offsets the vasodilatory action of the drug caused by central effects. Conversely, ketamine stimulates the sympathetic nervous system, causing tachycardia and increasing cardiac output and blood pressure (Muir III et al., 2013).

Glycemia

The mean glycemia of the animals decreased slightly from M0 to M3 (30 min later), albeit nonsignificantly, according to Tukey's range test ($p < 0.05$), which otherwise would be an adverse effect or even relevant hypoglycemia.

In some birds, glycemia clearly increased, whereas this parameter decreased in others. The hyperglycemic effect was expected due to the dexmedetomidine action on postsynaptic α -2 adrenergic receptors, which suppress the secretion of immunoreactive insulin from beta cells of the pancreatic islets, thereby lowering the insulin circulating in the blood (Saha et al., 2005). Conversely, the decrease in glycemia observed in the other birds may be related to

their fasting before anesthesia because birds have a high metabolic rate and small liver glycogen stores; therefore, under prolonged fasting, they may present with hypoglycemia (Altman, 1980; Franchetti & Klidge, 1978).

Latency and anesthetic recovery periods

Anesthesia was induced within 5 min, as scheduled in the beginning of the experiment, making it possible to remove the bird from its enclosure to the anesthetic monitoring site and to install the multiparametric monitor and electronic sphygmomanometer.

The average latency period (from drug administration to loss of muscle tone) was 2.4 ± 0.7 min, with no significant difference between scarlet macaws. The mean and standard deviation of the latency period matched the values reported by Monteiro (2012) in a study conducted with dexmedetomidine ($25 \mu\text{g}/\text{kg}$) and ketamine ($30 \text{ mg}/\text{kg}$) in turquoise-fronted amazons (*Amazona aestiva*), where the latency period ranged from 1.7 ± 1.2 to 3.7 ± 1.1 min. Atalan et al. (2002) found similar results of sedation quality and latency period in an experiment performed with a combination of ketamine, medetomidine, and butorphanol in pigeons. In contrast, Santangelo et al. (2009) assessed a long mean latency period of 4 ± 1.5 min when conducting a study exclusively using dexmedetomidine ($25 \mu\text{g}/\text{kg}$) to anesthetize raptors. Combining different classes of drugs presumably accelerates anesthetic induction.

The mean anesthetic recovery time (from application of the proposed anesthetic protocol to the full recovery of the birds) was 99.3 ± 32.4 min. Scarlet macaws were deemed recovered from anesthesia from the moment they showed stability in the bipedal position and adequate phalangeal flexion. No significant difference in the recovery time of the birds was found in this study.

Anesthetic recovery

The quality of the anesthetic recovery of each bird was assessed using a graduated scale to score each of the eight stages of anesthetic recovery, as outlined in Table 1. The results are summarized as follows (Table 3).

Of the animals under study, 75% had low scores, corresponding to an "excellent" anesthetic recovery. The remaining 25% of the animals had "good" anesthetic recovery scores. No bird had "fair" or "poor" scores.

The anesthetic recovery time and quality were not related. Even in the animals with a shorter or longer recovery time, the anesthetic recovery was considered smooth and uneventful, devoid of stress from the environment.

Table 3 – Scores, in increasing order, of the VIII anesthetic recovery stages of the eight scarlet macaws sedated with S(+) ketamine (20 mg/kg), dexmedetomidine (25 µg/kg), and butorphanol (0.4 mg/kg). Lower scores indicate a smoother anesthetic recovery, whereas higher scores express a more agitated anesthetic recovery.

| | Stage I | Stage II | Stage III | Stage IV | Stage V | Stage VI | Stage VII | Stage VIII | Total Score |
|-----------------|---------|----------|-----------|----------|---------|----------|-----------|------------|-------------|
| Scarlet macaw 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8 |
| Scarlet macaw 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 10 |
| Scarlet macaw 5 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 10 |
| Scarlet macaw 2 | 1 | 1 | 1 | 1 | 6 | 1 | 3 | 3 | 17 |
| Scarlet macaw 4 | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 10 | 22 |
| Scarlet macaw 3 | 1 | 2 | 1 | 1 | 6 | 1 | 10 | 1 | 23 |
| Scarlet macaw 7 | 1 | 1 | 1 | 1 | 6 | 1 | 10 | 3 | 24 |
| Scarlet macaw 8 | 1 | 3 | 1 | 1 | 6 | 6 | 3 | 3 | 24 |

Conclusion

Combining S(+) ketamine (20 mg/kg), dexmedetomidine (25 µg/kg), and butorphanol (0.4 mg/kg) proved to be a safe and adequate option for the chemical restraint of scarlet macaws.

The quality of the anesthesia was deemed excellent. The animals showed good muscle relaxation without requiring drug re-administration for anesthetic maintenance during the monitoring period. The specimens anesthetized using the protocol under study showed an uneventful anesthetic recovery, however prolonged, until regaining consciousness and walking adequately.

The main physiological changes included a decreased HR and BT, which highlights the importance of monitoring these parameters during the anesthetic procedure, especially when using dexmedetomidine. The changes in these parameters were not significant to the point of compromising the homeostasis of the birds, thus demonstrating the safety of the proposed anesthetic protocol for the chemical containment of scarlet macaws.

Based on the results from this study, the combination of S(+) ketamine with dexmedetomidine and butorphanol provides a good quality, rapid-acting sedation and with a long latency period, in addition to promoting a calm anesthetic recovery; hence, the anesthetic protocol used in the present study is highly indicated. Nevertheless, this combination may have strong cardiovascular and thermal effects, which must be monitored during anesthetic procedures in the field or in the operating room. The protocol is indicated for approximately 1-h procedures, in the field or in a surgical center.

Conflict of Interest

The authors have no conflicts of interest to declare.

Ethics Statement

All procedures were performed according to the Animal Research Ethics Committee (Comissão de Ética no Uso de Animais) of the Faculty of Science of Tocantins (Faculdade de Ciências do Tocantins), registration number 11.2022/01,

and the Biodiversity Authorization and Information System (Sistema de Autorização e Informação da Biodiversidade) of the Chico Mendes Institute for Biodiversity Conservation (Instituto Chico Mendes de Conservação da Biodiversidade), protocol number 82032.

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