The Mode of Action of the Broadhead-tipped Hunting Arrow
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Summary
Modern hunting weapon projectiles, expanding bullets or broadhead-tipped arrows, are both effective in quickly immobilizing and killing the quarry and are largely equivalent. The advantages of arrow with broadhead tip are several, which are explained.
The advantages of bullets are, above all, the relative ease of harvesting quarry due to the suitability of rifles for use at much longer ranges and thereby higher time efficiency.

The essay explains the reasons for the characteristical effects of the broadhead tip:
*** the very rapid time course until death, usually due to immediate loss of blood pressure,**
*** the profuse and rapid bleeding with the physiological explanations for it,**
*** the advantage of the arrow as a projectile in the event of a bad hit, and**
*** the explanation for the great penetration ability of the hunting arrow.**

In addition, simple information about possible pain in relation to the hunting arrow's projectile effects is provided.

Enclosed this article is, as a reference, an appendix in the form of video episodes firstly illustrating immobilization of mammals within 5-10 seconds after central lung- or heart hit (1).

Purpose of the essay
The main task of the thesis is to describe, in the light of mammalian anatomy and physiology, the effects of the hunting arrow on mammals, primarily deer, wild boar and moose.
The thesis does not seek to substantiate what has been said with extensive literature references because all reasoning and information submitted are basic knowledge in the human and veterinary fields of anatomy and physiology. Nevertheless some literature references are given.

The purpose of the esssay is to raise awareness of the biological basis for hunting with bow and arrow in the public and the politicians who represent them, in authorities, and among hunters and other nature lovers interested in modern wildlife management.

Introduction

All hunting projectiles, both arrow with broadhead tip and expanding bullet, have a fast killing potential by disrupting the blood circulatory system, causing circulation collapse. Such an effect is primarily dependent on the projectile hitting vital organs with their blood vessel supply. Hunting arrow characteristics and effects on blood circulation is a purification of this desired projectile action.

All hunting with projectile weapons have the ambition to ensure that the prey succumbs quickly. An immediate killing effect is achieved exclusively through hit in the brain, but would thereby present an unacceptable high risk of a crippling injury. Thus, shots directed at the brain are not compatible with responsible hunting practice except in extreme cases. Therefore, the weapon instead should be aimed at a large target area with vital organs, the chest with heart and lungs. As a result, the animal usually moves during the course of death. The median range for roe deer when hunting with rifle was 25-34 meters according to an article in the magazine Svensk Jakt (2), and when hunting with a bow 20 meters according to Association of Danish Bow Hunters, FADB, in 1990 (3)(4) (Figure 1). For moose hunting with bullets, the distance of movement is usually 30 - 150 m (Figure 2). The animal falls when the circulatory collapse causes unconsciousness. When nerve reflexes with muscle tension or leg kicks have ceased, it may appear dead. However, death does not occur by then, but only when the abrogated oxygen supply to the brain after about 5 minutes has led to irreversible brain cell damages.

The animal normally takes advantage of the opportunity to escape freely from the shooting area, but not always. Some animals remain appearently undisturbed at the site after the hit, although running from the site is by far most common. Movement after a shot can vary from a calm pace to a sprint, much depending on whether the animal was relaxed or in alert mode immediately before the shot. The escape reaction is a normal protective behavior to any sudden disturbance and should not be construed as evidence of pain, anxiety or fright.

The medical term anxiety means a deep fear that the subject can find no cause for. Attributing the term anxiety to an animal because it has been hit by a hunting projectile is likely a consequence of a human projection of its own discomfort, when confronted by animal behaviour, but is not a reality for the animal (9).

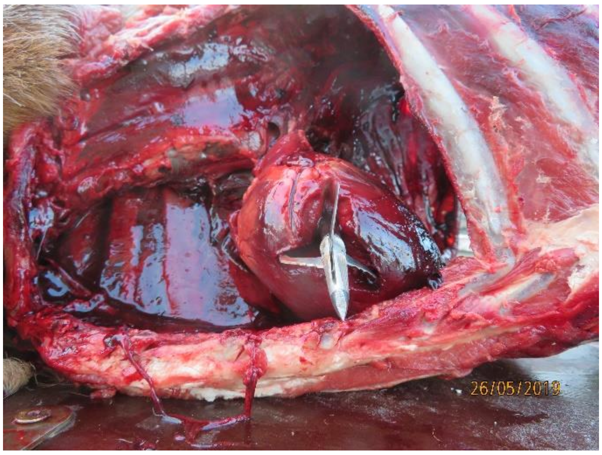


Figure 1. Heart from an adult roe deer buck shot through with mechanical broadhead tip with cutting width 44 mm. Pericardium removed and arrow repositioned in the heart. The cut surfaces illustrate the ¨rubber band effect¨. Shot distance 14 meters. Movement until immobilisation 39 meters.

Figure 2. Heart from an moose bull pierced with expanding bullet 9.7 grams caliber 7x57 R. Firing distance 35 meters. Movement until immobilisation 135 meters in full rush.

The hunting arrow

The effect of the arrow in the prey is mainly defined by the characteristics of the arrowhead. Modern arrowheads are separate units and screwed onto the arrow shaft. They can be of different types depending on the property desired. Arrowheads used for most game species, ranging in size from hare to wapiti or African buffalo, are known as broadheads, and there are a large number of variants. A broadhead is defined as an arrowhead that has the property of providing a wide wound channel and is designed so that it results in rapid killing of the prey. It is provided with 2-4 blades and usually the cutting width is 25 - 35 mm, but can be up to 60 mm. 3-bladed tips are most common as they are supposed to provide the widest wound channel with the greatest probability of hitting blood vessels in relation to the penetration depth (Figure 3). The blades may be fixed or so-called mechanical. Mechanical blades turn out from the ferrule in contact with the game so that the wide cutting action is ensured. But in flight, the blades are cohesive, resulting in less air resistance and more stable arrow trajectory. This feature allows mechanical broadheads to be manufactured with a wider cutting edge than fixed blade broadheads, up to 60 mm.

The penetration ability of the hunting arrow is regularly greater than that of the expanding bullet. When hunting Nordic small and medium-sized deer, throughshots defined as the broadhead in total having perforated through the hide on the far side, are, in the opposite of hits with expanding bullets, normal when hit from the side (Figures 4 and 5).

Archers should use razor sharp broadhead blades. The projectile then causes immediate or rapid loss of blood pressure and profuse bleeding. The animal succombs quickly. In several situations, a razor-sharp bladed broadhead is more effective than an expanding bullet.

Figure 3. Broadhead tip with fixed blades.

Loss of blood pressure at central lung hit

Both if the aorta is cut off, in whole or in part, if other large arteries in the thoracic cavity are cut off, or if the heart is severly damaged, the blood pressure in the arteries to the brain ceases immediately or almost immediately. It simultaneously causes cessation of oxygen transport to the brain leading to unconsciousness after about 5 seconds. (5).

Figure 4 and 5. Test shooting against an already fallen moose. Oneida SE 600, 67 lb. Both arrows towards the chest side penetrated fully and continued into background vegetation and soil. The third arrow, shot toward the front of the shoulder blade with its bone crest (spina scapulae) penetrated throughout the thorax.

Also, when cutting off the large veins, pulmonary veins or superior vena cava with an arrow hit in the central lung area, a rapid loss of returning blood volume to the heart results in seriously low blood pressure impairing brain function.

Rapid blood loss with other hits
The blood pressure in reindeer arteries is between 130 and 153 mm Hg (6). Measurements on moose have shown the same blood pressure levels (7). Probably other deer animals have comparable blood pressure. This means that the pumping of the heart gives the blood an overpressure in rein deer capable of raising a mercury pillar 130 - 153 mm. Since mercury is 13.6 times heavier than water, it means that an upwardly cut artery hoses blood about two meters up in the air. The aorta adjacent to the heart of roe deer has an inner diameter of 8 mm (measured by the author).
It is easy to comprehend the rapid loss of blood that is the result of a severed large artery.

Stress hormones released
When the volume of blood rapidly decreases during heavy bleeding, the circulation system automatically strives to compensate for this. It occurs partly by an increase in pulse rate and partly by a redistribution of blood. Blood from the body surface, abdominal organs and legs is redirected to the heart, brain and muscles. This automation works partly through an increased secretion of stress hormones, mainly adrenaline, and partly through nerve reflexes.

Withstands 20% blood loss
Such compensation for blood loss can be greatly accentuated if the injured animal becomes frightened. Then its ability to withstand shock is enhanced by the increased secretion of adrenaline. Adrenaline rases the frequency and contraction strength of the heart, thus giving the animal further ability to run away. In this way, a rapid decrease in blood volume of up to 20% could be compensated for, causing maintenance of blood pressure without losing the vitality of the animal. In addition, thirst increases and the animal might seek water to drink, thereby replenishing the blood volume.

Hypovolemic shock
If the blood loss becomes greater, the animal falls into a shock state, a so-called. hypovolemic shock. This is characterized by lowered blood pressure, increased heart rate, decreased alertness, increased disturbance and pale mucous membranes. The state of shock occurs when about 35% of the blood volume is lost, if the loss developes quickly. Compensastory mechanisms counteracting decreasing blood pressure will fail when mean arterial pressure falls below 50 mm Hg (16). When mean arterial pressure falls below 40 mm Hg, oxidativ metabolism in the brain starts to become compromised, and pressures below 30 mm Hg lead to irreversible brain tissue damage (13).
With further bleeding, the central functions of the system can no longer be maintained, the animal becomes unconscious and dies.

The time-lapse (13)

<u>A central hit in the heart-lung area</u>
When the heart or major arteries, aorta, or other large arteries in the center of the lung area are intersected, blood pressure ceases almost immediately. The blood supply to the brain then completely ceases, and unconsciousness occurs about 5 seconds (5) thereafter (figure 6).

Example: A roe deer, which, at the time of the shot and frightened by other hunters already speeding maximally, was shot by the author with broadhead-tipped arrow in Denmark with a broadside shot at 3 meters. The aorta was completely cut close to the heart by the broadhead with immediate loss of blood pressure to the brain as a result. The hunter counted seconds from the shot - it was 5 seconds until the sound of the animal falling on a bed of dry branches was heard. The distance run was measured being 105 m.

<u>Large veins cut</u>
If, instead, the large veins centrally in the pulmonary region, but not the largest arteries, are damaged, decrease or cessation of blood pressure very quickly occurs as the heart then does not receive blood enough to pump out with sufficient pressure.

The brain cells are irreversibly damaged when no oxygenated blood reaches the brain, and brain death starts to develope after 4-5 minutes (5).

The author's measurements on an adult roe deer resulted in a heart-pulmonary central hit area at a broadside shot of about 220 cm^2. Of this area, the heart and the largest blood vessels with a surrounding border of 8 mm width, represent 120 $cm^{2.}$ This equals 55% of the broadside lung area. The border constitute an additional area since the target area for a broadhead with at least 25 mm cutting edge naturally is somewhat wider than the most central vital area. Hits within these 55% of the broadside lung area result in complete loss of blood pressure immediately or within a few seconds, and unconsciousness occurs 5 seconds thereafter.

On hits outside of the most central vital area of the thorax resulting in double-sided pulmonary collapse, the time course is determined more by greatly reduced blood reflux to the left heart side from the pulmonary circulation along with internal bleeding. More on this below.

Laceration of medium or smaller arteries

Medium-sized arteries are for example those in the legs or in the center of the digestive system. In case of injury to them or to smaller arteries, different mechanisms come into action to conteract the bleeding.
If the bleeding hereby is slowed down, the process until unconsciousness and death is delayed. In practical hunting with a bow and arrow, in such cases, the animal is usually found dead in it´s cover within 50 - 100 meters from the shooting site.
On the other hand, the animal might survive and recover if the blood loss was not too profuse.

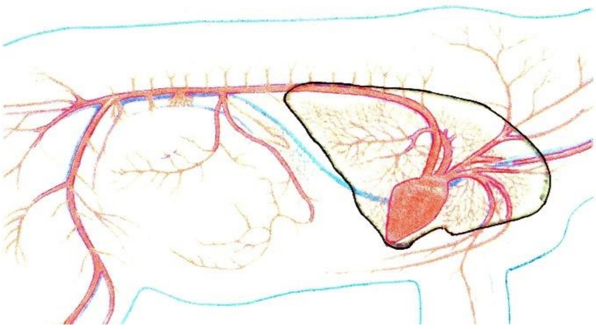


Fig. 6. The large arteries of white-tailed deer in one body half. The reader should thus image the arteries doubled with exeption of aorta. Together with the heart they constitute a broadside hit zoneof the lung area (marked). In addition there are corresponding vascular trees of veins.
Image: Deer & deer hunting (8).

Pulmonary collapse (pneumothorax)(13)

Bilateral pneumothorax

When the arrow penetrates through the lungs of both sides, a double-sided lung collapse occurs. Such a condition is always fatal, even if the arrow has not hit the central heart- and lung area. In large trauma with wide openings of the chest wall, but where the central heart-lung area is not hit, unconsciousness usually occurs within a time interval of 1/2 - 4 minutes.

Short time-lapse

The explanation for the short time-lapse until unconsciousness compared to a person's ability to hold their breath, is the following: Immediately as the thoratic wall on both sides are opened by a broadhead-tipped arrow the negative pressure between the outer and inner layers of the pleura, holding the lung tissue in an air-filled and blown up position, no longer exists because of air leaking in through the chest walls. Thereby the lungs collapses, due to the intrinsic tension of their tissues, into an organ volume considerably much lesser than the original lung volume. The pulmonary collapse obstructs blood circulation from the right heart side from passing through the capillaries of the collapsed lung tissue, and from there via the pulmonary veins to reach the left half of the heart, from where the oxygenated blood then would have been pumped into the aorta.

The obstruction of the passage of blood through the collapsed lung tissue is partly explained by the blood pressure in the pulmonary circulation being much lower than the blood pressure in the large arterial circulation, and partly by the contraction of the pulmonary tissues excerting compression of their capillaries and veins causing obstruction of blood passage (13).

<u>Unilateral pneumothorax</u>
Unilateral pulmonary collapse without significant simultaneous bleeding is not fatal. This only happens as rare exceptions during responsible bowhunting.

Lateral shot in the lung area - summary
Broadside shots that hit the central lung area produce immediate, or almost immediate, loss of blood pressure resulting in unconsciousness within 5-10 seconds (1).

For remaining broadside shots with hits in the lung area, the time course until unconsciousness is likely to be within 1/2 - 4 minutes. These given time figures are referring to double-side lung collapse with the consequence of an obstruction of blood passage through the lung tissue, thus strangling blood supply to the left half of the heart. As a result, the heart's pumping function is obstructed, blood pressure drops, and sufficient flow of oxygenated blood does not reach the brain.

Anti-bleeding mechanisms (Fig. 7)

<u>1. Trombosis formation</u>
A medium or small sized artery, which is torn off or ruptured in whole or in part, can within a short time stop bleeding by contracting the exposed vessel end around a blood trombosis at the injury. This occurs if extensive enough tissue damage have affected the blood vessel. The blood clot formation is triggered by the injury surface of the vessel wall causing the platelets in the blood to become stuck and quickly accumulate into a plug that clogs the blood vessel. Substances, that are released from the injury, cause the formation of a rigid network of fibrin in the blood clot, which makes it strong. At the same time as the plug formation, the artery end contracts around the plug through cramp in the muscle layer of the vessel wall. The larger the damage is to the blood vessel wall, the more efficient and faster the blood clot and the vasoconstriction develops.
Cf. surgeons' use of what is called blunt dissection to avoid local bleeding when an operating area needs to be expanded, using a scissors with blunt ends, not cutting, but stripping the tissues apart by spreading the shanks of the scissors.

<u>2. Arterial spasm</u>
A medium or small sized artery that is exposed to blunt force against the vessel, or is torn off, can develop a cramp in the muscle layer of the vessel wall (vasoconstriction), tightening the blood vessel so firm that he blood flow is completely shut off. The spasm can extend over several centimeters in length of the artery and last for 24 hours. Large arteries, like the aorta, has no muscle layer and therefore are unable to develop arterial spasm.

<u>3. Coagulation</u>
Two coagulation mechanisms - one slow, and one fast.
The slow coagulation reaction is started by a damaged internal wall surface of a blood vessel activating a protein agent. This gives rise to the first step in a chain of slow reactions, which finally activates the very rapid final phase of blood coagulation. The rapid coagulation reaction is started by the release of a lipid agent from damaged tissue. In the event of major tissue damage to and around a blood vessel, a sufficient amount of this substance is rapidly triggered to directly activate the rapid final phase of coagulation. The blood therefore coagulates faster if more cells are damaged in or around a blood vessel. An example of prolongated bleeding by sharp cuts, is the bleeding from cuts when shaving with razor blades.

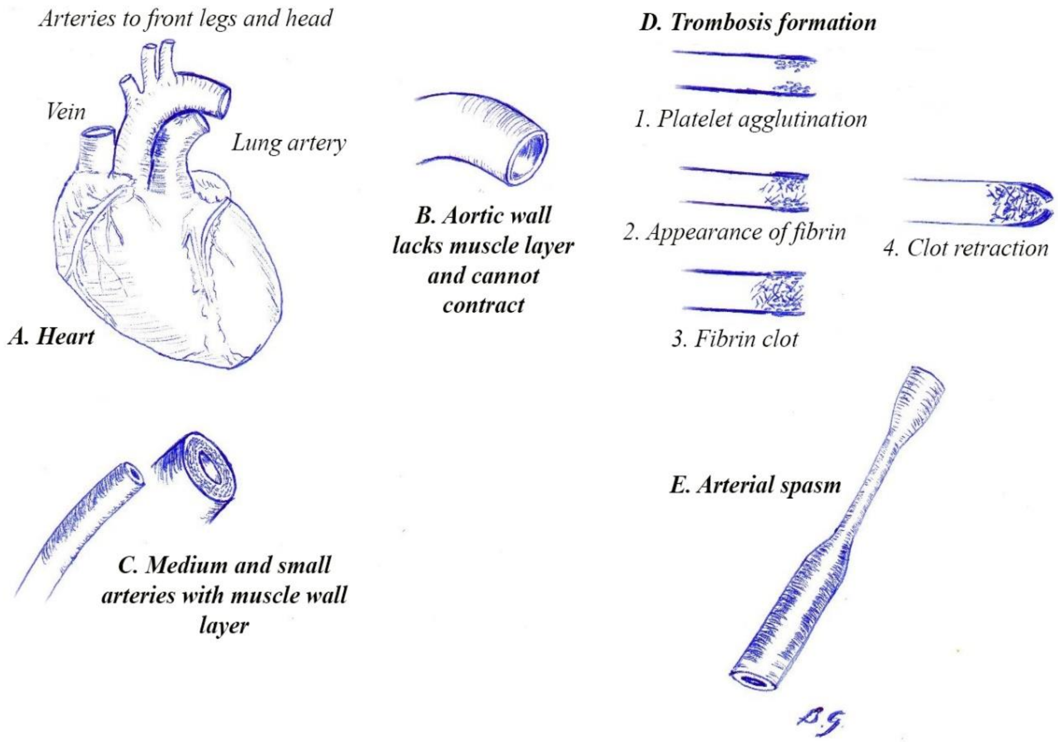


Figure 7. A. Human heart seen from the front.
B. The aortic wall lacks muscle layers and cannot contract.
C. A medium or smaller artery has a muscle layer in the vessel wall. Arteries with muscle layer can stop blood flow through muscle spasm in case of injury.
D. Development of thrombosis.
E. Blunt force or more widespread injury results in larger and stronger spasm reaction.

4. Increased tissue pressure

In those cases where a damaged artery is located within a muscle or between other strong tissue structures, the bleeding is quickly reduced by the increasing tissue pressure that arises around the blood vessel. If the injury widely opens up the tissue around the artery, or if the tissue around the blood vessel is more loose, as in the thoracic or abdominal cavity, the pressure of the blood stream meets less resistance and the bleeding can continue freely. A broadhead-tipped arrow opens large enough cavities so that bleeding is not stopped by an increased tissue pressure. The opening is also enlarged by the permanent intrinsic tension of muscle fibers which exists also at rest. When cut off this results in retraction of the muscle bundles, similar to cutting a tensioned rubber band.

Razor sharp arrowhead blades

The three first-mentioned mechanisms, which can reduce or stop bleeding from injured arteries, are substantially more activated with increased damage to the vessel wall or surrounding tissues. This is one reason why broadhead blades should be kept razor sharp. It explains why the bleeding can be more profuse, and the blood loss develop faster, after a hit by an arrow than by an expanding bullet. It also explains why the hit surface of the animal to quickly achieve a killing effect is larger for a razor sharp, broadhead-tipped hunting arrow than for an expanding bullet. The difference is particularly important in the event of an abdominal hit with no penetration to the thoracic cavity. Such a hit by a hunting arrow usually kills the game within few hours in contrast to a time course of up to more than a day with expanding bullet.

Arrow is advantageous in case of a bad hit
A hit of an broadhead-tipped arrow with razor-sharp blades lacerating skin, or both skin and muscle tissue, is far less serious than the corresponding hit with expanding bullet.
A broadhead-tipped arrow results in a relatively clean wound where few skin particles and hair are inserted. In muscle tissue, a broadhead wound bleeds profusely, which causes the wound to become cleaner with less risk of severe infection.

<u>Less risk for crippling or death</u>
A broadhead also gives much less tissue damage, thereby with less risk for tissue death (necrosis), both adjacent to, and in a distance from the wound canal, compared to the case of an expanding bullet. Tissue damages resulting in necrosis lead to increased inflammation processes, most often with severe infections, resulting in prolonged wound healing, crippling or death.
An arrow hit does not cause any remote damage at all and the damage is without crushing or splitting effects. When not fataly located this type of injury usually heals quickly with less complications, often without affecting the general health of the animal.

<u>Compared to expanding bullet</u>
Corresponding hits with an expanding bullet, and especially at high speed, are more serious. It usually causes extensive, local crush damage leading to tissue necrosis, and additionally hair and skin particles penetrating into crushed tissues. The bullet also provides a remote effect in the form of secondary splinters from bone tissue, lead and mantle residues. In addition, an explosive effect can be obtained, for example with a hit in the liver, by the pulsating cavity formed at the passage of the bullet.

The hunting bullet type of injury carries a significantly higher risk over time for the development of wound infection, sepsis, and toxic shock effects of degradation products from the damaged tissue. This results in difficulties to heal from infections and a obstructed healing process.
As a result, more pain follows the injury, prolonged pain in the later stages, and above all, significantly less chance for the injured animal to survive the injury.

Pain experience in the prey animal (9)
In connection with the traditional hunting weapon projectiles, the question of whether the projectile's hit, or immediate effects by the hit, gives pain to the prey, is never discussed. However, this is not the right forum to bring forward the topic of pain effect of bullet projectiles.
The situation is another when it comes to the hunting arrow as a projectile, as legalizing this type of weapon for hunting is under discussion in several countries. The issue, therefore, is made topical here.
Neurophysiology is a comprehensive field of knowledge. Only a few basic mechanisms will be presented here.

<u>What is pain (9)</u>
Pain is the discomfort the individual experiences when pain receptors are activated and give rise to a signal in the nerve fiber of the pain receptor, and the signal has reached the brain's consciousness. Pain receptors for mechanical damage are so-called free nerve endings of special nerve fibers (C-fibers), which have the task of being activated by specific stimuli, e.g. mechanical damage.
Cutting a nerve does not cause pain but only loss of nerve function, such as the ability to feel or muscle movement. If a projectile hit activates a pain receptor but the same projectile immediately cuts off the current nerve fiber, pain will not occur.
In contrast, an inflammatory or chemical irritation to a nerve can cause pain.

Although experiences of pain in humans to some characteristics may be different from pain in other mammals, some of the knowledge from human emergency clinics is of use to understand pain from injuries in animals.

Excerpt from Gregory, NG (13), 2005:

«There are anecdotes in humans that arrow injuries are not immediately painful (Petersen 2000). This is consistent with experience at emergency clinics in hospitals, where severe lacerating injury have been reported as being painless at the time of the injury (Table 1) (Melsack et al 1982). The depth of an injury influences whether it will be immediately painful. When injuries are deep (eg fractures, crushes, amputaions, and deep stabs), 72% of subjects experience prompt pain. When injuries are limited to skin (eg.lacerations, cuts, abrasions, burns), 53% of subjects have a pain-free period immediately following the injury. Persistent pain developes later when the pressures associated with hemorrhage, oedema and inflammation develop, and when pain receptor agonists released from the injured tissue accumulates at the wound (Gregory 2004). These types of pain would be relevant in bowhunting cases where shot animals have survived for days.»

Pain inhibition (10), (11)

The nervous system has extensive intricate systems to modulate a pain impulse, both at the spinal cord level and in the brain. Such modulations include the possibility of pain inhibition, which consists of systems that reduce or completely remove pain signals.
A commonly known example is to apply a competing pain - pinching the skin near an injury makes it less painful.
Another application of pain inhibition is that in a danger situation, survival takes precedence over the advantage of the warning signal from pain. Then the pain is prevented from reaching the consciousness because it is more important to cope with the danger than to be hampered by pain. For example, in a battle situation when the soldier sometimes does not experience pain despite a serious acute injury, but where the pain comes only after he has been brought to, or himself reached, safety.

Spinal pain inhibition

Similarly, so-called spinal pain inhibition (reflexive nerve reaction in the spinal cord that extinguishes or diminishes a pain signal) extinguishes or decreases the degree of pain impulse in a projectile hit animal so that pain should not become an obstacle to escape and seek shelter. But when the emergency situation is averted, the pain returns. This then causes the animal to keep still, which increases the possibility of survival.

Pain sensitive structures

Some organs lack pain receptors. It has the logical reason that pain receptors are mainly located where they give advantages by creating a warning signal. Just as the Vikings kept their shields in front of them in battle - and did not have shields behind their backs - the body has located the pain receptors where a signal of injury can give a protective defense response.
The pain-sensitive organs, therefore, are mainly: Skin, bone membrane, outer lung sac blade, meninges and articular capsules. However, the inner lung sac blade, lungs, cartilage and brain are completely without pain receptors. The intestines almost lack pain sense, and muscles have only limited amount of pain sense receptors (12).
In addition, the pain receptors are variously closely located - on the inside of the hand and fingers are they very closely positioned, in contrast to the markedly sparse appearance on the back. A wound cut in the finger, therefore, hurts much more than the same wound on the back.

Triggers a small number of pain receptors.

The hit surface area at a lateral shot and impact in the lung region is extremely small - almost exclusively the cut edges of the skin, the periosteum, and the outer blades of the lung sacs. Few pain receptors are then activated. This explains why bow hunters sometimes can tell you that a through-shot deer showed no sign of having noticed anything abnormal until they fall into unconsciousness after a few seconds (1). Among humans there are many examples of a serious stabbing not being perceived with pain at all.

Pain is lacking in bleeding-induced shock

Haemorrhagic shock (so-called hypovolemic shock) is described above. This occurs if rapid bleeding has caused about 35% blood volume loss. In hypovolemic shock, it is known from human medicine that pain does not exist, and that analgetics are not needed until the shock state is about to be lifted by fluid infusion.
The consequence in a hunting situation is that a shot animal with high blood loss, and after reaching the state of a hypovolemic shock condition, does not experience pain, but
- first of all - a high degree of weakness.

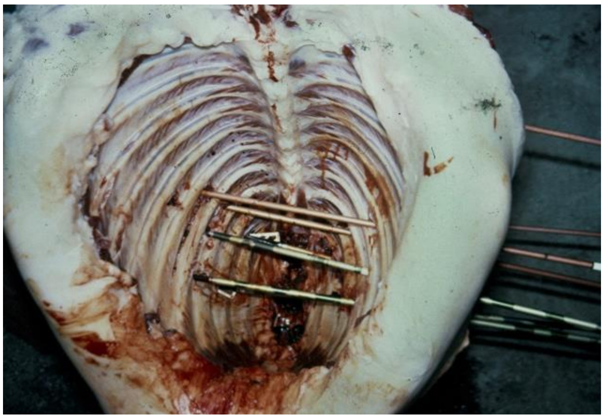
Pain summary
How often and to what extent animals feel pain after being hit by a broadhead-tipped arrow is unknown. Several known physiological factors and nerve mechanisms indicate that pain after such an arrow hit usually is limited, or may even be absent. In case of a misplaced hit which has resulted in a state of hypovolemic shock there is no pain. In case of a misplaced hit with longer survival, a hit by a hunting arrow is likely to have a lower degree of pain suffering than what is the case after a corresponding hit by an expanding bullet.

Hunting arrows penetration ability

<u>Some real examples from the author's own, or other controlled/verified cases:</u>
The normal course of broadside shots with arrow on medium-sized deer, roe deer, and small game is through-shot with the arrow found buried in the ground after the shot.

Test shots with broadhead-tipped arrows in broadside shots to the chest of an already fallen moose resulted in throughshots Figures 4 and 5).

Test shooting with hunting arrows conducted on an already killed very large 11-year-old wild boar (205 kg) in a suspended standing position, demonstrating the great penetration ability, is here reported on (Figures 9, 10 and 11).



Figures 9 (photo Hans Johansson) and 10. Test shots on a killed 205 kg wild boar with length 200 cm performed after death stiffness. Shot distance 20 m. Bows Oneida SE 600, 72 lb, Oneida T 250, 44 lb, Golden Eagle 67 lb. Broadheads used to the back and the shoulder blade were 2-bladed, all others 3-bladed, 32 or 35 mm cutting width. One arrow had first perforated both the shoulder blade and the 2nd rib, and one cracked the rib on the exit side. The arrow to the back did cut off the spine. The arrow against the shoulder blade crest cracked both it and the shoulder blade but did not penetrate further.

Figure 11. The collagen-like subcutaneous shield was 2.5 - 4 cm thick. It was impossible to punch through with a sharp pointed hunting knife. Hits made noice as if a gravel pile was hit. Photo: Hans Norgren

Test shooting against free-preparated fresh ribs from moose, densely bundled in a package with a thickness of 4 layers of ribs, gave through-shot (Fig. 8). A pack of 6 layers of ribs burst all the way through.

Moose shoulder blades are easily cut through with broadhead-tipped arrow. Striking the humerus of a deer the broadhead breaks the bone, but then most often is hindered to penetrate deeper. The spine of moose and wild boar would be completely cut through by a broadhead-tipped hunting arrow, and such a hit most often would cause immediate paralysis by the cut through the spinal cord (1).

A broadside shot of a world record sized eland bull with an estimated live weight of 800 kg gave full chest penetration with cracked rib on the exit side.

Statistics from bowhunting in Denmark proves that hunting arrows nearly always (92.5%) perforate totally through roe deer at broadside hits (local regulations: 3-bladed with cutting width >25 mm, >25 g, E0>40 J) (14).

Penetration degree	***Numbers of roe deer***	
Arrow passed through completely	*62*	*92,5%*
Full broadhead penetration with arrow remaining in deer	*5*	*7,5%*
Partial broadhead penetration	*0*	*0%*

Figure 8. Pack of fresh ribs from moose tightly bundled in 4 layers of ribs. Through-shot with hunting tip inserted into stump behind.

An arrow hit on a roedeer (Fig. 13) cut two ribs on the entry side, perforated the heart (Fig. 1), cut a rib and the humerus bone at an olbique angle on the exit side (Fig. 14) before it stopped in the elbow joint on the exit side. Draw weight of the bow was set at 55 pounds.

Figures 13 and 14. Roe deer buck taken at 14 meters from 5 m high tree stand. 3 ribs cut. Heart pierced (see Figure 1). When exiting one broadhead blade cut through the humerus at an oblique angle before being stopped in the elbow joint (at the left side of the photo).

Penetration into a sack of sand

Although the essay focuses on the hunting arrow's mode of action in mammals, it might be interresting to note the difference in penetration between a broadhead-tipped arrow and an expanding bullet when shot in sand. The difference is largely explained by the fact that the front surface of the bullet is enlarged during and after the impact, while the very minimal front surface of the broadhead penetrates unchanged. (Figures 15 and 16)

The explanation of the high penetration ability of the hunting arrow is twofold.

Small impact area / front surface = high impact momentum per unit area

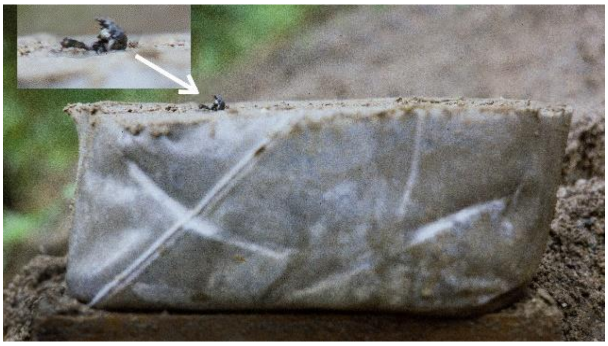
Here, the explanation is similar to that described above for the limited number of pain receptors hit - an extremely small impact area.

Rubber band effect

All living tissues with only a few exceptions are under tension.

Cut wounds in the skin divides. Cut off muscle tissue immediately retracts (Figure 1). Blood vessels and nerves that have been cut off may, in the case of surgical treatment have to be searched for while they retract up to several centimeters away from the site of the injury.

As a consequence, when the broadhead blades cut living structures, the tissues immediately divides, and the shaft and vanes of the hunting arrow project through the animal body with significantly reduced contact with the tissues that have been cut, and thus causing the arrow to reach a greater penetration.



Figures 15 and 16. The minimal front surface of the hunting tip is the reason for the full penetration of a 30 cm sandbag - notice the arrow tip!
In the same sandbag an expanding bullet, here 9.7 grams cal. 7 x 57R, came to a standstill at 9 cm. The sandbag was cut down to level after the shot, and the sand was carefully removed until the projectile was found.

REREFENCE VIDEO EPISODES

1. Selected video segments from different videos, in most cases made public on Youtube, demonstrating the common time course of 5-10 seconds until unconsciousness after central chest hit by broadhead-tipped arrow. Video segments are selected to be uncut from the hit until immobilization. The segments also demonstrates the hunting arrows ability to cut through the spine of adult moose, and examples of absence of excape reaction or signs of fright sometimes seen after hit by a broadhead-tipped arrow.

https://drive.google.com/file/d/12Km5SnZETe2Qh68r5igfYbfxUf3Ulz0v/view?usp=sharing

Video viewing instruction: Place cursor on link. Press Ctrl at the same time as a single click!

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