POULTRY STUNNING: A REVIEW OF CURRENT AND EXPERIMENTAL TECHNIQUES
A LITERATURE BASED ASSESSMENT OF WELFARE ISSUES AND OTHER FACTORS
ABSTRACT

In this literature-based review, several aspects of current and experimental stunning techniques for broilers have been investigated. The aim of this study was to compare poultry stunning techniques with regard to animal welfare, product quality and possibility of application in a commercial poultry processing plant. Furthermore, current affairs of ritual slaughter of broilers was reviewed with an emphasis on stunning methods suitable for the Halal-market.

Electrical stunning methods (head-only single bird stunning, head-to-cloaca single bird stunning and transcranial magnetic stimulation) and controlled atmosphere stunning methods (controlled atmosphere stunning and low atmosphere pressure stunning) were assessed with reference to conventional electrical water bath stunning, currently the most common applied stunning method for broilers in the EU. Alternative stunning techniques were reviewed based on the extent to which they could eliminate the main concerns of electrical water bath stunning, being

1) animal welfare issues: pre-stun handling of birds and insufficient stunning
2) product quality issues: high percentage of broken bones and muscle hemorrhages

As far as electrical stunning is concerned, head-only stunning seems a promising alternative for water bath stunning. Not only does this method increase stunning efficiency by stunning each bird individually, it also increases meat quality and therefore the revenue of poultry products. As stunning is reversible, this system is Halal-approved. Furthermore, a head-only stunning device is now available for commercial application.

Head-to-cloaca stunning and transcranial magnetic stimulation have proven to eliminate some of the welfare issues associated with water bath stunning in experimental settings, but still require intensive pre-stun handling of broilers by means of uncrating, inversion and shackling. More research is needed to evaluate the possibility of application of these electrical stunning alternatives in large scale poultry processing plants.

Controlled atmosphere stunning does not require intensive pre-stun handling of broilers, as the birds can be stunned either in their crates or after transfer on a conveyor belt. However, gas stunning by means of the current two-phase CO₂ system induces breathing distress in birds, while low atmospheric pressure stunning must be precisely controlled to prevent pain and adverse behavior of the birds. Controlled atmosphere stunning eliminates the problem of insufficient stunning, as all broilers are directly killed, and has a positive effect on product quality. This stun/kill method is however not Halal-approved.

It can be concluded that a head-only single bird stunning system is currently the most promising alternative for conventional electrical water bath stunning.
INTRODUCTION

European Union countries have humane slaughter laws for food animals, including poultry. These laws are designed to ensure that any unnecessary pain, stress, anxiety and distress for the animal are avoided during the slaughter process. EU legislation 1099/2009 prescribes that broilers, other than slaughtered in a religious manner, should be stunned prior to slaughter. Stunning is described as ‘any painless method that renders an animal in a state of insensibility and unconsciousness, including methods that induce immediate death’ (EU, 2009).

Given the great number of broilers currently raised for human consumption, it is believed that the poultry industry has an ethical duty towards the welfare of broilers during stunning and slaughter (Shields & Raj, 2010). A stunning method for broilers is considered ethical when 1) it limits any unnecessary negative experiences for the bird as much as possible, 2) it induces immediate unconsciousness and insensibility, 3) the period of unconsciousness lasts until death occurs, and 4) the percentage of insufficiently stunned or unstunned birds is next to zero (Buhr, n.d.).

Currently, electrical water bath stunning is the most applied stunning method for broiler chickens in the EU. With this type of stunning, conscious birds are uncrated, inverted and shackled, after which their heads are immersed in an electrical live water bath (Raj, 1998). Various studies have shown that this stunning technique no longer meets the criteria of a humane stunning method, as the intense pre-stun handling of the birds and the low stunning efficiency are of great concern from a welfare point of view (Shields & Raj, 2010). Furthermore, animal welfare standards and high product quality are not compatible with electrical water bath stunning, and therefore electrical water bath stunning will be phased out in The Netherlands (Blekert, 2011; Hindle et al., 2010).

These problems have led to a search for alternatives to conventional electrical water bath stunning. One alternative stunning method, namely controlled atmosphere stunning, is already operational in some Dutch slaughterhouses. Other alternative stunning techniques are currently installed (head-only single bird stunning) or still in a more experimental phase like head-to-cloaca single bird stunning and low atmosphere pressure stunning.

The primary purposes of this literature review are fourfold:

1. Describe conventional stunning methods in poultry slaughterhouses (electrical water bath stunning and gas stunning), with a special emphasis on animal welfare issues.
2. Identify research outcomes of newer stunning methods (mechanical stunning, head-only single bird electrical stunning, head-to-cloaca single bird electrical stunning, transcranial magnetic stimulation and low atmosphere pressure stunning) concerning improvement of bird welfare compared to conventional stunning techniques.
3. Outline the welfare issues associated with religious slaughter of poultry.
4. Present possible ways to improve broiler welfare at stunning without compromising product quality.
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1. ELECTRICAL STUNNING TECHNIQUES

1.1. CONVENTIONAL ELECTRICAL WATER BATH STUNNING

1.1.1 SUMMARY

Advantages
- An efficient method of stunning when properly performed
- Relatively cheap to install in poultry processing plants compared to other stunning techniques
- Meets Halal-slaughter requirements

Disadvantages
- Uncrating, inversion and shackling causes pain and distress in the broilers
- Risk of pre-stun electrical shocks
- Risk of missing the stun bath
- High prevalence of carcass defects

1.1.2. TECHNIQUE

In the 1950’s, commercial application of electrical stunning of poultry prior to slaughter was initiated to facilitate automated bleeding and faster processing line speeds (Fletcher, 1999). Today, electrical water bath stunning is the most common method of stunning poultry in commercial slaughterhouses where large throughput rates are required (EFSA, 2004; Raj, 2006).

A conventional electrical water bath stunning system consists of a narrow polyester water bath that allows passage of multiple birds at one time. Broilers are uncrated and the conscious birds are hung upside down on a moving metal shackle line and are passed through the electrified water bath. The birds are submerged in the water bath up to their shoulders. A metal electrode along the full length of the water bath serves as the positive electrode, whilst the earthed shackle forms the negative electrode (Figure 1) (EFSA, 2004; Morgenstern et al., 2009). The electrical current between these electrodes causes either epilepsy or cardiac arrest in the bird, inducing unconsciousness or death (Raj, 1998). There are then two broad ways in which the birds are killed: one method is to cut a combination of veins and arteries in the neck, and the other is decapitation, although the latter is not currently widely used in Europe. After bleeding, the birds are scalded, defeathered, eviscerated, chilled and processed (Allewelt et al., 2004).

![Fig.1. Schematic drawing of a conventional electrical water bath stunner (Adapted from hsa.org, 2013)](image-url)
Electrical water bath stunners under commercial conditions are all supplied with constant voltages, which cause an immediate electric current to flow through the bird as soon as it contacts the water. The resistance in this electric circuit between water and shackle is determined by the bird’s resistance and the shackle resistance. Both resistances are variable: resistance in the bird depends on body weight, body fat percentage, feathering, resistance in the brain, etcetera (Raj, 1998). Resistance of the shackles depends on the degree of contamination and the contact between the shackles and the bird’s feet. Due to this variation in resistance, a different current flows through each bird, causing some birds to be insufficiently stunned, while others receive an electrical overdose. Consequently, both animal welfare and product quality may be compromised (see further) (EFSA, 2004; Morgenstern et al., 2009).

In general, the waveform and frequency (Hz) of the electric current, the amount of current (mA) applied to individual broilers, and the number of birds in the water bath stunner at once varies widely among slaughterhouses. Furthermore, the duration of stunning varies according to the length of the water bath used and the speed of the processing line (Raj, 2006; Shields & Raj, 2010). To achieve an effective stun, a minimal current of 105 mA and a frequency of 50 Hz is advised for broilers (Morgenstern et al., 2009). According to Raj (1998), lower frequencies (50-200 Hz) and currents greater than 105 mA induce an acute cardiac arrest in most birds, but result in more broken bones and hemorrhages. This causes a conflict between the bird’s welfare and product quality: high frequencies and low currents negatively affect animal welfare, but reduce muscle stimulation (which causes broken bones and bleeding) and thereby have a positive effect on product quality (see further) (Raj, 1998).

1.1.3. LEGISLATION

European regulations for electrical water bath stunning of broilers are described in the new ‘Regulations for the protection of animals during killing’. Aim of this legislation, which is valid from January 1st 2013, is to protect animals from any unnecessary pain, stress, anxiety or distress during the slaughter process (EU, 2009).

In these regulations, electrical water bath stunning is described as a form of ‘simple stunning’. This means that stunning does not lead to immediate death of the animal, and has to be followed by a killing method (e.g. neck cut). According to the EU law, electrical water bath stunning is described as ‘exposure of the whole body to an electrical current that induces an epileptiform EEG and could possibly lead to heart fibrillation or cardiac arrest’ (EU, 2009).

The following parameters are crucial when electrical water bath stunning is applied:

- Minimal current (mA), voltage (V) and frequency (Hz)
- Avoidance of pre-stun electrical shocks
- Minimize pain of shackling live birds
- Optimizing the electrical circuit in the bird
- Maximum pre-stun shackling time
- Depth of immersion of the birds (i.e. to the shoulder base)
- Maximum time interval between stunning and killing (EU, 2009)

**Shackling**

Birds should always be shackled with both feet. Furthermore, birds should not be shackled when too small, or when shackling can cause pain or increase existing pain (e.g. when an animal is visually
injured). These broilers should be killed otherwise. Conscious birds are not allowed to be shackled for more than 60 seconds. Furthermore, the size and shape of the shackles should be adjusted to the diameter of the birds’ shank to decrease electrical resistance (EU, 2009).

**Water bath**

Water bath stunners should not overflow at the entrance and should have an electrically isolated entry ramp, which facilitates the birds’ head into the water bath. The electrodes in the water bath must be applied over the full length of the water bath, and should form an electrical circuit with the metal shackle electrodes (EU, 2009).

**Electrical settings**

In Table 1, an overview of the required settings of the electrical water bath stunner for broilers is given. For all electrical settings, the minimum duration of stunning is 4 seconds (EU, 2009).

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 200 Hz</td>
<td>100 mA</td>
</tr>
<tr>
<td>200-400 Hz</td>
<td>150 mA</td>
</tr>
<tr>
<td>400-1500 Hz</td>
<td>400 mA</td>
</tr>
</tbody>
</table>

*Table 1. Overview of required electrical settings for electrical water bath stunning of broilers (Adapted from EU, 2009)*

### 1.1.4. PHYSIOLOGY

Electrical stunning can be either reversible (causing a grand mal seizure) or irreversible (causing ventricular fibrillation or cardiac arrest) (Allewelt et al., 2004). The basic principle involved in reversible electrical stunning, is that an electric current passes through the brain to induce epilepsy (Raj, 1998). This epileptic process is characterized by a rapid and extreme polarization of the neuron membrane potential and a synchronized electric potential in the brain cells (Lambooij & Gerritzen, 2004). Grand mal epilepsy is considered to be incompatible with normal neuron function and thus the persistence of unconsciousness (EFSA, 2004). A typical human electroencephalogram (EEG) of such an epileptiform insult consists of three distinct phases

1) **tonic phase:** relatively small waves increasing in amplitude
2) **clonic phase:** waves decreasing in frequency
3) **iso-electric/quiescent phase:** strong depression of all electrical brain activity

In humans, the occurrence of a grand mal seizure is considered to be an indicator of unconsciousness. Based on brain analogy and similarities in behavioral patterns between humans and vertebrates, a vertebrate is also considered to be unconsciousness and insensible during such an insult (Lambooij & Gerritzen, 2004; Raj, 1998). However, chickens do not always show similar grand mal epileptic activity in the brain following an electrical stun. Some birds show a polyspike brain activity (unipolar, high amplitude and low frequency electrical activity) that is similar to that of petit mal activity in humans, which is not always associated with unconsciousness. However, it is thought that if this kind of brain activity is immediately followed by a quiescent phase in the EEG, is can be assumed that the bird is accurately stunned and thus insensible and unconscious (Figure 2) (Raj,
The duration of this insensibility should be the sum of the time from the end of stunning to neck cutting and the time it would take for brain failure to occur through blood loss (Figure 3) (Raj, 1998).

An epileptiform insult only occurs when the current received surpasses the threshold of the neurons (Lambooij & Gerritzen, 2004). Several studies have been conducted to determine the minimum current necessary to render birds unconscious. It was concluded that stunning with a 105 mA, 50 Hz
current induced cardiac arrest in 80% of the birds and provided at least 52 seconds of insensibility. However, when a 120 mA sine wave AC of 50 Hz was used, stunning induced cardiac arrest in 100% of the birds (Prinz, 2007; Raj, 1998). A cardiac arrest at the point of electrical stunning has welfare advantages for chickens, because the delay between the end of stunning and neck cutting and the efficiency of neck cutting becomes less important (Raj, 1998). Induction of a cardiac arrest was also found to be the quickest method to induce brain failure, due to the lack of supply of oxygenated blood to the brain (Prinz, 2007; Raj, 1998). Higher current levels thus eliminate the potential problem of resumption of consciousness in the birds but, as mentioned earlier, can negatively affect meat quality (Raj, 1998).

1.1.5. WELFARE ASPECTS

Currently, electrical water bath stunning is the most common method used in European commercial poultry slaughterhouses. It is considered a humane stunning method on the basis of the scientific principle that stimulation of the brain with a sufficient electric current will induce a grand mal seizure in the brain (Hindle et al., 2010; Raj, 2006). However, although theoretically electrical water bath stunning could induce a state of unconsciousness rapidly, it is known that the correct electrical settings are not always maintained and that there is a conflict between effective stunning of the birds and product quality (Shields & Raj, 2010). Furthermore, obtaining an efficient, humane stun using the electrical water bath is quite complex: parameters such as frequency, voltage, current, wave form, resistance of the apparatus and resistance of the birds all influence the success of the stun (Hindle et al., 2010).

In 2010, Shields & Raj wrote a critical review outlining the established welfare issues associated with current electrical water bath stunning practices. According to the authors, the bird’s welfare at electrical water bath stunning is compromised by shackling, pre-stun electric shocks, missing of the stun bath and insufficient stunning (Shields & Raj, 2010).

**Shackling**

Before stunning, the broilers are uncrated, inverted and hung upside down by their legs in metal shackles (Figure 4) on an overhead conveyor (Shields & Raj, 2010). The time between shackling and stunning varies according to the layout of the processing plant. EU legislation prescribes that the shackling duration of conscious broilers must be less than 60 seconds (EFSA, 2004; EU, 2009). Research of Bedanova et al. (2007) pointed out that when the shackling period exceeds 60 seconds, the stress effect of shackling on broilers is markedly increased. Plasma stress indicators, such as corticosterone, glucose and lactate were significantly higher in birds shackled for 120 seconds, compared to birds shackled for 60 seconds (Bedanova et al., 2007). However, a time lapse between shackling and stunning is unavoidable, because an efficient stun requires the birds to become settled in the hanging position before entering the water bath. Ideally, it should take no longer than 12 seconds for the bird to hang rather motionless before it gets stunned (DEFRA, 2007).

![Fig.4 Shackle design for broilers](Adapted from DEFRA, 2007)
Shackling is a stressful event as hanging upside down is an unnatural physiological position for broilers. Also, being uncrated and inversed by the hanging operators are traumatic events. The stress can cause the birds to flap their wings immediately after shackling, possibly leading to dislocated joints, broken bones or hemorrhages of the wing tip (Shields & Raj, 2010). The size and shape of the shackles should be adapted to the legs of the broilers to ensure a proper electrical circuit between the water bath electrode and the shackle electrode (EU, 2009). However, the leg diameter of individual broilers may vary, causing the hanging operators to use considerable force to fit the bird’s legs into the shackles. Leg diameter varies especially between male and female broilers, with male broilers having thicker shanks than females. These male birds are found to struggle more violently and longer than female birds. This ante-mortem struggling can cause bruising of and therefore downgrading of the carcass (Satterlee et al., 2000; Shields & Raj, 2010). Although ideally a shackle line should be able to accommodate birds of different sizes in order to minimize the pain of Shackling, such line design is not commonly used under the existing processing conditions (EFSA, 2004).

Shackling is considered to be a painful process that is worse in animals suffering from diseases or abnormalities, such as dislocated joints or bone fractures (Shields & Raj, 2010). It is therefore forbidden to shackle birds that are visually injured, and these birds should be killed otherwise (EU, 2009).

In order to minimize stress and pain during shackling, several measures can be taken. First of all, hanging operators placing birds into shackles must be properly trained how to handle broilers in such a way to avoid injuries, pain and stress (DEFRA, 2007). According to EU regulation 1099/2009, a breast comforting plate must be applied along the line. Support in the breast area while hanging in an upside down position has a quietening effect in chickens (EFSA, 2004; EU, 2009). In addition, duration and intensity of wing flapping are significantly decreased when the light intensity of the shackling area is 5 lux or less, or when blue or violet light is used (Figure 5) (EFSA, 2004).

Pre-stun electric shocks
Pre-stun shocks occur when any body part of the bird touches the electrical water bath before it is effectively stunned (DEFRA, 2007). Often, this happens when the bird’s wings make contact with the water bath before the head is immersed (Shields & Raj, 2010). Wing flapping at the entrance of the stunning bath predisposes the occurrence of painfully, pre-stun electrical shocks (EFSA, 2004). Also, pre-stun shocks can occur when electrically live water flows out of the stunning bath and on to the entry ramp (British Humane Slaugther Association, 2006). Pre-stun shocks lead to wing flapping, and may cause the bird to lift its head and miss the stun bath (also referred to as “flying the stunner”).
To this date, the incidence of pre-stun shocks in broiler chicken stunned with a conventional electrical water bath stunner is unknown (DEFRA, 2007). The occurrence of pre-stun shocks can be reduced by measurements that have a calming effect on the bird and therefore reduce wing flapping. As mentioned previously, this includes a breast comforter, adjusted light color or intensity and minimal shackling time. Furthermore, electrical water bath stunners should not overflow at the entrance and should have an electrically isolated entry ramp which facilitates the bird’s head into the water bath (Figure 6). Also, shackling lines can be designed with a ‘dip’ to immerse the bird’s head into the electrical bath (British Humane Slaughter Association, 2006; DEFRA, 2007; EFSA, 2004).

**Fig.6.** Diagram of how pre-stun shocks may be reduced by using an entry ramp which swings the birds head into the electrical water bath stunner. Notice that the water level is lower than the entry ramp to avoid overflow of electrically live water on to the ramp (Adapted from British Humane Slaughter Association, 2006)

**Missing the stun bath**

As stated above, wing flapping and lifting of the head prior to entering the electrical water bath can cause birds to miss the stunner (Shields & Raj, 2010). This could also occur when the height of the stunner is not adjusted properly, or when the bird is too small to reach the water bath (Shields & Raj, 2010). EU regulation therefore prohibits the shackling of broilers which are too small for water bath stunning to prevent insufficient stunning prior to slaughter (EU, 2009).

**Insufficient stunning**

In a laboratorial setting, stunning efficiency can be assessed by recording brain activity with an electroencephalogram (EEG). To record brain electrical activity in a great number of broilers in a fast and feasible way, a non-invasive EEG device was developed: the chicken EEG clamp (CHEC)(Coenen et al., 2007). This clamp consists of a framework with two pointed electrodes, which are placed firmly on the skin of the chicken’s skull (Figure 7) (Coenen et al., 2007).

**Fig.7.** Non-invasive ‘chicken EEG clamp’ (CHEC). The bird’s head is moved in the metal rail when the electrode rack is lifted. When the skull is in the proper position, the electrode rack is moved down until the electrodes make tight and stable contact with the bird’s head (Adapted from Coenen et al., 2007).
A good stunning efficiency is indicated by the occurrence of an iso-electric EEG with less than 10% of the electrical brain power as recorded prior to stunning. A percentage higher than 10% of the baseline brain activity indicates inadequate stunning. Furthermore, failure of the bird to resume breathing after stunning is an indicator of cardiac arrest (Prinz, 2007).

In a processing plant, all broilers leaving the electrical water bath stunner should be checked by a line operator for being sufficiently stunned or killed before continuing the slaughter process. According to the UK Department for Environment, Food and Rural Affairs, stun/kill efficiency of an electrical water bath stunned bird can be recognized by the physical signs as indicated in Table 2 (DEFRA, 2007).

<table>
<thead>
<tr>
<th>Effective stun</th>
<th>Ineffective stun</th>
<th>Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>• no rhythmic breathing for 10-20 seconds after leaving the water bath</td>
<td>• return of rhythmic breathing</td>
<td>• fixed, central, dilated pupil</td>
</tr>
<tr>
<td>• neck arched with head directed vertically</td>
<td>• a corneal or third eyelid response</td>
<td>• no rhythmic breathing</td>
</tr>
<tr>
<td>• dilated pupils</td>
<td>• tension in the neck muscles</td>
<td>• no response to any stimuli</td>
</tr>
<tr>
<td>• absence of a corneal or third eyelid response</td>
<td>• other voluntary muscle movements</td>
<td>• limp carcass</td>
</tr>
<tr>
<td>• no reaction to comb pinch</td>
<td>• vocalization</td>
<td></td>
</tr>
<tr>
<td>• wings held close to the body</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• rigidly extended legs (not an appropriate indicator when a bird is held in a shackle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• constant body tremors (movement)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Physical signs of stun/kill efficiency of electrical water bath stunned broilers. (Adapted from DEFRA, 2007)

Although the physical signs of a seizure (i.e. arched neck, rigidly extended legs, wide open eyes and absence of the blinking reflex) may be visible after stunning, this does not always indicate a state of unconsciousness and insensibility in the bird. In other words, the amount of current necessary to induce an iso-electric EEG is higher than the amount needed to induce the physical signs of a seizure. Therefore, it is impossible to distinguish a state of electrically induced paralysis from a state of genuine unconsciousness based on physical signs (Shields & Raj, 2010). This further compromises the welfare of electrical water bath stunned broilers, as ineffective stunned birds could be missed by the line operators and therefore be killed while conscious.

In the European Union, broilers are stunned in multi bird electrical water baths with frequencies ranging from 50 Hz to 2000 Hz. Constant voltage water baths can lead to insufficient stunning as the birds form parallel circuits and the actual current per bird is thus determined by its individual resistance (Prinz, 2007). Birds with high resistance receive currents that are too low to induce unconsciousness, while birds with low resistance receive higher currents that are potentially lethal (Shields & Raj, 2010). A broiler’s resistance is determined by many factors, like depth of immersion, body weight, body fat percentage and plumage condition (Shields & Raj, 2010). Individual resistance can also be sex-determined. For example, Rawles et al. (1995) showed that the electrical resistance in female broilers is higher than in males. Female broilers posses more body fat tissue, which has a high resistance to current flow. These female birds should therefore be stunned with a greater
current to induce unconsciousness (Rawles et al., 1995). Moreover, female birds tend to have smaller shanks than male birds, causing a looser fit between the shank and the shackle. This also increases the resistance in the current flow (Prinz, 2007). Also, the conditions in the electrical water bath are of influence on the electrical circuit that can be formed between bath and bird: a high mineral content or dirt concentration of the water bath can negatively affect the conductivity of the water (Shields & Raj, 2010).

When stunned according to EU legislation (100 mA, 50 Hz, 4 seconds), stunning efficiency is approximately 90% (i.e. 90% of the broilers dies of cardiac arrest) (EU, 2009; Hindle et al., 2010; Prinz, 2007). In practice however, applied currents and frequencies vary greatly among slaughterhouses (Hindle et al., 2010). According to Shields & Raj (2010), various studies provide data confirming that, with commercially attractive settings of the electrical water bath stunner (i.e. high frequency and low current to assure good carcass quality) stunning efficiency can be as low as 36% (Shields & Raj, 2010).

It can be concluded from the above, that controlling the proper variables needed to induce an effective stun for each bird passing the multi bird electrical water bath stunner, is very difficult, not to say impossible when using a constant voltage water bath. Also, an effective stun cannot be recognized by physical signs only (Shields & Raj, 2010).

### 1.1.6. PRODUCT QUALITY

As mentioned previously, a major issue of conventional electrical water bath stunning is the difficulty to induce an effective stun without diminishing carcass quality. When stunned according to EU legislation (100 mA, 50 Hz, 4 seconds), a tetanic spasm occurs in the bird’s body which can cause broken pectoral bones and breast muscle hemorrhages (Raj et al., 1997; Goksoy et al., 1999).

Hindle et al. (2010) concluded from a survey of practices in Dutch poultry slaughterhouses in 2008 that, despite of EU regulation, low current or high frequency electrical water bath stunning is often applied on broilers (Hindle et al., 2010). Indeed, research has shown that stunning poultry with a low current or a high frequency has a positive effect on meat and carcass quality (Shields & Raj, 2010).

Xu et al. (2010) investigated the effect of various stunning currents and frequencies on broilers stunned by electrical water bath. Results indicated that low currents and high frequencies positively affect meat quality by reducing shear value, hemorrhages and cooking loss of the breast muscles. However, from plasma corticosterone measurements, it was concluded from the same experiments that with low current, high frequency stunning birds suffered the most severe stress (Xu et al., 2011).

Also, effective stuns at high frequencies require higher currents to induce a state of unconsciousness in broilers (Hindle et al., 2010; Xu et al., 2011). This study represents the dilemma poultry processing plants are presented with when using conventional electrical water bath stunning: increasing animal welfare at the cost of product revenues, or increasing product revenues by decreasing the bird’s welfare.

### 1.1.7. CONCLUSIONS CONVENTIONAL ELECTRICAL WATER BATH STUNNING

Although currently the most applied stunning method in large poultry processing plants, scientists suggest phasing out conventional electrical water bath stunning for broilers. They argue that current standards for animal welfare and high product quality are not longer compatible within this stunning technique (Hindle et al., 2010; Bleker, 2011).
Although several measurements can be taken to increase the bird’s welfare before and during stunning, it has been proven difficult to control all parameters necessary to induce an effective electrical water bath stun (Shields & Raj, 2010). Furthermore, electrical settings are often adjusted to increase product quality (Hindle et al., 2010). As a result, birds suffer from pre-stun pain and stress, pre-stun electrical shocks, missing the stun bath or insufficient stunning (Shields & Raj, 2010). It is therefore desirable to displace conventional electrical water bath stunning systems with a system that ensures sufficient stunning of birds whilst diminishing product quality losses.
1.2. HEAD-ONLY SINGLE-BIRD ELECTRICAL STUNNING

1.2.1. SUMMARY

Advantages

- Minimal wing flapping and therefore an increase in product quality
- Individual stunning with high stunning efficiency
- Monitoring of each individual stun
- Reduction of stress and discomfort for the birds by means of post-stun shackling
- Reduction of water waste
- Compatible in existing slaughter lines
- Available for application in commercial poultry processing plants
- Meets Halal-slaughter requirements

Disadvantages

- Only a short period of unconsciousness is induced, therefore the neck cut should follow immediately after stunning
- High investment costs and annual costs
- Extra labor costs due to prolonged cleaning time of the device

1.2.2. INTRODUCTION

Conventional electrical water bath stunning induces a whole body electrical current in broilers. This causes vigorous muscle contractions which, combined with the unnatural inversed position of the bird, can lead to rupture of small muscle blood vessels and fibers (Lambooij et al., 2010). Electrical water bath whole body stunning can therefore lead to considerable carcass damage when the water bath is set according to the regulations of the European Council (i.e. minimal 100 mA current) (EU, 2009; Lines et al., 2011). An alternative approach to electrical stunning of poultry is head-only single bird stunning, where the current is passed across the head of the bird instead of the body (Lambooij et al., 2010). Several studies have been conducted to evaluate head-only single bird electrical stunning feasibility as a means of generating immediate and long lasting unconsciousness while avoiding carcass damage. Furthermore, in 2011 the Dutch Ministry of Economic Affairs, Agriculture and Innovation (EL&I) asked for an economic and environmental evaluation of a head-only stunning method to evaluate the possibilities of a large-scale future application in poultry processing plants (Janssens & Baltussen, 2011).

1.2.3. PILOT STUDIES FOR HEAD-ONLY ELECTRICAL STUNNING

Lambooij et al. (2010) approached a method for head-only single bird stunning of broilers. The objective of their study was to evaluate the behavioral, neural, and physiological responses after head-only electrical stunning in broilers. Also, meat quality after stunning was compared with the conventional electrical water bath stunning method in a commercial setting (Lambooij et al., 2010). In this head-only stunning study, 47 broilers were individually shackled by the feet and their bodies were placed in specially developed cone-shaped restrainers. The head was fixed on both sides by pin-electrodes outside the cone (Figure 8). An electrical current of 240 mA and 50 Hz was passed through the head for 1 to 5 seconds as soon as the head was fixed between the electrodes. The set current was stabilized in relation to the measured resistance in the individual broiler, so that each bird received a proper current. Brain electrical activity and heart activity were recorded by means of
EEG and ECG. After stunning, a comb pinch was used as a pain stimulus to assess unconsciousness (Lambooij et al., 2010).

At the beginning and sometimes during the head-only stun, broilers showed wing flapping. 5 out of 47 birds showed severe wing flapping. EEG recordings indicated that a general epileptiform insult was induced when a set current of at least 190 mA (50 Hz) was applied. Under these settings, the chance of an effective stun with all broilers lied between 0.95 and 1.00. When stunned for 0.5, 3 or 5 seconds, the birds remained unconscious for 18, 12 and 16 seconds respectively. ECG showed heart fibrillation after stunning, followed by a recovery of the heart rate (Lambooij et al., 2010).

![Experimental head-only stunning set up](Adapted from Lambooij et al., 2010)

**Fig. 8.** Experimental head-only stunning set up: birds are shackled upside down by the feet. The body is held in a cone-shaped restrainer, while the head is clamped between two electrodes (Adapted from Lambooij et al., 2010)

To compare the meat quality of head-only stunned broilers with conventional electrical water bath stunned broilers, a different group of 50 broilers was divided in half. 25 broilers (control group) were stunned by means of conventional water bath stunning (100 mA, 100 Hz for 10 seconds), whilst the other 25 (experimental group) were stunned in the head-only stunner (240 mA, 50 Hz for 5 seconds). Postmortem, the temperature, pH, color, cooking loss and shear force of the breast muscle were measured. Furthermore, breast and thigh muscles were classified according to the occurrence of hemorrhages (class 1: hemorrhage-free to class 5: severe hemorrhaging) (Lambooij et al., 2010). Results showed that pH after chilling was significantly lower in the head-only group. Furthermore, the percentage of breast fillets with no hemorrhages was 80% in the experimental group, compared to 16% in the conventional stunned broilers. Also, blood splashing in fillets and thighs of the electrical water bath stunned broilers was more severe (Lambooij et al., 2010).

The authors concluded from these experiments, that head-only single bird stunning could induce unconsciousness and insensibility in broilers. It was recommended to use a set current of 250 mA in practical applications to overcome the various resistances in individual birds. Because unconsciousness lasted for approximately 12-18 seconds, the stun should be immediately (within 10 seconds) followed by the neck cut to prevent recovery. As for meat quality, carcass quality of head-
only stunned broilers was only slightly decreased by hemorrhaging, despite of the sometimes severe wing flapping during stunning (Lambooij et al., 2010).

1.2.4. LEGISLATION
Head-only electrical stunning is considered to be a form of ‘simple’ stunning, as it does not induce immediate death. It is described as ‘exposure of the brain to an electrical current that induces an epileptiform EEG’ (EU, 2009). The crucial parameters are largely the same as those for conventional electrical water bath stunning, with an additional mentioning of the proper placement of the electrodes. The electrodes should be placed on either side of the brain and should be adapted to the size of the bird’s head. For broilers, a minimal current of 240 mA must be applied (EU, 2009).

1.2.5. ECONOMICAL & ENVIRONMENTAL ASPECTS OF HEAD-ONLY STUNNING
To investigate a possible commercial application, in 2011 the Dutch Ministry of EL&I asked for an economical and environmental assessment of the head-only stunning technique as described in the article of Lambooij et al. (2010). In the report of the LEI (Agricultural and Economical Institute of Wageningen University) all results of head-only single bird stunning were compared to those of conventional electrical water bath stunning. The information of the head-only stunning system was based on the method as developed by TopKip (see further) (Horne et al., 2011).

Economical analysis
For the economical analysis, the following aspects were taken into account:

- The price for the stunning devices (based on number of slaughtered broilers per day) and installation costs
- Depreciation, interest and maintenance
- Operational costs (e.g. energy costs, water costs)
- Labor costs
- Possible differences in yields, meat quality (hemorrhages) and broken wings (Horne et al., 2011)

When comparing the conventional electrical water bath stunning system with the experimental head-only stunning system, there is a difference in investments for equipment, costs of water and costs of cleaning (Table 3). The investments and annual costs of head-only stunning equipment are both approximately 5 times those of a conventional water bath device (based on a Dutch slaughterhouse processing 10 000 broilers per hour with 10-hour operating days and 25 million slaughtered broilers per year). Labor costs are higher with head-only stunning, for an additional half an hour labor per day is needed to clean the head-only stunning device. Costs of water however are significantly lower, as water is only needed for ‘fogging’ of the system (dampening the stunning device increases the contact between the broiler’s head and the electrodes) and for cleaning (Horne et al., 2011).

Meat quality data was based on the study of Lambooij et al. (2010), as described above (Table 4). It is assumed that the relation between meat quality and meat price is linear, with the price for meat of class 1 (no hemorrhages) is stated as 100%. With head-only stunning, quality of breast and thigh meat was higher, resulting in an additional revenue of 14 eurocents per broiler (Horne et al., 2011).
Environmental analysis

For the environmental analysis, the following aspects were taken into account:

- Use of water
- Use of energy
- Waste
- Emissions (Horne et al., 2011)

Total water use ($m^3$ per year) for stunning and cleaning is $3750 m^3$ for electrical water bath stunning, compared to $200 m^3$ for head-only stunning. As the amount of waste water is directly related to the use of water, waste of water is much lower in the head-only system. Because the use of electricity for stunning is less than 1% of total electricity use in a slaughterhouse, no detailed information on electricity use was available. It was therefore assumed that costs of electricity were comparable in both stunning systems. Emissions were approximately equal in both systems (Horne et al., 2011).

From this report is was concluded that head-only stunning, although costs for equipment and cleaning are significantly higher, could be an economical attractive alternative to conventional electrical water bath stunner, because the additional revenue per broiler is considerably high (14 eurocents/broiler). Due to a significant decrease in water waste, head-only stunning is also an environmental friendly alternative to water bath stunning (Horne et al., 2011).

Table 3. Costs of equipment and other variable costs for the electrical water bath and head-only stunning system (in euro’s per year) (Adapted from Horne et al., 2011)

<table>
<thead>
<tr>
<th></th>
<th>Water bath</th>
<th>Head-only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stunning equipment</td>
<td>10,325</td>
<td>60,125</td>
</tr>
<tr>
<td>Extra labour costs for cleaning</td>
<td>0</td>
<td>3,750</td>
</tr>
<tr>
<td>Energy costs</td>
<td>625</td>
<td>625</td>
</tr>
<tr>
<td>Water costs</td>
<td>6,375</td>
<td>340</td>
</tr>
<tr>
<td>Total costs per year per slaughterhouse</td>
<td>17,325</td>
<td>64,840</td>
</tr>
<tr>
<td>Total costs per broiler (euro)</td>
<td>0.0007</td>
<td>0.0026</td>
</tr>
</tbody>
</table>

Table 4. Percentage of blood splashes in the fillets and legs according to a score of 1 to 5 in carcasses of broilers stunned in an electrical water bath (at 100 mA and 100 Hz) or head-only stunning system (at 240 mA and 50 Hz) (Adapted from Horne et al., 2011)

<table>
<thead>
<tr>
<th>Meat quality score a)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fillets</td>
<td>16</td>
<td>8</td>
<td>16</td>
<td>48</td>
<td>12</td>
</tr>
<tr>
<td>Legs</td>
<td>6</td>
<td>8</td>
<td>30</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Head-only stunning method</td>
<td>80</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Fillets</td>
<td>16</td>
<td>8</td>
<td>16</td>
<td>48</td>
<td>12</td>
</tr>
<tr>
<td>Legs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Percentage of blood splashes according to a score of 1 to 5, with 1 = none, 5 = severe blood splashes in fillets or legs.*
1.2.6. TOPKIP HEAD-ONLY STUNNING DEVICE

Data of the LEI-report on economical and environmental aspects of head-only single bird stunning was based on a stunning device as developed by TopKip. TopKip is a Dutch company specialized in developing, manufacturing and selling of machinery for the poultry-processing industry. At this time, the company has a patent pending for a head-only stunning device similar to the set-up used in the study of Lambooij et al. (2010).

In the basic version of TopKip’s head-only stunning device, birds are suspended from the legs in metal shackles. The birds pass through a carousel which puts them in cones. These cone-shaped restrainers minimize wing flapping during stunning. Before stunning, the heads of the broilers are moistened by spray nozzles to increase electrical conductivity. Two electrodes are automatically placed next to the bird’s head and an electrical current of 240 mA (50 Hz) flows through the head for 3 seconds (Figure 10). The stunning of each bird is constantly monitored: birds that are not or insufficiently stunned will ignite an LED light signal running parallel to that specific bird. In this way, the line operator can identify insufficiently stunned birds and remove these bird from the line. After the birds are stunned they leave the carousel to continue the normal slaughter process (TopKip, 2013).

In the extended version, birds are manually placed in a cone-shaped holder while their legs are fitted in a synthetic positioning plate. The slaughter shackles run parallel to the cones behind the positioning plate (Figure 11). Stunning takes place in the same way as in the basic head-only stunner. After the birds are stunned, the shackle line automatically suspends the birds from their feet. Shackling after stunning reduces stress and discomfort prior to slaughter (Topkip, 2013).

Currently, the first TopKip head-only stunning devices are applied in commercial slaughterhouses.

![Fig.10. In the basic version of the TopKip head-only stunner, birds are shackled from their feet with their bodies in a cone-shaped restrainer. The electrodes are automatically brought into position on either side of the head (Adapted from TopKip, 2013)](image-url)
1.2.7. CONCLUSIONS HEAD-ONLY SINGLE BIRD STUNNING

Despite high installation costs, a head-only single bird stunning device could be a commercially attractive alternative to electrical water bath stunning. Not only does the individual electrical stunning of birds result in higher quality of products that are also suitable for the Halal market, it also benefits the bird’s welfare by means of a high stunning efficiency (Horne et al., 2011). To further decrease pre-stun stress in broilers, shackling of live birds prior to stunning could be replaced by shackling of unconscious birds, as shown by the extended TopKip head-only stunner. Currently, the first head-only single bird stunners are put in to operation in various slaughterhouses that formally used a conventional electrical water bath system (TopKip, 2013).
1.3. HEAD-TO-CLOACA SINGLE-BIRD ELECTRICAL STUNNING

1.3.1. SUMMARY

Advantages

- Application of an electrode in or around the cloaca reduces resistance in the electrical circuit, therefore lowering the current needed to induce an effective stun
- Lower resistance in the electrical circuit decreases the percentage of insufficiently stunned birds
- Lower currents positively affect carcass quality by diminishing hemorrhages and broken bones
- Meets Halal-slaughter requirements

Disadvantages

- A commercially adapted head-to-cloaca stunning system is yet to be designed
- A penetrating cloaca electrode might be an aspect of concern when commercially applied
- Uncrating, inversion and shackling of the birds prior to stunning is stressful and could lead to wing flapping, resulting in broken boned and pre-stun electric shocks

1.3.2. INTRODUCTION

Under existing multiple-bird, electrical water bath stunning, there is a conflict between bird welfare and meat quality (Shields & Raj, 2010).

As mentioned in Chapter 1.1., a minimum current of 120 mA per bird is recommended to properly stun/kill broiler chickens. This relatively high current can negatively affect carcass quality, for it causes intense muscle contractions resulting in the rupture of small blood vessels in skin and/or flesh and shattering of bones (Morgenstern et al., 2009; Raj, 1998; Shields & Raj, 2010). Although these quality losses can be overcome by applying a lower current at a higher frequency, these settings are questionable on welfare grounds because some broilers may not be effectively stunned (Morgenstern et al., 2009; Raj, 2006).

Furthermore, the standard procedure of hanging conscious birds upside down in shackles is considered unacceptable in terms of animal welfare (Hindle et al., 2009). As mentioned earlier, the shackles are also an important source of resistance in conventional electrical water bath stunning and decrease the efficiency of the stun (Hindle et al., 2009). In studies of Lambooij et al. (2008;2010) it was hypothesized that a different placement of electrodes in order to bypass the feet and legs would decrease the resistance of the electrical circuit, thereby lowering the required current to achieve an effective stun, while improving bird welfare and meat quality (Hindle et al., 2009).

1.3.3. PILOT STUDIES FOR HEAD-TO-CLOACA SINGLE BIRD ELECTRICAL STUNNING

In a pilot study of Lambooij et al. (2008), a head-to-cloaca single bird electrical water bath stunning method was tested to identify an electrical current and exposure duration that would render broiler chicken unconscious instantaneously at slaughter (Lambooij et al., 2008). It was hypothesized that an electrode placed inside or at the region around the cloaca would improve the contact between electrodes and the bird, resulting in a lower current to be used for an effective stun/kill (Lambooij et al., 2008).
In 2010, a second study was performed to further determine the settings by which a head-to-cloaca single bird stunner could induce a successful stun/kill of broilers, and to what extend meat quality was affected by this stunning method (Lambooij et al., 2010).

In the first study of Lambooij et al. (2008), a total of 103 broilers were hung individually by the feet from shackles above a water bath. The water in which the head was immersed was one electrode, and a steel-coned (‘inside cloaca’) or cutaneous U-shaped (‘outside cloaca’) electrode was the other electrode. EEG recordings were made to determine the occurrence of a grand mal seizure, whilst an ECG recorded the effect of the electrical current on the heart. The water bath was lifted and the birds were stunned for 1 second.

Two different stunning methods were tested. In the ‘Head to Inside Cloaca’ experiment (Figure 12), the broilers were subjected to electrical stunning from the head to inside the cloaca using a penetrating cloaca-electrode. An electrical circuit was formed between the electrode in the water bath and the steel-coned electrode in the cloaca. In the ‘Head to Outside Cloaca’ experiment (Figure 13), an U-shaped steel electrode was placed at the skin around the cloaca, rather than inside the cloaca.

Various wave forms, frequencies, currents and stunning durations were applied to determine the conditions at which the head-to-cloaca single bird stunner would render the birds unconsciousness immediately and for a period of time that would be suitable for a commercial slaughter processes. After stunning, the carcasses were scored for hemorrhaging to determine meat quality (Lambooij et al., 2008).

In both experiments (Head to Inside Cloaca and Head to Outside Cloaca), a 640-Hz sinusoidal current with an average current of 111 mA applied for 1 second, caused both an epileptiform insult and heart fibrillation in all birds. After approximately 5 minutes, all heart activity stopped and due to a gradual loss of blood pressure and lack of oxygen to the brain, all brain activity ceased (Figure 14). The broilers were thus unconsciousness until death occurred by a neck cut.
When an alternating pulsed square wave current was used, broilers in the Head to Inside Cloaca were successfully stunned with a current of approximately 33 mA (peak of 600 Hz) for 1 second. The duration of unconsciousness lasted on average 25 seconds. When these broilers were bled within 14 seconds after stunning, they remained unconscious and the heart activity stopped after 237 ± 103 seconds. In both settings (640 Hz + 111 mA and 600 Hz + 33 mA) carcass hemorrhages were minimal or absent. (Lambooij et al., 2008).

![Fig.14. EEG and ECG before and after electrical stunning with the head- to-cloaca water bath stunner: A) Brain and heart activity immediately before stunning. B) Induced general epileptic insult which developed into an iso-electric line (EEG) due to the induced heart fibrillation (ECG) immediately after stunning. C) Both brain and heart activity cease approximately 444 ± 87 s after stunning (Adapted from Lambooij et al., 2008)]](image)

In 2010, a comparable study was performed for and sponsored by the Dutch Ministry for Agriculture, Nature and Food quality. A total of 55 broilers were restrained upside down in shackles in a specially designed carousel (Figure 15), after which a water bath was lifted and a cloaca pin lowered so it touched the cloaca (Head to Outside Cloaca) when the head reached the water. A current of either 70 mA + 70 Hz or 100 mA + 100 Hz flowed through the birds for 1 or 1.5 seconds. The efficiency of these head-to-cloaca controlled stunning methods were assessed using EEG, ECG and a pain stimulus (comb pinching) after stunning. A general epileptiform insult was observed in broilers stunned during 1.5 seconds with a current of 70 mA + 70 Hz. These birds remained unconsciousness for approximately 15 seconds and the heart rate decreased significantly after stunning, to recover afterwards. In birds stunned with a current of 100 mA + 100 Hz for 1.5 seconds, the same phenomenon was observed, although unconsciousness rendered for approximately 20 seconds or more (Lambooij et al., 2010). The authors recommend using a 100 mA - 100 Hz - 1.5 second setting for head-to-cloaca stunning, as it renders the broilers unconsciousness for the longest period of time. A neck cut should follow within 10 seconds of stunning, to prevent the birds from recovering to consciousness during exsanguination (Lambooij et al., 2010).

In order to compare meat quality, a different group of 60 broilers was split in half. 30 broilers were stunned by conventional electrical water bath stunning (control group), whilst the other 30 were stunned by the Head to Outside Cloaca method (experimental group). Temperature, pH, cooking loss and shear force in the breast muscle were measured and hemorrhages in the breast and thigh muscles were quantified by a visual grading system (Lambooij et al., 2010). The meat of broilers stunned by the head-to-cloaca method had a significantly lower pH and was more tender (lower shear force) than the meat of broilers stunned by means of the conventional electrical water bath. Furthermore, in the head-to-cloaca stunned broilers, the percentage breasts and thighs without
hemorrhaging was increased, whereas the percentage with severe bleedings was decreased compared to the electrical water bath stunned broilers (Lambooij et al., 2010).

1.3.4. CONCLUSIONS HEAD-TO-CLOACA SINGLE BIRD STUNNING

Both studies of Lambooij et al. (2008; 2010) showed that a head-to-cloaca controlled stunning method can induce an effective stun in broiler chickens, while having a positive effect on both animal welfare and product quality. By implementing an electrode in or around the cloaca, the resistance that is provided by the feet and shackles in conventional electrical water bath stunning can be overcome (Lambooij et al., 2008; Lambooij et al., 2010). This results in a more effective stun of individual broilers, whilst the reduction in resistance results in a lower current needed to accurately induce unconsciousness in the birds. This has a positive effect on meat quality, as a lower current reduces muscle contractions after stunning and diminishes the percentage of carcass bleedings (Morgenstern et al., 2009).

Although placing an electrode in or around the cloaca increases stunning efficiency and animal welfare, the birds still have to be handled and restrained prior to stunning. This involves uncrating, inversion and shackling, which are traumatic and stressful events for the birds. This causes most birds to flap their wings vigorously, which may lead to broken bones and pre-stun electric shocks (Shields & Raj, 2010). However, because the shackles are no longer part of the electrical circuit with head-to-cloaca stunning, a different and less stressful restraining method could be considered to further improve the bird’s welfare prior to stunning.

Up till now, head-to-cloaca controlled stunning has only been performed in laboratorial settings. More research is needed to adapt this stunning method to commercial poultry processing plants (Lambooij et al., 2010). One could imagine that the placing of a penetrating cloaca electrode might be an aspect of concern. It was mentioned by Lambooij et al. (2008) that broilers responded to the penetration of the cloaca electrode by contracting the annular fold muscle (Lambooij et al., 2008). This however, was observed in a laboratory setting. The possible welfare issues of an inside cloaca electrode should be carefully considered when designing a commercial head-to-cloaca stunning device.
1.4. TRANSCRANIAL MAGNETIC STIMULATION (TMS)

1.4.1. SUMMARY

**Advantages**
- Non-invasive and possibly pain-free stunning method
- Meets Halal-slaughter requirements

**Disadvantages**
- Not suitable yet as a commercial alternative stunning method
- The effects on animal welfare and meat and carcass quality have not been investigated
- Handling and restraining of the birds is stressful and reduces their welfare

1.4.2. INTRODUCTION

In the mid-1980’s, it was demonstrated for the first time that a brief and strong external magnetic field could stimulate the human motor cortex and peripheral nerves (Barker et al., 1985). Transcranial magnetic stimulation (TMS) involves the creation of an electromagnetic field that induces an electrical current within the brain, which causes temporary depolarization of brain cells (Lambooij et al., 2011; Nollet et al., 2003). TMS is now routinely used in humans to treat depression with pulses to frontal lobe, to induce seizures and to measure conduction times of the motor neuron system (Lambooij et al., 2011; Nollet et al., 2003).

In human TMS devices, a magnetic field is generated by passing an electric current through a magnetic coil of wire which is placed above the scalp. This electric current causes a magnetic pulse in the coil, which in turn induces a current in an electrically conductive region, such as the brain. The electric current flows perpendicularly to the magnetic field up to a few centimeters from the coil (Figure 16). Because the currents induced by magnetic stimulation can cross the extracerebral layers (scalp, skull and meninges) with minimal to no activation of the nociceptors, the sensation is very slight and considered painless by human subjects (Nollet et al., 2003).

**Fig. 16.** A magnetic field is produced by passing an electric current through a coil of wire. In an air-core winding, the magnetic field intensity is directly proportional to the current flowing through the coil (Adapted from Nollet et al., 2003)

1.4.3. PRELIMINARY TRIAL OF TMS STUNNING

Application of TMS in other species than humans is rare, but it was mentioned that Anil et al. (2000) have shown that it is possible to render rabbits unconscious using magnetic stimulation (Lambooij et al., 2011). Hindle et al. (2009) and Lambooij et al. (2011) conducted preliminary trials to induce unconsciousness in broilers using transcranial magnetic stimulation (TMS) as an alternative electric stunning method.
The objective of these studies was to determine if TMS with an adapted coil for broilers had the potential to be a non-invasive stunning method. Materials, methods and results of both studies were similar, so below the more recent study of Lambooij et al. (2011) is described.

In the study of Lambooij et al. (2011), a total of 25 broilers were placed one-by-one in a specially designed restrainer for stunning and recording of an EEG and ECG. The birds were then suspended individually by the head from shackles. The device used (TMS Stimulator Magstim Rapid 2®) was designed to deliver a magnetic stimulus to the broiler’s brain via an electric current passing through a copper coil built in to a probe placed close to the brain. Either a double probe was placed over the skull or a single probe was placed on the back of the skull (Figure 17) (Hindle et al., 2009; Lambooij et al., 2011). The size of the device was adapted to the head of a 5- to 6-weeks old broiler (Lambooij et al., 2011).

The effects of TMS were registered by using EEG’s (electroencephalograms) and ECG’s (electrocardiograms). An EEG registers electrical brain activity that can be distinguished as delta (0-4 Hz), theta (4-7 Hz), alpha (8-13 Hz) and beta (> 13 Hz) frequency bands. Within the alpha and beta bands, animals are considered to be conscious, whereas predominance of theta and delta bands and appearance of spikes of the EEG indicate cassation of brain activity (Lambooij et al., 2011). The broilers behavior was monitored for the occurrence of tonic cramps, clonic cramps, exhaustion (absence of muscle tone) and recovery wake up.

The EEG’s and ECG’s were recorded for 30 seconds before and until 5 minutes after the TMS in 25 broilers. After each stun, which lasted 5 seconds, the broilers were observed for their responses to pain stimuli (comb pinch) for a maximum of 5 minutes.

The EEG outcomes were analyzed by using correlation dimension (CD), a technique that has been used to measure depth of anaesthesia in humans. High CD values correspond with consciousness, while low values indicate a state of unconsciousness: in birds, a reduction in CD to 60% of the baseline value is seen in unconscious birds (Lambooij et al., 2011).

In contrast to other electrical stunning techniques, an epileptiform insult after TMS was not observed. However, analysis of the EEG showed theta and delta waves and no responses to the pain stimulus (comb pinching) were observed for approximately 20 seconds after stunning. This indicates that the birds were indeed in a state of unconsciousness after TMS. Both single and double probe
induced unconsciousness for approximately 15 to 20 seconds in the birds. After 20 seconds, the birds displayed drowsiness and recovered (Lambooij et al., 2011; Hindle et al., 2009).

1.4.4. CONCLUSIONS TMS STUNNING

As mentioned earlier, there is a need for a non-invasive stunning method, suited for commercial poultry slaughterhouses. With TMS, an intense magnetic field is generated by passing a large amount of current through a copper coil, which is positioned close to the brain. Lambooij et al. (2011) and Hindle et al. (2009) showed that this non-invasive and potentially pain-, anxiety- and stress-free method can induce a state of unconsciousness in broilers. It is therefore thought that transcranial magnetic stimulation is a potential stunning alternative for broilers. However, the device needs to be improved to induce a period of unconsciousness that is long enough to be useful in a slaughterhouse, and to accommodate large throughput rates (Lambooij et al., 2011). Also, when a commercial device is available, it should be further tested on animal welfare and product quality aspects.
2. MECHANICAL STUNNING

2.1. CAPTIVE BOLT STUNNING

2.1.1. SUMMARY

Advantages
- An accurate air line pressure and bolt diameter induces a direct kill
- Direct killing prevents birds of regaining consciousness before the neck cut
- Captive bolt stunning reduces tetanic muscle spasms after stunning, and therefore diminishes broken bones and hemorrhages

Disadvantages
- A suitable restraining and stunning device for commercial use is not available to this date
- Restraining of the birds can be a stressful and painful event
- Does not meet Halal-slaughter requirements

2.1.2. INTRODUCTION

Captive bolt devices have been used widely in Europe for stunning of red meat animals, especially cattle and sheep (Raj & O’Callaghan, 2001). As for poultry, captive bolts are normally used for stunning/killing as a backup method in processing plants when other methods fail, emergency killing or for disease control purposes (DEFRA, 2007). Although currently not used in commercial poultry slaughterhouses, further research for a commercially suitable captive bolt stunning device for broilers is desirable, as captive bolt stunning has a positive effect on both animal welfare and meat quality (Lambooij et al., 1999; Raj & O’Callaghan, 2001).

2.1.3. TECHNIQUE

Captive bolt devices can be either penetrating or non-penetrating and are fired using compressed air or cartridges. For poultry, these devices have been developed specifically to kill, rather than stun (EFSA, 2004). Because the broilers slaughtered for human consumption are of young age, the bones in their skulls are not fully ossified. Therefore, captive bolt stunning results in severe skull fractures and brain-damage leading to death, rather than a brain concussion as is induced in red meat animals (DEFRA, 2007; EFSA, 2004).

To achieve a humane stun/kill when using captive bolts, the bolt diameter, velocity, air line pressure, shooting angle and penetration depth are critical parameters (EFSA, 2004; Raj & O’Callaghan, 2001). Raj & O’Callaghan (2001) conducted two experiments to study the effectiveness of captive bolt stunning in broilers. In the first experiment, the effectiveness of 4 different angles of shooting the captive bolt was evaluated by using spontaneous behavior and physical reflexes as indicators of effective stunning. For the second experiment, spontaneous behavior, EEG and VEP’s (visually evoked potentials) were evaluated when shooting broilers with two different bolt diameters and two different air line pressures. They found that only when shot perpendicular (90 degree angle) to the skull, an effective stun/kill was induced. Deviations from the perpendicular shooting of more than 20° failed to stun a considerable portion of the birds and did not cause immediate death in any of the broilers tested (Table 6). Post-mortem examination of the broilers which survived non-perpendicular
shooting revealed that the bolt had either induced a compressed fracture or punctured a hole through the skin and slipped along the surface of the skull (Raj & O’Callaghan, 2001).

<table>
<thead>
<tr>
<th>Bolt diameter (mm)</th>
<th>Air line pressure (kPa)</th>
<th>Angle of shooting</th>
<th>Number of birds</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>827</td>
<td>90°</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>827</td>
<td>&gt;90°</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Effect of angle of shooting a captive bolt on the efficiency of stunning broilers (Adapted from Raj & O’Callaghan, 2001)

As for the bolt diameters and air line pressure, a 6 mm bolt and an air line pressure of 827 kPa resulted in an immediate stun leading to death in all the birds. Although a 3 mm bolt did penetrate the skull, it failed to induce a stun, as spontaneous EEG and VEP’s remained as that of pre-stunning. Also, when an airline pressure of 620 kPa and a 6 mm bolt were used, the bolt did penetrate the skull, but only caused hairline fractures in the bone and did not induce unconsciousness or death (Raj & O’Callaghan, 2001).

The results of this study indicate that, to achieve an effective stun/kill in broilers when using a captive bolt device, the shooting angle, bolt diameter and air line pressure are equally important.

2.1.4. LEGISLATION

In the EU legislation, both non-penetrating as penetrating captive bolt stunning are legal stunning methods to apply on broilers. Non-penetrating captive bolt stunning is described as ‘severe and irreversible damage to the brain caused by the pressure and penetration of a bolt’, whereas penetrating captive bolt stunning is described as ‘severe damage to the brain caused by the pressure of a bolt, without penetration’. Both forms of mechanical stunning are considered as ‘simple’ stunning (not inducing immediate death), but as mentioned before, mechanical stunning of broilers always leads to death as their immature skull bones become irreversibly damaged (DEFRA, 2007; EFSA, 2004; EU, 2009). Crucial parameters for mechanical stunning are as follows:

- Shooting angle
- Adequate velocity, diameter and shape of the bolt
- Depth of penetration
- Maximum time interval between stunning and the neck cut (EU, 2009)

2.1.5. WELFARE ASPECTS

As shown by Raj & O’Callaghan (2001) a humane stun/kill using a captive bolt device requires a proper application on the bird’s skull and the right shooting power and depth (Raj & O’Callaghan, 2001). This requires professional handling and knowledge of how to recognize an effective stun.

According to the European Food Safety Authority, a successful captive bolt stun/kill of a broiler can be indicated by

- Completely destroyed skull and brain
- Immediate onset of apnoea
• Dilated pupils
• Absence of corneal reflex
• Severe wing flapping
• Bleeding through the wound (EFSA, 2004)

On animal welfare grounds, captive bolt stunning is preferred over decapitation or neck dislocation as a killing method. When operated in the right manner, captive bolt stunning will cause immediate death. In contrary, brain activity and consciousness may continue up to 2 minutes after decapitation, whereas neck dislocation does not concuss the brain and therefore does not always cause immediate insensibility (DEFRA, 2007).

To facilitate accurate captive bolt stunning, the birds should be uncrated and restrained in cones, shackles, head-only or by hand (EFSA, 2004). It is likely that these handling procedures impose considerable stress on the birds (Raj, 1998).

2.1.6. PRODUCT QUALITY

In 1999, Lambooij et al. compared the effects of captive bolt stunning using air pressure and electrical water bath stunning on broiler carcass and meat quality. Broilers were either restrained by shackling or placed in a cone. They found that air pressure stunning reduced the prevalence of broken clavicles and coracoids, caused less hemorrhaging in filets and thigh muscles, and resulted in a more tender meat than electrical water bath stunning (Lambooij et al., 1999). A reduction in the prevalence of broken bones and hemorrhaging could be due to the reduction of clonic convulsions after captive bolt stunning, which are thought to be the cause of broken bones and bleeding in electrical stunning methods (Lambooij et al., 1999). The authors concluded that air pressure stunning has benefits over electrical whole-body stunning, but more research is needed to develop a suitable stunning and restraining device for captive bolt stunning (Lambooij et al., 1999).

2.1.7. CONCLUSIONS CAPTIVE BOLT STUNNING

Captive bolt stunning is currently not applied as a commercial stunning method for broilers (DEFRA, 2007). However, mechanical stunning could eliminate some of the welfare- and meat quality issues of conventional electrical water bath stunning. Insufficient stunning is less likely to occur, as a properly executed captive bolt stun results in immediate death (DEFRA, 2007; EFSA, 2004). Furthermore, research showed that mechanical stunning resulted in a better product quality than conventional electrical water bath stunning (Lambooij et al., 1999). It is therefore worthwhile to invest in research for commercially applicable captive bolt stunning devices for broilers.
3. GAS STUNNING

3.1. CONTROLLED ATMOSPHERE STUNNING (CAS)

3.1.1. SUMMARY

**Advantages**
- Reduction of pre-stun stress for broilers
- Higher product quality due to a decrease in broken bones and muscle hemorrhages
- Stun/kill of broilers eliminates the problem of regained consciousness before the neck cut
- Possible lower labor costs

**Disadvantages**
- Installation costs up to 10 times higher compared to those of electrical water bath stunners
- Additional costs of purchase and storage of gasses
- Higher energy costs when compared to electrical stunning methods
- Breathing discomfort induces distress in birds
- Working with gaseous mixtures causes a health risk for slaughter line operators
- Does not meet Halal-slaughter requirements

3.1.2. INTRODUCTION

Based on welfare – and meat quality issues, alternatives for conventional electrical water bath stunning are desired. As shown in Chapter 1, several alternative electrical stunning methods are investigated or currently put in operation. However, because most of these electrical stunning techniques still require intensive handling of live broilers, other alternatives are being sought to minimize pre-stun distress in the birds (Gerritzen et al., 2013).

One of the proposed methods is controlled atmosphere stunning (CAS, gas stunning), a stunning method that has been used for stunning pigs (Raj, 2006). It is thought that gas stunning could eliminate the pre-stun stress of uncrating and shackling of live birds. Furthermore, it could also eliminate the welfare problem of birds receiving insufficient currents (Raj, 2006). However, induction of unconsciousness by means of gas is a gradual process, so controlled atmosphere stunning systems should use non-aversive gas mixtures and the stunning process itself should not distress the broilers (Raj, 2006).

Over the past years, several gas mixtures and gas stunning methods have been researched to offer an acceptable alternative to conventional electrical water bath stunning (Morgenstern et al., 2009). Currently, one controlled atmosphere system is operational in the Netherlands: the two-phase CO₂ system (Morgenstern et al., 2009).

3.1.3. PHYSIOLOGY & TECHNIQUE

Controlled atmosphere stunning includes the exposure of poultry to gaseous mixtures that produce anoxic or hypoxic loss of consciousness (Hoen & Lankhaar, 1999). Like electrical stunning, gas stunning can be either reversible or irreversible (i.e. inducing death) (Morgenstern et al., 2009). To prevent birds stunned by CAS to regain consciousness before the neck cut, all current commercial CAS installations apply a stun/kill method (McKeegan et al., 2007).
The main gases used to stun broilers are carbon dioxide (CO\textsubscript{2}), argon (Ar) or nitrogen (N\textsubscript{2}) \citep{Morgenstern2009}. CO\textsubscript{2} directly affects the central nervous system, whereas Ar and N\textsubscript{2} displace oxygen from the breathing air \citep{Gerritzen2000}.

At present, two types of CAS systems are operational in the EU. In one system, broilers in crates are led through a gas chamber with an Ar/N\textsubscript{2}/CO\textsubscript{2} mixture. In the other system, birds are uncrated and transferred to a conveyer belt, that leads them through several gas chambers with CO\textsubscript{2}/O\textsubscript{2} mixtures.

In the Netherlands, one CAS system is currently operational: the so-called two-phase CO\textsubscript{2} system. In the UK, one or two slaughterhouses apply the Ar/N\textsubscript{2}/CO\textsubscript{2} stunning system \citep{Morgenstern2009}.

Argon is not readily available in the Netherlands and has to be imported from the United Kingdom or another country: therefore, CAS systems using Ar as a main component of the gaseous mixture would be relatively expensive to apply in Dutch poultry processing plants \citep{Morgenstern2009}. The scope of the evaluation of controlled atmosphere stunning will therefore be on CO\textsubscript{2} stunning systems.

**CO\textsubscript{2} stunning**

With the inhalation of high CO\textsubscript{2} concentrations, pCO\textsubscript{2} in the blood increases while pO\textsubscript{2} decreases. An increase of pCO\textsubscript{2} in the blood lowers the pH of cerebral fluid. When the pH of cerebral fluid (normally 7.4) decreases to approximately 7.0, a state of analgesia and anesthesia will occur. Also, an increase of pCO\textsubscript{2} stimulates breathing and therefore causes a higher intake of CO\textsubscript{2} from the surrounding air.

What follows is a cascade that ultimately leads to death due to the lack of oxygen supply to the brain and the rest of the body \citep{Morgenstern2009}.

CO\textsubscript{2} is an acidic gas that causes an unpleasant sensation on the mucosa and creates a sense of breathlessness in broilers \citep[see further]{Gerritzen2000, Lambooij2004, Raj1998}. Addition of O\textsubscript{2} to the breathing air can reduce the distress caused by high CO\textsubscript{2} concentrations.

Therefore, a two-phase CO\textsubscript{2} system has been developed: in the first phase, unconsciousness is induced by exposing birds to a mixture of CO\textsubscript{2} and O\textsubscript{2} in air, while death occurs in the second phase when exposed to a high concentration of CO\textsubscript{2} in air \citep{Gerritzen2013}.

Although adding O\textsubscript{2} to the breathing air is beneficial for the bird’s welfare, it also slows down the onset of unconsciousness \citep{Gerritzen2013}. Experiments are therefore conducted with the two-phase CO\textsubscript{2} stunning system to find an acceptable balance between the intensity and duration of the stun, and the amount of distress for the broilers \citep[see further]{Gerritzen2013}.

The Dutch firm Stork has developed a device for two-phase CO\textsubscript{2} stunning \citep{Figure18}. Broilers are unloaded from their crates onto a conveyor belt which takes them through the two-phase stunning system. In the first phase, birds are exposed for 1 minute to a mixture of 40\% CO\textsubscript{2} and 28\% O\textsubscript{2} in air. This causes a state of reversible unconsciousness in the birds. Next, the broilers are exposed to a mixture of 60\% to 80\% CO\textsubscript{2} in air for 2 minutes: this induces irreversible unconsciousness and thus death \citep{Marel2013}. The conveyor belt steepens at the end of the stunning device: because CO\textsubscript{2} is heavier than air, the main fraction of CO\textsubscript{2} stays in the stunning chambers. Only a small percentage of CO\textsubscript{2} is exported outside the stunner between the bird’s feathers: this is removed by special extractors when the birds leave the device. After stunning, birds are bled through a neck cut, after which electro-stimulation of the carcass is applied to accelerate the onset of post-mortem tenderization \citep{Marel2013}.
It should be mentioned that working with gasses is an additional health risk factor for slaughter-line employees. The oxygen concentration in the working environment should therefore be closely monitored, and any gas residues leaving the stunning device between the bird’s feathers should be removed by special extractors (Morgenstern et al., 2009).

3.1.4. LEGISLATION

The regulations for commercial controlled atmosphere stunning are described in EU regulation 1099/2009. Two-phase CO$_2$ stunning is described as ‘consecutive exposure of animals to a gas mixture containing less than 40% CO$_2$, followed by an exposure to a higher CO$_2$ concentration when unconsciousness is induced’ (EU, 2009). Direct exposure of birds to a gaseous mixture with a CO$_2$ concentration higher than 40% is not allowed (EU, 2009).

Crucial parameters when applying a two-phase CO$_2$ stunning method are

- CO$_2$ concentrations
- Duration of exposure of birds to the gas mixture
- Quality and temperature of the gas (EU, 2009)

Stunning by means of a gaseous mixture of < 40% CO$_2$ and an inert gas (Ar or N$_2$) is allowed for broilers, and is considered a form of ‘simple’ (reversible) stunning when the birds are exposed to a minimum of 30% CO$_2$ for a maximum of 3 minutes (EU, 2009). Stunning could also be performed by direct or gradual exposure to a mixture of inert gasses (Ar and N$_2$), inducing hypoxia. This is also considered a ‘simple’ form of stunning when exposure to hypoxia is less than 3 minutes (EU, 2009).

3.1.5. WELFARE ASPECTS

A main reason for the development of gas stunning methods was to improve the bird’s welfare at slaughter. With gas stunning, pre-stun stress due to inversion and shackling of live birds and the risk of insufficient stunning can be diminished (Morgenstern et al., 2009). Although some of the welfare issues of electrical water bath stunning can thus be eliminated through gas stunning, controlled atmosphere stunning comes with its own set of possible welfare issues. First of all, with gas stunning, induction of unconsciousness is gradual. It is therefore important that the period to induce unconsciousness and the extent of stress for the bird are well balanced (Morgenstern et al., 2009).

The main stress inducing factors at CAS are

- Aversion to the gas
• Irritation of the mucosa
• Breathing discomfort (Morgenstern et al., 2009)

Furthermore, a gas overdose can lead to paralysis of the respiratory muscles, causing death of the bird by suffocation (Lambooij, 1999). Another problem with the administration of gasses, is that a phase of excitation occurs, in which there is a stage of increased activity and strong muscle contractions. This could cause distress in the birds, as they are not always unconscious during this phase (Lambooij, 1999). The duration and intensity of the excitation phase depend on the gas mixture administrated and way of administration (Lambooij, 1999).

Although CO$_2$ is known to have a narcotic effect, it also is an acidic gas that is irritating to the mucosa and causes stress in animals exposed to high concentrations. Also, inhalation of CO$_2$ causes an unpleasant respiratory response in birds (Gerritzen et al., 2000; McKeegan et al., 2007). Studies on the impact of different percentages of CO$_2$ in a gas chamber on the behavior of chickens during the first 10 seconds of exposure, revealed that most broiler chickens seemed to tolerate concentrations up to 40% CO$_2$. Higher concentrations were likely to cause pain and higher unpleasantness, as more birds began to withdraw from the gas chamber (EFSA, 2004).

Ar and N$_2$ are inert gasses that are tasteless and odorless, and do not cause an unpleasant sensation of the mucosa (Gerritzen et al., 2000). However, these gasses tend to cause convulsions that can lead to the bird physically damaging itself during stunning. This damage in turn leads to lower carcass and meat quality (Webster & Fletcher, 2004).

Several studies have been performed on the welfare implications of stunning broilers with various gasses and gaseous mixtures. McKeegan et al. (2007) exposed individual broilers to gas mixtures that were capable of inducing unconsciousness and euthanasia. During stunning, the behavioral, cardiac (ECG), respiratory and neurophysiological (EEG) responses were measured simultaneously (McKeegan et al., 2007). Broilers were exposed to either 1) N$_2$ in air with < 2% O$_2$ (inducing anoxia), 2) Ar in air with < 2% O$_2$ (inducing anoxia), 3) 30% CO$_2$ in Ar (inducing hypercapnic anoxia), 4) 40% CO$_2$ in N$_2$ (inducing hypercapnic anoxia), 5) two-phase CO$_2$ (40% CO$_2$ + 30% O$_2$ + 30% N$_2$, followed by 80% CO$_2$ in air). Animal welfare was assessed by the extend of unpleasant experiences for the conscious bird. Results showed that anoxic CAS was associated with vigorous behavioral responses, as birds showed tonic and clonic convulsions (in the form of powerful wing flapping and twitching) while being conscious. These convulsions were not observed in the two-phase CO$_2$ system. Stunning with CO$_2$ mixtures however induced visible respiratory discomfort, by means of mandibulation and hyperventilation (McKeegan et al., 2007). The authors concluded that, although the respiratory distress caused by CO$_2$ stunning is an understandable source of welfare concern, the potentially negative behavioral responses and associated injuries caused by anoxia would be a greater threat to the birds’ welfare (McKeegan et al., 2007).

One way to diminish the negative effects of initial high CO$_2$ concentrations, is the addition of O$_2$ to the breathing air. However, the addition of oxygen tends to slow down the induction of unconsciousness (Gerritzen et al., 2013). Another way to decrease stress associated with CO$_2$ stunning, is a more gradual increase in CO$_2$ concentration. In the two-phase CO$_2$ stunning method as currently applied in the Netherlands, birds
are initially numbed with a mixture of maximum 40% \(\text{CO}_2\) and a decreasing amount of \(\text{O}_2\). This is followed by a phase where the birds are killed with a \(\text{CO}_2\) concentration up to 80% \((\text{Gerritzen et al., 2013})\). Gerritzen et al. (2013) conducted experiments to determine which method of gradual two-phase \(\text{CO}_2\) stunning would offer an acceptable balance between the intensity and duration of the stun, and the amount of distress for the birds \((\text{Gerritzen et al., 2013})\). Broilers were exposed to either treatment 1 or 2. Treatment 1 was a 5-stage incremental scheme for \(\text{CO}_2\) supply, taking 6 minutes to complete, involving exposure to 20, 30, 40, 50 and 60% \(\text{CO}_2\). Treatment 2 was a 4-stage incremental scheme for \(\text{CO}_2\) supply, taking 4 minutes to complete, involving exposure to 20, 35, 45 and 65% \(\text{CO}_2\). Treatments were tested in a semi-commercial setting and the behavior of the birds was observed. All broilers were stunned and killed with both treatments. It was concluded that all birds lost consciousness before they were exposed to a \(\text{CO}_2\) concentration above 40% (as observed by the loss of posture), but all showed some signs of discomfort (i.e. head shaking) before loss of consciousness. The authors concluded that both treatments offered an effective stun/kill in all broilers, with the 6-minute, 5-stage treatment having the lowest risk on convulsions \((\text{Gerritzen et al., 2013})\).

### 3.1.6. PRODUCT QUALITY

Hoen & Lankhaar (1999) evaluated meat quality of broilers stunned either by conventional, multiple bird electrical water bath stunning (control group) or by two-phase \(\text{CO}_2\) stunning (experimental group). The control group was stunned by means of a 120 mA, 50 Hz current applied for 4 seconds. The experimental group was first exposed for 1 minute to a gas mixture of 30% \(\text{O}_2\), 40% \(\text{CO}_2\) and 30% \(\text{N}_2\) to induce unconsciousness, and killed in the second phase by exposure to a 80% \(\text{CO}_2\) and 5% \(\text{O}_2\) mixture for 2 minutes \((\text{Hoen & Lankhaar, 1999})\). Meat quality was determined by shear force value, meat color, blood spots, and drip and cooking losses. Results showed that stunning by means of gas had a positive effect on carcass and meat quality, as it improved meat tenderness and drip loss, while decreasing blood spots in breast and thigh meat \((\text{Hoen & Lankhaar, 1999})\). A possible explanation for the observed quality differences could be as follows: electrical water bath stunning results in vigorous convulsions of the whole body. Intense contractions of antagonist muscle pairs often results in damage and hemorrhage of the weaker muscle and severe strain on the skeleton, leading to broken pectoral bones. Controlled atmosphere stunning practically eliminates hemorrhages and broken pectoral bones, as convulsions are less likely to occur during stunning \((\text{Abeyesinghe et al., 2007})\).

In 2007, McKeegan et al. compared the effects of a one phase 60% \(\text{Ar}/30\% \text{CO}_2/2\% \text{O}_2\) in air stunning process and a two-phase \(\text{CO}_2\) stunning method (phase one 40% \(\text{CO}_2/30\% \text{O}_2/30\% \text{N}_2\), phase two 80% \(\text{CO}_2/5\% \text{O}_2/15\% \text{N}_2\) on carcass and meat quality. Stunning was performed in a commercial processing plant in Belgium with an average throughput of 9000 birds per hour. Carcass and meat quality were determined by assessment of meat color, fillet pH, shear force value, occurrence of hemorrhages and broken bones, and cooking loss \((\text{McKeegan et al., 2007})\). It was concluded that there was a clear advantage to the processor in using the two-phase \(\text{CO}_2\) stunning method rather than the one phase \(\text{Ar}/\text{CO}_2/\text{O}_2\) method, as the use of the two-phase system resulted in a much smaller number of wing fractures and fewer blood spots in the breast fillets \((\text{McKeegan et al., 2007})\). Other meat quality parameters were not affected by the type of gas mixture used. Behavioral observations during stunning showed that birds stunned by the \(\text{Ar}/\text{CO}_2/\text{O}_2\) gas mixture displayed more wing flapping than birds stunned in the two-phase system. This could explain the higher percentage of broken wing...
bones in the one-phase stunned broilers (McKeegan et al., 2007). The higher occurrence of hemorrhages in the one-phase stunned broiler fillets was not explained by the authors, but behavioral observations showed that birds stunned by the Ar/CO₂/O₂ displayed not only more wing flapping, but also more jumping, leg paddling and twitching (McKeegan et al., 2007). These movements could possibly induce injuries resulting in muscle bruising and bleeding. The same results were found in a study of Abeyesinhe et al. (2007), who conducted experiments with similar one-phase and two-phase gas stunning systems. The authors concluded that the different CAS methods indeed had different behavioral and physiological effects, which in turn might have affected meat quality (Abeyesinghe et al., 2007).

It was noted by McKeegan et al. (2007), that for both CAS methods used, it took up to 7 hours for the carcass to attain full rigor mortis (McKeegan et al., 2007). Poultry carcasses are portioned and deboned after the occurrence of rigor mortis, as the meat then starts to obtain tenderness. In commercial poultry processing plants, the line speed is set to de-bone and portion the carcasses after 2 to 3 hours post mortem. When CAS is used, this short time interval could thus lead to tough meat, as the rigor mortis has not set in yet. This can be overcome by using electrical stimulation of the carcass as a tenderizing treatment: this accelerates the onset of rigor mortis, allowing gas stunned broiler carcasses to be de-boned and portioned within 3 hours post-mortem. This method is applied by most commercial European processing plants as an additional step in the processing of poultry carcasses stunned by CAS (McKeegan et al., 2007; Sams & Dzuik, 1999).

3.1.7. ECONOMICAL ASPECTS OF CONTROLLED ATMOSPHERE STUNNING

In 2009, the Animal Science Group (ASG) and the Agricultural and Economical Institute (LEI) of the Wageningen University in the Netherlands conducted an economical analysis of CAS compared to conventional electrical water bath stunning (Morgenstern et al., 2009).

It has proven difficult to compare the economical aspects of electrical water bath stunning to those of controlled atmosphere stunning, because 1) the installation costs of a CAS system strongly depend on the individual circumstances in slaughterhouses, and 2) it is difficult to assess the economical benefits of meat quality improvements (Morgenstern et al., 2009).

The following aspects should be taken into account when analyzing the economical aspects of controlled atmosphere stunning:

- Costs of installation of the stunning device
- Costs of the gas mixture (CO₂/O₂)
- Energy costs
- Water costs
- Labor costs
- Product revenue due to quality differences (Morgenstern et al., 2009)

According to the ASC and the LEI, investments in a controlled atmosphere stunning device are up to 10 times as high as the those for a water bath installation. It is thought that the size of the processing plant (i.e. number of slaughtered broilers per week) is an important factor in the costs of a CAS installation (Morgenstern et al., 2009).
Other than with electrical water bath stunning, controlled atmospheres stunning brings extra costs for the purchase and storage of gaseous mixtures. It is unknown what these costs are for the CO$_2$/O$_2$ mixture as used in the two-phase CO$_2$ system (Morgenstern et al., 2009).

CAS systems bring additional energy costs, as the use of electricity is higher compared to the water bath system. On the other hand, the use of water is lower with a CAS system (Morgenstern et al., 2009).

As far as labor is concerned, a CAS system could reduce labor costs as unconscious birds can be shackled faster than live birds. Furthermore, it is thought that people working on a CAS line suffer from less dust- and RSI related health problems, which could decrease sickness absence of employees. However, there is no data available on the possible decrease of labor costs when using a controlled atmosphere stunning system (Morgenstern et al., 2009).

As mentioned earlier, gas stunning improves product quality as it results in less hemorrhages and broken bones compared to electrical water bath stunning. It is thought that the revenues of namely the breast fillets are higher when broilers are stunned with gas, although this is difficult to determine. It has been estimated that the additional costs of CAS stunning are 0.075 to 0.2 eurocents per broiler when the two-phase CO$_2$ system is applied. However, it seems that these additional investments are repaid quickly by the extra revenues of the high quality products (Morgenstern et al., 2009).

It is difficult to determine whether a CAS system is profitable when compared to conventional electrical water bath stunning, as the economical factors are strongly influenced by specific characteristics of the poultry processing plant and their market (Morgenstern et al., 2009).

3.1.8. CONCLUSIONS CONTROLLED ATMOSPHERE STUNNING

Controlled atmosphere stunning eliminates one of the main welfare issues associated with electrical stunning methods, namely the intensive pre-stun handling of broilers. Also, it overcomes the problem of insufficient stunning, as the currently applied two-phase CO$_2$ stunning device induces death in all birds. This however makes poultry products form gas-stunned broilers unsuitable for the Halal-market, as stunning is irreversible. Furthermore, stunning by means of CO$_2$ induces breathing discomfort in birds (Gerritzen et al., 2000; McKeegan et al., 2007; Morgenstern et al., 2009).

Another advantage of CAS systems, is the decrease of carcass defects, resulting in higher product revenues. On the downside however, installation costs for the stunning device and additional costs of purchase and storage of gasses are high. To this date, it is unknown to what extend CAS is an economical beneficial stunning method for large poultry processing plants (Morgenstern et al., 2009).
3.2. LOW ATMOSPHERE PRESSURE STUNNING (LAPS)

3.2.1. SUMMARY

Advantages
- Induces an effective and humane stun/kill in broilers when the LAPS system is precisely controlled
- Direct killing eliminates the problem of birds regaining consciousness prior to the neck cut
- Does not require storage of gas mixtures under pressure
- Requires fewer modifications of the processing plant when compared to a CAS stunning device
- Meat quality of LAPS stunned birds is at least as good as that from conventional electrical water bath stunned birds
- Reduction of pre-stun stress for broilers as uncrating, inversion and shackling is not needed

Disadvantages
- Disapproved as a humane stun/kill method by the American Veterinary Medical Association based on animal welfare grounds
- Not approved as a stunning method in Europe
- No processing variables have been determined for decompression stunning of broilers of 42 days of age
- More research is needed to further prove the feasibility and humanity of low atmospheric pressure stunning systems
- Does not meet Halal-slaughter requirements

3.2.2. INTRODUCTION

From various studies on controlled atmosphere stunning (CAS) it has been concluded that this stunning method could overcome some welfare issues associated with electrical water bath stunning, such as uncrating (not in the two-phase CO₂ system), inversion and shackling of live broilers (EFSA, 2004; Raj, 1998). Concerns of CAS however, are the debate on which gas mixture to use for an effective and humane stun, the potential dangers of storage of gas mixtures under pressure, and the required modifications of the processing plant to operate with a gas stunning system (Vizzier-Thaxton et al., 2010).

A different method of controlled atmosphere stunning is decompression (low atmosphere pressure stunning, LAPS, vacuum stunning), by which a vacuum pump is used to reduce the oxygen tension (pO₂) in the atmosphere of an air-tight chamber. Due to the decrease of pO₂, unconsciousness is induced by lack of oxygen delivery to the brain (Vizzier-Thaxton et al., 2010).

Low atmosphere pressure stunning is not allowed as a stunning method by the European Union (EU, 2009). Also, in the United States, low atmosphere pressure stunning is not legally accepted as a stunning method, because the American Veterinary Medical Association (AVMA) has stated that it is an inhumane method for euthanasia (Vizzier-Thaxton et al., 2010). The main objections of the AVMA to decompression as a stunning method are as follows:
• ‘Many chambers are designed to produce decompression at a rate 15 to 60 times faster than that recommended as optimum for animals, resulting in pain and distress attributable to expanding gases trapped in body cavities’
• ‘Immature animals are tolerant of hypoxia, and longer periods of decompression are required before respiration ceases’
• ‘Accidental recompression, with recovery of injured animals, can occur’
• ‘Bleeding, vomiting, convulsions, urination, and defecation, which are aesthetically unpleasant, may develop in unconscious animals’ (AVMA, 2007)

Despite the fact that decompression is currently not allowed as a stunning method for broiler chickens, studies have indicated that, when accurately performed, low atmosphere pressure stunning could nevertheless offer a humane alternative to current stunning techniques.

3.2.3. PILOT STUDIES ON LOW ATMOSPHERE PRESSURE STUNNING

To this date, only little research is done regarding low atmosphere pressure stunning as a stunning method for modern poultry processing plants.

In order to determine the operating range of atmospheric pressure and the optimum pressure to stun or stun/kill broilers via low atmospheric pressure stunning, Purswell et al. (2007) conducted a study using a test LAPS unit. In the test unit, oxygen pressure was lowered within two minutes to pressures ranging from 70.9 kPa to 17.8 kPa (Purswel et al., 2007). During stunning, broilers (60 to 63 days old) in the unit were observed for loss of posture (LOP): the inability to stay in a seated position or to maintain neck tension, which occurs at the onset of unconsciousness. Furthermore, breathing movements by means of keel movement were observed to indicate the cessation of the respiratory apparatus (Purswell et al., 2007). From these experiments, it could be concluded that the effective range of pressure was between 29.5 and 17.8 kPa, with a 75% death rate of birds exposed to 29.5 kPa and a 100% death rate when exposed to 17.8 kPa. The estimated pressure resulting in death of 99.9% of the broilers was 19.4 kPa (Purswell et al., 2007).

The study of Purswell was purely conducted to identify process variables for low atmosphere pressure stunning in broilers: it did by no means include animal welfare measurements. Vizzier-Thaxton et al. (2010) however, argued that if there were a LAPS method in which all of the above AVMA objections could be eliminated, low atmosphere pressure stunning could be a humane and useful stunning method in commercial processing plants (Vizzier-Thaxton et al., 2010). As far as the first objection of the AVMA was concerned (i.e. pain and discomfort resulting from expanding gas trapped in body cavities), Vizzier-Thaxton et al. (2010) argued that this was not likely to occur in chickens due to the structure of their respiratory system. In contrast to mammals, the respiratory system of chickens consists of fixed lungs and 9 air sacs that fill up all the cavities in the abdomen and thorax. The lack of a diaphragm causes chickens to use their intercostals muscles to inhale and exhale. During respiration, the movement of air in and out the sacs and lungs is a constant process. It is therefore thought that trapping of air in body cavities is unlikely to occur during LAPS (Vizzier-Thaxton et al., 2010).

To further investigate how the established welfare issues of decompression stunning could be diminished, Vizzier-Thaxton et al. (2010) conducted a pilot study. In their experiments, a prototype
commercial LAPS unit (Figure 19 & 20) was used to determine the operating parameters needed to ensure a humane stun of broilers by decompression. The LAPS unit consisted of a cylindrical chamber with a capacity for 2 commercial broiler transport cages. The transport cages were moved in and out the LAPS unit via a transfer conveyors. Oxygen pressure reduction by vacuum pumps was computer controlled, and video cameras were installed so that the broiler’s behavior could be observed during the experiments (Vizzier-Thaxton et al., 2010).

For 6 months, broilers (age not specified) were stunned in the LAPS unit. According to the findings of Purswell et al. (2007), birds stayed in the LAPS unit for 2 minutes with the oxygen pressure slowly decreasing to 19.4 kPa (Purswell et al., 2007).

The following measurements were performed: 1) post-stun recovery: recovery was determined by any movement of the bird, including eye movement, 2) movements during stunning: signs of discomfort such as head shaking, mandibulation, deep breathing, bill breathing and wing flapping, 3) post-stun damage: dislocated joints, broken bones and bruising, 4) hemorrhages in the lungs, liver, intestinal tract and breast muscle 5) blood flow after neck cut in order to evaluate whether an adequate bleed could be achieved after LAPS and 6) post-stun plasma corticosterone concentrations as a stress indicator during the stunning process (Vizzier-Thaxton et al., 2010).

No post-stun recovery was observed after stunning, as expected from previous findings by Purswell et al. (2007). The percentage of wing damage was higher in broilers stunned by LAPS when compared to those stunned by conventional electrical water bath stunning: this was probably due to the fact that the birds were stunned in the transport cases, and any wing flapping against the cage wall during stunning could result in wing damage. Blood flow from the LAPS-stunned birds was within the acceptable range for processing (Vizzier-Thaxton et al., 2010).

From the behavioral observations, it occurred that only 6% of the birds stunned by LAPS showed wing flapping. Wing flapping seemed to occur in a typical pattern of 3 episodes of 5 seconds each: the first flapping movements were seen approximately 60 seconds after pressure reduction, probably due to the bird’s awareness of pressure change in the unit. After 70 seconds in the LAPS unit, birds started head shaking followed by wing flapping. No mandibulation nor bill breathing or deep breathing was observed (Vizzier-Thaxton et al., 2010).
As for the corticosterone analysis, concentrations were lower in LAPS stunned birds when compared to birds stunned by electrical water bath stunning. It was thought that part of the lower corticosterone concentration was due to not inverting and shackling birds prior to stunning, proceedings that are part of the conventional electrical water bath stunning method. Finally, no hemorrhagic lesions were found in the tissues of LAPS stunned birds, with carcass quality being at least equal to that of electrical water bath stunned broilers (Vizzier-Thaxton et al., 2010).

Meat quality of LAPS stunned broilers was further investigated in a study of Schilling et al. (2010) and Battula et al. (2008). In both studies, breasts and thighs of birds stunned by either conventional electrical water bath or LAPS were measured for color, pH, cooking loss and shear force values. From both studies it was concluded that there was no significant difference in meat quality between the two stunning methods (Battula et al., 2008; Schilling et al., 2010).

3.2.4. CONCLUSIONS LOW ATMOSPHERE PRESSURE STUNNING

Based on the welfare issues associated with low atmosphere pressure stunning as pointed out by the American Veterinary Medical Association, LAPS is currently not approved as a humane stunning method in commercial poultry processing plants in the US, nor in the European Union. Research has shown that when the LAPS system is precisely controlled, it could however induce an effective stun/kill in broilers, without compromising the bird’s welfare or meat quality (Purswell et al., 2007; Vizzier-Thaxton et al., 2010). Experiments with a commercial pilot LAPS system showed that, when decompression was done under the right process variables, no adverse behavior, tissue damage or carcass quality defects occurred in the stun/killed birds (Vizzier-Thaxton et al., 2010). Furthermore, in contrast to conventional electrical water bath stunning, pre-stun stress can be reduced as uncrating, inversion and shackling of the broilers is not needed when a LAPS system is used (Vizzier-Thaxton et al., 2010).

Compared to gas stunning, LAPS does not require storage of gas mixtures under pressure, nor does it require extensive modifications of the existing processing lines in the poultry plant (Purswell et al., 2007; Vizzier-Thaxton et al., 2010).

Although it can be concluded that some of the welfare issues associated with LAPS could be overcome by precise settings of the stunning device, no literature is available on the effects of decompression stunning of young broilers (i.e. 42 days of age). The AVMA argues that immature animals have a higher threshold for hypoxia and decompression periods should be adjusted accordingly (AVMA, 2007).

More research is thus needed to prove that a LAPS system could indeed meet current broiler stunning welfare standards while measuring up to the demands of a modern poultry processing plant.
4. RITUAL SLAUGHTER

4.1. KOSHER AND HALAL SLAUGHTER

4.1.1. INTRODUCTION

In modern Western society, animal products are an important source of dietary protein and they are highly appreciated for their taste and texture (Kijlstra & Lambooij, 2008). For some religious communities, the consumption of animal products is regulated by dietary laws originated from ancient writings (Regenstein et al., 2003). In the Netherlands, the Jewish and Muslim populations are the main religions that produce, process and consume animal products according to ritual laws (Kijlstra & Lambooij, 2008). To this date, over one million Muslims and approximately 50 000 Jews are living in the Netherlands, and their number is expected to increase (CBS, 2013).

Muslim dietary laws, as derived from the Quran and the Hadith, prescribe to only consume foods that are ‘Halal’ or permitted for Muslims. The Jewish kosher dietary laws (referred to as ‘Halacha’), as prescribed in the Talmud, determine which foods are ‘kosher’ or fit for proper consumption (Regenstein et al., 2003).

Both Jewish and Muslim dietary laws prescribe ritual slaughter of animals, including poultry. Part of ritual slaughter is the killing of a conscious animal by bleeding through a neck cut (Kijlstra & Lambooij, 2008). This method of slaughter is in conflict with non-religious slaughter regulations, that state that all animals should be stunned prior to slaughter to induce immediate unconsciousness and insensibility (EU, 2009). It is therefore that ritual slaughter is a topic of discussion in Dutch society and politics. Although ritual slaughter is allowed in the Netherlands based on freedom of religion, opponents of ritual slaughter argue that religious beliefs do not weigh up to the unnecessary pain and discomfort for the animal (Kijlstra & Lambooij, 2008). Islamic organizations permit some forms of stunning, but with the regulations for stunning of poultry changing from January 2013, there is a growing concern on whether stunning poultry prior to slaughter can still be considered Halal (Halalaudit.nl, 2013).

4.1.2. KOSHER AND HALAL SLAUGHTER OF POULTRY

Broilers are considered ‘kosher’ or ‘Halal’ by respectively Jewish and Muslim dietary laws, when ritually slaughtered (Kijlstra & Lambooij, 2008). According to both Jewish and Islamic holy writings, an animal should be intact and alive when receiving the neck cut: stunning methods like captive bolt stunning or electrical stunning could affect the integrity of the animal (Kijlstra & Lambooij, 2008). EU legislation permits the unstunned slaughter of poultry based on religious beliefs (EU, 2009). Slaughterhouses that want to perform ritual slaughter, must report this to the Dutch Food and Consumer Product Safety Authority (NVWA) (Kijlstra & Lambooij, 2008). The Dutch regulations for ritual slaughter are specified in the ‘Resolution for Religious slaughter’ and the ‘Covenant on ritual slaughter’ (Besluit ritueel slachten, 1996; Convenant onbedwelmd slachten volgens religieuze riten, 2011). As far as the actual slaughter is concerned, it is prescribed that the neck cut should be performed with a sharp knife, cutting both jugular veins and arteries in one fluent motion (EU, 2009; Kijlstra, A. & Lambooij, 2008; Besluit ritueel slachten, 1996).

There is no data available about the number of broilers that are currently ritually slaughtered in the Netherlands, but it is estimated that poultry accounts for approximately 3% of all religious slaughtered animals (Kijlstra & Lambooij, 2008).
**Kosher slaughter of broilers**

Kosher slaughter of broilers, the so-called *Shechita*, strictly forbids stunning of the birds prior to the neck cut. Therefore, each conscious bird is restrained manually to the *shochet* (slaughterman), who cuts both arteries and jugular veins with a sharp knife, called *chalaf*. The bird is then placed head down in a cone-shaped restrainer to bleed out till death occurs (*Barnett et al., 2007; Kijlstra & Lambooij, 2008*). A neck cut can be a painful, as the neck region contains numerous pain receptors and the cutting of nerves in this area (namely the phrenicus nerve) can cause a sensation of suffocation. It was reported that kosher slaughtered broilers remain conscious for approximately 25 seconds after the neck cut. Furthermore, research showed that in 42% of the broilers slaughtered according to *Shechita*, only one of both jugular arteries was cut, causing the period to the onset of unconsciousness to be even longer (*Kijlstra & Lambooij, 2008*).

After exsanguination, the birds are inspected for abnormalities and accordingly appreciated as ‘kosher’ (fit to consume) or ‘non-kosher’ (*Barnett et al., 2007*).

**Halal slaughter of broilers**

During traditional Halal slaughter of broilers, the heads of the birds should be pointed in the direction of Mecca. The conscious bird is restrained and both arteries and jugular veins are cut by a Muslim slaughterman while pronouncing the words “bismillah Allahu akbar”, after which the bird bleeds out. After inspection, the carcass is then appreciated as ‘Halal’ (fit to consume) or ‘Haram’ (impure, not fit for consumption) (*Kijlstra & Lambooij, 2008*).

In contrast to kosher slaughter, the rules for Halal slaughter are not formally described. Therefore, some stunning methods prior to the neck cut are accepted, as long as unconsciousness is reversible and the integrity of the bird is guaranteed (*Kijlstra & Lambooij, 2008*). Currently, there is a lot of debate among Muslim groupings which stunning methods for broilers are Halal, and which are not. The difficulty is that, at this moment, there is no uniform standard for Halal poultry processing. Currently, there are several Halal-certifying organizations, that certify poultry slaughterhouses for Halal slaughter. However, there organizations do not always apply the same standards (*Kijlstra & Lambooij, 2008; Vesseur, 2013*).

According to the front man of the Association of Dutch Poultry Processing Industries (Vereniging van de Nederlandse Pluimveeverwerkerende Industrie, NEPLUVI), in large poultry processing plants certified by a Halal-organization, no broilers are currently slaughtered without stunning. All birds are stunned prior to the neck cut, by a stunning method that is approved by a Halal-certifying organization (*Vesseur, 2013*).

In principle, stunning prior to slaughter is only considered Halal when reversible: if not followed by a neck cut, the bird should regain consciousness after stunning. Irreversible stunning is not Halal-approved (*Vesseur, 2013*). Until recently, conventional electrical water bath stunning was considered Halal, as stunning was reversible. However, with the growing concerns about the animal welfare issues associated with this technique of stunning (namely insufficient stunning), EU regulation demands a different setting of current and frequency for electrical water bath stunners from January 2013. This may result in a higher percentage of birds dying of cardiac arrest, causing an irreversible stun that is no longer Halal-approved (*Halalaudit.nl, 2013*).

Gas stunning in this case, is no alternative for conventional electrical water bath stunning. The gas-stunning method approved in the Netherlands, namely the two-phase carbon dioxide system, induces unconsciousness in the first, but death in the second phase of CO₂ stunning. Therefore, gas-
stunning is irreversible and not approved by Halal-organizations (Kijlstra & Lambooij, 2008; Halalcorrect.com, 2013).

It seems that the only alternative stunning method, which is now suitable for application in large poultry processing plants as well as Halal-approved, is head-only single bird electrical stunning. Indeed, TopKip claims that their patented head-only stunner is Halal-approved (TopKip, 2013). In the head-only stunning system, birds are individually stunned, resulting in a higher stunning efficiency. Secondly, depending on the system-type, birds can be shackled after stunning, thereby diminishing pain and distress prior to stunning. Furthermore, unconsciousness is reversible and thus Halal stunning requirements are met (Lambooij et al., 2010; TopKip, 2013). On the other hand, installation costs of the head-only stunner are high, and currently the system is not operational in slaughterhouses yet, although the first head-only stunners are installed at the publication of this review (Horne et al., 2011).

4.1.3. CONCLUSIONS RITUAL SLAUGHTER

From the above it can be concluded that traditional kosher slaughter of broilers, where no form of stunning is allowed, is not conformable with modern Western slaughter practices. However, this form of slaughter is allowed by the Dutch government, based on the freedom of religion (EU, 2009). Halal slaughter does not really differ from conventional slaughter, since reversible stunning of broilers is allowed. Most of the large poultry processing plants that serve the Halal market, use conventional electrical water bath stunners. It can therefore be said that with Halal slaughter, the same animal welfare issues are associated as those with conventional electrical water bath stunning (Kijlstra & Lambooij, 2008).

Over the last years, the public debate on animal welfare during slaughter has been focused mainly on religious slaughter practices. This has led to the ‘Covenant on ritual slaughter’: an agreement between the Dutch government, slaughterhouses and Muslim- and Jewish groupings to improve animal welfare at religious slaughter (Convenant onbedwelmd slachten volgens religieuze riten, 2011). As stated before, this covenant does not really concern broilers, as in practice there is no difference between conventional and large scale Halal slaughter of broilers. On the other hand, the European Union has also tightened the rules for conventional stunning- and slaughter methods by means of the ‘Regulations for the protection of animals during killing’ (EU, 2009). These regulations in fact do concern Halal slaughter, as the renewed minimal settings for conventional electrical water bath stunners cause a higher percentage of broilers to die during stunning, making this stunning method no longer Halal-approved. With the new head-only stunning technique, a stunning method that serves both animal welfare as Muslim groupings seems to be available in the near future.
OVERALL CONCLUSION

Conventional electrical water bath stunning, although currently the most applied stunning method for broilers, no longer seems to meet modern animal welfare and product quality standards. Main points of critique are 1) pre-stun stress for broilers due to uncrating, inversion and shackling, 2) low stunning efficiency resulting in birds being unstunned prior to the neck cut, 3) meat quality defects by means of hemorrhages and broken bones. Alternatives for conventional electrical water bath stunning are therefore desired.

The ideal alternative stunning method for broilers should eliminate both animal welfare and product quality issues associated with conventional electrical water bath stunning. Two main categories of alternative stunning techniques can be distinguished: 1) electrical stunning and 2) gas stunning. Experimental electrical stunning techniques aim at a higher stunning efficiency and increased product quality. However, it seems that some degree of pre-stun handling of the live birds remains necessary, so additional measurements should taken to diminish pre-stun stress for broilers.

Gas stunning techniques have the purpose of diminishing pre-stun stress for broilers, while increasing product quality. These stun/kill methods could however in other ways be stressful or painful for birds, and moreover are not approved by Halal-certifying organizations since the induced unconsciousness is irreversible.

A head-only single bird electrical stunning device currently seems to be the most promising alternative stunning method. The advantages of this stunning alternative are that it 1) lowers pre-stun stress for broilers by the option to shackle the birds after unconsciousness is induced, 2) decreases discomfort of the inversed bird by means of a cone-shaped restrainer, 3) increases stunning efficiency by stunning each bird individually, 4) lowers the percentage insufficient stunned birds to enter the slaughter process by means of individual monitoring of each bird, 5) increases product quality and revenues by diminishing broken bones and muscle hemorrhages, 6) is environmental friendly as the amount of waste water is low, 7) is a Halal-approved stunning system. At the publication of this review, the first head-only stunning devices are installed in Dutch poultry processing plants. Future research should validate that head-only stunning is indeed an economical attractive alternative stunning method for large scale slaughterhouses that benefits both broiler welfare as product quality.
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