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BLOOD STOP ON FRONT AND HIND LIMBS OF MEDIUM AND LARGE SIZED DOGS

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Contents

List of abbreviations

Na+	Sodium
Ca++	Calcium
K+	Potassium
Mg++	Magnesium
Cl	Chloride
kg	Kilogram
BWG	Body weight gain
cm	Centimeter
mmHg	Millimeter mercury column
HC	HemaClear®

1 Introduction

For over 100 years, two methods have been used in human medicine to operate on extremities without bleeding [1]. By operating without bleeding, the surgeon has a better view of the surgical area and can thus perform the operation faster and more effectively. In addition less blood is lost due to the blood stop.

In human medicine there is a new product called HemaClear®, which has increased efficiency to perform bloodless surgery [1].

In my thesis I want to investigate whether the HemaClear® method, which has been successfully used in human, can also be beneficial in animals in order to perform surgeries more often without blood in the future.

1.1 Definition of tourniquet and bloodlessness

Tourniquet
Tourniquet is the artificial throttling of blood circulation in a limited circulatory area. It is used during operations on the extremities and serves to provide a better overview of the surgical area and to save transfusions. In this procedure an inflatable cuff is placed around the affected limb as close as possible to the trunk of the body and inflated to a pressure significantly higher than the patient's arterial systolic blood pressure [2]. This interrupts the flow of blood. There are two known types of tourniquet, which include the traditional and the pneumatic tourniquet.

Bloodless
If the surgical area has to be viewed particularly closely, the residual blood in the limb may become noticeable in the surgical area. In such cases, the blood is removed from the limb before closing the tourniquet for example with the aid of an Esmarch bandage bonding [2].

1.2 Reasons for a tourniquet and areas of application

Up to about 70% of all human surgical operations on the extremities are performed bloodless. For a population consisting of about 1 million people, there are about 4,000 to 10,000 bloodless surgeries [3].

The aim of the tourniquet is to provide a better visual impression of the surgical area. Blood loss is kept low so that atraumatic operation is possible. Less blood loss can save on blood transfusions [2]. Surgical operations on extremities are easier and faster to perform for these reasons, because a more accurate anatomical structural representation is available, thus avoiding damage to the vessels [4].

1.3 Areas of Application

The following operations are relevant in human medicine in bloodless applications [5]:

1. Knee Arthroplasty & Arthroscopy
2. Foot & Ankle Surgery & Podiatry (treats foot disease and disorders)
3. Upper Extremity & Hand
4. Pediatric Orthopedics
5. Vascular Surgery
6. Trauma

1.4 Function and performance of exsanguination

There are two common exsanguination methods in combination with the Esmarch bonding:

Blood occlusion via a regular/traditional tourniquet
In the first step, the traditional tourniquet is positioned proximally on the limb as shown in Figure 1.1. By rolling up the Esmarch bandage on the extremity, the blood on the limb is removed, shown in Figure 1.2. Then the tourniquet proximal to the limb is closed so that no new blood can enter the limb, descripted in Figure 1.3.

Blood occlusion via a pneumatic tourniquet
The pneumatic cuff is also positioned proximally on the limb as shown in Figure 1.4. The Esmarch bandage is rolling up on the extremity, the blood on the limb is also removed, shown in Figure 1.5. Then the tourniquet proximal to the limb (pneumatic cuff) is inflated so that no new blood can enter the limb, descripted in Figure 1.6 [6].

In both methods the extremity is bloodless.

Figure 1.1: 1. method 1. step: Loose placement of a traditional tourniquet on the extremity [7]

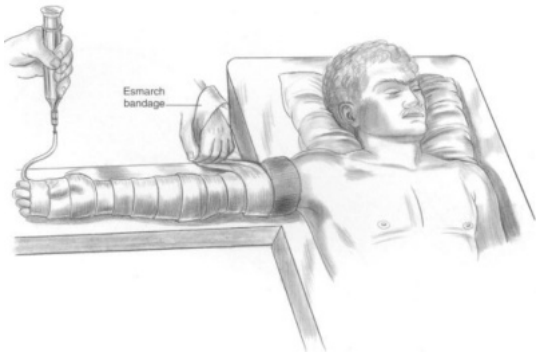

Figure 1.2: 1. method 2. step: Esmarch bandage is rolled up (blood drainage of the extremity) [8]

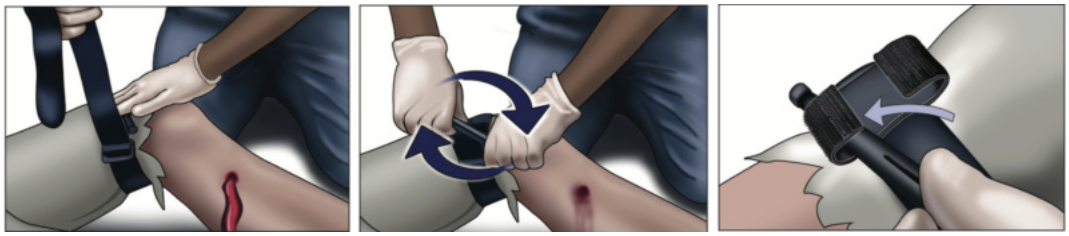

Figure 1.3: 1. method 3. step: Regular Tourniquet is applied to the extremity for blood occlusion, tightened until no more blood comes out of the wound, and fixed (blood stop) [9]

1.5 Contraindications of tourniquets

Patients with peripheral vascular disease or an underlying prosthetic vascular graft, sickle cell disease, open fractures, and patients with intramedullary nails, should generally be excluded [4].

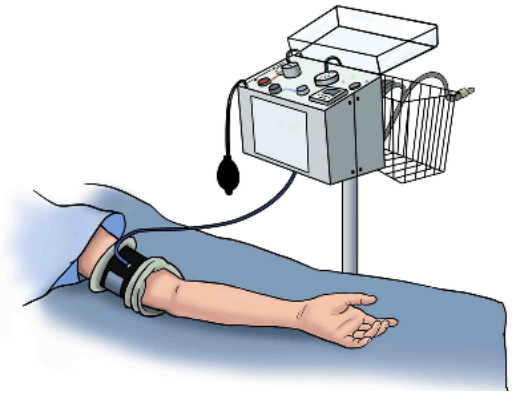

Figure 1.4: 2. method 1. step: Tourniquet pneumatic [10]

Figure 1.5: 2. method 2. step: Beginning of the exsanguination process of the elevated left upper extremity using a tightly wrapped Esmarch bandage at the base of the distal tourniquet [11]

Figure 1.6: 2. method 3. step: Keeping the Esmarch bandage tightly wrapped [11]

1.6 Tourniquet side effects

In general, side effects rarely occur [12]. However, due to increased tissue pressure created by the tourniquet, nerves can be damaged or nerve paralysis and subsequent postoperative neurologic deficits can occur as a result of the tourniquet application [13] [1] [14] [15] [16] [17]. In the worst case, limb paralysis can occur due to nerve injury [18]. But also pain, deep vein thrombosis or hemarthrosis can occur [19]. Postoperative swelling, wound complications, delayed muscle strength recovery, compression neurapraxia, wound hematoma with the potential for infection, vascular injury, tissue necrosis, compartment syndrome, and systemic complications have been reported in the literature. Iatrogenic burns during use of a pneumatic tourniquet have been reported rarely [20] [21]. Common side effects include postoperative blood loss, as well as venous thrombosis, neuromuscular or cutaneous damage, and delayed rehabilitation. In particular, a tourniquet time of more than 100 minutes increases the risk [22]. Another complication, as in most surgeries, can be wound infection [12]. But in summary, severe complications due to tourniquet use are very rare and mortality is almost eliminated [23].

1.7 Optimization of the tourniquet through the HemaClear® product

HemaClear® is a simplified combination product to combine blood extraction by rolling up a ring and blood stopping by leaving the ring proximal to the limb without spending much time. It provides better blood extraction of the limb while creating a sterile larger environment than a tourniquet. It is easy to use and is used in human medicine worldwide. Little to no tissue damage is caused by the small ring and the side effects that could occur with the tourniquet have been almost eliminated by this optimization [24].

2 Literature review

2.1 Tourniquet in veterinary medicine

2.1.1 Anatomical difference between human and dogs

Tourniquet is required in human mainly in the field of military use. Despite its crucial role in human medicine, the tourniquet has not yet established its place in veterinary medicine [25].

One reason for this is the difference in anatomy. In the dog's body, the great femoral and axillary arteries are located on the inside and therefore are well covered by the leg, which protects them better than in human. When the dog is standing upright, the large arteries are located close to the body and are therefore more difficult to reach by the tourniquet. In human less body mass lies over the large vessels. Therefore, in dogs, the tourniquet must be applied very high on the limb to be able to stop the blood. The course of a dog's limb, unlike that of a human, is funnel-shaped, which allows the tourniquet to slip easily. The limb is smaller in diameter toward the toes, so the tourniquet slips more quickly and fits more loosely [25].

A tourniquet is most often used in veterinary medicine only for major bleeding, such as amputations.
The size of the dogs plays an important role when putting on a tourniquet. In medium to large dog breeds, human tourniquets fit optimally. For this reason, I conducted the trials with the HemaClear® blood stop exclusively on medium-sized and large dogs. For smaller breeds of dogs (e.g. a Chihuahua), the human tourniquets available on the market can work if they are pulled tight enough. Especially in dogs with very short legs it is also very difficult to apply a tourniquet (e.g. Basset Hound, English Bulldog). These dogs have very thick thighs in relation to the short limbs and a low-hanging body, which makes applying a tourniquet almost impossible. For small dogs, therefore, one would usually use an elastic TK-4 or SWAT-T tourniquet. With elastic tourniquets, the diameter can be adjusted to any size.

Since there is no standard technique in veterinary medicine, most veterinarians improvise and have their own tourniquet techniques. They have experience with a wide variety of tapes and bandages. These can be more effective than commercially available elastic tourniquets. Research and practice show that normal tourniquets can be useful in dogs in certain, but rather rare, situations [25].

2.1.2 Effect of blood stop duration

When using a blood stop, the duration of two hours is not allowed to be exceeded [25]. To date, there have been few studies on the use of tourniquets on animals. In a study "Pathophysiologic Effects Distal to a tourniquet in the Dog" [26] in dogs, it was found that a blood stop with the pneumatic tourniquet on hind limbs on dogs should not exceed 1 to 1½ hours. If a procedure takes longer than one hour, the tourniquet should be released for 10 minutes to prevent secondary damage. As a result of ischemia in the limb, lactic acid levels rise steadily, causing muscle damage and degeneration in the tissues. The blood stop creates a state of tissue hypoxia, hypercarbidity and acidosis in the limb. After one hour, the values have risen so high that this leads to permanent damage to the tissue. This can only be prevented by opening the blood stop for at least 10 minutes. After 10 minutes, the tourniquet can be closed again [26].

2.1.3 Pneumatic tourniquet on Animals

In a study of rabbits "Tourniquet-induced neuromuscular injury A recent review of rabbit and clinical experiments" [27], tissue injury was found, as in human, after application of the pneumatic tourniquet. Uneven tissue deformations were observed. Depending on the time, tourniquet compression injuries occurred. Muscle injuries were dependent on cuff pressure. A topographic pattern of necrosis after tourniquet compression was observed after two hours. After four hours, skeletal muscle injury under the cuff became quite evident. In addition to muscle damage, physiological and morphological nerve abnormalities occurred after two hours with a tourniquet at the pressure of 350 mmHg. This demonstrates that neuromuscular injuries distal to the tourniquet may result from the use of pneumatic tourniquets.

When deciding to use a tourniquet, the systemic effects of limb ischemia from compression injury induced by pneumatic tourniquet models should be considered. Surgeons must weigh the advantages of a bloodless field of view against the disadvantages of tourniquet-induced neuromuscular injury. In human medicine, the bloodless surgical area is a very important component of extremity surgery for surgeons [27].

When using pneumatic tourniquets, the perfect pressure and duration must be considered to keep neuromuscular injuries low, as they may affect postoperative rehabilitation. Due to the small number of studies on tourniquet in animals, there is little data on pressure and time thresholds. Difficulties in performing controlled studies of tourniquet compression on cone-shaped limbs of animals are a major problem. The lack of documented knowledge makes muscle and nerve injuries under tourniquet more likely in animals [27].

It was not until 2006 that the first report was published of a dog suffering from injury after the use of a tourniquet on the distal limb. This 5-year-old, neutered male Bichon Frise was examined for swelling, lameness, and licking of the limb [28]. A report and review of the studies published to date on the use of tourniquet on animals and human was then discussed and recorded. Most studies showed that tourniquets were applied over a relatively short period of minutes to hours. Tourniquet applications in human medicine can be traced back for centuries, whereas the extent in the history of veterinary surgery is minimal. The trials described in human medicine show the risks associated with the use of tourniquets, e.g. Volkmann's contracture, nerve palsies, ischemic skin necrosis, secondary injuries, injuries during the application of bandages and myocyte damage [28]. It is interesting to note that a study published 2012 using rabbits observed that under the same inflation pressure, wider tourniquet caused greater skeletal muscle damage compared to narrow cuffs [29].

From the studies examined, it can be concluded that injuries can be caused by the traditional use of pneumatic tourniquets. The wider the tourniquet and longer the application time, the more serious the damage caused can be.

2.2 HemaClear® in human

To reduce the possible harm of traditional use, special products have been developed in human medicine instead of the tourniquet. The following information refers to human medical use. Until today, no study has been conducted on the use of HemaClear® in animals.

The newer sterile exsanguination HemaClear® product has been used in over 1 million human surgeries worldwide [24] [30]. HemaClear® is a simplified combination product for bloodless surgery. HemaClear® consists of an elastic silicone ring wrapped in a stockinet. Two wrapped pull straps with handles are used for simplified attachment. Electrical power or compressed air, as with the pneumatic tourniquet, are not required.

2.2.1 Advantages of HemaClear®

By using a much thinner HemaClear® ring, a larger surgical area is available compared to traditional wider tourniquet cuffs [31]. Studies in human medicine show that the use of the HemaClear® ring leaves no skin damage nor damage to nerves. The pressure and resulting pain at the place of attachment is less than with other tourniquet methods. The simpler, faster application and better quality of the surgical area results in shorter surgical time [19].

HemaClear® is a sterile packaged product, which is intended for a one-off use and thus reduces the risk of infection in the surgical area [1]. It creates a sterile environment of the surgical area by covering the stockinet. It is easier and faster to use and the initial cost is lower. When applying HemaClear®, a time saving of 15 seconds can be achieved compared to 12 minutes with conventional tourniquet [6].

In human extremities, HemaClear® results in superior exsanguination (blood removal) of up to 95% [1]. Other tourniquet methods result in 45%-67% exsanguination. This improves the bloodless and dry surgical area and minimizes the risk of complete blood removal from the limb. Anatomical structures can be seen more clearly. Postoperative sequelae such as pulmonary embolism or thrombosis are reduced. Reduced blood loss results in less need for blood transfusions.

In over 800,000 operations performed with HemaClear® worldwide, no nerve or muscle damage to the patient's limbs has been reported. Whereas neurapraxia with a pneumatic tourniquet wide cuff has been demonstrated in several studies [1].

Traditional tourniquets have wider cuffs, resulting in approximately 20.7% of patients experiencing skin injuries at the place of attachment and 39.7% of patients describing pain at extremities [24]. Due to the extremely narrow ring of HemaClear®, no skin lesions have been left to date. With HemaClear®, the skin is not pinched or burned, so pain triggered by this is minimized. The patient's pain is also minimized as a result [19]. It has been found that in order to stop arterial blood flow, it is only necessary to occlude a few millimeters of the artery, which can be efficiently achieved even with the narrow ring of HemaClear®. It is not necessary to compress a much larger volume of tissue to block the flow in an artery. To stop blood flow with a wide cuff, a much larger area of tissue must be compressed. In addition, nerves are lengthened by a wide cuff, which can lead to nerve damage [4]. According to data in JBJS, 1:4200 nerve injury has been noted with a wide cuff, while none are known to date with the narrow HemaClear® [16] [32].

Figure 2.1: Difference between the pneumatic tourniquet (left) and the HemaClear® product. [5]

2.2.2 Areas of Applications

HemaClear® is particularly suitable for any extremity surgery operations [33]. The following specific operations have been discussed and studied:

Fractures There are two publications where HemaClear® has worked well on fractures. There is a relative contraindication for open fractures. The surgeon should weigh the risk against the benefit depending on the patient. [4].

Amputations In amputations, HemaClear® can be used if there is no malignancy of the limb. It must be remembered that vascular disease, diabetes or other arterial occlusive disease (e.g., Buerger's disease), may cause the extremity to become ischemic. It must be monitored that the tissue at the amputation site is healthy and has a good blood supply [34].

Orthopedic operations in children The HemaClear® blood stop also works in children. In children, the place of attachment and the age of the children must be taken into account. The existing HemaClear® sizes are also applicable for infants and young children [31].

Varicose veins or thrombosis HemaClear® has been used with considerable success by some surgeons in the removal of varicose veins. However, in cases of superficial or deep vein thrombosis, it is better not to use HemaClear® because of the increased risk of heart infarct [19].

2.2.3 Local anaesthesia

Minor operations with local subcutaneous anesthesia are possible in combination with HemaClear®. In this case, the anesthetics are applied first and only then the HemaClear® [24].

2.2.4 Contraindication of HemaClear® use

HemaClear® should not be used on patients with poor peripheral circulation, edema or deep vein thrombosis. If infection is present, blood stopping with HemaClear® should be refrained from. If the patient's skin is fragile or shows significant lesions, HemaClear® should not be used. However, it is possible to apply a sterile ace bandage in advance for protection in patients with sensitive skin [33].

2.2.5 Atypical patients

In case of pathological obese patients, HemaClear® is used up to a circumference of 85 cm of limbs. However, in obese patients it is important to monitor their blood pressure throughout the period of blood stop. An obese leg contains up to 1.5 liters more blood. By rolling up HemaClear® too quickly, a significant transient increase in blood pressure may occur and the risk of tourniquet failure or the development of a hemorrhage is increased. To counteract this, a one-minute pause is taken when rolling up the HemaClear® at knee level [35].

2.2.6 Application of HemaClear®

HemaClear® is applied by the surgeon to the patient's extremity and pulled up proximally with the handles. HemaClear® rolls up the patient's limb and the stockinet unrolls in the process. Each time the ring rolls up the extremity, it exerts a pressure on the tissue that is greater than the patient's systolic blood pressure. This directs blood away from the extremity into the main circulation. This function of exsanguination, which can be performed quickly and effectively, has been perfected by HemaClear®. When the ring reaches the place of occlusion, the surgeon's traction motion is stopped. At this place, the ring applies pressure to the extremity, which interrupts arterial blood flow to the extremity. During traction over the extremity, a stockinet unrolls, completely covering the extremity up to the place of occlusion. This thus immediately serves as a sterile drape for the surgical area. The preparation time takes less than 12 seconds [6] [31].

The places of attachment of HemaClear® to the extremity:

- On the thigh, HemaClear® is placed as close as possible to the groin.
- Distal to the knee, HemaClear® can also be placed in the middle of the thigh
- At the ankle, the ring should be placed up to 15 cm proximal to the malleolus lateralis
- On the upper arm, HemaClear® is placed as close to the axilla as possible
- On the forearm, the ring is left in place up to 10 cm proximal to the wrist

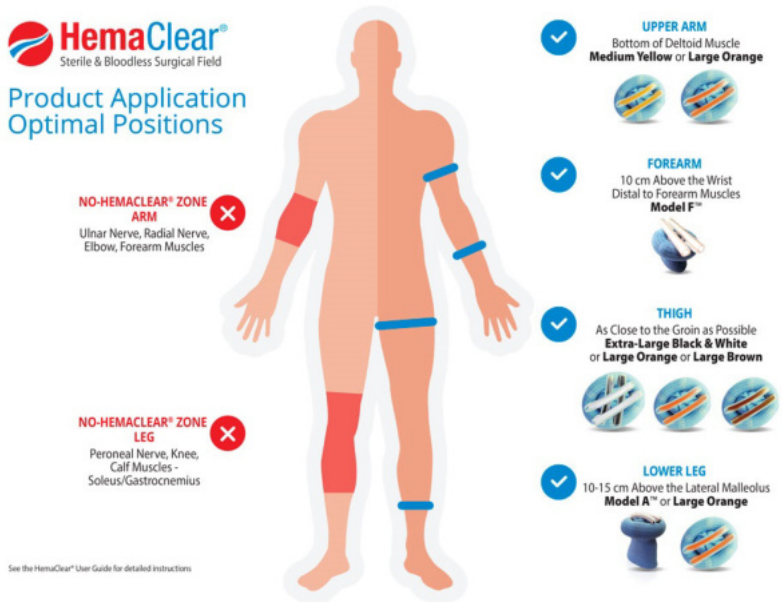

Figure 2.2: HemaClear® places of attachment in the adult with the right choice of models.

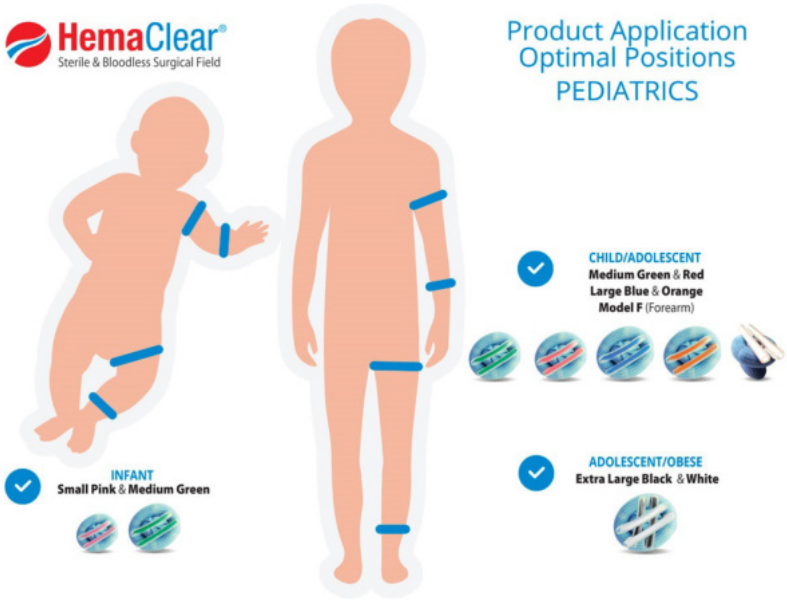

Figure 2.3: HemaClear® places of attachment on children with the right choice of models

2.2.7 HemaClear® Models

There are four main models. These differ mainly in size. They are placed proximally to the extremities (axilla and thigh) depending on the size. They are suitable for adults and children with an extremity circumference of 14 cm to 85 cm. The circumference of the place of attachment is measured with a special tape measure provided by HemaClear® (see Figure 2.4, Figure 2.5).

Figure 2.4: Special measuring tape for all HemaClear® models depending on the circumference at the attachment point

Figure 2.5: Special measuring tape for all HemaClear® models depending on the circumference at the attachment point

In addition, there are two more specialized HemaClear® models designed specifically for forearms (Model F) and for ankles (Model A). The correct choice of HemaClear® model can be determined by measuring the point of application on the extremity and the patient's systolic blood pressure, as shown in Figure 2.6 [24].

Figure 2.6: Currently available HemaClear® models

2.2.8 Consequence in case of wrong model

If the wrong model size is selected, all the blood cannot be removed from the extremity and bleeding will occur. If a kind of blood stasis occurs instead of a blood stop and the blood is flowing excessively, the ring should be cut immediately. If a model that is too small is selected, it will be very difficult to roll the ring over the extremity. This may cause pain to the patient [24].

2.2.9 Dangers during exsanguination

Any type of tourniquet and also HemaClear® should not be maintained for more than 120 minutes. Time should be measured from the time of application until the ring is cut. Generally, tissues of extremities are less susceptible to ischemia than neurons in the brain. This is due to the lower metabolic demand of tissue in extremities and fewer ATP reserves in the form of creatine phosphate and oxygen bound to myoglobin. Many studies show that HemaClear® does not cause irreversible changes under a blood stop duration of 2 hours. To counteract this tissue damage, cut the ring after 90 or 120 minutes at the latest. As soon as reperfusion has occurred after about 10 minutes, a HemaClear® can be applied again. A disadvantage of the pneumatic tourniquet is that after reperfusion the cuff is re-inflated and blood remains in the limb. This blood in the limb can clot and this can lead to pulmonary and cerebral embolization after tourniquet opening. By re-exsanguination, which is ensured by reattachment of the HemaClear® ring, such secondary damage can be counteracted [24] [30].

2.2.10 Pressure on the extremities

The pressure is different for each HemaClear® model and is determined and calibrated during manufacture. The exact pressure depends on the limb circumference at the occlusion site and the distance from this site to the fingers or toes. The correct model can be determined on the HemaClear® pressure tables in the user manual. This pressure corresponds respectively to the maximum systolic blood pressure such as the models for children with 130/160/190 mm Hg [4] [33] [36]. The pressure of 200 to 250 mmHg is used for the upper limbs and a pressure of 300 to 350 mmHg for the lower limbs [34]. This force on the extremity is just sufficient to ensure safe and effective occlusion of arterial blood flow. Therefore, it is important to measure the patient's systolic blood pressure. During surgery, blood pressure should be kept as constant as possible. The difference between HemaClear® and the pneumatic tourniquet is that with HemaClear® the pressure always remains the same and cannot vary due to air fluctuations. With the pneumatic tourniquet, accidental overpressure can occur more quickly, whereas with the HemaClear® ring the pressure always remains the same.

2.2.11 Removal without skin damage

In order not to damage the skin during removal, the "protective cutting card" specially made by HemaClear® is placed under the ring before cutting. This card is also sterilely packed together with the ring and the cutting is performed by the surgeon [6].

Risk Avoidance of accidentally damaged blood vessels during surgery, not detectable through the bloodless surgical area, which can then lead to increased bleeding later.

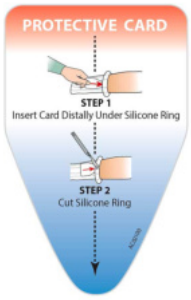

Figure 2.7: HemaClear® cutting card [37]

HemaClear® can be cut before wound closure. This ensures that no blood vessels have been damaged.

3 Goals

The aim of this thesis is to find out whether the successful experience with the application of HemaClear® in human can be applied to veterinary medicine. In this context, a blood stop with HemaClear® was produced during extremity operations of medium to large dogs. With the help of HemaClear®, blood loss during surgery should be reduced, resulting in a better visual field for the surgeon.

The trials will investigate the following questions:

1. Can HemaClear® application decrease blood loss during surgery and improve visibility of anatomical structures?
2. Does HemaClear® prevent a greater drop in systolic blood pressure due to bleeding during surgery?
3. Can a application of HemaClear® shorten the average operation time and thereby also the anesthesia time?
4. Does HemaClear® leave skin redness at the place of attachment?
5. Does the application of HemaClear® show differences in age groups, sex and size of the dogs?
6. Is HemaClear® equally easy to place on the forelimbs and hindlimbs and does it cause the same blood stop?

4 Materials and methods

For the present study, the trials were performed on medium and large sized dogs treated at the Kellerwessel Small Animal Clinic in Cologne, Germany, with different diagnostic procedures. The dogs belong to private individuals who consulted the Small Animal Clinic Kellerwessel for neoplasm removals or incisions of the extremities. In my thesis planned surgical operations and animals admitted to the emergency consultation were included.

4.1 Study design

4.1.1 Inclusion and exclusion criteria of the dogs

The dogs in this study were allowed to be no younger than 6 months and no more than 15 years old. Both male and female dogs, neutered or not, were operated. The body weight of the dogs is ignored in this study, because only the circumference of the extremities is relevant for the application of HemaClear®. The shoulder height of the dogs was taken as a benchmark for the selection of medium to large sized dogs. The shoulder height of a medium dog is defined from 40 cm, from 60cm an animal is classified as a large dog. With a stick measure the shoulder height was determined. The Figure 4.1 shows schematically the measurement of shoulder height on a dog. All dogs taller than 40cm were included in the study.

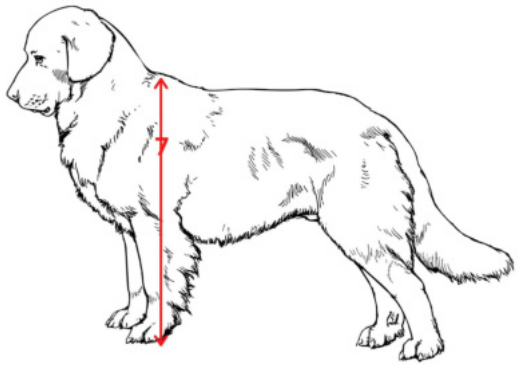

Figure 4.1: Schematic diagram of the measurement of shoulder height on the dog [38]

All dogs were clinically examined by Dr. Elisabeth Kellerwessel and myself. Only dogs with inconspicuous vital signs were included in the study. Especially the parameters

of the circulation were of special importance. The capillary refill time was measured on the mucosa of the dogs' chaps. This refill time was <2 seconds in all dogs. The mucous membranes in the dogs' mouths were all pink and the surface without any particular findings. The auscultated hearts in all dogs were loud and strong with a normal rhythm and no murmurs. The associated heart rate was recorded. This had to be within the normal range of 60 to 120 beats per minute. The skin turgor of each dog was also less than 1 second. The turgor was recorded by pulling up a skin fold in the inter-shoulder area. Respiration was assessed by inspection and had to be physiologically costoabdominal in all dogs with a respiratory rate between 10-30 breaths per minute. Temperature was measured rectally with a thermometer and was not allowed to be below 37.5°C or above 39°C. However, the greatest attention was paid to systolic blood pressure, because it can be influenced most rapidly by bleeding during surgery. Therefore, this was measured both before and after surgery. Only dogs that had a blood pressure between 110 and 140 mmHg before surgery were included. In the chapter subsection 4.3.2, the accurate measurement of systolic blood pressure in the dogs is explained. In planned surgical operations, the dogs were operated in fasting state. They have not been fed since the previous evening. Dogs admitted to the emergency department have not been fasting during surgery.

4.1.2 Classification of the experimental groups

The dogs were divided into two groups.

Group I: Control group without HemaClear® application These dogs were operated on in the absence of HemaClear®. Systolic blood pressure before and after surgery, type of surgery, surgery time, number of ligations, visual quality of the surgical area, and blood loss were recorded.

Group II: Group with HemaClear® application For the dogs in this group, in addition to the data from Group I, data on HemaClear® application were also recorded. This included the place of attachment, limb circumference and resulting HemaClear® model to be applied, time of attachment, ease of placement of HemaClear®, duration of blood stop, disruption of the HemaClear® ring during surgery and intraoperative problems, time of HemaClear® removal, and whether skin redness was visible at the place of attachment early after surgery.

4.2 Structure and operation of HemaClear®

Trials were performed on the forelimbs and hindlimbs of dogs using one of a choice of sterile HemaClear® products. The products are shown in Figure 4.2, Figure 4.3 and Figure 4.4.

Figure 4.2: HemaClear® box with the two products (small/pink and medium/yellow) and a measuring tape for measuring the circumference of the extremity

HemaClear® is sterile packed in a double plastic package and is intended for single use as a surgical tourniquet. Two different sizes or models of HemaClear® have been used. The small model is pink/small and the yellow model is medium/yellow in size. Each model consists of a stockinet around a silicone ring. There are two handles with strings that are used for better rolling up. These are not fixed to the ring. There is also a sterile small "cutting card" in each sterile package that is used for HemaClear® removal after surgery to protect the dog.
Choosing the right size:
There is a measuring tape specially made by HemaClear® shown in Figure 4.5 and

Figure 4.3: HemaClear® product small (pink) and medium (yellow) with 1 and 2 fold plastic covers

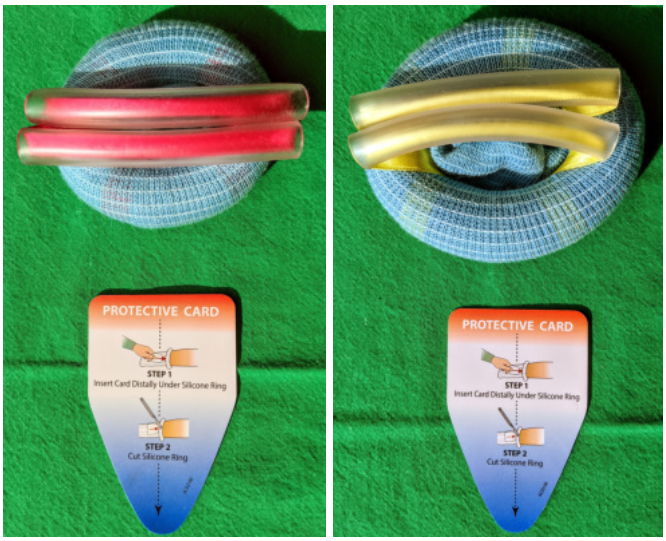

Figure 4.4: HemaClear® product small (pink) and medium (yellow) unpacked

Figure 4.6. With which you measure the place of attachment on the thigh or upper arm of the dog. The different sizes and models are marked on the tape measure. Depending on the circumference, the smaller or larger model was used.

Figure 4.5: Special HemaClear® measuring tape for measuring extremity circumference at the HemaClear® place of attachment to determine the selection of the HemaClear® ring to be used

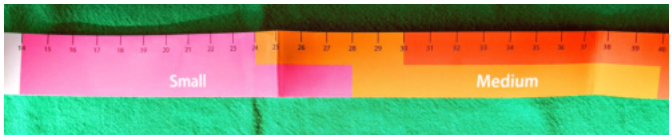

Figure 4.6: Section of the HemaClear® measuring tape with the special area used for the medium and large dogs

In the Figure 4.7 you can see a schematic representation of the HemaClear® placement.

4.3 Operation preparations

4.3.1 Anesthesia, analgesia, infusion, shearing, positioning

The dogs receive a mixture of Ketamine® 10% (ketamine 100 mg/ml, 1-3 mg/kg) and Dorbene vet® (medetomidine 1 mg/ml, 0.01-0.03 mg/kg) as intramuscular injection anesthesia. After sedation, a venous access (VasoVet® 20 G, 1.1 x 33mm, color pink)

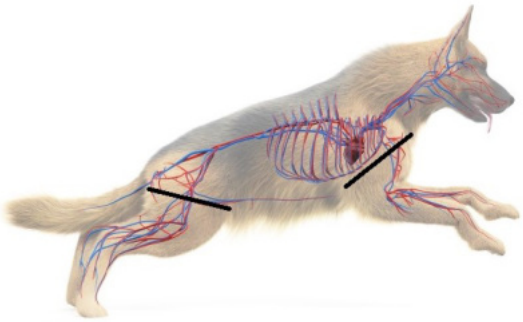

Figure 4.7: HemaClear® placement on right forelimb or hindlimb of a dog [39]

is inserted to stabilize the circulation. This is connected with an infusion tube to a Deltajonin® perfusion solution (content of infusion solution see bellow). The perfusion rate is adjusted in a dog without special findings using a perfusomator with the dosage of the conservation needs (= 70 × kĝ0.75 or 2 ml/kg BWG/h) [40].
In most cases, anesthesia must be deepened or maintained as needed. This is done with intravenous administration of Proposure® (10 mg propofol/ml, 2-4 mg/kg BWG) and Midazolam® (midazolam hydrochloride, 1 mg/ml, 0.1 - 0.25 mg/kg BWG). For analgesia, Insistor® (methadone hydrochloride, 10 mg/ml, 0.8 mg/kg BWG) is injected as an intramuscular injection.

The skin of the surgical area is shaved and suctioned. If the surgical area has been contaminated, such as incisions, these are cleaned with the same Deltajonin® solution as mentioned above. This blood loss will not be documented in the study. The incisions are first measured in length and width, and the depth is estimated during surgery after a wound refreshment. The dog is fixed in the lateral position or on the back on the operating table at the extremities with cloth straps. The side of the leg to be operated on is on top to avoid having to move the dog during the operation. To counteract the lowering of temperature under anesthesia, the dog lies on a self-regulating heat mat (Dormosafe model). A side table (mayo table) is placed by the limb and the leg to be operated is placed on it. The shaved surgical area is disinfected.

Deltajonin® Full Electrolyte Solution Infusion Solution Ingredients. The active ingredients are contained in 1000 ml infusion solution:

Natriumacetat	6,124 g
Natriumchlorid	5,552 g
Kaliumchlorid	0,298 g
Calciumchlorid	0,368 g
Magnesiumchlorid-Hexahydrat	0,203 g
Hydrochloric acid 10% for adjusting the pH value	
Water	1000 ml
Na+	140 mmol/l
K+	4 mmol/l
Ca++	2,5 mmol/l
Mg++	1 mmol/l
Cl	106 mmol/l
Acetat	45 mmol/l
pH	6,7 – 7,7 mmol/l
Theoretical osmolarity	299 mmol/l
Titratable acidity	<1 mmol NaOH/l

4.3.2 Systolic blood pressure measurement

Systolic blood pressure is measured five times with the HDO® (High Definition Oscillometry) device at the root of the dog's tail. The mean value is then calculated. In the Figure 4.8 the application of the blood pressure measurement is shown.

Figure 4.8: Placement of the blood pressure cuff at the root of the dog's tail (systolic blood pressure measurement).

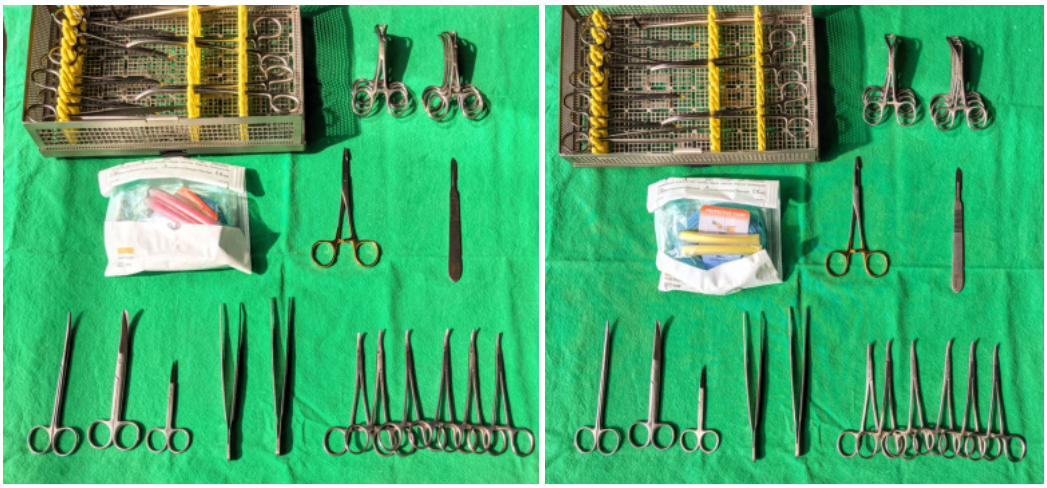

Figure 4.9: Mayo table with sterile surgical instruments and HemaClear® models pink/small and medium/yellow

4.3.3 Selection of the HemaClear® model

The circumference of the thigh or upper arm of the dog's limb is measured with a special HemaClear® flexible tape measure. For a circumference size of 14-28 cm, the smaller/pink model was selected, and for a circumference size of 28-40cm, the medium/yellow model was selected. The corresponding models for the respective leg circumference were read directly from the measuring tape.

The selected HemaClear® is placed out of the outer plastic packaging, sterile on the surgical side table (mayo table with disinfected table with sterilized cloth). In addition, the sterile surgical instruments are placed on the surgical side table. In the Figure 4.9 the two models of HemaClear® with the corresponding surgical cutlery are shown.

4.3.4 Sterile cover

A sterile surgical drape with a large hole is placed around the limb to be operated on, so that the rest of the dog's body is covered with sterile drapes and only the limb to be operated on is visible, as shown in Figure 4.10.

4.4 Application of HemaClear®

4.4.1 Attachment and measurements of HemaClear®

The HemaClear® is taken sterile from the side table. The last plastic wrapping is removed and the ring is placed distally on the limb around the paw. For proper placement on the leg, the selected HemaClear® model is placed distally on the paw. The handles are positioned dorsally and palmar on the forelimb or dorsally and plantar on

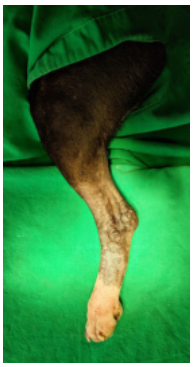

Figure 4.10: Hind limb of a dog shortly before HemaClear® attachment

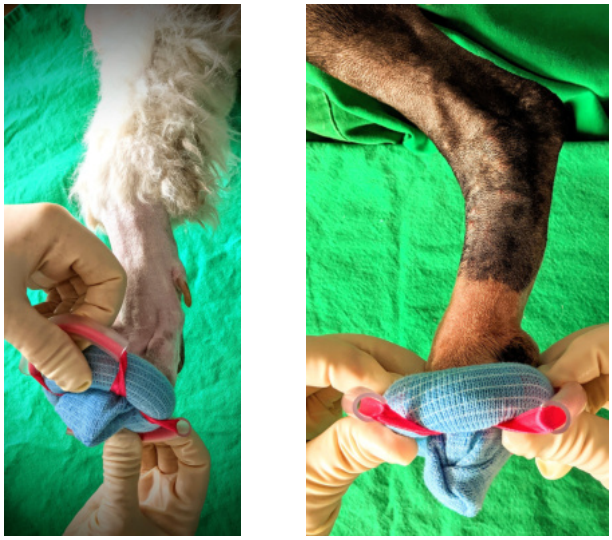

Figure 4.11: Placement of the HemaClear® distally on the forelimb and hindlimb of a dog before rolling off

the hindlimb.

The leg is held sterilely vertically upwards and the ring is pulled proximally by the surgeon using the two handles. The silicone ring inside HemaClear® is rolled up as far as possible over the limb at the previously measured place of attachment and the entire limb is automatically covered with the compression stocking. The pressure of the ring displaces the blood from the limb during application and blocks the blood flow at the occlusion site.

The tapes are wrapped around the limb and knotted. The compression stocking is then opened with sterile surgical pointed-truncated scissors at the surgical area. The effort and complexity of applying HemaClear® is rated by the surgeon using a scale of 1 (very easy) to 5 (very difficult). Once the HemaClear® ring is in place, the blood stop time is started. According to the manufacturer, the blood stop should not remain on

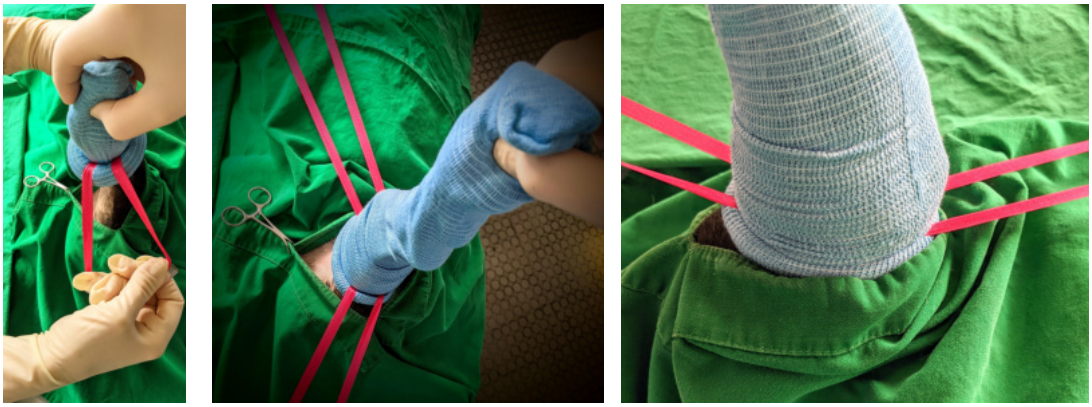

Figure 4.12: Course of application of HemaClear® to the hind limb of a dog by unrolling the ring through the manual traction on the handles by the surgeon

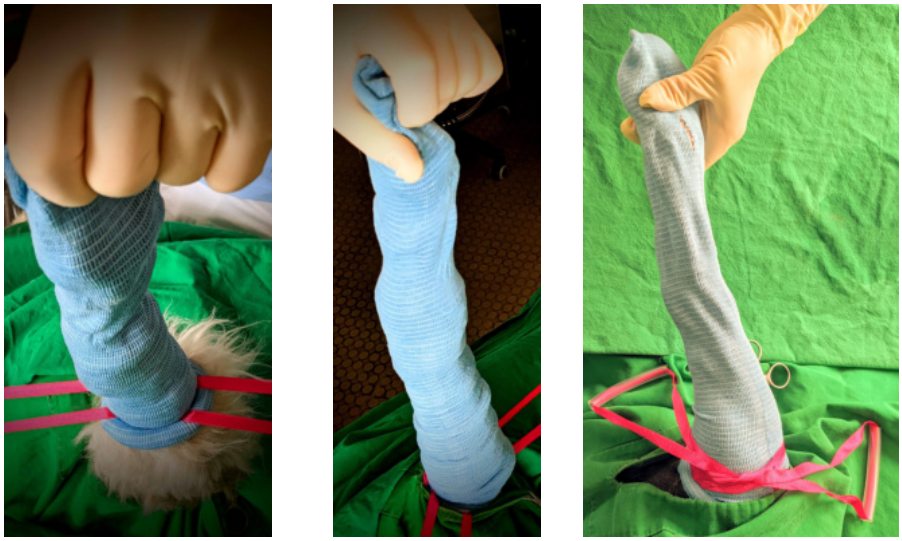

Figure 4.13: HemaClear® attachment by rolling from distal to proximal on a dog's forelimb and tying the ligaments in knots

the limb for more than 120 minutes. For this reason, mainly minor surgical operations on the limbs of the dogs such as neoplasms and incisions were selected in this study.

4.4.2 Operation and measurements for bleeding

The operation is performed exclusively by Dr. Elisabeth Kellerwessel. The measurements and evaluations were performed and recorded by me under the supervision of the surgeon. Minor surgical operations that were allowed for this dissertation include incisions and removals of neoplasms. The length and width of incisions were measured with a tape measure before the surgical procedure. Depth was estimated by the surgeon during surgery. Neoplasms are measured for length, width, and height after extraction.

The surgical start is recorded by an exact time of day. To stop bleeding, only ligatures with an absorbable Polysorb (2-0 taper absorbable) suture are placed on large vessels. The ligatures are counted. An electrocautery is generally not used in both group I and group II dogs. The blood is collected exclusively with white Askina gauze compresses (5x5cm) and the swabs, which are completely saturated with blood, are weighed one by one directly on a precision balance, as show in Figure 5.5. This ensured deviations due to drying of the blood and better control over the exact blood loss during the operation time. The weight of the used compresses is subtracted from the weighed weight. The weight of a sterile unused compress is 0.6 grams. In case of incisions, the wound edges are refreshed with the scalpel. Visual quality throughout the operation is rated on a scale of 1-5.

1. All anatomical structures directly visible, no bleeding
2. Structures visible after one dabbing, no secondary bleeding
3. Structures visible for several minutes after dabbing, intermittent rebleeding
4. Structures only visible after dabbing, regular bleeding
5. Hardly any structures visible, blood-soaked

Intraoperative problems are noted, such as a failure or lessening of the blood stop or if the bleeding tendency becomes more severe.

4.4.3 Removal of HemaClear® with measurements

When the wound suture is closed, the operation time is stopped. Depending on whether the HemaClear® model has remained clean or not, it is decided whether the ring is cut or can be reused. The HemaClear® "cutting card" is slid under the ring and the scalpel is used to cut the ring. The compression stocking is pulled off the limb distally. During this process, the time is measured and the end time of the blood stop is recorded.

4.5 Post operative measurements and care

The surgical drapes are removed. Systolic blood pressure is measured five times with HDO® at the root of the dog's tail. The mean value is then calculated. In the Figure 4.8, the application of the blood pressure measurement is shown. The place of attachment of the HemaClear® is checked for skin redness and recorded as yes or no. The dog is taken from the operating table to the recovery room for controlled awakening. He is placed on a warming bed, which consists of several hot water bottles, blankets, and towels. Analgesic coverage of postoperative pain with Vetalgin® (500 mg metamizole sodium monohydrate/ml, 20 mg/kg) was injected subcutaneously into the dogs. Antibiotics were injected subcutaneously into the dogs as needed with Synulox® RTU 140/35 mg (140 mg amoxicillin with 35 mg clavulanic acid, 8.75 mg/kg KGW). Infusion administration remains at the maintenance requirement until the dog is able to stand.

5 Results and conclusions

In the trials performed, a total of 32 dogs were studied. The operations took place in 2020. Figure 5.1 shows an overview of all recorded measurement data of the 32 dogs. The first 15 dogs were operated with HemaClear®, the following 17 dogs without a blood stop. In the table, the following criteria are shown in the columns:

1. Identification number of the dogs
2. Age of the dogs
3. Sex of the dogs
4. Are the dogs neutered or not
5. Shoulder height of the dogs measured in cm
6. Systolic blood pressure before surgery
7. Systolic blood pressure after surgery
8. Surgery type
9. Front or hind leg
10. Length of neoplasia or incision measured in cm
11. Width of neoplasia or incision measured in cm
12. Depth of neoplasia or incision measured in cm
13. Duration of surgery
14. Visual quality of the surgical area on a scale of 1-5 (visible bleeding to structure recognition).
15. Number of ligatures placed on larger vessels
16. Calculated blood loss per minute from total blood loss divided by surgical time
17. Total blood loss resulting from the operation in grams
18. Measured leg circumference at the place of attachment of the HemaClear®
19. Selected HemaClear® model with color and size
20. Estimation of manual application (roll up) of HemaClear® on the limb by the surgeon
21. Measured time of manual application (roll up) of HemaClear® on the limb
22. Time taken for the HemaClear® at the place of attachment to keep the blood in the limb completely drained of blood.
23. Time measured while the surgeon removes the HemaClear®

Dog	Age	Gender	Neutered	Shoulder height (cm)	Systolic blood pressure prae OP (mmHg)	Systolic blood pressure post OP (mmHg)	Type of surgery	limb front/ hind	Size L	Size B	Size T/H	Operation duration (min)	Visual quality	ligatures	Blood loss g/min	Blood loss (g)	Leg circumference (cm)	Applied model	HC placement	Application-time of HC (sec)	Bloodstop-time (min)	Removal time of HC (sec)
1	9	male	no	69	132	135	Neoplasm	hind	1.5	2	1.5	11	1	0	0.09	1	30	medium/yellow	4	24	16	8
2	9	male	yes	64	119	120	Neoplasm	front	3	2	1.5	9	2	1	1.11	10	26	small/pink	3	13	15	7
3	8	male	no	60	135	139	Neoplasm	hind	2	2	1.5	15	1	0	0.40	6	30	medium/yellow	3	25	21	8
4	4	female	no	56	128	130	Neoplasm	hind	1.9	2	1.5	10	1	0	0.20	2	25	small/pink	3	27	14	9
5	2	male	no	68	139	138	Neoplasm	hind	11	10	10	27	2	1	1.15	31	34	medium/Yellow	4	58	32	8
6	4	male	no	65	131	137	Neoplasm	front	2	2.5	1	15	1	0	0.27	4	31	medium/Yellow	2	23	18	8
7	8	female	no	74	136	136	Incision	hind	7	1	1	13	2	1	1.54	20	35	medium/Yellow	4	26	18	8
8	12	female	yes	63	120	116	Incision	front	11	1	3	19	2	2	2.79	53	23	small/pink	1	17	22	6
9	12	female	yes	64	122	122	Neoplasm	front	1.5	2	1	10	1	0	0.20	2	26	small/pink	2	14	14	7
10	7	male	yes	58	112	111	Incision	front	5	1	1	13	1	1	1.92	25	25	small/pink	1	11	19	9
11	1	male	no	60	123	119	Incision	front	15	1	3	31	2	2	2.94	91	27	small/pink	2	23	34	9
12	3	male	no	55	128	130	Neoplasm	front	1	1	1.5	6	1	0	0.17	1	24	small/pink	1	11	9	8
13	3	male	no	53	113	115	Incision	front	6	1	2	13	2	2	1.46	19	25	small/pink	2	15	17	10
14	1	female	no	59	123	119	Incision	front	6	1	1	16	2	2	2.56	41	26	small/pink	2	22	19	7
15	9	male	no	57	126	116	Neoplasm	front	9	9	8	35	5	3	4.11	144	25	small/pink	3	58	39	8
16	12	female	yes	60	123	124	Neoplasm	front	2	1.5	2	22	2	1	1.86	41						
17	11	male	no	62	131	118	Neoplasm	hind	14	16	15	58	5	4	5.03	292						
18	6	female	no	67	117	120	Neoplasm	hind	1.8	1.5	1.5	19	3	1	2.05	39						
19	12	male	no	60	121	121	Neoplasm	front	1.5	2	1.8	20	2	1	1.75	35						
20	12	female	yes	58	138	140	Neoplasm	hind	1	1	1	17	2	1	1.29	22						
21	3	female	yes	61	115	118	Neoplasm	front	1.5	2	1.5	20	3	1	1.85	37						
22	5	male	yes	71	119	113	Neoplasm	hind	10	8	10	46	4	2	3.72	171						
23	2	female	yes	49	126	111	Incision	hind	9	1	3	32	5	3	5.75	184						
24	1	male	yes	62	119	110	Incision	front	13	1	2	34	5	3	6.35	216						
25	3	male	no	57	135	133	Incision	hind	6	1	2	24	4	2	3.38	81						
26	8	male	yes	62	115	109	Incision	front	9	1	2	35	5	2	5.34	187						
27	3	male	yes	69	122	113	Incision	front	10	1	2	32	5	2	6.41	205						
28	5	female	yes	50	134	130	Incision	front	6	1	3	24	3	4	3.71	89						
29	8	female	yes	65	120	121	Neoplasm	hind	5	6	5	24	3	1	2.42	58						
30	8	male	yes	60	123	123	Neoplasm	front	3	2	2	19	2	1	1.74	33						
31	3	male	no	54	138	140	Neoplasm	front	1	1	1	15	2	0	1.20	18						
32	10	male	no	55	132	133	Neoplasm	front	1	1	1	17	2	0	1.18	20						

Figure 5.1: Overview of all measurement data for all dogs examined

5.1 Blood loss and surgical area

5.1.1 Blood loss

Blood loss depends on the type of surgery and the size of the surgical procedure. Of the 32 dogs operated on, 12 dogs had incisions and 20 dogs had neoplasms removed. Both incisions and neoplasms were of different sizes. The smallest incision (Case 10) was 5 cm long, 1 cm wide, and 1 cm deep, whereas the largest incision (Case 11) was 15 cm long, 1 cm wide, and approximately 3 cm deep. The 3 smallest neoplasms were (Case 20, 31, 32) 1x1x1 cm in size, and the largest neoplasm was 14 cm long, 16 cm wide, and 15 cm high. Six of the dogs with incisions were operated on with HemaClear® and six without HemaClear®. Surgical operations of different sizes of neoplasms and incisions affect surgical time and blood loss. To better compare the trials with each other, blood loss per minute is calculated from blood loss and operation time. By calculating the blood loss per minute, the bleeding tendency during surgery is comparably represented. In the following evaluations, the blood loss per minute is therefore applied.

The scatter plot Figure 5.2 shows the blood loss of each dog. The light and dark red dots show the blood loss per minute during the operations without applying HemaClear®. The light and dark blue dots represent the operations of incision wound treatment and removal of neoplasms with the application of HemaClear®. Comparing incision surgeries both with and without HemaClear® application (dark blue and dark red dots) with neoplasia removals (light blue and light red dots), it can be seen that incision surgeries have higher blood loss per minute. The respective spreads of the two operation types with and without HemaClear® correspond to the standard deviation of the average of the respective group. For neoplasms with HemaClear®, the spread of the measured values ranges from 0 g/min to 2.07 g/min, without HemaClear® from 1.07 g/min to 3.32 g/min. For incisions with HemaClear®, from 1.61 g/min to 2.79 g/min and without HemaClear®, from 3.96 g/min to 6.36 g/min. In neoplasms with HemaClear®, an outlier can be seen, which is 4.11 g/min. The reason for this intraoperative problem is described in more detail in subsection 5.1.4.

A comparison in terms of loss of blood loss should not be made between neoplasia (with and without HemaClear® application) and incisions. This is due to the fact that in incisions, larger blood vessels are already damaged by the trauma, whereas in neoplasia surgery, fewer blood vessels are damaged by the targeted incisions. In the trials performed, the neoplasms were all located in the subcutaneous tissue and none extended to the depth of the bones. Bleeding from the bones can therefore be excluded. Larger neoplasms are supplied with larger vessels and lead to increased bleeding when removed.

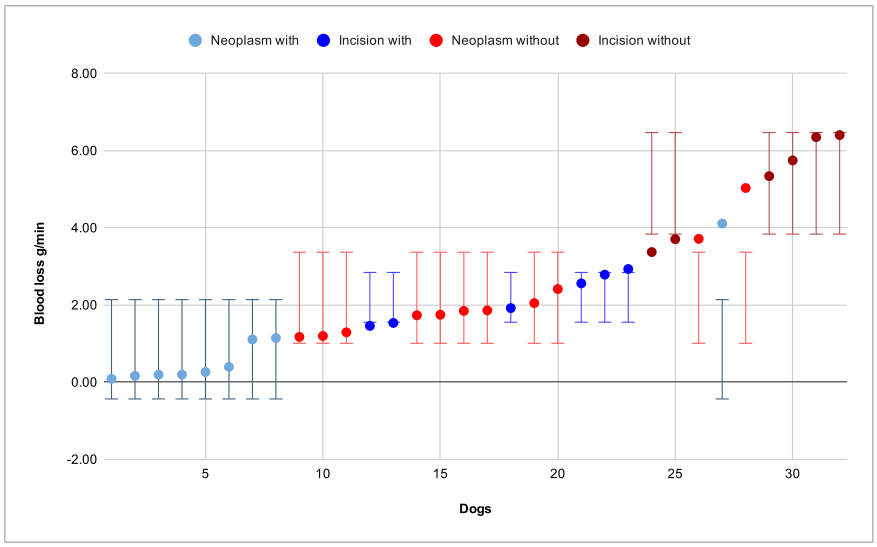

Figure 5.2: All measurement points of blood loss per minute of the dogs per operation type with and without HemaClear®.

Looking at the neoplasms with (light blue dots) and without HemaClear® (light red dots), it can be seen that the application of the HemaClear® blood stop significantly reduces blood loss per minute. For incisions, blood loss per minute was also significantly minimized with the use of HemaClear® (dark blue) compared to surgeries without HemaClear® (dark red). This amplifies the spread shown.

The bar chart Figure 5.3 again clearly shows that the average blood loss in surgeries with incisions is about a factor of 2.4 higher than in the removal of neoplasms. The use of HemaClear® significantly reduced blood loss from 5.1 g/min to 2.2 g/min for incisions as well as from 2.19 g/min to 0.86 g/min for neoplasms.

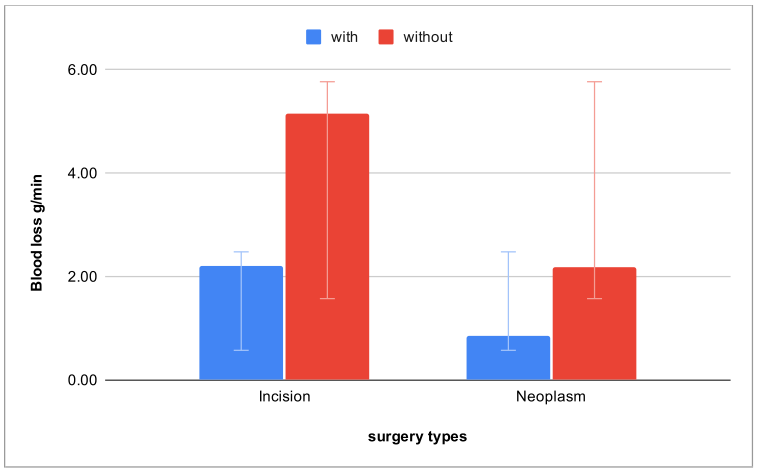

Figure 5.3: Blood loss per minute of the two operation types with and without HemaClear®

Forelimb and hindlimb blood loss in the test data is not significant. This could be due in part to the size of the test data, as 5 dogs underwent hindlimb surgery and 10 dogs underwent forelimb surgery with HemaClear®. Without the use of HemaClear®, 7 dogs underwent hindlimb surgery and 10 dogs underwent forelimb surgery. Here it would be interesting to verify the results with a larger number of measurements.

5.1.2 Visual quality of the surgical area

Visual quality depends not only on the type of surgical procedure, but also on the bleeding tendency during surgery. As previously noted, there was more blood loss per minute in incisions than in neoplasms. In the following Figure 5.4, it can be seen that with the use of HemaClear® (blue bars) in neoplasia removal and incision surgeries, the view of anatomical structures improved significantly.

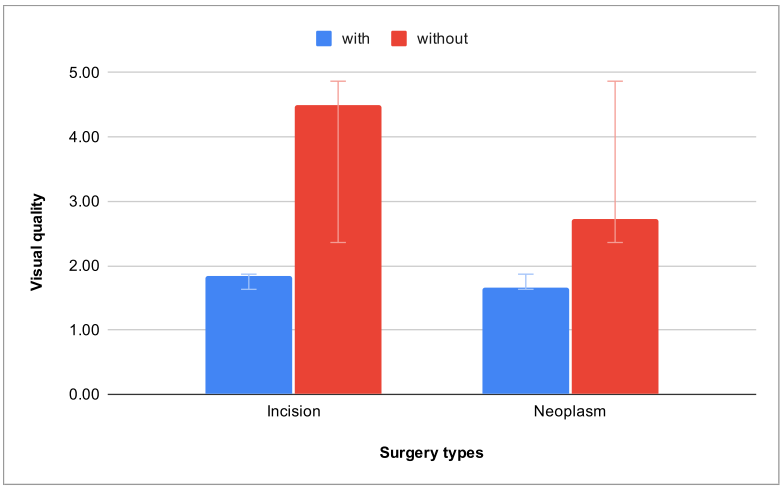

Figure 5.4: Visual quality assessment

In both incisions and neoplasia removals, the use of HemaClear® described the surgical area with an average grade between 1 and 2. This describes a view of all anatomical structures directly or after a single dabbing. This shows a clear difference to a surgical area without HemaClear® application, where a score of 4-5 was given on average. This describes the wound as blood-soaked with regular rebleeding, which only regular dabbing can reveal the anatomical structures. These findings could be attributed to the pre-inflicted traumatic injuries to the vessels, which triggered an increased bleeding tendency during surgery. This bleeding could be reduced with the HemaClear® blood stop. The view of a surgical area of neoplasia without HemaClear® is described between grade 2 and 3. This describes a surgical area with no or intermittent postoperative bleeding and good visualization of the anatomical structures for several minutes after a single dabbing. The standard deviations, visible as dashes above the bars, show the variation in the surgeon's score. In contrast, with the use of HemaClear®, the

variation is much smaller. This shows that despite different surgery types, the visual image can be consistently well displayed with HemaClear®.

Figure 5.5 and Figure 5.6 show the difference of the surgical area between the removal of a pea-sized neoplasm with HemaClear® (Case 1) and without HemaClear® (Case 31).

Figure 5.5: Photo of the surgical area of a pea-sized neoplasm removal without blood stop

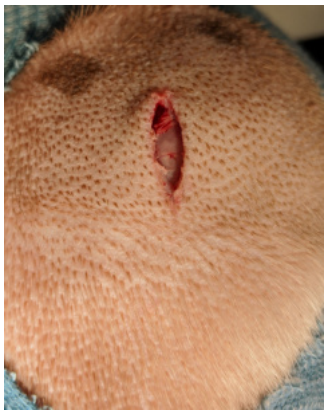

Figure 5.6: Photo of the surgical area of a pea-sized neoplasm removal with HemaClear®

5.1.3 Ligatures

In the following Figure 5.7, it can be seen that fewer ligatures were needed for surgeries with HemaClear® (blue bar) than for surgeries without HemaClear® (red bars). Incisional injuries averaged 1.67 ligatures with HemaClear® and 2.67 ligatures without HemaClear®. Neoplasms also performed better with 0.56 ligations and 1.18 without HemaClear®. Because of the blood void created and the resulting better visibility,

the surgeon injured fewer vessels and thus had to place fewer ligatures. The standard deviations show that there were more or fewer ligatures to place depending on the size of the neoplasm or incision. On deeper injuries, where larger vessels were injured, more ligatures had to be placed, regardless of whether HemaClear® was applied or not.

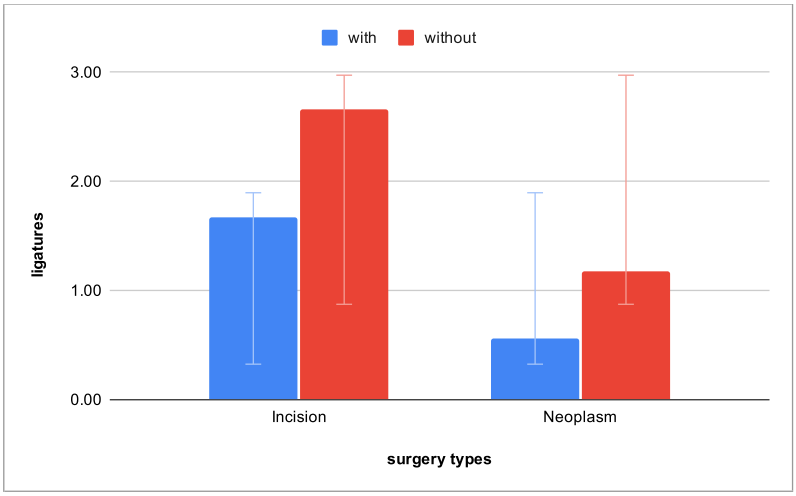

Figure 5.7: Set ligatures compared to incisions and neoplasms with and without HemaClear®

5.1.4 Intraoperative problems

In 14 of 15 dogs, there were no problems with HemaClear® during surgery. The blood stop was constant in these dogs from the beginning to the end of the surgery. There were no increased bleeding tendencies during the surgeries. Only in the dog Case 15 with mandarin-sized neoplasm (9 cm long, 9 cm wide, 8 cm high), which was pulled from lateral to medial, the leg had to be moved several times. The movement of the leg caused the ring to move, resulting in an increased bleeding tendency. This increased bleeding tendency not only increased the blood loss per minute to 4.11 g/min, but also the total blood loss was increased up to 144 g. As a result, after the leg was moved several times, the visual surgical area was blood-soaked and anatomical structures were barely recognizable. The operation time increased to 35 minutes and 3 vessels had to be ligated. This outlier is clearly outside the spread of average measurements in Figure 5.2.

5.2 Systolic blood pressure

Systolic blood pressure has an influence on blood loss. Therefore, the optimal model of HemaClear® must be selected to stop blood flow to the limb. It is of great importance that the systolic pressure is kept constant. In 5 out of 15 dogs, a systolic blood pressure

of more than 130 mmHg was measured before application. For these dogs the yellow model with the size medium was selected.

In the Figure 5.8, the difference of systolic blood pressure before and after surgery of the dogs is shown in relation to blood loss. The two logarithm functions (red and blue lines) indicate that with increased blood loss, systolic blood pressure decreases. By using HemaClear®, the deviations of systolic blood pressure during surgery could be minimized. The systolic blood pressure could be kept more constant. Both with and without HemaClear®, systolic blood pressure decreased minimally on average despite blood loss. However, with extreme blood loss, such as in the Case 15 dog, systolic blood pressure drops from 126 mmHg to 116mmHg despite infusion therapy. The small deviations both with and without HemaClear® can be attributed to the constant infusion administration during the entire preparation, operation, and aftercare time intravenously (perfusion rate controlled with a perfusomator) with a Deltajonin® full electrolyte solution. This measure has the effect that the systolic blood pressure is maintained or in some cases even slightly increased despite the blood loss.

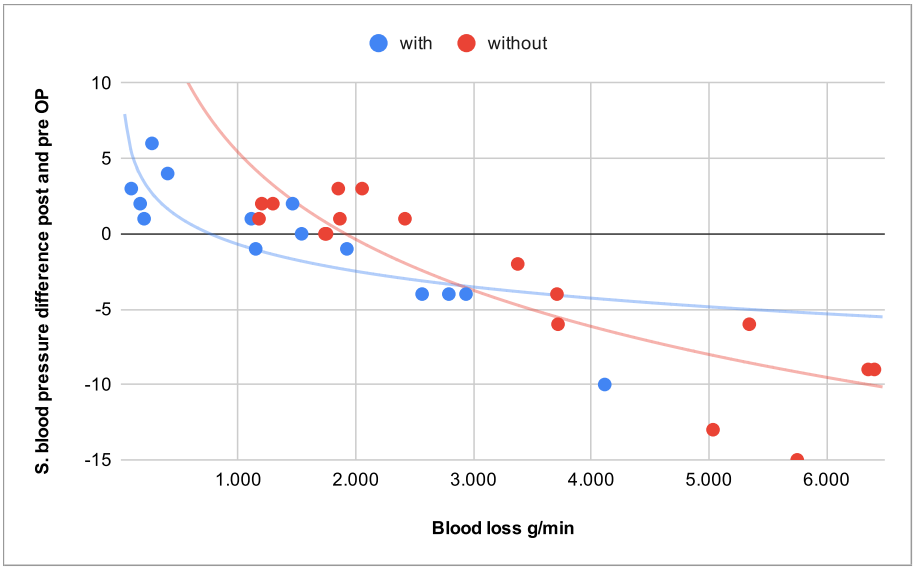

Figure 5.8: Dependence of systolic blood pressure before and after surgery with and without HemaClear®.

5.3 Preparation and operation duration

5.3.1 Operation duration

The duration of surgery depends on the size of the incision or neoplasia. The larger the neoplasia, the more time was required for the surgical procedure. In the following

Figure 5.9, blood loss is related to surgery duration. This illustrates the surgical duration of neoplasms and incisions with and without HemaClear®. It is clear that incisions (light red and light blue dots) require on average a longer operation time than the removal of neoplasms. However, 2 of the neoplasms stand out as having both more blood lost and a longer surgical time. These neoplasms were larger than the others and infiltrated with more vessels, resulting in increased bleeding. Case 17, with the longest duration of 58 minutes, and Case 22, with a surgical time of 46 minutes, deviate from the average.

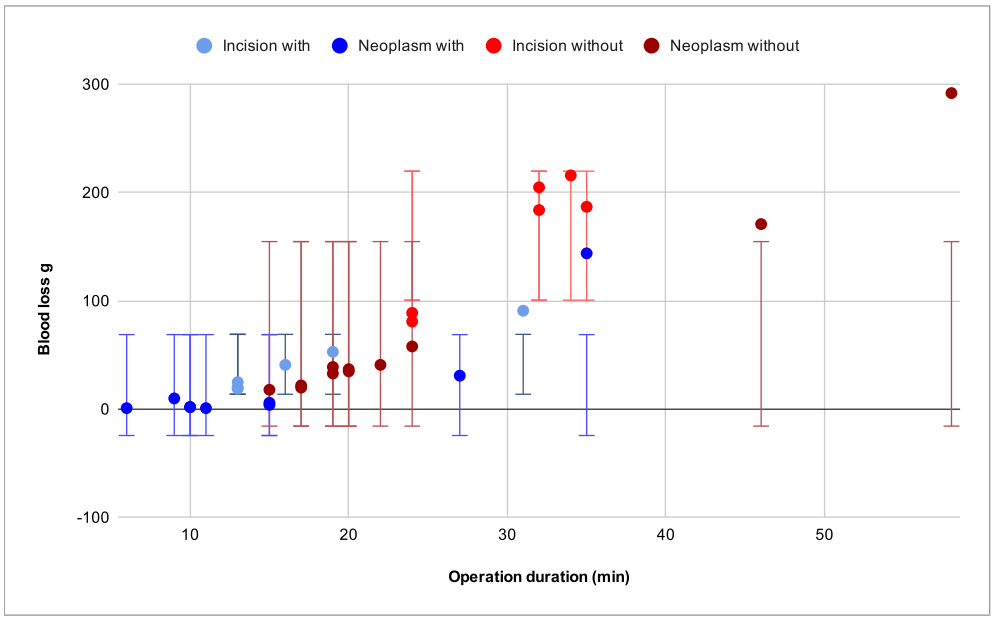

Figure 5.9: Ratio of blood loss to operating time of the two different types of surgery with and without the use of HemaClear®

In the case of an incision, where the vessels have already been injured in advance, there is a longer operation time, both without (light red dots) and with HemaClear® (light blue). In subsection 5.1.2 it was found that an increased blood loss per minute affects the view of the anatomical structures. As a result, the surgeon needed more time for incision operations. With the use of HemaClear® (light blue dots) the operation time is on average shorter than when operating without a blood stop (light red dots). Fewer ligatures lead to a shorter operation time (subsection 5.1.3). The standard deviation is significantly smaller for the operation time with HemaClear® than without HemaClear®. Therefore, it can be concluded that with the use of HemaClear® a significantly predictable operation time can be achieved. This could simplify surgery planning in the clinic.

In addition, the Figure 5.9 clearly shows that there is a relationship between blood loss and operation time. The longer the operation time, the greater the blood loss.

5.3.2 HemaClear® removal

HemaClear® removal was not influenced by any parameters. It took the surgeon between 6 seconds (Case 8) and 10 seconds (Case 13) to remove it. Therefore, I conclude that the removal of HemaClear® does not significantly increase the surgical time.

5.3.3 Disturbance of the ring during surgery

In none of the applications did the ring interfere during surgery. Only dogs whose incisions or neoplasms were distal to the thigh or upper arm and thus had enough distance to the place of attachment were selected.

5.4 Postoperative skin examination

No skin redness was found in any of the dogs after removal of the HemaClear® ring at the place of attachment.

5.5 Differences of the dog characteristics

5.5.1 Ages

The dogs were between 1 and 12 years old. There was only one dog older than 8 years from an incision injury (Case 8). In my trials, younger dogs with incisions and older dogs with neoplasms came to the clinic in greater numbers.

In the following figure Figure 5.10 the dogs are divided into 3 age groups (young, middle age, old). In the trials, young dogs were classified as a dog between 1-4 years, middle age between 5-7 years, and old between 8-12. Age is shown in terms of blood loss per minute with HemaClear® (blue bars) and without HemaClear® (red bars).
However, this diagram could create a false picture, that young dogs basically lose more blood than older dogs. It is important to consider that younger dogs with incisions and older dogs with neoplasms were operated more frequently. Since incisions lose more blood on average, the main focus of this graph must be the standard deviation, which can be seen above the bars. It can be seen from the standard deviations that blood loss per minute with and without HemaClear® is not affected by age. Both older (8-12 years) and younger dogs (1-4 years) may bleed at different rates during surgery. Thus, no significant conclusion about the bleeding of the different age groups can be determined from the test results. However, it is clear that bleeding is lower on average in all 3 age groups when using HemaClear® than in the dogs without the use of a blood

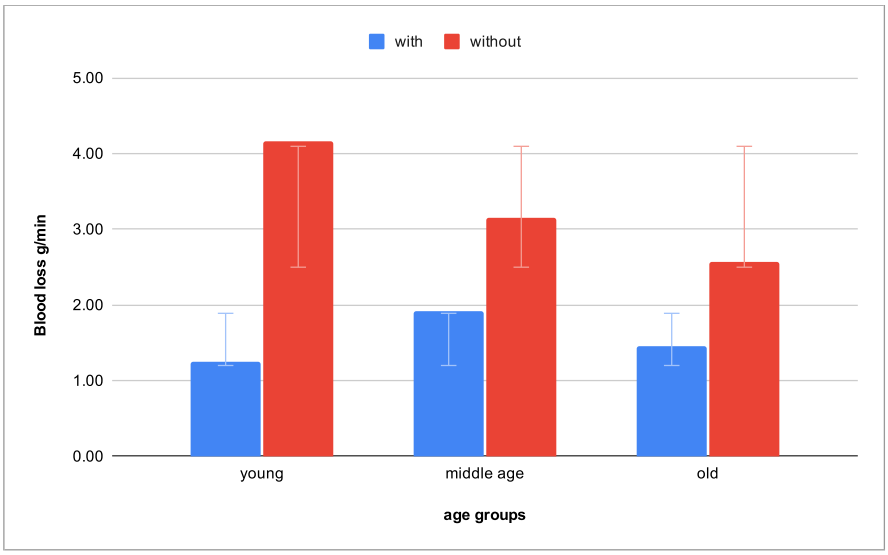

Figure 5.10: Dependence of blood loss per minute per age

stop. Thus, the HemaClear® blood stop was able to significantly decrease blood loss per minute in each age group of dogs.

5.5.2 Gender

More male than female dogs were operated. There were a total of 12 female and 20 male dogs. In the following Figure 5.11, the two sexes are shown in relation to blood loss per minute. It can be seen that in both male and female dogs, blood loss per minute can be significantly reduced with the HemaClear® application (blue bar). The test data does not indicate that blood loss differs between male and female dogs.

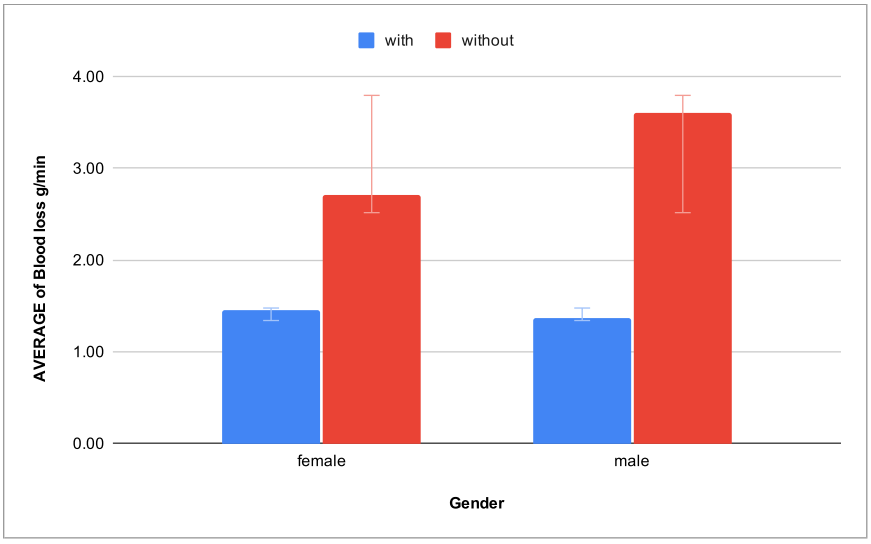

Figure 5.11: Dependence of blood loss per minute per sex

5.5.3 Stock size

12 of the operated dogs were medium breeds and 20 dogs were among the large breeds. In the following Figure 5.12, the size of the dogs is shown in relation to blood loss per minute. It can be seen that the size of the dogs has no significance on blood loss per minute with (blue bars) or without HemaClear® (red bars). Both medium and large sized dogs can lose different amounts of blood per minute. However, it can be seen that with the use of HemaClear® (blue bar) there is less blood loss per minute in both medium and large sized dogs.

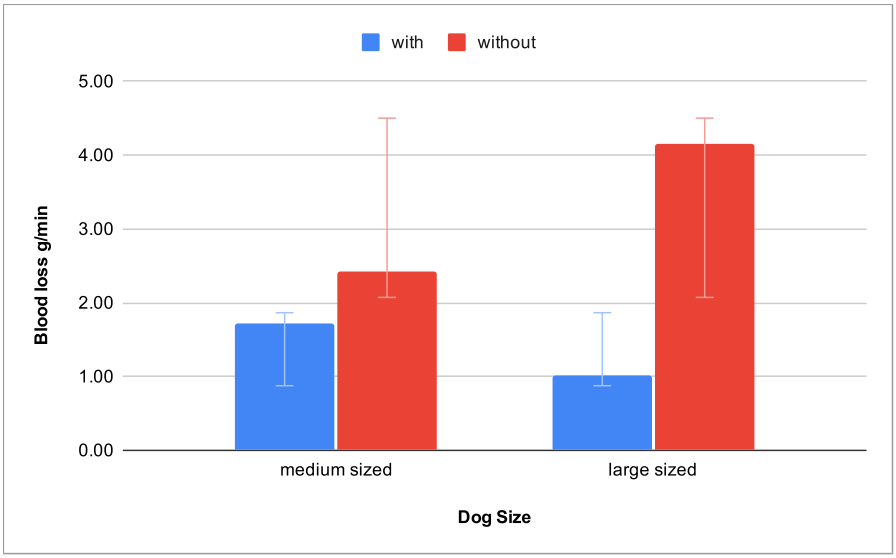

Figure 5.12: Dependence of blood loss per minute per size of dogs

5.6 Comparison forelimbs and hindlimbs

5.6.1 Extent to the place of attachment, anatomical difference.

The circumference of the limbs were measured with values between 24 cm (Case 12) and 35 cm (Case 7). The value depends on how pronounced the muscles are and how obese the dog is. The more fat is stored in the muscle, the larger the leg circumference of the dog is measured. In the trials between medium to large dogs, circumferences of the upper arm and thigh of up to 11 cm were measured. In 10 out of 15 dogs the model small was used.

5.6.2 HemaClear® placement

Overall, more dogs underwent forelimb surgery than hindlimb surgery. Of 32 trials, 10 dogs with HemaClear® and 11 dogs without HemaClear® underwent forelimb surgery.

The difficulty of attaching the HemaClear® varied depending on the size of the neoplasm or incision. It was noted by the surgeon that the application of HemaClear® to the forelimbs is generally easier than to the hindlimbs.

In the Figure 5.13, the assessment of HemaClear® placement of forelimbs and hindlimbs is presented in comparison. Forelimb placement was rated between 1-2, describing easy to moderately difficult placement. In contrast, on the hindlimb, a score of 3-4 was given, describing a moderately difficult to difficult roll-up of the ring.

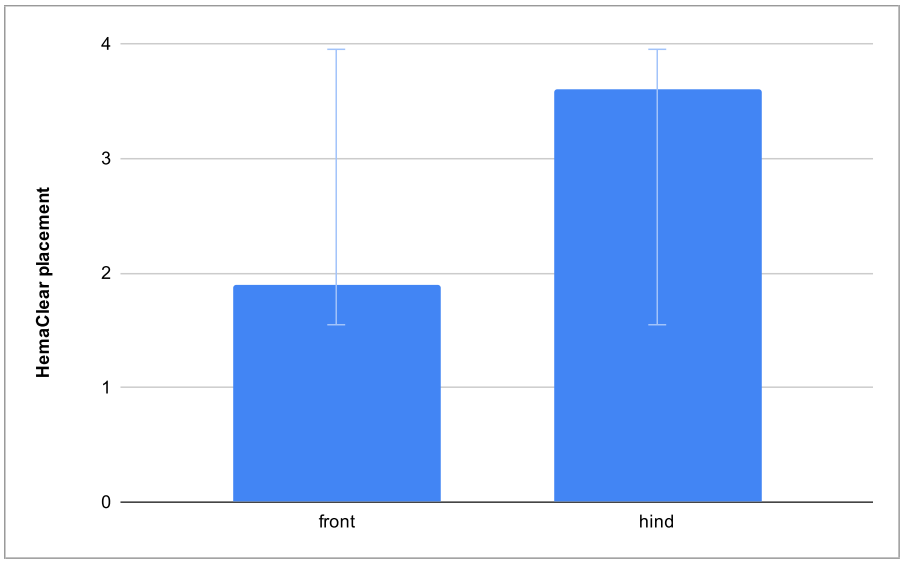

Figure 5.13: Comparison of HemaClear® attachment to the front and rear dimensions

This can be attributed to the differences in the anatomical structure of the forelimbs and hindlimbs. The forelimbs are straight and the muscles are more evenly distributed. Therefore, the ring can be placed more quickly on the forelimb with a time expenditure between 11 sec (Case 10) and 58 sec (Case 15). However, proximal to the ankle joint, it is significantly more difficult to roll the ring over the thigh muscles and to place it at the end in such a way that the ring no longer rolls back. On the hind leg, it is initially easier and quicker to roll distally because the muscles are tight distal to the ankle. Here, the time required ranged from 24 sec (Case 1) to 58 sec (Case 5).

A view of the comparison of blood loss per minute of the forelimb and hindlimb is shown in Figure 5.14. Incisions and neoplasms with and without the use of HemaClear® are compared. Because there are more forelimb surgeries and therefore greater variation in the size of neoplasms and incisions, the variations are significant. However, both forelimb and hindlimb show a significant reduction in blood loss per minute with the use of HemaClear®.

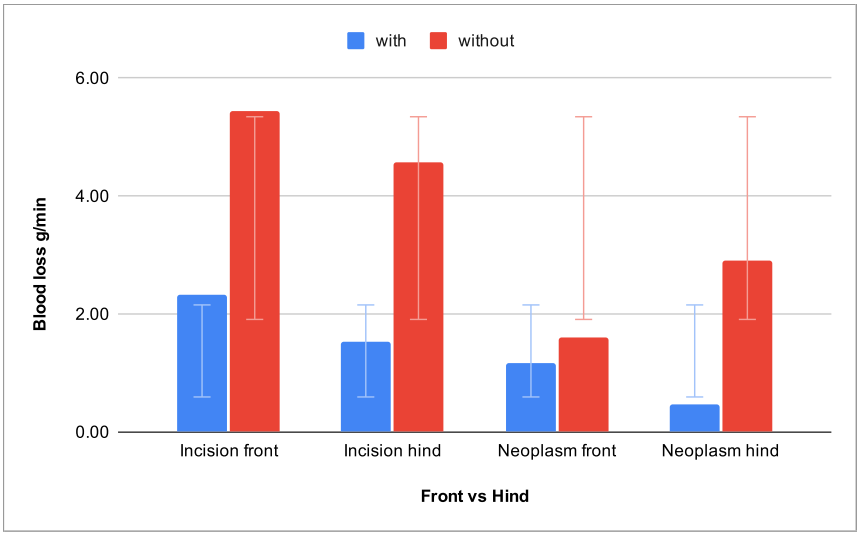

Figure 5.14: Difference of forelimbs and hindlimbs in the two types of surgery with and without the application of HemaClear® in relation to blood loss per minute

5.7 Prospecting future

5.7.1 Age, sex, size of the dogs

HemaClear® worked well in both younger and older dogs. To determine more precise differences in age or sex, a study with more dogs would have to be conducted.

In my thesis, only medium and large dogs were considered. It would be interesting to know if HemaClear® models with a smaller diameter can also be used for smaller dogs and cats.

5.7.2 Type of operation

In my thesis, only neoplasms and incisions were studied. Major surgical operations such as cruciate ligament tears or bone surgery were excluded from this thesis.

In addition to the trials described, I also performed HemaClear® as an outlook on two major surgeries. The first trial was a cruciate ligament tear surgery and the second was a radial ulna fracture. These surgeries had complications due to increased motion when straightening the radius bone. The HemaClear® ring was moved after only a few minutes and the blood stoppage turned into blood stasis. This resulted in increased bleeding. The HemaClear® ring had to be cut directly. No further trials were undertaken. From my point of view, a trial with HemaClear® for major surgical

operations would be very profitable. The product would have to be modified so that the HemaClear® ring does not slip or move.

5.7.3 Costs

The trials did not address the cost of the HemaClear® product. In addition, no attention was paid to reusability. However, less material (swabs and sutures) would be consumed by its use. These would need further analysis to consider routine use of HemaClear®.

6 Summary

Based on the results of the present investigations, the objectives from chapter 3 can be answered as follows:

1. Blood loss and surgical area
    a) HemaClear® can be successfully used for neoplasms and incisions of various sizes on the extremities.
    b) HemaClear® can significantly reduce blood loss during surgery.
    c) HemaClear® provides a visually better view of the anatomical structures in the surgical area. Fewer vessels are unintentionally injured during the surgical procedure, resulting in fewer ligatures to be placed.
    d) During major surgical operations where the leg must be moved, the ring may shift, resulting in increased bleeding.
2. Systolic blood pressure
    a) HemaClear® prevents a major drop in systolic blood pressure due to bleeding during surgery.
3. Duration of preparation, surgery, anesthesia
    a) Placement and removing of HemaClear® takes less than one minute.
    b) On average, the duration of surgery could be shortened by HemaClear®. This automatically reduced the anesthesia time for the dog as well.
    c) The HemaClear® ring did not interfere with the surgical procedure in any of the surgical operations.
4. Postoperative skin examination
    a) No skin redness was identified in any of the place of attachments.
5. Differences of dog characteristics
    a) The age and sex of the dogs had no noticeable effect on HemaClear® use.
    b) HemaClear® could be used on both medium and large dogs as a blood stop without any problems.
6. Forelimb and hindlimb
    a) HemaClear® could be used on both forelimbs and hindlimbs. The placement on the forelimbs was easier and faster to perform than on the hindlimbs.
    b) There were no discernible differences in blood loss with HemaClear® use on forelimbs and hindlimbs.

7 Short abstract

Eller, Anna (2021): Blood stop on front and hind limbs of medium and large sized dogs

In this thesis it is investigated whether the blood stop combination product HemaClear®, which is successfully used in human medicine, can also be used in veterinary medicine. The aim was to investigate whether the use of HemaClear® reduces blood loss during extremity surgery in dogs, the anatomical structures are better recognized by the surgeon, the operation time and therefore the anesthesia time can be shortened and the systolic blood pressure can be kept stable. The trials are used to gain an impression about the placement and removal of HemaClear®. It is also to be evaluated whether the HemaClear® ring disturbs the surgeon during the operation.

Trials were performed on medium and large sized dogs which were treated with different diagnostics at the Small Animal Clinic Kellerwessel in Cologne. The dogs belonged to private persons who consulted the Small Animal Clinic Kellerwessel because of neoplasm removals or incisions on the extremities. The operations were performed by the surgeon Dr. Elisabeth Kellerwessel. All remaining measurements, evaluations and analysis were done by me.

The studies were performed on 15 dogs with the use of HemaClear® and 17 dogs without any tourniquet. Of the forelimb and hindlimb surgeries, 12 were incisions and 20 were neoplasms of varying severity. The age of the dogs ranged from 1 to 12 years. Female and male dogs, neutered and not neutered, were surgically treated. Only medium to large sized dogs with a shoulder height of 40 cm or more were included. Systolic blood pressure was not allowed to be less than 110 mmHg or greater than 140 mmHg. The clinical vital signs of the selected dogs had to be clinically without any special findings before anesthesia (capillary refill time, mucous membranes, heart, respiration, temperature, and skin turgor).

The HemaClear® product was selected using a special tape measure around the circumference of the upper arm/thigh. In the trials, the dog legs had a circumference between 24 cm and 35 cm and therefore two HemaClear® models were applied. The

small pink model (<28 cm) was used more frequently than the medium yellow model.

Prior to the start of surgery, the selected HemaClear® model was placed. The placement was rated and the time to roll up the HemaClear® ring proximally was measured. Placement on the forelimb was rated as easy to moderately difficult, depending on the size of the neoplasm that had to be rolled over. Application to the hindlimb was rated as moderate to difficult. The duration of attachment to the forelimb ranged from 11 to 58 sec, whereas hindlimb time was slightly longer at 24 to 58 seconds.

The total duration of surgery and blood stop was noted. The duration of surgery ranged from 15-58 minutes without HemaClear® and from 6-35 minutes with HemaClear®. During surgery, visual quality was rated and whether if any problems occurred due to blood stop. Better visibility could be achieved with HemaClear®. If ligatures had to be placed on vessels, they were counted. Fewer ligatures were counted in neoplasms and with the use of HemaClear® than without blood stop. In addition, it was noted whether the ring interfered with the surgeon in any way during the surgical operations. Intraoperative problems occurred exclusively during the largest neoplasia removal. Increased movement of the leg caused the HemaClear® ring to be displaced, resulting in increased bleeding. To rate blood loss after the trials, blood was collected during surgery with white gauze compresses and weighed directly. To better assess blood loss in relation to the size of the incision/neoplasia and resulting longer surgery times, blood loss per minute was calculated. Blood loss per mintue could be reduced with HemaClear®. After the surgical procedure, the time of HemaClear® removal was measured. This was between 6 and 10 seconds. Since the neoplasms and incisions were all located at a good distance from the place of attachment of HemaClear®, the ring did not interfere with any of the surgical operations. After surgery, systolic blood pressure was rechecked for deviations from the preoperative value. Systolic blood pressure was supported by whole-electrolyte infusion during the entire procedure. Thus, no major deviations of the systolic blood pressure could be detected. Only in incisions did the blood pressure decrease slightly, which was due to increased blood loss from the trauma-induced increased injured vessels in advance. Finally, the place of attachment of the HemaClear® ring was examined for visible skin redness after removal.

In summary, the research found that HemaClear® can be successfully used in veterinary medicine for medium and large dogs. It reduced surgical time for both incisions and neoplasms. The additional effort to surgery caused by HemaClear® was of short duration and minor effort. The ring did not interfere with any surgery. Due to less blood loss per minute, the anatomical structures could be viewed clearly directly or after a single dabbing of the blood, whereas without HemaClear® there was regular

rebleeding. The resulting better visual quality on anatomical structures due to the blood stop prevented unintentional injuries of vessels, so that fewer ligatures had to be placed. In combination with infusion therapy, HemaClear® can help maintain systolic blood pressure more consistently during surgery. After removal of the ring at the place of attachment, no skin redness was noted in any of the 15 dogs operated on.

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I would especially like to mention my great mother, who always encouraged me to keep at it, gave me the idea of the subject, made it possible for me to realize the trials in her clinic, accompanied me during every trial and supported me in every way.

List of Figures

Appendix 6. Electronic License Agreement and Copyright Declaration

HuVetA

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- *facilitate professional relations and collaboration;*
- *support open access.*

Appendix 4. Supervisor counter-signature form

I hereby confirm that I am familiar with the content of the thesis entitled BLOOD STOP ON FRONT AND HIND LIMBS OF MEDIUM AND LARGE SIZED DOGS

written by ANNA ELLER (student name)

which I deem suitable for submission and defence.

Date: Budapest, 29 day 03 month 2021 year

ÁLLATORVOSTUDOMÁNYI EGYETEM Sebészeti és Szemészeti Tanszék és Klinika 1787 BUDAPEST

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