INFLUENCE OF HIGH FREQUENCY ELECTRICAL STUNNING AND DECAPITATION ON BROILER ACTIVITY DURING SLAUGHTER AND CARCASS AND MEAT QUALITY

by

WALTER DAVID McNEAL

(Under the direction of Daniel L. Fletcher)

ABSTRACT

The effects of high frequency electrical stunning and decapitation on broiler activity, carcass and meat quality, and rigor development were measured in two experiments. In the first experiment broilers were killed by conventional neck cutting, and decapitation independently or following a high frequency electrical stun. Broilers were subjectively scored for severity of activity during slaughter, carcasses scored for processing defects (broken bones, red tails, red wing tips, and number of feathers), and 24 h postmortem muscle pH values, color, cook yield and Allo-Kramer shear. In the second experiment, conventional slaughter was compared to high frequency stunning and decapitation on early rigor development by measuring breast meat pH, R-values, color, cook yield, and shear of fillets deboned at 2, 4, and 24 h postmortem. Results indicated that decapitation following high frequency electrical stunning was comparable to conventional stunning and killing.

INDEX WORDS: Broiler, Electrical Stunning, Decapitation, Carcass Quality, Meat Quality

INFLUENCE OF HIGH FREQUENCY ELECTRICAL STUNNING AND DECAPITATION ON BROILER ACTIVITY DURING SLAUGHTER AND CARCASS AND MEAT QUALITY

by

WALTER DAVID McNEAL

B.S.A., University of Georgia, 1996

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA
2002

INFLUENCE OF HIGH FREQUENCY ELECTRICAL STUNNING AND DECAPITATION ON BROILER ACTIVITY DURING SLAUGHTER AND CARCASS AND MEAT QUALITY

by

WALTER DAVID McNEAL

Approved:

Major Professor: Daniel L. Fletcher

Committee: Jeff R. Buhr
Dean Pringle

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
August 2002

ACKNOWLEDGMENTS

The author wishes to express his sincere gratitude to the following:

Dr. Fletcher- Thanks for allowing me this opportunity and for being a friend, generous with help and patient in giving assistance.

Dr. Northcutt- Thanks for the constant inspiration to face life s challenges and for taking care of me.

Nicki Taylor- Thanks for your friendship and encouragement.

Nicole Bartenfeld, Lynda Jones, Mustafa Simmons, Max Petracci and Maurizio Bianchi- Thanks for the laughs while we all worked together.

Dr. Jeff Buhr- Thanks for being so generous with time spent in support of me and for your willingness to help.

Dr. Dean Pringle- Thanks for the suggestions and criticism in this work.

My family- sincere gratitude is expressed to my mother Mary, sister Nancy and my late father Alton, for their love.

TABLE OF CONTENTS

INTRODUCTION

Issues associated with animal welfare and meat quality in poultry over the past 20 years have led to extensive research in the area of slaughter technology. Concerns for bird welfare during slaughter center on handling, stunning, and the possibility of birds regaining consciousness prior to death. Stunning must be of sufficient duration to allow neck cutting and blood loss to result in brain failure and death. USDA humane slaughter regulations require poultry to be slaughtered using methods which will result in proper bleed-out and cessation of breathing movements before birds enter the scalder. However, stunning per se is not required and therefore specific stunning requirements are not mandated in the U. S.

In Europe, present regulations dictate a high current stun, one in excess of 105 mA per bird, that delivers an instantaneous and irreversible unconsciousness to broilers. These stun-to-kill systems have also been associated with increased carcass damage due to hemorrhages and broken bones. In an effort to resolve the apparent conflict between welfare and meat quality following high current stunning killing systems other slaughter methods such as alternative electrical systems, gas stunning and killing, and other methods, such as mechanical concussion systems have been evaluated.

Gas killing for example has been used successfully in Europe to allow for both humane killing and reduced carcass damage. In the U. S., severe carcass damage has not been associated with electrical stunning. The most widely used electrical stunning systems in the U. S. use high frequency pulsed DC current. These high frequency stunning systems have been shown to reduce post-stun bird activity and maintain good carcass quality.

Decapitation, although considered a humane method of slaughter, results in massive unconscious muscular reactions. The purpose of this project was to examine the combined use of high frequency electrical stunning and decapitation on activity during slaughter and carcass and meat quality.

LITERATURE REVIEW

The slaughter process includes unloading, shackling, stunning, killing, bleeding and if used, electrical stimulation (ES). Time from unloading to birds entering the scalder is between 2.5 and 5 min, depending upon type of poultry being slaughtered (Fletcher, 1999). Each of the steps which occur during the slaughter process will affect ultimate carcass and meat quality and thus are inseparably linked (Fletcher, 1999).

Slaughter Technology - A General Overview

Slaughter is defined as the killing of animals for food (Merriam-Webster 1993). In Europe and North America, modern slaughter practices are based on traditions requiring that animals to be killed specifically for food be properly bled prior to consumption (Kotula and Helbacka, 1966a). Modern slaughter of poultry is a process whereby stunning, killing and bleeding are highly integrated and cannot easily be discussed out of context with each other (Fletcher, 1999).

Pre-slaughter immobilization (stunning) can be divided into one of the following categories: electrical, gas, or mechanical (Bilgili, 1992b). However electrical stunning has proven to be the most widely accepted and widely used method for immobilizing birds prior to slaughter (Bilgili, 1999). Electrical stunning systems have been easily adapted for high speed automation, are relatively inexpensive, ideal in immobilizing birds for alignment into mechanical killing machines, and are beneficial in minimizing carcass damage due to unconscious muscular activity during bleeding (Fletcher, 2000).

The humane aspects of electrical stunning and slaughter may be considered to be controversial. The Humane Slaughter Act of 1958, and as amended in 1994, (Anonymous, 1958; 1994) states that processors of food animals must render USDA- inspected animals insensible to pain by stunning prior to exsanguination. Poultry is specifically excluded from the stunning requirement for humane slaughter (Anonymous, 1958; 1994). Thaler (1999) reported that in subsequent reexamination of slaughter regulations, stunning of poultry was not included because electrical stunning was voluntarily used by the majority of poultry processors (Heath et al., 1994).

Overall, slaughter technology, at least stunning, neck cutting, and bleeding, was developed primarily to allow automation and to prevent carcass defects (Bilgili, 1999). In the early to mid 1980's, the logistical benefits associated with electrical stunning became secondary to animal welfare considerations in Europe. One third of some of the birds were reported to be under stunned (Heath, 1984). These observations led to a concerted effort in Europe to improve stunning systems such that birds would not potentionally regain consciousness during slaughter. In 1992, van Hoof reported that an European Union (EU) Commission recommended that birds be stunned in a manner which results in instantaneous and irreversible unconsciousness (stunned to death).

Problems associated with the use of high current stunning, which results in instantaneous and irreversible unconsciousness, include higher incidences of carcass defects such as broken bones, dislocated joints, muscle hemorrhages, and increased redness in wing tips (Gregory and

Wilkins, 1989a). As a result of the conflict between high current stun-to-kill systems and carcass quality, additional research in the general area of slaughter technology has been conducted, particularly since the late 1980's to improve both traditional systems, such as electrical stunning, as well as to explore alternative methods of slaughter, such as gas and concussion stun and kill systems.

Stunning and Killing Systems

Of all the areas of slaughter technology, stunning and killing have received by far the most attention. Stunning and killing are controversial topics relative to animal welfare issues and both have been documented to influence bird activity during slaughter, thus affecting both carcass and meat quality (Bilgili, 1992b). Although stunning is often regarded as an independent issue, some developments in electrical stunning as well as alternative stunning methods, using gas or concussion, actually kill the bird, making the distinction between stunning and killing less distinct (Fletcher, 2000).

Electrical Stunning

Satisfactory electrical stunning is achieved by passing a sufficient amount of current through the central nervous system of birds for a given duration of time (Bilgili, 1992b). Unconsciousness is obtained when the electrical stun impedes the impulses from the reticular activating and somatosensory systems (Heath et al., 1994). It has been postulated that brain activity similar to that occurring during a gran mal seizure (epileptic event) results in unconsciousness and there by insensibility to pain (Gregory, 1989).

Electrical stunning systems for poultry were initially developed to immobilize the bird long enough to allow automated neck cutting and to reduce carcass damage due to unconscious muscular activity during bleeding. Commercial electrical stunning often utilizes an electrified brine water bath stunner for a duration of 2 to 11 seconds (Bilgili, 1992b).

In 1984, Heath reported that large numbers of birds were understunned. Numerous research papers reported on the use of high current electrical stunning to irreversibly stun the bird (Veerkamp, 1988; Wabeck, 1988). Based on these results the EU recommends a minimum of 105 mA per bird (van Hoof, 1992). Current poultry processing facilities in Europe commonly use high current stunning (> 105 mA per broiler and > 125 mA per turkey) for pre-slaughter immobilization which induces cardiac fibrillation (stopping blood flow) reducing the likelihood of birds regaining consciousness during slaughter (Gregory and Wotton 1990b). Heath et al. (1983) reported that using a stun 150 V would kill birds and result in a more humane death. These same researchers also reported that increasing the stun up to 200 V would not negatively affect the quality of processed carcasses.

Gregory and Wotton (1986) investigated various slaughter techniques in order to determine the quickest method that most rapidly produced brain failure. Methods included ventricular fibrillation, decapitation, electric stun followed by cutting both carotid arteries, electric stun followed by cutting one carotid and one jugular vein, spinal cord transecting without respiratory ventilation, asphyxia, spinal cord transecting with respiratory ventilation, and electric stun followed by cutting both jugular veins. Results indicated that brain failure was achieved fastest when inducing cardiac arrest and second most rapid by decapitation. These authors concluded that there were welfare advantages in a quick kill with less opportunity for birds to regain consciousness prior to death. Although high current stunning killed the birds quickly, Gregory and Wilkins (1989a) reported that high current stunning resulted in high incidences of red wing tips, engorged veins, broken bones, and dislocated joints. These factors all lower the quality of the carcass.

In order to avoid this carcass damage associated with the whole body reaction to high current stunning, several researchers examined the potential use of head only stunning (Veerkamp et al., 1987; Gregory and Wotton 1990a). Gregory and Wotton (1990a) reported head-only stunning to be effective in producing unconsciousness and insensibility to pain. Head only stunning, however, creates difficulty in commercial application because it is difficult to achieve proper immobilization and positioning of birds. A whole body stun relaxes the muscles making the bird more maliable. A head only stun can be better utilized when it is combined with a whole body relaxation current, such as high frequency (Hillebrand, 1993).

Historically, electrical stunning systems have used a wide variety of voltages, current wave forms (AC or DC), methods of application, and frequency. In a survey of 329 poultry plants in the U.S., Heath et al. (1994) reported that 92.1% used electrical pre-slaughter stunning for immobilization and 66 % of these plants used low voltage, high frequency (10 to 25 V and greater than 500 Hz) stunning.

Recent advances in electrical stunning, especially in North America, have focused on using direct contact plates (partially submerged in a brine solution); longer stunning times (10 to 12 s), lower stunning voltages (less than 20 V); and high frequency (500 Hz), pulsed DC (Bilgili, 1999). Electrical stunning has been found to prevent cardiac arrest and produce fewer broken bones when high frequencies are used, e.g. 1,500 Hz as compared to 50 Hz (Gregory et al., 1990). Increasing frequencies were also associated with a lower incidence of cardiac arrest in turkeys (Mouchoniere et al., 1999). Contreras and Beraquet (2001) tested various electrical frequencies, 60, 200, 350, 500 and 1000 Hz at 40 V and reported that 1000 Hz resulted in unconsciousness in 90 % of the birds, maximum blood loss, and the fewest number of carcass defects. Craig et al. (1999) compared the effects of no stun, low-voltage electrical stun, and high-current electrical stun with or without electrical stimulation (1 s on/ 1 s off pulses of 440 V AC) on rigor development and meat quality attributes. Results showed that low-voltage stunning was less effective at accelerating the onset of rigor than high-current stunning.

Effects of Electrical Stunning on Feather Removal

The effects of electrical stunning on defeathering efficiency and feather retention forces (FRF) have been conflicting. Electrical stunning was shown to improve feather removal in studies by Dickens and Shackelford (1988) and Kuenzel et al. (1986). Dickens and Shackelford (1988) studied the effects of no-stun, electrical stunning, scalding time, and scalding temperature on FRF. Results showed a 18 % reduction in FRF from electrical stunning and a 81 % reduction in FRF when scalding at 56 C for 2.5 min compared to 52 C for 1 min.

Buhr et al. (1997b) compared the effects of electrical and carbon dioxide stunning on FRF measured ante-, peri-, and post-mortem. No significant differences were found from ante- to peri-mortem from either stunning method on sternal or femoral feather tracts. However, a 7 % increase was observed on the pectoral tract from ante- to peri-mortem. Values for FRF were lower for post-mortem observations than ante- or peri-mortem in the sternal feather tract with (40 to 60 % CO_2 for 30 s).

Buhr and Rowland (1999) investigated the mechanism by which feathers were held in the follicles of broilers. Nerve trunks for the sternal feather tracts were severed unilaterally (left or right side) or bilaterally. Following four days of recovery, FRF were determined before and after stunning and bleeding. Results showed no significant differences between FRF from birds with innervated and denervated pectoral or sternal tracts. The authors concluded that disabling the central nervous system (CNS) may indirectly lower FRF by altering cutaneous metabolism rather than the CNS directly affecting feather release and that smooth muscle located directly below feather tracts played a greater role in feather release, than any other physiological factor.

Results from these studies and others suggest that feather removal efficiency is only slightly improved with electrical stunning and is affected more by scalding temperature and immersion time (Mahoney et al. 1971; Klose et al. 1962; Dickens and Shackelford 1988; Walker and Griffis 1994; Buhr et al 1997a; Buhr et al 1997b).

Effects of Electrical Stunning on Carcass Quality

Stunning with high voltage is known to produce strong generalized muscular contractions that negatively affect meat quality (Bilgili, 1992a; Sams, 1999b). These contractions may result in red wing tips which cause a loss of yield and saleable product as they are often trimmed during final inspection of carcasses. The incidence of red wing tips was nine times higher in birds which exhibited vigorous wing flapping as opposed to birds which remained calm during commercial shackling (Gregory et al., 1989). In regards to stunning, Veerkamp and de Vries (1983) reported that as voltage increased, the occurrence of red wing tips and red tails increased. Furthermore, Gregory and Wilkins (1989a) reported that high current stunning increased the incidence of red wing tips, broken bones, dislocations, and hemorrhaging of deep breast muscle and wing veins in broilers. Walker et al. (1993) also reported that electrical stunning significantly increased the incidence of hemorrhaging in leg muscles of broilers. Gregory and Wilkins (1989b) investigated the effects of electrical stunning with 75, 150 or 250 mA on carcass quality defects in turkeys. Their results showed a significantly greater incidence of deep breast muscle hemorrhaging with increasing stunning current.

Effects of Electrical Stunning on Rigor Development and Meat Quality

Numerous investigations have studied the effects of electrical stunning on postmortem rigor development and meat quality (Lee et al., 1979; Thompson et al., 1986; Murphy et al., 1988; Kim et al., 1988; Dickens and Lyon 1993; Papinaho and Fletcher 1995a; Papinaho and Fletcher 1995b; Papinaho et al., 1995; Papinaho and Fletcher 1996). Electrical stunning was shown to reduce initial pH values when compared to unstunned controls (Thomson et al., 1986; Murphy et al., 1988; Kim et al., 1988 and Papinaho and Fletcher 1995b).

Papinaho et al. (1995) compared the effects of physically restraining birds to free struggle with and without stunning (0, 50, or 125 mA) during slaughter on breast meat aged for 15 min and 24 h postmortem. Significant differences were found in pH, R-values and Allo-Kramer shear measured at 15 min post-mortem between unstunned and electrically stunned birds allowed to struggle freely. Physically restraining birds was found to significantly affect pH and R-values of electrically stunned and unstunned birds at 15 min post-mortem through a reduction in muscular activity. Comparing breast muscle from unstunned physically restrained and unstunned unrestrained birds exhibited ph values of 6.21 and 6.07, respectively and R-values of

0.90 and 0.96, respectively. For the 50 mA treatment, pH values were 6.23 and 6.15, and R-values were 0.89 and 0.93, respectively. No differences were reported in Allo-Kramer shear on carcasses aged 24 h for any treatment. The authors concluded that stunning primarily affects early rigor development through a reduction in peri-mortem struggle.

Papinaho and Fletcher (1996) studied the effects of stunning amperage on early rigor development and breast meat quality of broilers. In each trial, birds were divided evenly between three stunning treatments; 0 (no stun), 50, and 125 mA using a constant amperage stunner. The total stunning duration was 5 s and birds were killed by conventional unilateral neck cut. Breast muscles were deboned at 0.2, 1, 2, 4, 6, 8, 10, 12, and 24 h postmortem. Values for pH and R-values were measured immediately upon deboning using one breast fillet while the second fillet from each carcass was held for 48 h of aging and used for cook loss and Allo-Kramer shear determination. Results showed that stunning at 50 or 125 mA produced significantly higher pH values and lower R-values up to 6 h postmortem. There was no effect on cook loss from any stunning treatment and stunning at 125 mA produced significantly tougher meat up to 10 h postmortem than meat from unstunned birds or birds stunned at 50 mA. The authors concluded that effects of electrical stunning on early rigor development disappear approximately 4 to 6 h postmortem.

Alternative Stunning and Killing Systems

The use of gas for stunning of poultry has been investigated since the mid 1950's (Drewniak et al., 1955; Kotula et al., 1957). Recent interest in gas stunning has been renewed for two primary reasons. First, gas stunning, as an alternative to the high current stunning recommended in Europe, results in less carcass defects (Mohan Raj et al., 1990). Second, gas stunning has an advantage over electrical stunning in that birds can be stunned and killed in their transport coops reducing stress and carcass damage associated with unloading and shackling (Mohan Raj and Gregory 1990).

The majority of modern gas stunning research has focused on the use of CO_2 by itself or in combination with Argon (Ar) and other gases (Hoen and Lankhaar, 1999). Carbon dioxide has an ability to provide anaesthetic effects to poultry and may also serve as an euthanatizing agent (American Veterinary Medical Association, 1986).

Benefits from gas stunning and killing systems are dependent upon which gas is being used and the type of electrical system to which it is being compared (Fletcher, 2000). In recent years, stunning with Ar or a combination of Ar and CO_2 was shown to produce a rapid decrease in breast muscle pH, indicating an acceleration of rigor development and a potential for early deboning (Mohan Raj et al., 1991; Mohan Raj, 1994). Mohan Raj et al. (1992) reported that Ar stunning caused unconscious convulsions (wing flapping) during death, which consumed adenosine triphosphate (ATP) and glycogen, produced lactic acid, and lowered muscle pH.

Sams and Dzuik (1999) compared Ar stunned birds to unstunned controls, electrically stimulated (ES) carcasses (450 V, 750 mA, AC, 60 Hz, 2 s on/ 1 s off for 5 pulses) and Ar + ES using differences in pH, R-values and Allo-Kramer shear. Values for pH from Ar stunned birds were significantly lower than unstunned controls after 1 h aging. No differences were detected in R-values between Ar stunned birds and unstunned controls but significant differences were detected in R-values when comparing Ar to Ar + ES. No benefits were detected in shear values between Ar and Ar + ES. It was concluded that Argon stunning moderately enhances the ability of ES to accelerate postmortem metabolism but that there is little tenderness advantage in combining Argon stunning and killing and postmortem ES. There have been numerous carcass and meat quality benefits realized when comparing gas stunning to high voltage stunning (Mohan Raj and Gregory, 1991a; Hoen and Lankhaar, 1999) but relatively few advantages over low voltage high frequency stunning and conventional killing commonly practiced in the U.S. (Poole and Fletcher, 1998; Fletcher, 1999; Kang and Sams, 1999).

The advantages of mechanical stunning have been well documented in the red meat industry (Blackmore, 1979; Daly et al., 1987). Several studies in recent years investigated the effectiveness of mechanical stunning on carcass and meat quality compared to conventional electrical stunning and killing and head only stunning. Hillebrand et al. (1996) studied (broiler meat quality) using electric whole-body and head-only stunning with varying voltages (25 vs 100 V) and frequencies (50 vs 200 Hz), and mechanical captive bolt stunning. Broilers were subjected to restraint either by shackling, restraining of the head, or placed in a bleeding cone. Bird activity during and after stunning was subjectively scored in 30 s periods for up to 2 min (as none, mild, moderate, or severe convulsions) and 24 h pH, color, and hemorrhaging was measured on breast and thigh muscles. Convulsions were less severe in whole-body stunning at 50 Hz, followed by whole-body stunning at 200 Hz. Head-only stunning and captive bolt stunning producing the greatest amount of convulsive activity. No differences in terminal pH were observed. Head-only stunning produced significantly darker and redder breast muscles than whole-body stunning. Significantly fewer hemorrhages in breast and thigh muscles were found in captive bolt stunned and cone restrained carcasses compared to whole-body stunning

(100 V, 50 Hz, shackled) and little difference was observed in hemorrhages between head-only stunning and captive bolt stunning.

Lambooij et al. (1999) compared the effects of captive bolt stunning and electrical water bath stunning on carcass and meat quality characteristics. Treatments compared high current electrical stunning and captive bolt using high air pressure stunning. Bird activity during stunning and exsanguination was subjectively scored. Blood loss was determined as a percentage of live weight and pH values were measured at 20, 60, 140 min and 24 h. Broken bones and wing hemorrhages were also subjectively scored. Color, cook loss, and differences in meat texture were also assessed. Results showed that bird activity (convulsions) was greater using air-pressure stunning and blood loss was lower compared to conventional stunning. However, there were significantly fewer broken bones, lower pH values in breast meat and fillets were determined to be more tender in carcasses subjected to air-stunning compared to electrical stunning. Thigh muscle hemorrhaging was significantly reduced in broilers restrained in a cone regardless of stunning method and no differences were found in cook yield between treatments.

Goksoy et al. (1999) compared the effects of concussion and electrical stunning on carcass and meat quality of broilers. Broilers were subjected to either an electrical stun (100 V, 80 mA, 50 Hz sinusoidal waveform AC) or concussion using a non-penetrative captive bolt gun with or without restraint. Results showed that carcasses from electrically-stunned broilers had a significantly higher number of broken coracoid, broken furculum (clavicle) bones, and hemorrhages than carcasses from concussion treatments. In the concussion-stunned treatments, the incidence of red wing tips and shoulder hemorrhages was significantly higher than other treatments. Blood loss was greatest in electrically stunned and nonfibrillated birds. Ten minute postmortem pH values were lowest in concussion-stunned and unrestrained birds. Breast fillets deboned at three hours postmortem were significantly more tender from the concussion-stunned birds than those electrically stunned.

Effects of Slaughter on Blood Loss

In Western society, traditional slaughter practices followed those described in the Old Testament where God instructed Noah and Moses to refrain from consuming the blood of slaughtered animals (Old Testament - Genesis 9:4; Leviticus 17:14; Deuteronomy 12:16). These practices are still followed in modern commercial Kosher killing of poultry as allowed by the humane slaughter act (Anonymous, 1958, 1994). Poultry inspection regulations (USDA, 1984) dictate that poultry will be slaughtered in a manner resulting in a thorough bleeding of the carcass. Blood loss has always been a chief concern for poultry processors as a quality issue as reported in several early studies in the 1950's (Newell and Shaffner 1950a; Newell and Shaffner 1950b; Pino et al., 1951; Davis and Coe, 1954).

Newell and Shaffner (1950b) quantified blood loss and reported that chickens lose between 35 and 50 % of their total volume of blood after neck cutting or approximately 4 % of live weight. Since these early studies, there have been numerous research investigating the biological mechanisms which affect bleeding following various slaughter techniques (Kotula and Helbacka 1966a; Kotula and Helbacka, 1966b; Kuenzel and Ingling, 1977; Abram and Goodwin, 1977; Harris and Carter 1977). Comparisons between research reports are difficult due to differences in stunning and killing methods such as electrical (low and high voltage), mechanical (concussion), gaseous, variations in application of the neck cut, and method of measuring actual blood loss. Blood loss is often considered to be a major issue in commercial processing (Kuenzel and Ingling, 1977). Modifications in slaughter technology, such as electrical stunning, high-current stunning, and alternative methods all effect blood loss.

Kotula and Hellbecka (1966b) compared the effects of no stun, concussion stunning and electrical stunning on blood loss and found electrically stunned birds lost the least amount of blood. Kuenzel and Ingling (1977) investigated blood loss in broilers using two types of stunners (a plate stunner and a brine stunner) and two types of circuits (AC at 60 Hz or DC). Results showed that plate stunners were inadequate in stunning broilers with AC or DC circuitry citing inconsistent contact between birds and the steal plate but that AC stunning was superior to DC stunning for maximizing bleed-out. In another experiment, Kuenzel et al. (1978) reported no significant difference between variable frequency DC stunners and AC stunner set at 50 V and 60 Hz. It was commonly believed that a beating heart would increase blood loss (Kuenzel and Walther, 1978). However, recent studies have shown no significant effects of high-stunning currents, which induce cardiac fibrillation, or CO_2 stunning ultimate blood loss (Heath et al., 1983; Schutt-Abraham, 1983; Weise et al., 1987).

Papinaho and Fletcher (1995a) studied the effects on blood loss when subjecting broilers to electrical stunning with 100 V AC for 0, 5, 10, 20, or 40 s, killed with a conventional neck cut and bled for 180 s. Longer stunning durations (10, 20 and 40 s) resulted in significantly less blood losses than birds stunned for (0 or 5 s). Later investigations have suggested that electrical stunning may affect initial blood loss but not ultimate blood loss or fillet quality (Gregory and Wilkins 1993; Papinaho and Fletcher 1995b; Craig and Fletcher 1997).

Alternative slaughter methods to electrical stunning and killing include gas and mechanical stunning and killing. Numerous investigations found no significant differences in blood loss from birds stunned and killed with carbon dioxide as compared to non-stunned or electrically stunned birds (Kotula and Helbecka, 1966b; Wilson and Brunson, 1968; Hirscler and Sams, 1993). However, several researchers reported slower initial blood losses, but no ultimate differences in total blood loss (Kotula et al., 1957; Zeller et al., 1988; Mohan Raj and Gregory, 1991b; Mohan Raj and Gregory, 1991a). Gas killing with Argon resulted in no significant difference in blood loss after 60 s when compared with electrically stunned birds (Mohan Raj and Gregory, 1991a). Poole and Fletcher (1995) compared the effects of argon, carbon dioxide and nitogen stunning and killing to un-stunned controls and found gas stunned birds lost significantly less blood than unstunned controls during bleeding.

Davis and Coe (1954) compared the effects of blood loss after 20 sec and 3 min of venesection in White Leghorn males with five different slaughter procedures. Slaughter methods included the following: Lot 1. A single carotid artery and jugular vein severed; Lot 2. Carotid arteries and jugular veins from both sides were cut; Lot 3. Birds were beheaded; Lot 4. Birds were debrained and both carotid arteries and jugular veins were severed; Lot 5. Birds were concussion stunned with a stick severing a single carotid artery and jugular vein. Results indicated that there was very little difference in blood loss after 3 min except from birds beheaded in Lot 3 which lost the least amount of blood. These results are in agreement with Newell and Shaffner, (1950b) which reported that beheaded birds lost significantly less blood than birds killed by a one sided neck cut or debraining and a one sided neck cut.

Lambooij et al. (1999) reported that birds stunned with a captive bolt using air pressure (non-penetrating) had a lower degree of blood loss than electrically stunned and bled birds (10 s, 110 mA, 300 Hz). Goksoy et al. (1999) compared the effects of electrically stunned birds fibrillated and non-fibrillated to concussion stunning restrained or unrestrained and found that non-fibrillated electrical stunning resulted in the greatest percentage of blood loss followed by concussion stunning restrained, electrical stunning fibrillated, and concussion stunning unrestrained losing the least amount of blood after 120 s.

Electrical Stimulation

Electrical stimulation (ES) is a process of passing an electric current through a dead or dying animal to stimulate muscular contraction. Electrical stimulation can be traced backed to 1749, when Benjamin Franklin observed that killing turkeys with electricity caused them to become tender (Lopez and Herbert, 1975). Electrical stimulation, first used commercially in red meat, was reported by Carse (1973) to tenderize red meat due to rapid glycolysis that prevented cold shortening. The use of electrical stimulation in red meat is generally categorized into low voltage 120 V, or high voltage, > 120 V, (Ashgar and Henrickson, 1982).

Three theories into the mechanisms by which ES works were reviewed by Cross (1979). First, the depletion of ATP is accelerated, resulting in the prevention of cold shortening. Secondly, as carcass muscles are stimulated and exercised, cellular pH levels are rapidly lowered while muscle temperature are still high, potentially enhancing the action of endogenous proteases responsible for tenderization during the aging process. Finally, ES could tenderize meat through physical disruption of muscle fiber structure.

In poultry, the primary purpose of ES is to reduce toughness in meat associated with early deboning (less than 4 h) by accelerating the process of rigor mortis and abbreviating the aging process. The effectiveness of electrical stimulation on increasing the rate of rigor development and subsequently affecting meat quality was shown in numerious early studies using various ES durations, frequencies, currents, and voltages as reviewed by (Li et al., 1993; Sams, 1999a; Sams, 1999b). Electrical stimulation in poultry carcasses can be in the low range (0-200 mA) or high range (350-500 mA) but high amperage is more effective in reducing the need of carcass aging for tenderness (Sams, 1999a; Sams, 1999b).

The mechanisms of electrical stimulation in poultry are similar to those reported for red meat. Birkhold and Sams (1995) used transmission electron micrographs to show pictures of ES-treated muscles in which the myofilaments were torn, resulting in more tender meat. Low (0 to 200 mA) and high (350 to 500 mA) amperage ES cause muscles to contract and relax, resulting in an acceleration of rigor onset (Sams, 1999a; Sams, 1999b). However, both low and high amperage ES use low frequencies to stimulate the muscles.

Many of the previous studies on the effects of electrical stimulation on rigor development in poultry are in agreement when measuring physiological and textural changes in poultry breast meat (Jenson et al.,1979; Maki and Froning, 1987; Froning and Uijttenboogaart 1988; Birkhold and Janky 1989; Janky and Birkhold 1989; Lyon et al., 1989; Sams et al., 1989; Wakefield et al., 1989; Birkhold and Sams 1990; Sams, 1990; Walker et al., 1995; Walker et al., 1991; Zocchi and Sams, 1999, and Alvarado and Sams, 2000). All of the previous studies showed significant decreases in breast pH values after ES. R-values for breast meat significantly increased in studies by Thompson et al. (1987), Lyon et al. (1989), Sams, (1990), Sams et al.

(1989), Walker et al. (1995), Zocchi and Sams, (1999) and Alvarado and Sams, (2000). Benefits in breast meat texture have also been observed after ES (Making and Froning, 1987; Sams et al., 1989; Birkhold and Janky, 1989; Birkhold and Sams, 1990; Griffis et al., 1990, Griffis et al., 1991; Birkhold et al., 1992; Birkhold and Sams, 1993; Walker et al., 1995; Young and Lyon 1997; and Hirschler and Sams, 1998). All frequencies of electrical stimulation used in the above experiments would be considered low (50-60 Hz).

Griffis et al. (1990, 1991) examined the effects of various voltage and frequency and high-temperature conditioning on broiler breast meat. The authors used voltages of 0, 20, 40, and 120 V DC and frequencies of 1, 5, 10, 20, 60 and 120 Hz with a duty cycle of 1%. Results showed decreases in shear values after ES and that average shear values decreased as voltage increased at a frequency of 10 Hz. A frequency of 5 Hz resulted in the lowest shear values. Electrical current (low voltage and high frequency) when applied to the live bird (stunning) before death delays rigor whereas electricity (pulsated low frequency high voltage) applied seconds later to the dead or dying bird (stimulation) accelerates rigor development (Fletcher, 1999).

REFERENCES

Abram, J., and T. L. Goodwin, 1977. Factors affecting chicken bleed out - A review. World Poult. Sci. J. 33:69-74.

Alvarado, C. Z., and A. R. Sams, 2000. The influence of postmortem electrical stimulation on rigor mortis development, calpastatin activity, and tenderness in broiler and duck pectoralis. Poultry Sci. 79:1364-1368.

American Veterinary Medical Association, 1986. Report of the AVMA Panel on Euthanasia. JAVMA. 188 (3):252-268.

Anonymous, 1958. United States Statues at Large, 1958. Volume 72, Part 1:862-864.

Anonymous, 1994. United States Code, 1994. Volume 2, Title 7 - Agriculture, Chapter 48, Sections:1901-1912.

Ashgar, A., and R. L. Henrickson, 1982. Post-mortem stimulation of carcasses: Effects on biochemistry, biophysics, microbiology, and quality of meat. CRC Cri. Rev. Food Sci. Nutr. 18:1-58.

Bilgili, S. F., 1992a. Broiler quality: grads are posted. Broiler Industry. 53(1):32-40.

Bilgili, S. F., 1992b. Electrical stunning of broilers-basic concepts and carcass quality implications: A review. J. Appl. Poultry Res. 1:135-146.

Bilgili, S. F., 1999. Recent Advances in Electrical Stunning. Poultry Sci. 78:282-286.

Birkhold, S. G., and D. M. Janky, 1989. The effects of high voltage post-mortem electrical stimulation and muscle tensioning on tenderness and postmortem metabolism of early-harvested broiler fillets. Poultry Sci. 68 (Suppl. 1):13. (Abstr.)

Birkhold, S. G., and A. R. Sams, 1990. Fragmentation, tenderness, and postmortem metabolism of early-harvested broiler breast fillets from carcasses treated with electrical stimulation and muscles tensioning. Poultry Sci. 69(Suppl. 1):19.(Abstr.)

Birkhold, S. G., D. M. Janky, and A. R. Sams, 1992. Tenderization of early-harvested broiler breast fillets by high-voltage postmortem electrical stimulation and muscle tensioning. Poultry Sci. 71:2106-2112.

Birkhold, S. G., and A. R. Sams, 1993. Fragmentation, tenderness, and post-mortem metabolism of early-harvested broiler breast fillets from carcasses treated with electrical stimulation and muscle tensioning. Poultry Sci. 72:577-582.

Birkhold, S. G., and A. R. Sams, 1995. Comparative ultrastructure of *Pectoralis* fibers from electrically stimulated and muscle-tensioned broiler carcasses. Poultry Sci. 74:194-200.

Blackmore, D. K., 1979. Nonpenetrative percussion stunning of sheep and calves. Vet. Rec. 20:372-375.

Buhr, R. J., J. A. Cason and G. N. Rowland, 1997a. Feather retention force in broilers, ante-, peri-, and post-mortem as influenced by carcass orientation, angle of extraction and slaughter method. Poultry Sci. 76:1591-1601.

Buhr, R. J., J. A. Cason and G. N. Rowland, 1997b. Feather retention in broilers ante-, peri-, and post-mortem as influenced by electrical and carbon dioxide stunning. Poultry Sci. 76:1602-1606.

Buhr, R. J. and G. N. Rowland, 1999. Subcutaneous feather tract does not alter feather retention force ante- and postmortem in broilers. Poultry Sci. 78:608-613.

Carse, W. A., 1973. Meat quality and the acceleration of postmortem glycolysis by electrical stimulation. J. Food Technol. 8:163-166.

Contreras, C. C., and N. J. Beraquet, 2001. Electrical stunning, hot boning, and quality of chicken breast meat. Poultry Sci. 80:501-507.

Craig, E. W., and D. L. Fletcher, 1997. A comparison of high current and low voltage electrical stunning systems on broiler breast rigor development and meat quality. Poultry Sci. 76:1178-1181.

Craig, E. W., D. L. Fletcher, and P. A. Papinaho, 1999. The effects of antemortem electrical stunning and postmortem electrical stimulation on biochemical and textural properties of broiler breast meat. Poultry Sci. 78:490-494.

Cross, H. R., 1979. Effects of electrical stimulation on meat tissue and muscle properties - A review. J. Food Sci. 44:509-514.

Daly, C., N. G. Gregory, and S. B. Wotton, 1987. Captive bolt stunning of cattle: Effects of brain function and role of bolt velocity. Br. Vet. J. 143:574-580.

Davis, L. L., and M. E. Coe, 1954. Bleeding of chickens during killing operations. Poultry Sci. 33:616-619.

Dickens, J. A., and C. E. Lyon, 1993. Effect of two stunning voltages on blood loss and objective texture of meat deboned at various post-mortem times. Poultry Sci. 72:589-593.

Dickens, J. A., and A. D. Shackelford, 1988. Feather-Releasing Forces to Stunning, Scaling Time, And Scalding Temperature. Poultry Sci. 67:1069-1074.

Drewniak, E. E., E. R. Baush, and L. L. Davis, 1955. Carbon dioxide immobilization of turkeys before slaughter. U.S.D.A. Circular 958.

Fletcher, D. L., 1999. Slaughter Technology. Poultry Sci. 78:277-281.

Fletcher, D. L., 2000. Stunning of Poultry. Proceedings of XXI World Poultry Congress, Montreal, Canada. Paper S3.13.

Froning, G. W., and T. G. Uijttenboogaart, 1988. Effect of post-mortem electrical stimulation on color, texture, pH, and cooking losses of hot and cold deboned chicken broiler breast meat. Poultry Sci. 67:1536-1544.

Goksoy, E.O., L. J. McKinsty, L. J. Wilkins, I. Parkman, A. Phillips, R. I. Richardson, and M. H. Anil, 1999. Broiler Stunning and Meat Quality. Poultry Sci. 78:1796-1800.

Gregory, N. G., 1989. Stunning and Slaughter, In: Mead, G. C. (Ed.) Processing of Poultry, pp. 31-63 (Barking, Elsevier Applied Science).

Gregory, N. G., and S. B. Wotton, 1986. Effect of slaughter on the spontaneous and evoked activity of the brain. Br. Poult. Sci. 27:195-205.

Gregory, N. G., and L. J. Wilkins, 1989a. Effect of stunning current on carcass qulaity defects in chickens. Vet. Rec. 124:530-532.

Gregory, N. G., and L. J. Wilkins, 1989b. Effect of stunning current on downgrading in turkeys. Br. Poult. Sci. 30:761-764.

Gregory, N. G., S. D. Austin and L. J. Wilkins, 1989. Relationship between wing flapping at shackling and red wingtips in chicken carcases. Vet Rec. 1989. 124, 62.

Gregory, N. G., and S. B. Wotton, 1990a. An evaluation of the effectiveness of handheld stunners for stunning chickens. Vet. Rec. 126:290-291.

Gregory, N. G., and S. B. Wotton, 1990b. Effect of stunning on spontaneous physical activity and evoked activity in the brain. Br. Poult. Sci. 31:215-220.

Gregory, N. G., L. J. Wilkins, S. D. Eleperuma, A. J. Ballantyne, and N. D. Overfield, 1990. Broken bones in domestic fowls: Effect of husbandry system and stunning method in end- of lay hens. Br. Poultry Sci. 31:59-69.

Gregory, N. G., and L. J. Wilkins, 1993. Causes of downgrading. Broiler Industry. 56:42-45.

Griffis, C. L., T. J. Siebenmorgen, J. T. Walker, Y. Li, and M. F. Slavik, 1990. Effects of electrical stimulation on poultry meat tenderness and microorganism contamination. The ASAE Paper No. 906044, the American Society of Agricultural Engineers, St. Joseph, MI.

Griffis, C. L., T. J. Siebenmorgen, J. T. Walker, R. L. Dake, J. E. Webb, and R. E. Wolfe, 1991. Effects of electrical stimulation with precisely controlled square wave voltages on texture on broiler pectoralis muscles. Arkansas Farm Res. 40:5.

Harris, C. E., and T. A. Carter, 1977. Broiler blood losses with manual and mechanical killers. Poultry Sci. 56:1827.

Heath, G. B. S., D. J. Watt, P. R. Waite, and P. A. Meakins, 1983. Further observations on the slaughter of poultry. Br. Vet. J. 139:285-290.

Heath, G. B. S., 1984. The slaughter of broiler chickens. World s Poultry Science Journal, 40(2):151-159.

Heath, G. E., A. M. Thaler, and W. O. James, 1994. A survey of stunning methods currently used during slaughter of poultry in commercial poultry plants. J. Appl. Poult. Res. 3:297-302.

Hillebrand, S. J. W., 1993. The sensory quality of turkey meat-with special reference to the effects of electrical stunning and chilling rate. Dissertation, Utrecht University, The Netherlands.

Hillebrand, S. J. W., E. Lambooij, and C. H. Veerkamp, 1996. The effects of alternative electrical and mechanical stunning methods on hemorrhaging and meat quality of broiler breast and thigh muscles. Poultry Sci. 75:664-671.

Hirschler, E. M., and A. R. Sams, 1993. Comparison of carbon dioxide and electricity for the preslaughter stunning of broilers. Poultry Sci. 72 (Suppl. 1):143 (Abst.)

Hirschler, E. M., and A. R. Sams, 1998. The influence of commercial-scale electrical stimulation on tenderness, breast meat yield and production cost. J. Appl. Poultry Res. 7:99-103.

Hoen, T., and J. Lankhaar, 1999. Controlled atmosphere stunning of poultry. Poultry Sci. 78:287-289.

Janky, D. M., and S. G. Birkhold, 1989. Tenderness and physical characterisitcs of early - harvested turkey breast tissue following various durations of high voltage post-mortem electrical stimulation. Poultry Sci. 68(Suppl. 1):72.(Abstr.)

Jenson, J. H., M. Jul, and O. Zinck, 1979. Electrical stimulation of chickens. Page 124 *in*: Proceedings of the Fifth International Congress of Food science and Technology, Kyoto, Japan. (Abstr.).

Kang, I. S., and A. R. Sams, 1999. Bleedout efficiency, carcass damage and rigor mortis development following electrical stunning or carbon dioxide stunning on a shackle line. Poultry Sci. 78:139-143.

Kim, J. W., D. L. Fletcher, and D. R. Campion, 1988. Research note: Effect of electrical stunning and hot boning on broiler breast meat characteristics. Poultry Sci. 67:674-676.

Klose, A. A., E. P. Mecchi, and M. F. Pool, 1962. Feather release by scalding and other factors. Poultry Sci. 41:1277-1282.

Kotula, A. W., and N. V. Helbacka, 1966a. Blood retained by chicken carcasses and cut-up parts as influenced by slaughter method. Poultry Sci. 45:404-410.

Kotula, A. W., and N. V. Helbacka, 1966b. Blood volume of live chickens and influence of slaughter technique on blood loss. Poultry Sci. 45:684-688.

Kotula, A. W., E. E. Drewniak, and L. L. Davis, 1957. Effect of carbon dioxide immobilization on the bleeding of chickens. Poultry Sci. 37(3):585-589.

Kuenzel, W. J., A. L. Ingling, M. D. Denbow, J. H. Walther, and M. M. Shaefer, 1978. Variable frequency stunning and a comparison of two bleed-out time intervals for maximizing blood release in processed poultry. Poultry Sci. 57:449-454.

Kuenzel, W. J., and J. H. Walther, 1978. Heart beat, blood pressure, respiration and brain waves of broiler as affected by electrical stunning and bleed-out. Poultry Sci. 57:655-659.

Kuenzel, W. J., and A. L. Ingling, 1977. A comparison of plate and brine stunners, A. C. and D. C. circuits for maximizing bleed-out in processed poultry. Poultry Sci. 56:2087-2090.

Kuenzel, W. J., J. Walther, and W. Collins, 1986. The effect of pre- and post stunning on bleed-out and feather release in processed broilers. Pages 62-66 in: Proceedings 21st National Meeting Poultry Health Condemnations, Ocean City, MD.

Lambooij, E., C. Pieterse, S. J. W. Hillebrand, and G. B. Dijksterhuis, 1999. The effects of captive bolt and electrical stunning and restraining methods on broiler meat quality. Poultry Sci. 78:600-607.

Lee, Y. B., G. L. Hargus, J. E. Webb, D. A. Rickansrud, and E. C. Hagberg, 1979. Effect of electrical stunning on postmortem biological changes and tenderness in broiler breast muscle. J. Food Sci. 44:1121-1122, 1128.

Li, Y., T. J. Siebenmorgen, and C. L. Griffis, 1993. Electrical stimulation in poultry: A review and evaluation. Poultry Sci. 72:7-22.

Lopez, C. A., and E. W. Herbert, 1975. The Private Franklin: The man and his family. 1st ed. W. W. Norton and Co., New York, NY.

Lyon, C. E., C. E. Davis, J. A. Dickens, C. M. Papa, and J. O. Reagan, 1989. Effect of electrical stimulation on the post-mortem biochemical changes and texture of broiler pectoralis muscle. Poultry Sci. 68:249-257.

Mahoney, W. A., G. W. Newell, and G. Olson, 1971. Feather release as related to stunning methods. ASAE Paper No. 71-865. American Society of Agricultural Engineers, St. Joseph, MI.

Maki A., and G. W. Froning, 1987. Effect of post-mortem electrical stimulation on quality of turkey meat. Poultry Sci. 66:1155-1157.

Mish, F. C., (Ed) 1993. Merriam Webster s Collegiate Dictionary Tenth Edition. Merriam-Webster, Incorporated Springfield, Massachusetts.

Mohan Raj, A. M., and N. G. Gregory, 1990. Investigation into the batch stunning/killing of chickens using carbon dioxide or argon-induced hypoxia. Res. Vet. Sci. 49:364-366.

Mohan Raj, A. B., T. C. Grey, A. R. Audsely, and N. G. Gregory, 1990. Effect of electrical and gaseous stunning on the carcass and meat quality of broilers. Br. Poult. Sci. 31:725-733.

Mohan Raj, A. B., and N. G. Gregory, 1991a. Carcass and meat quality of gas stunned broilers. Proceedings of 10th European Symposium on the Quality of Poultry. May 12-17, 1991. Doorwerth, Netherlands.

Mohan Raj, A. B., and N. G. Gregory, 1991b. Efficiency of bleeding of broilers after gaseous or electrical stunning. Vet. Rec. 128:127-128.

Mohan Raj, A. B., T. C. Grey, and N. G. Gregory, 1991. Effect of early filleting on the texture of breast muscle of broilers stunned with argon-induced anoxia. Br. Poult. Sci. 32:319-325.

Mohan Raj, A. M., G. R. Nute, S. B. Wotton, and A. Baker, 1992. Sensory evaluation of breast fillets from argon-stunned and electrically-stimulated broiler fillets from argon-stunned and electrically-stimulated broiler carcasses processed under commercial conditions. Br. Poult Sci. 33:963-971.

Mohan Raj, A. B., 1994. Effect of stunning method, carcass chilling temperature and filleting time on the texture of turkey breast meat. Br. Poultry Sci. 35:77-89.

Mouchoniere, M., G. Le Pottier, and X. Femandez, 1999. The Effect of current frequency during waterbath stunning on the physical recovery and rate and extent of bleed out in turkeys. Poultry Sci. 77:485-489.

Murphy, B. D., R. J. Hasiak, and J. G. Sebranek, 1988. Effect of antemortem electrical stunning on functional properties of turkey muscle. Poultry Sci. 67:1062-1068.

Newell, G. W., and C. S. Shaffner, 1950a. Blood volume determinations in chickens. Poultry Sci. 29:78-87.

Newell, G. W., and C. S. Shaffner, 1950b. Blood loss by chickens during killing. Poultry Sci. 29:271-275.

Old Testament. Genesis 9:4; Leviticus 17:14; Deuteronomy 12:16.

Papinaho, P. A., and D. L. Fletcher, 1995a. Effects of electrical stunning duration on post-mortem rigor development and broiler breast meat tenderness. J. Muscle Foods 6:1-8.

Papinaho, P. A., and D. L. Fletcher, 1995b. Effect of stunning amperage on broiler breast muscle rigor development and meat quality. Poultry Sci. 74:1527-1532.

Papinaho, P. A., and D. L. Fletcher, and R. J. Buhr, 1995. Effect of electrical stunning amperage and per-mortem struggle on broiler breast rigor development and meat quality. Poultry Sci. 74:1533-1539.

Papinaho, P. A., and D. L. Fletcher, 1996. The effects of stunning amperage and deboning time on early rigor development and breast meat quality of broilers. Poultry Sci. 75:672-676.

Pino, J. A., H. S. Weiss and P. D. Sturkie, 1951. Blood volume determinations in the fowl using diptheria antioxoid. Proc. 9th World s Poultry Congress, 3: 102-108.

Poole, G. H., and D. L. Fletcher, 1995. A comparison of Argon, Carbon dioxide, and Nitrogen in a broiler killing system. Poultry Sci. 74:1218-1223.

Poole, G. H., and D. L. Fletcher, 1998. Comparison of a modified atmosphere stunning-killing system to conventional electrical stunning and killing on selected broiler breast muscle rigor development and meat quality attributes. Poultry Sci. 77:342-347.

Sams, A. R., 1990. Electrical stimulation and high temperature conditioning of broiler carcasses. Poultry Sci. 69:1781-1786.

Sams, A. R., 1994. Electrical stimulation at commercial line speeds. Broiler Industry. December.

Sams, A. R., 1999a. Commercial implementation of postmortem electrical stimulation. Poultry Sci. 78:290-294.

Sams, A. R., 1999b. Meat quality during processing. Poultry Sci. 78:798-803.

Sams, A. R., D. M. Janky, and S. A. Woodward, 1989. Tenderness and R-value changes in early harvested broiler breast tissue following post-mortem electrical stimulation. Poultry Sci. 68:1232-1235.

Sams, A. R., and C. S. Dzuik, 1999. Meat quality and rigor mortis development in broiler chickens with gas-induced anoxia and postmortem electrical stimulation. Poultry Sci. 78:1472-1476.

Schutt-Abraham, I.., H. -J. Wormuth, and J. Fessel, 1983. Electrical stunning of poultry in view of animal welfare and meat production. Pages 187-196 in: Stunning of Animals for Slaughter. G. Eikelenboom, ed. Martinus Nijhoff Publishers, Boston, MA.

Thaler, A. M., 1999. The United States perspective towards slaughter. Poultry Sci. 78:298-301.

Thompson, J. E., C. E. Lyon, D. Hamm, J. A. Dickens, D. L. Fletcher, and A. D. Shackelford, 1986. Effects of electrical stunning and hot deboning on broiler breast meat quality. Poultry Sci. 65:1715-1719.

Thompson, L. D., D. M. Janky, and S. A. Woodward, 1987. Tenderness and physical characteristics of broiler breast fillets harvested at various times from post-mortem electrical stimulated carcasses. Poultry Sci. 66:1158-1167.

USDA., 1984. Poultry Inspection Regulations. Subpart I-Operating Procedures. Section 381.65c., USDA, Washington, DC.

van Hoof, J. B. M., 1992. Final remarks and recommendations. Proceedings EC workshop on pre-slaughter handling and stunning poultry, Brussels, November 9-11, 1992, page 69.

Veerkamp, C. H., and A. W. de Vries, 1983. Influences of electrical stunning on quality aspects of broilers. Pages 197-207 in: Stunning Animals for Slaughter. G. Eikelenboom, ed. Martinus Nijhoff Publishers, Boston, MA.

Veerkamp, C. H., A. H. H. Rincker, C. Pieterse, and A. W. de vries, 1987. Onderzoek naar de verdovngscondities op de kwaliteit van slachtkuikens. Spelderholt Institue for Poultry Research, Publication 469, Beekbergen, The Netherlands.

Veerkamp, C. H., 1988. What is the right current to stun and kill broilers. Poult.-Misset June/ July:30-31.

Wabeck, C., 1988. How stunning affects product quality. Poult. Int. February:48-52.

Wakefield, D. K., E. Dransfield, N. F. Down, and A. A. Taylor, 1989. Influence of post-mortem treatment on turkey and chicken meat texture. Int. J. Food Sci. Technol. 24:81-92.

Walker, J. M., R. J. Buhr, and D. L. Fletcher, 1993. Investigation of processing factors contributing to hemorrhagic leg syndrome in broilers. Poultry Sci. 72:1592-1596.

Walker, J. T., and C. L. Griffis, 1994. Effects of electrical stimulation on feather pulling force. Trans. ASAE 37:541-544.

Walker, L. T., S. D. Shackelford, K. A. Mills, and A. R. Sams., 1991. Proteolytic mechanisms of tenderization of *Pectoralis* from broiler carcasses receiving rigor-accelerating treatments. Poultry Sci. 70(Suppl. 1):127. (Abstr.).

Walker, L. T., S. D. Shackelford, S. G. Birkhold and A. R. Sams, 1995. Biochemical and structural effects of rigor-accelerating treatments in broiler pectoralis. Poultry Sci. 74:176-186.

Weise, E., H. -J. Wormuth, I. Scjutt-Abraham, and R. Levetzow, 1987. High voltage stunning of chickens and its effect on the quality of the meat. Fleischwirtsch. 67:345-350.

Wilson, J. G., and C. C. Brunson, 1968. The effects of handling and slaughter method on the incidence of hemorrhagic thighs in broilers. Poultry Sci. 47:1315-1318.

Young, L. L., and C. E. Lyon., 1997. Effect of electrical stimulation in combination with calcium chloride or sodium chloride treatments at constant ionic strength on moisture binding and textural quality of early-harvested breast fillets. Poultry Sci. 76:1446-1449.

Zeller, W., D. Mettler, and U. Scjatzmann, 1988. Stunning poultry with carbon dioxide Fleischwirtsch. 68(10):1308-1312.

Zocchi, C., and A. R. Sams, 1999. Tenderness of broiler breast fillets from carcasses treated with electrical stimulation and extended chilling times. Poultry Sci. 78:495-498.

CHAPTER 1

EFFECTS OF STUNNING AND DECAPITATION ON BROILER ACTIVITY DURING BLEEDING, BLOOD LOSS, CARCASS AND BREAST MEAT QUALITY[1]

[1] W. D. McNeal, D. L. Fletcher and R. J. Buhr, Submitted to Poultry Science

ABSTRACT Four experiments were conducted to determine the effects of electrical stunning and decapitation on bird activity as well as carcass and meat quality. In Experiment 1, broilers were subjected to one of four stunning and killing methods; no stun and neck cut; stun and neck-cut; no stun and decapitation; and stun and decapitation. Birds were scored for severity of physical activity on a scale of 1-4 with 1 being no activity and 4 being severe wing flapping and muscular contractions. Carcasses were also scored for red wing tips, and broken bones. In Experiment 2-4, all birds were stunned prior to neck cut or decapitation. Carcasses were scored as described in Experiment 1 as well as measurements of blood loss, feather removal, and breast meat pH, color, cook loss, and tenderness. Based on carcass activity in Experiment 1, decapitation following stunning was similar to a conventional stun and unilateral neck cut except there was almost no late activity (after 60 s) observed in the decapitated birds. Decapitation following stunning did not result in any consistent carcass quality defects and was comparable to conventional killing in the four experiments. No differences were found in 24 h lightness values, yellowness, cook yield, tenderness, and ultimate pH, between conventionally killed and decapitated birds. Blood loss and breast meat redness were inconsistent. These results indicate that high frequency stunning and decapitation may be an acceptable alternative to conventional slaughter based on carcass and meat quality and by ensuring an irreversible loss of consciousness.

Keywords: electrical stunning, decapitation, carcass quality, meat quality

INTRODUCTION

Electrical stunning systems for poultry were initially developed to immobilize the bird long enough to allow physical manipulation of the bird for alignment in automated neck cutting equipment (killer) and to reduce carcass damage due to unconscious physical activity such as wing flapping and violent muscular contractions during bleeding. Commercial processing plants presently slaughter birds at a rate of up to 140 to 180 birds a minute. Occasionally, due to a lack of bird uniformity, or, due to poorly adjusted and maintained equipment, birds may miss one or both the automated stunning or killing equipment necessitating the need for manual back-up. Consistency in making a proper unilateral neck cut, one which severs both the carotid artery and the jugular vein to allow rapid blood loss sufficient to kill the bird prior to entering the scalder requires continual monitoring and equipment adjustment.

In the early 1980's, it was observed in Europe that as many as 30% of birds were understunned (Heath, 1984). Research was undertaken that led to the European Union recommendations for high current stunning sufficient to cause instantaneous and irreversible unconsciousness in order to ensure a humane slaughter (Van Hoof, 1992). These high current, stun-to-kill methods have been associated with increased carcass and meat quality defects. According to Gregory and Wilkins (1989) high current stunning increases the incidence of red wing tips, broken bones, dislocations and hemorrhaging of deep breast muscle and blood engorged wing veins. Due to the importance of both humane slaughter and meat quality issues, slaughter technology (live bird handling, stunning, killing, and bleeding) has received considerable research interest over the past 15 years as reviewed in recent years by several authors (Bilgili 1999, Fletcher 1999, 2000).

Effective electrical stunning is produced when a sufficient amount of electrical current is passed through the central nervous system of birds for a given amount of time (Bilgili, 1992). According to Heath et al. (1994) more than 92% of all poultry plants in the U.S. subject poultry to electrical stunning with 66% using low voltage. Recent advances in electrical stunning have focused on extending stunning times and lowering stunning voltage, with the use of high frequency (500 Hz) pulsed direct current (Bilgili, 1999). Humane slaughter may be obtained by an electrocution (stun-to-kill), as it reduces the risk of birds regaining consciousness from an insufficient stun, a lengthy stun-to-cut interval, or a improper neck cut (Kettlewell and Hallworth, 1990). These authors also reported, a high voltage stun using 105 to 110 mA per bird would achieve 90% heart fibrillation and lower the risk of birds regaining consciousness during slaughter. According to Gregory and Wotton (1990), the purpose of high-current stunning is to induce an EEG epileptic waveform. It is theorized that birds exhibiting such brain activity are insensible to pain and are unconscious, since there is no pain reported by humans who have experienced a gran mal or epiliptic seizure.

Li et al. (1993) reviewed the various methods of postmortem electrical stimulation (ES) used to accelerate rigor development in birds. Electrical stimulation was found to hasten the development of rigor as measured by a rapid decrease in pH in thigh muscles of turkeys and to significantly reduce breast muscle shear values (Maki and Froning, 1987). Electrical stimulation can be utilized at a low (< 200 mA) or high (350-500 mA) amperage but is most effective when high amperage systems are used (Sams, 1999a ; 1999b). Electrical current when applied to the live bird (stunning) before death delays rigor whereas electrical current applied seconds later to the dead or dying bird (electrical stimulation) accelerates rigor development (Fletcher, 1999).

It has been suggested that high frequency (500 Hz) currents affect the central nervous system (CNS) more than the muscular system compared to low frequency (50 to 60 Hz) which may have more affect on the muscle system. This observation was made by comparing the results of high and low frequency current on stunning (Craig and Fletcher, 1997) and the lack of rigor acceleration when using high frequency ES (unpublished data, Fletcher 1998). Killing birds via decapitation is considered an acceptable means of killing an animal by the American Veterinary Medical Association (AVMA, 1993). Although decapitation may be acceptable from a welfare standpoint, the massive involuntary wing flapping and muscular activity following decapitation results in unacceptable carcass damage as well as a poor aesthetic image. Based on the observations of high frequency stunning affecting the CNS, it might be possible to kill birds using decapitation following a high frequency stun without the massive muscular contraction. Thus the objective of this study was to determine if decapitation following commercial high frequency stunning would affect carcass muscular activity during bleeding and ultimate carcass and meat quality.

MATERIALS AND METHODS

Experiment 1

In each of two trials, 80 broilers were obtained from the live holding area of a commercial processing plant, transported to the university pilot processing facility, and processed immediately (within 1 h). In each of the trials birds were weighed live and subjected to one of four stunning and killing treatments: no stun and unilateral neck cut (modified Kosher kill); stun followed by unilateral neck cut (conventional kill); no stun followed by decapitation (no stun:decap); and, stun followed by decapitation (stun:decap). Stunning was conducted at 14 V, pulsed DC at approximately 500 Hz for 18 s, followed by 14 V, 60 Hz AC for 9 s using a commercial stunner[2]. Killing was done by hand cutting the carotid artery and jugular vein on one side of the neck (unilateral cut). During bleeding, the birds were subjectively scored for severity of early muscular activity (0 to 10 s post kill), intermediate activity (10 to 60 s post kill), and late activity (greater than 60 s post kill). Reactions were scored on a scale of 1-4 (1 = none to mild muscle quivering; 2 = mild wing flapping; 3 = moderate spasmodic body movement and full wing flapping; and, 4 = violent wing flapping and full body movement capable of damaging the carcass). After 120 s, the birds were scalded[3] at 54 C for 120 s and picked using a commercial in-line picker[4] for 30 s. The heads were removed from the non-decapitated carcasses and NY dressed carcasses were weighed and chilled in a static ice and water mixture for 2 h. Carcasses were randomized and subjectively scored blind (scorer had no way to identify treatments) for occurrence and severity of the following carcass defects; red wing tips, red tails, and number of broken bones (clavicles and wing bones). Carcasses were scored on a scale of 0 to 2 (0 = no defects; 1 = moderate redness or one broken bone; and, 2 = severe redness or two or more broken bones).

[2]Simmons model SF-7001, Simmons Engineering Co., Dallas, GA 30132.

[3]Cantrell Model SS300CF, Cantrell Machine Co., Inc., Gainesville, GA 30503

[4]Cantrell Model CPF-60, Cantrell Machine Co., Inc., Gainesville, GA 30503

Experiment 2

In each of two trials, 100 broilers were obtained and processed as described in Experiment 1 with the following exceptions: all birds were weighed, stunned and divided equally among two kill methods either using a unilateral neck cut (conventional kill) or decapitation. Following bleeding, approximately 120 s post-kill, the heads were removed from the conventionally slaughtered carcasses prior to weighing. Blood loss (including head) was estimated by the difference between live weight and headless bled weight divided by live weight. Following scalding and picking, the NY dressed carcasses were chilled as previously described. Carcasses were randomized and subjectively scored for occurrence and severity of red wing tips, red tails and number of feathers: 0 = no defects or no feathers; 1 = moderate redness or less than three feathers; 2 = severe redness or more than three feathers.

Experiment 3

In each of two trials, 100 broilers were obtained and processed as described in Experiment 2 with the following exceptions: in each trial there were 50 male and 50 female birds, and the decapitated heads were kept with the carcasses. Blood loss was determined by the difference between live weight and bled weight divided by live weight (not including the loss of the head as in Experiment 2).

Experiment 4

In each of four trials, 100 broilers were obtained and subjected to the same treatments described in Experiment 2 except that birds were not weighed and carcasses were bled for 120 s prior to scalding, picking and chilling of the NY dressed carcasses. Carcasses were scored for occurrence and severity of defects as described in Experiment 2, after which the carcasses were covered with ice which was allowed to drain and held for 24 h at 2 C. Breast fillets (Pectoralis major) were removed from both sides of the carcass. The right side was used for pH determination using a modification of the iodoacetate method of Jeacocke (1977) as described by (Qiao et al., 2001). The left side was used to measure color, cook yield and Allo-Kramer shear value. Breast fillet color was measured in triplicate on the medial surface and averaged for each fillet. Color was measured using the CIELAB color values of lightness (L*), redness (a*), and yellowness (b*) using a reflectance colorimeter[5] as described by (Qiao et al., 2001). Breast fillets were cooked in steam at 98 C for 20 minutes. Cook yield was determined as follows: ((cooked weight / initial weight) x 100). Shear values were determined using an Allo-Kramer shear cell on an Instron Universal Testing Machine[6] according to the procedure described by Papinaho and Fletcher (1996).

Statistical Analyses

Data within each experiment were analyzed using the ANOVA option of the general linear model (GLM) procedure of SAS® (SAS Institute, 1988). Main effects for treatment (stunning and killing treatments), trials, and treatment by trial interactions were tested using residual error. Where the treatment by trial interaction was significant, that error term was used to test treatment main effects. Means were separated using Duncan s Multiple-Range Test option of the GLM procedure (SAS Institute, 1988), using the appropriate mean square error as described above.

---

[5] Minolta Chroma Meter CR-300, Minolta Corp., Ramsey, NJ 07446.

[6] Instron Corp., Canton, MA 02021.

RESULTS AND DISCUSSION

Experiment 1

Bird live weights, carcass yields, reaction scores and carcass defect scores for Experiment 1 are presented in Table 1.1. No differences were found among treatments in bird weights (1715 g) NY dressed weight (1540 g) or NY dressed yields (89.8 %).

Reaction scores during bleed-out differed significantly between the four treatments. Birds in the no-stun:decap treatment reacted immediately (Early) with violent wing flapping and body motion. This activity steadily diminished in severity during the Intermediate and Late periods and was almost completely ended by 90 seconds post-decapitation. These observations were expected and are consistent with birds which are decapitated or subjected to cervical dislocation.

Birds in the no-stun and conventional kill treatment (modified Kosher killing) exhibited little response to the handling and neck-cut (Early) but began exhibiting strong muscular contractions and wing flapping approximately 30 seconds post-kill that continued through Intermediate and Late scoring periods. The activity response for this treatment was also expected based on experiences with unstunned modified Kosher killing .

Birds stunned and killed with a unilateral neck cut (conventional killing) produced almost no initial reaction (Early), mild wing flapping and muscular contraction in the Intermediate and Late stages of bleed-out, with some minor movement and quivering at 90 s. These activity observations are also consistent with those of birds killed in commercial plants.

The reaction of birds which were decapitated following stunning (stun:decap) were almost identical in activity to the conventionally slaughtered bird in the Early and Intermediate time. However, compared to the conventional kill there was almost no activity after 60 s (Late). This was attributed to decapitation separating the brain from the carcass and killing the bird quicker without the lag time between neck cutting and the time required for blood loss to result in oxygen depletion to the brain as occurs during conventional slaughter.

Reaction scores in all of the activity areas throughout bleed-out were higher for both the no-stun treatments compared to the two stunned treatments. The highest scores were produced by the no-stun:decap treatment with 3.3, 3.9 and 2.4 respectively for the Early, Intermediate and Late scoring intervals. The lowest reaction scores for Early, Intermediate and Late activity were from the stun:decap treatment with 1.0, 1.6 and 1.5 respectively.

No differences were found in the occurrence of red wing tips or number of broken bones among treatments. There was a significantly higher number of red tails in the conventional stun and kill treatment than in the other treatments. The carcasses were scored for redness and broken bones because of comments from processors who stated that decapitation (usually following a missed stun or kill) often resulted in poor bleeding, red discolorations, poor picking, and broken wings (personal communications with numerous processing plant supervisors). Based on the reactions noted for the no stun:decap treated birds, these observations would be consistent with bird activity but were not reflected in the actual scores. Because of the clear difference in reactions between the stunned and non-stunned treatments, all subsequent experiments were conducted following high frequency stunning to focus on the comparison of conventional killing to decapitation following stunning.

Experiment 2

Live bird weights, bled weights, blood and head loss %, and carcass defect scores for Experiment 2 are presented in Table 1.2. No differences were found in live or bled weights among treatments.

Blood and head loss percentage for the conventional treatment was significantly higher than the decapitated treatments, 5.6 % and 5.4 %, respectively. Assuming that the head weights would be randomly distributed, it is assumed that the difference in combined loss was due primarily to differences in blood loss. There were no differences in the occurrence of red wing tips, red tails and number of feathers observed between the treatments.

Based on previous research conducted with electrical stunning (Schutt-Abraham et al., 1983; Papinaho and Fletcher, 1995), these results are expected based on the strong heartbeat of the conventionally killed birds facilitating a faster bleeding rate but with no effect on ultimate blood loss or carcass appearance when compared to birds killed with high current stunning designed to cause heart fibrillation. However, estimating blood loss by weight difference in which the head-weight was included may have been a confounding factor. Therefore, a method of keeping the detached head with the carcass was used in the subsequent experiment to focus strictly on the treatment effects on blood loss.

Experiment 3

Blood loss percentages for males and females from conventional and decapitated slaughtered treatments are presented in Table 1.3. There was a significant treatment by gender interaction, so the treatment effects were tested within gender. There were no significant treatment effects for either the males, 3.47 and 3.49, or females, 3.06 and 3.22, for the conventional or decapitated birds, respectively. Males had a significantly greater blood loss in the conventional treatment, 3.47 %, compared to females, 3.06 %, respectively. These results do not agree with those in Experiment 2 indicating that blood loss may not be a consistent issue regarding method of slaughter or estimating blood loss by weight difference is not consistent, especially when the head is included in the calculations. Decapitation may not result in immediate heart fibrillation thereby reducing the difference in blood loss rate when conventional killing is compared to electrocution.

Experiment 4

Carcass defects and 24 hour broiler breast meat pH, L*, a*, b*, cook yield, and Allo Kramer shear values from Experiment 4 are presented in Table 1.4. There were no differences in the occurrence of red wing tips, red tails and number of feathers between the slaughter treatments.

There were no significant differences between the breast meat pH from conventionally killed birds, 5.82, and the meat from decapitated birds, 5.83 indicating that killing treatment did not affect 24 h postmortem rigor development. There was no significant difference in breast meat color between killing treatments for lightness (L*) or yellowness (b*). However, the breast meat from the decapitated birds were significantly more red (2.6) than the breast meat from the conventionally killed birds (2.4). Although these values are numerically significant, they are of a magnitude that may not be visually significant. There were no killing treatment effects on breast meat cook yield or Allo-Kramer shear values.

It has been recommended that humane slaughter best be accomplished with instantaneous and irreversible loss of consciousness during stunning and bleeding (van Hoof, 1992). Although decapitation is not universally accepted as being humane, it is considered to be relatively rapid (loss of brain activity within 15 s, AVMA 1993) and it would have to be considered irreversible. However, decapitation results in massive uncoordinated muscular activity immediately upon severing the spinal cord which has been associated with increased carcass damage and may often be viewed negatively from an aesthetic point of view. Since decapitation, or cutting the spinal cord, was related to severe reactions and the perception by processing plant personal of increased carcass damage (not directly supported by our data), decapitation has not received much interest as a possible method for commercial slaughter. These results indicate that high frequency stunning followed by immediate decapitation may be an acceptable method of slaughter based upon rapid death, suppression of muscular activity upon severing the spinal cord, and no apparent carcass quality or meat defects. Further research is necessary to determine if decapitation following stunning would be applicable under commercial conditions relative to line speeds, carcass spacing on the line (6 inch commercial standard versus 12 inch in this study), and the occurrence of defects that may be significant in the large numbers associated with commercial slaughter (hundreds of thousands per day as opposed to 200 to 400 per experimental trial.

ACKNOWLEDGMENTS

This study was supported in part by state and Hatch funds allocated to the Georgia Agricultural Experiment Station. The authors also express their appreciation to Nicole Bartenfeld, Dianna Bourassa, Nicole Taylor, and Mustafa Simmons for technical support and assistance with data collection.

REFERENCES

American Veterinary Medical Association, 1993. Report of the AVMA Panel on Euthanasia. JAVMA. 202 (2):229-249.

Bilgili, S. F., 1992. Electrical stunning of broilers- basic concepts and carcass quality implications: A review. J. Appl. Poultry Res. 1:135-146.

Bilgili, S. F., 1999. Recent Advances in electrical stunning. Poultry Sci. 78:282-286.

Craig, E. W., and D. L. Fletcher, 1997. A comparison of high current and low voltage electrical stunning systems on broiler breast rigor development and meat quality. 76:1178-1181.

Fletcher, D. L., 1999. Slaughter Technology. Poultry Sci. 78:277-281.

Fletcher, D. L., 2000. Stunning of Poultry. Proceedings of XXI World Poultry Congress, Montreal, Canada S3.13 Aug, 24 2000

Gregory, N. G., and L. J. Wilkins, 1989. Effect of stunning current on carcass quality defects in chickens. Veterinary Record, 124: 530-532.

Gregory, N. G., and S. B. Wotton, 1990. Effect of stunning on spontaneous physical activity and evoked activity in the brain. Br. Poult. Sci. 31:215-220.

Heath, G. B. S., 1984. The slaughter of broiler chickens. World s Poultry Science Journal, 40(2):151-159.

Heath, G. E., A. M. Thaler, and W. O. James, 1994. A survey of stunning methods currently used during slaughter of poultry in commercial poultry plants. J. Appl. Poultry Res. 3:297-302.

Jeacocke, R. E., 1977. Continuous measurements of the pH of the beef muscle in intact beef carcasses. J. Food Technol. 12:375-386.

Kettlewell, P.J., and R.N. Hallworth, 1990. Electrical stunning of chickens. J. Agric. Eng. Res. 47: 139-151.

Li, Y., T. J. Siebenmorgen, and C. L. Griffis, 1993. Electrical stimulation in poultry: A review and evaluation. Poultry Sci. 72:7-22.

Maki A., and G. W. Froning, 1987. Effect of post-mortem electrical stimulation on quality of turkey meat. Poultry Sci. 66:1155-1157.

Papinaho, P. A., and D. L. Fletcher, 1995. Effects of electrical stunning duration on post-mortem rigor development and broiler breast meat tenderness. J. Muscle Foods 6:1-8.

Papinaho, P. A., and D. L. Fletcher, 1996. The effects of stunning amperage and deboning time on early rigor development and breast meat quality of broilers. Poultry Sci. 75:672-676.

Qiao, M., D. L. Fletcher, D. P. Smith, and J. K. Northcutt, 2001. The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. Poultry Sci. 80:676-680.

Sams, A., 1999a. Meat quality during processing. Poultry Sci. 78:798-803.

Sams, A., 1999b. Commercial implementation of postmortem electrical stimulation. Poultry Sci. 78:290-294.

SAS Institute, 1988. SAS®/STAT Guide for Personal Computers. Version 6.03 Edition. SAS Institute Inc., Cary, NC.

Schutt-Abraham, I., H.-J. Wormuth, and J. Fessel, 1983. Electrical stunning of poultry in view of animal welfare and meat production. Pages 187-196 in : Stunning of Animals for Slaughter. G. Eikelenbonnm, ed. Martinus Nijhoff publishers, Boston, MA.

van Hoof, J. B. M., 1992. Final remarks and recommendations. Proceedings EC workshop on pre-slaughter handling and stunning of poultry, Brussels, November 9-11, 1992, page 69.

Table 1.1 Mean and standard error of the mean for Live weight , New York (NY) dressed weight, NY dressed yield, early (Early), intermediate (Intermediate), or late (Late) reaction severity, occurrence of red wing tips, red tails, and broken bones from birds subjected to a conventional unilateral neck cut (Cut) or decapitation (Decap) without or following stunning in Experiment 1 (n = 40 observations per mean).

Variable	No Stun		Stun		
	Cut	Decap	Cut	Decap	*P*
Live weight (g)	1689 ± 45	1722 ± 50	1711 ± 32	1740 ± 360	.8510
NY dressed weight (g)	1516 ± 41	1543 ± 45	1538 ± 29	1565 ± 33	.8390
NY dressed yield (%)	89.8 ± .14	89.7 ± .2	89.9 ± .2	89.9 ± .2	.7100
Early[1,2]	1.8^{b} ± .31	3.3^{a} ± .32	1.2^{c} ± .05	1.0^{c} ± .13	.0001
Intermediate[1,2]	3.0^{b} ± .19	3.9^{a} ± .06	2.0^{c} ± .10	1.6^{c} ± .13	.0001
Late[1,2]	2.6^{a} ± .13	2.4^{a} ± .19	1.9^{b} ± .08	1.5^{c} ± .10	.0001
Red wing tips[3]	1.7 ± .11	1.7 ± .15	1.6 ± .10	1.5 ± .11	.6656
Red tails[3]	1.5^{b} ± .10	1.5^{b} ± .12	1.8^{a} ± .13	1.5^{b} ± .09	.0402
Broken bones[3]	1.1 ± .05	1.0 ± .03	1.1 ± .04	1.1 ± .05	.6028

[a, b, c] Means within a row followed by different superscript letters differ significantly (P<0.05).

[1] Reaction times; Early = 0-10 s, Intermediate = 10-60 s, Late = > 60 s

[2] Reaction scores; 1- 4 where 1 = none to mild muscle quivering; 2 = mild wing flapping; 3 = moderate spasmodic body movement and full wing flapping; and, 4 = violent wing flapping and full body movement capable of damaging the carcass

[3] Carcass defect scores; where 0 = no defects; 1 = moderate redness; 2 = severe redness.

Table 1.2 Mean and standard error of the mean for Live weight, Bled weight with the removal of the head, Blood loss %, occurrence of red wing tips, red tails and feathers from birds subjected to a conventional unilateral neck cut or decapitation following stunning in Experiment 2 (n = 100 observations per mean).

	Treatment		
Variable	Conventional	Decapitation	*P*
Live weight (g)	1908 ± 26	1923 ± 25	.7260
Bled weight (g)	1802 ± 25	1820 ± 23	.6376
Blood and head loss (%)	5.6 ± .1	5.4 ± .1	.0311
Red wing tips[1]	.91 ± .07	.89 ± .08	.5253
Red tails[1]	.48 ± .07	.51 ± .08	.8408
Feathers[1]	.18 ± .05	.21 ± .06	.5076

[1] Carcass defect scores where 0 = no defects or no feathers; 1 = moderate redness or less than three feathers; 2 = severe redness or more than three feathers.

Table 1.3 Mean and standard error of the mean for blood loss % for males and females subjected to Conventional killing or Decapitation in Experiment 3.

Gender	Treatment		*P*
	Conventional	Decapitation	
Males	3.47 ± .13	3.49 ± .10	.9032
Females	3.06 ± .15	3.22 ± .12	.4170
P	.0445	.1082	

N = 50 observations per mean

Table 1.4 Mean and standard error of the mean for occurrence of Red wing tips, Red tails, Feathers, breast meat pH, lightness (L*), redness (a*), yellowness (b*), Cook yield, and Allo-Kramer shear from birds subjected to a conventional unilateral neck cut (Conventional) or Decapitation following stunning in Experiment 4 (n = 200 observations per mean).

	Treatment		
Variable	Conventional	Decapitation	*P*
Red wing tips[1]	.93 ± .05	.94 ± .04	.8423
Red tails[1]	.80 ± .06	.68 ± .05	.1230
Feathers[1]	.06 ± .02	.05 ± .01	.6386
Breast meat pH	5.82 ± .01	5.83 ± .01	.5157
L*	49.8 ± .24	49.6 ± .23	.6227
a*	2.4 ± .07	2.6 ± .07	.0016
b*	6.3 ± .11	6.4 ± .12	.5842
Cook yield (%)	73.18 ± .18	73.41 ± .21	.4092
Allo-Kramer (Kg/g)	5.06 ± .16	4.94 ± .15	.5269

[1] Carcass defect scores where 0 = no defects or no feathers; 1 = moderate redness or less than three feathers; 2 = severe redness or more than three feathers.

CHAPTER 2

THE EFFECTS OF HIGH FREQUENCY ELECTRICAL STUNNING AND DECAPITATION ON EARLY RIGOR DEVELOPMENT AND MEAT QUALITY OF BROILER BREAST MEAT[1]

[1]W. D. McNeal and D. L. Fletcher, Submitted to Poultry Science

ABSTRACT Three independent trials were conducted to determine the effects of high frequency electrical stunning followed by decapitation on broiler breast meat rigor development and meat quality. All birds were stunned and half of the birds were killed using a conventional unilateral neck cut and half were killed by decapitation. Both groups were allowed to bleed for 120 seconds prior to scalding and picking. New York dressed carcasses were chilled in a static ice-water bath for 90 minutes and held at 2 C prior to deboning. Breast fillets were removed from the carcasses at 2, 4 and 24 h postmortem. From the right breast fillet, R-values and pH were determined at time of deboning. The left fillet was wrapped in plastic and held for 24 h at 2 C prior to determining lightness (L*), redness (a*), yellowness (b*), cook yield and Allo-Kramer shear. Deboning time affected raw meat pH, R-value, cook loss and shear value, but had no effect on color. The breast meat from the decapitated birds had significantly higher pH values at 2 and 24 h postmortem than the conventionally killed birds. Other than for the effect on breast meat pH, decapitation had no effect on rigor development, R-value, meat color, or meat quality as measured by cooked-meat yield and Allo-Kramer shear.

Keywords: Broiler, Slaughter, Stunning, Decapitation, Breast meat quality

INTRODUCTION

The effects of electrical stunning, on the rate of rigor mortis development in poultry have been extensively researched. The effects of various electrical stunning systems on the rate of early post-mortem metabolism (glycolysis, lactic acid accumulation, ATP depletion, sarcomere lengths, R-values, etc.) and the effect on ultimate muscle pH and meat quality have been reported by numerous authors including Lee et al., (1979); Thomson et al., (1986); Murphy et al.,(1988); Kim et al., (1988); Papinaho and Fletcher, (1995ab). Electrical stunning has also been shown to negatively affect early blood loss (Kotula and Helbacka, 1966; Kuenzel and Ingling, 1977; Murphy et al.,1988; Papinaho and Fletcher, 1995a) but not ultimate blood loss (Schutt-Abraham et al., 1983; Gregory, 1993). Electrical stunning has been shown to have little effect on breast muscle pH and R-values after 4-6 hours post-mortem (Papinaho and Fletcher, 1996). High frequency, low voltage electrical stunning has been shown to delay the onset of rigor mortis, especially when compared to high current stunning (Craig and Fletcher, 1997) or when compared to post-mortem electrical stimulation (Craig et al., 1999).

The effects of alternative methods of stunning and killing on rigor development have also been reported. Gas stunning and killing has been shown to accelerate the rate of rigor development Mohan Raj and Gregory, (1990); Flemming et al., (1991); Poole and Fletcher, (1998); Kang and Sams, 1999. Lambooij et al. (1999) reported that captive bolt stunning using air pressure, when compared to high current electrical stunning, produced significantly lower pH values in breast muscles up to 140 min post-mortem.

The use of high frequency electrical stunning followed by decapitation has been shown to have little negative effects on 24 h carcass and meat quality (McNeal et al., 2002). The authors attributed this to the ability of high frequency electrical stunning to override the post-mortem muscular contractions associated with accelerated rigor. The purpose of this project was to compare the effects of high frequency electrical stunning followed by conventional neck cutting or decapitation on early rigor development and meat quality.

MATERIALS AND METHODS

Processing

In each of three independent trials, 120 birds were obtained from the live holding area of a commercial processing plant, transported to the university pilot processing facility, and slaughtered immediately (within 1 h). In each trial birds were stunned using a commercial stunner[2] set at 14 V, pulsed DC at approximately 500 Hz for 18 s, followed by 14 V, 60 Hz AC for 9 s. Half of the birds were killed manually with a knife using a conventional unilateral cutting of the carotid artery and jugular vein and half were killed by manual decapitation with a knife. Birds were allowed to bleed for 120 s, scalded[3] at 54 C for 120 s and picked[4] for 30 s using commercial in-line equipment. The non-eviscerated carcasses (NY dressed with the heads and feet removed) were chilled in a static ice-water slush for 90 minutes, drained, covered with ice (allowed to drain) and held at 2 C until deboning.

At 2, 4, and 24 h postmortem, 1/3 of the birds from each killing treatment were removed from the ice, and the breast fillets (Pectoralis major) were deboned from both sides of the carcass. The right side was used immediately for pH and R-value determination. The left side

---

[2]Simmons model SF-7001, Simmons Engineering Co., Dallas, GA 30132.
[3]Cantrell Model SS300CF, Cantrell Machine Co., Inc., Gainesville, GA 30503
[4]Cantrell Model CPF-60, Cantrell Machine Co., Inc., Gainesville, GA 30503

breast fillets, for the 2 and 4 h samples, were placed on trays, covered with plastic (to avoid surface drying) and held 24 h at 2 C for subsequent breast meat color, cook yield and Allo-Kramer shear determination. The 24 h deboned breast fillets were analyzed immediately upon deboning.

Analyses

Tissue samples were removed from the right breast muscle for pH and R-value determinations. Breast muscle pH was determined using a modification of the iodoacetate method of Jeacocke (1977) as described by Qiao et al. (2001). R-value, the ratio of adenosine to inosine nucleotides, was calculated using the absorbence at 250 and 260 nm as described by Honikel and Fischer (1977). Color was measured on the breast fillets 24 h postmortem in triplicate using the CIELAB color values of lightness (L*), redness (a*), and yellowness (b*) using a reflectance colorimeter[5] as described by Qiao et al. (2001). Cook yield was determined by dividing the weight of the cooked sample by the weight of the raw sample times 100. Shear values were determined using an Instron Universal Testing Machine[6] equipped with an Allo-Kramer shear cell on a single core removed from each cooked breast fillet as described by Papinaho and Fletcher (1996).

---

[5] Minolta Chroma Meter CR-300, Minolta Corp., Ramsey, NJ 07446.
[6] Instron Corp., Canton, MA 02021.

Statistical analyses

Multiple color readings were averaged for each individual breast fillet. Data were analyzed using the ANOVA option of the general linear models (GLM) procedures of SAS software (SAS Institute, 1988). For each test measurement, the data were analyzed for main effects of kill treatment (conventional or decapitation), trial (1, 2, and 3), and treatment by trial interactions tested using residual error. When the treatment by trial interaction was significant, it was used at the error term to test treatment main effects. Means were separated using Duncan s Multiple-Range Test option of the GLM procedure (SAS Institute, 1988), using the appropriate mean square error as described above.

RESULTS AND DISCUSSION

The results for pH and R-values are presented in Table 2.1. Breast muscle pH values decreased as postmortem deboning times increased from 2 to 4 h, but with no difference between the 4 and 24 h postmortem times for both methods of killing. Decapitation resulted in significantly greater pH values than the conventional killing at 2 and 24 h, 6.25 versus 6.07, and 5.92 versus 5.83, respectively, but there were no significant differences between kill treatments at 4 h postmortem (5.97 versus 5.90). These results are in contrast to earlier results in which decapitation had no significant effect on 24 h postmortem pH (McNeal et al., 2002).

R-values, the ratio of adenosine to inosine nucleotides, increased significantly with increasing postmortem deboning time for the breast meat from conventionally killed birds. R-values increased significantly between 2 and 4 h postmortem for breast meat from the decapitated birds, but there was no difference between the 4 and 24 breast meat R-values. There were no significant differences in R-values between the two killing treatments at any of the postmortem deboning times.

Results for CIELAB color values of the 24 h aged fillets are presented in Table 2.2. There were no significant differences between the conventional and decapitation methods of killing for any of the three color values, lightness, redness, or yellowness. In a previous report (McNeal et al., 2002), breast meat deboned at 24 h from decapitated birds showed a small, but significant, increase in redness, (2.6 vs 2.4) compared to the conventionally killed birds.

Results for 2, 4, and 24 h postmortem deboned breast meat cook yield and Allo-Kramer shear are presented in Table 2.3. There were no differences in cook yield between the 2 and 4 h postmortem fillets. Conventional cook yields were 74.1 and 74.8 % and decapitated cook yields were 75.4 and 75.0 %, for 2 and 4 h deboning times respectively. The fillets removed at 24 h postmortem had significantly lower cook yield 72. 4 and 73.4 % for conventional and decapitated kill treatments, respectively, than cook yields from 2 or 4 h postmortem. This effect may be due to lower water binding capacity associated with the significantly lower pH of the breast meat deboned at 24 h postmortem (Table 2.1). There were no significant differences in cook breast meat yields between the two killing treatments at any of the deboning times.

The results for the Allo-Kramer shear values were consistent with previous reports on the effects of deboning time on breast meat tenderness (Papinaho and Fletcher, 1996; Kang and Sams, 1999; Zocchi and Sams, 1999). Shear values decreased significantly between 2, 4, and 24 h postmortem deboned breast meat for both killing treatments. However, there were no significant differences in shear values between the two methods of killing at any of the three deboning times.

These results indicate that decapitation following high frequency electrical stunning has little effect on 24 h postmortem, meat quality, except for pH. These results, except for the difference in pH and redness, are consistent with those reported by McNeal et al. (2002).

The difference between conventional killing and decapitation in 2 and 24 h postmortem deboned breast meat pH values could be due to differences in muscular activity during slaughter. McNeal et al., 2002 reported that there was little difference in bird activity between conventional and decapitation following high-frequency stunning. The main difference is that the decapitated birds appear to die quicker and have less physical motion after 60 s post-kill. The difference in pH could reflect the decreased postmortem muscular activity which has previously been shown to slow early postmortem pH decline and rigor development (Papinaho et al., 1995).

ACKNOWLEDGMENTS

This study was supported in part by state and Hatch funds allocated to the Georgia Agricultural Experiment Station. The authors also express their appreciation to Nicole Bartenfeld, R. Jeff Buhr, Mustafa Simmons, and Lynda Jones for their technical support and assistance with data collection.

REFERENCES

Craig, E. W. and D. L. Fletcher, 1997. A comparison of high current and low voltage electrical stunning effects on broiler breast rigor development and meat quality. Poultry Sci.76:1178-1181.

Craig, E. W., D. L. Fletcher, and P. A. Papinaho, 1999. The effects of antemortem electrical stunning and postmortem electrical stimulation on biochemical and textural properties of broiler breast meat. Poultry Sci. 78:490-494.

Fleming, B. K., G. W. Froning, M. M. Beck, and A. A. Sosnicki, 1991. The effect of carbon dioxide as a preslaughter stunning method for turkeys. Poultry Sci. 70: 2201-2206.

Gregory, N. G., 1993. Causes of downgrading in chickens, turkeys and ducks. Broiler Ind. 56: 42-45.

Honikel, K. O., and C. Fischer, 1977. A rapid method for the detection of PSE and DFD porcine muscles. J. Food Sci. 42:1633-1636.

Jeacocke, R. E., 1977. Continuous measurements of the pH of the beef muscle in intact beef carcasses. J. Food Technol. 12:375-386.

Kang, I. S., and A. R. Sams, 1999. Bleedout efficiency, carcass damage, and rigor mortis development following electrical stunning or carbon dioxide stunning on a shackle line. Poultry Sci. 78:139-143.

Kim, J. W., D. L. Fletcher, and D. R. Campion, 1988. Research note: effect of electrical stunning and hot boning on broiler breast meat characteristics. Poultry Sci. 67:674-676.

Kotula, A. W. and N. V. Helbacka, 1966. Blood retained by chicken carcases and cut-up parts as influenced by slaughter method. Poultry Sci. 45:404-410.

Kuenzel, W. J. and A. L. Ingling, 1977. A comparison of plate stunners, A. C. and D. C. circuits for maximizing bleed-out in poultry processing. Poultry Sci. 56:2087-2090.

Lambooij, E., C. Pieterse, S.J.W. Hillebrand, and G. B. Dijksterhnis 1999. The effects of captive bolt stunning, and restraining methods on broiler meat quality. Poultry Sci. 78:600-607.

Lee, Y. B., G. L. Hargus, J. E. Webb, D. A. Rickansruci, and E. C. Hagberg, 1979. Effect of electrical stunning on postmortem biochemical changes and tenderness in broiler breast muscle. J. Food Sci. 44:1121-1128.

McNeal, W. D., D. L. Fletcher and R. J. Buhr, 2002. Effects of stunning and decapitation on broiler activity during bleeding, blood loss, carcass and breast meat quality. Poultry Sci. (Submitted).

Mohan Raj, A. B., and N. G. Gregory, 1990. Investigation into the batch stunning/killing of chickens using carbon dioxide or argon-induced hypoxia. Res. Vet. Sci. 49:364-366.

Murphy, B. D., R. J. Hasiak and J. G. Sebranek. Effect of antemortem electrical stunning on functional properties of turkey muscle. Poultry Sci. 67: 1062-1068.

Papinaho, P. A., and D. L. Fletcher, 1995a. Effects of electrical stunning duration on postmortem rigor development and broiler breast meat tenderness. J. Muscle Foods. 6:1-8.

Papinaho, P. A., and D. L. Fletcher, 1995b. Effect of stunning amperage on broiler muscle rigor development and meat quality. Poultry Sci. 74:1527-1532.

Papinaho P. A., D. L. Fletcher, R. J. Buhr, 1995. Effect of electrical stunning amperage and peri-mortem struggle on broiler breast rigor development and meat quality. Poultry Sci. 74:1533-1539.

Papinaho, P. A., and D. L. Fletcher, 1996. The effects of stunning amperage and deboning time on early rigor development and breast meat quality of broilers. Poultry Sci. 75:672-676.

Poole, G. H. and D. L. Fletcher, 1998. A comparison of a modified atmosphere stunning-killing system to conventional slaughter on broiler breast muscle rigor development. Poultry Sci. 77:342-347.

SAS Institute, 1988. SAS®/STAT Guide for Personal Computers. Version 6.03 Edition. SAS Institute Inc., Cary, NC.

Thomson, J. E., C. E. Lyon, D. Hamm, J. A. Dickens, 1986. Effects of electrical stunning and hot deboning on broiler breast meat quality. Poultry Sci. 65: 1715-1719.

Schutt-Abraham, I., H.-J. Wormuth, and J. Fessel, 1983. Electrical stunning of poultry in view of animal welfare and meat production. In stunning of Animals for Slaughter, (G. Eikelenboom, ed.) Martinas Nijhoff pub., Boston.

Qiao, M., D. L. Fletcher, D. P. Smith, and J. K. Northcutt, 2001. The effect of broiler breast meat color on ph, moisture, water-holding capacity, and emulsification capacity. Poultry Sci. 80:676-680.

Zocchi, C. and A. R. Sams, 1999. Tenderness of broiler breast fillets from carcasses treated with electrical stimulation and extended chilling times. Poultry Sci. 78:495-498.

TABLE 2.1 Broiler breast muscle pH and R-value (ratio of adenosine to inosine nucleotides at 250 and 260 nm) means and standard errors of the mean (SEM) for conventional and decapitated birds deboned at 2, 4 and 24 h postmortem

Measurement	Deboning Time Postmortem (h)	n	Killing Treatment		*P*
			Conventional	Decapitation	
pH	2	30	$6.07^{a} \pm .04$	$6.25^{a} \pm .02$	.0008
	4	40	$5.90^{b} \pm .03$	$5.97^{b} \pm .03$	.0940
	24	40	$5.83^{b} \pm .02$	$5.92^{b} \pm .03$	.0180
P			.0001	.0001	
R-value	2	40	$1.13^{c} \pm .02$	$1.12^{b} \pm .02$	.7500
	4	40	$1.28^{b} \pm .02$	$1.31^{a} \pm .02$	.1580
	24	40	$1.33^{a} \pm .01$	$1.33^{a} \pm .01$	.8120
P			.0001	.0001	

[a, b, c]Means within a column and measurement with differing superscripts are significantly different from each other.

TABLE 2.2 Broiler breast meat lightness (L*), redness (a*), and yellowness (b*) means and standard errors of the mean (SEM) at 24 h postmortem from conventionally killed or decapitated birds

Measurement	n	Killing Treatment		*P*
		Conventional	Decapitation	
L*	180	51.0 ± .23	50.7 ± .21	.3960
a*	180	2.5 ± .09	2.6 ± .08	.5290
b*	180	7.4 ± .11	7.4 ± .10	.7820

TABLE 2.3 Broiler breast meat cook yield (%) and Allo-Kramer (AK) shear means and standard errors of the mean (SEM) from conventionally killed and decapitated birds deboned at 2, 4 and 24 h postmortem

Measurement	Deboning Time Postmortem (h)	n	Killing Treatment		*P*
			Conventional	Decapitated	
Cook yield (%)	2	40	74.1[a] ± .56	75.4[a] ± .51	.0980
	4	40	74.8[a] ± .44	75.0[a] ± .43	.3320
	24	40	72.4[b] ± .37	73.4[b] ± .42	.0900
P			.0012	.0051	
AK shear (Kg shear / g sample)	2	40	10.0[a] ± .6	10.4[a] ± .7	.7120
	4	40	6.6[b] ± .4	6.4[b] ± .3	.6600
	24	40	4.3[c] ± .3	4.3[c] ± .3	.9490
P			.0001	.0001	

[a, b, c]Means within a column and measurement with differing superscripts are significantly different from each other.

SUMMARY AND CONCLUSIONS

Experiments were conducted to evaluate the feasibility of using high frequency electrical stunning followed by decapitation for commercial slaughter of broilers. Electrical stunning and decapitation did not adversely affect carcass quality, meat quality or rigor development compared to conventional stunning and neck cutting.

Decapitation eliminates the variability inherent in conventional slaughter associated with stunning and neck cutting. Advantages to this system are the assurance that there will be no resumption of consciousness during slaughter and the simplification of equipment maintenance. Both of these factors should improve the welfare status of poultry processing.

Further research is necessary to better establish the animal welfare status of stunning followed by decapitation. Also, the procedure needs to be tested in commercial plants to determine if the advantages found in the pilot studies transfer to industrial scale operations.