Bovine Dehorning

Assessing Pain and Providing Analgesic Management

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KEYWORDS

- Dehorning • Cattle • Analgesia • Animal welfare

KEY POINTS

- Dehorning causes behavioral, physiologic, and neuroendocrine changes, indicating a stressful or painful response in cattle.
- Following dehorning, an acute painful response is observed within the first 30 minutes followed by a period of suggested inflammatory pain lasting up to 8 hours.
- Local anesthetics provide analgesia for the initial acute pain response; however, a delayed cortisol response is observed, presumably once sensitivity returns to the anesthetized area.
- Acute pain following dehorning is mitigated using local anesthetics, nonsteroidal anti-inflammatory drugs (NSAIDs), and sedatives providing analgesia.
- NSAIDs help to attenuate the inflammatory mediated pain response following dehorning.
- A multimodal approach using local anesthetics, NSAIDs and, when possible, sedative-analgesics, is recommended for the most effective reduction of pain response in cattle following dehorning.

INTRODUCTION

Dehorning is a commonly performed practice in both beef and dairy cattle industries. Dehorning or disbudding in cattle is performed for a variety of reasons, including safety for handling, decreased incidence of carcass wastage due to bruising, requirement of less feeding-trough space, decreased risk of injury to other cattle, increased

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value of the animal, and fewer aggressive behaviors.[1] Disbudding is a method of removing horns in calves up to around 8 weeks old, when horn buds are 5 to 10 mm long and can be removed via a heated disbudding iron.[2] Once horns grow longer, they become attached to the underlying frontal sinus and must be removed by amputation. For the purpose of clarity, throughout this article all disbudding and dehorning is collectively referred to as dehorning.

Although cattle are naturally horned for protective purposes, modern commercial industries decrease the necessity of these defenses. Within these production systems, for reasons listed above, cattle without horns can be more desirable. Horn growth is a genetically heritable autosomal recessive trait.[3] Polled cattle, which are hornless animals, result from an autosomal dominance pattern that has been shown recently to be a result of allelic heterogeneity of the polled locus.[3] Because the polled genetic inheritance reflects that of an autosomal dominant inheritable trait, artificial genetic selection could result in the decline of this undesirable characteristic of intensively raised cattle. This artificial selection for polled cattle has been observed in the beef industry, with a 58% reduction in beef calves born with horns from 1992 to 2007 as a result of breeding for polled animals.[4] However, this breeding selection has not been adopted by the dairy industry, with a reported 94% of dairy operations in the United States dehorning calves.[5]

Management practices have been adopted to dehorn animals to better fit within the production system. There are 3 primary methods of dehorning cattle: (1) amputation using scoop dehorners such as Barnes, Keystone, gauges, saws, and gigli wire; (2) cautery using a hot iron powered electrically, by gas, or battery; and (3) chemical application of caustic paste, usually consisting of a strong alkalotic agent such as sodium hydroxide or calcium hydroxide. Regardless of the dehorning method, following the procedure a behavior change is noted that is consistent with an acute stress response.[6–8] As a result, dehorning cattle can be a welfare issue if concerns of pain are not addressed during dehorning. For a more detailed discussion and review of assessing pain in food animals, refer to the article from Coetzee concerning castration elsewhere in this issue.

Recently, there has been increased social concern and awareness regarding the proper treatment of livestock.[9] Routine procedures in cattle such as dehorning can have a negative public perception. Subsequently, several countries including those belonging to the European Union, Australia, and New Zealand have created dehorning welfare legislation.[2] In North America, The Canadian Code of Practice for Dairy Cattle recommends the use of a local anesthetic combined with analgesia and sedation for dehorning calves; however, there are no current regulations in the United States for the use of analgesics.[10] Although it should be noted that the American Veterinary Medical Association "supports the use of procedures that reduce or eliminate the pain of dehorning and castrating of cattle" and proposes that "available methods of minimizing pain and stress include application of local anesthesia and the administration of analgesics."[11]

Survey evidence in the United States suggests that routine procedures such as dehorning and castration are performed together (92%) and are usually completed without the use of analgesics.[12] A survey of north-central and northeastern United States dairy producers indicated that 12.4% use a local anesthetic nerve block and only 1.8% use systemic analgesia at the time of dehorning.[13] In addition, another survey of United States veterinarians determined that 49% of beef calves and 63% of dairy calves younger than 6 months of age were administered an analgesic at the time of dehorning.[14] A Canadian survey indicated that approximately 72% of veterinarians provided analgesia at the time of dehorning calves.[15] Of note, additional positive influences for providing analgesia to calves at dehorning included geographic locations where significant public outreach for animal welfare has occurred.[15]

The use of analgesics following dehorning such as local anesthesia, systemic anti-inflammatories, and sedatives with analgesic properties has been investigated by several studies using behavioral, physiologic, and neuroendocrine biomarkers for assessment of pain.[16] In general, when using cortisol concentrations as an indicator of stress and pain, evidence exists of a rapid cortisol increase following dehorning that peaks within the first 30 minutes. Cortisol concentrations then plateau from 1 to 6 hours and then decline, returning to baseline 7 to 8 hours following dehorning (**Fig. 1**). Local anesthetics mitigate the cortisol response for their respective duration of action (ie, lidocaine: 2 hours; bupivacaine: 4 hours) following the procedure, but a delayed cortisol response is observed presumably once sensitivity returns to the anesthetized area.[17–19] Anti-inflammatories have aided in the reduction of this delayed cortisol response.[19–22] In addition, the use of sedatives with suggested analgesia can contribute to the reduction of the initial cortisol response, improving procedural success.[23,24] Most studies evaluating stress and pain changes in dehorned cattle investigate the acute response; however, few studies have examined chronic pain or stress responses following dehorning.

Within the United States there exist sufficient challenges to accurately assess and manage pain in food animals. This review assesses tools specifically used in the evaluation of the effectiveness of pain relief following dehorning. In addition, supportive evidence on using analgesia in dehorning to moderate changes associated with a pain response are detailed, using published literature in an evidence-based approach. Studies included in this analysis were identified as those that addressed the pain associated with dehorning using either analgesic-treated or placebo-treated controls. Pain biomarkers determined in these studies were used to determine a percent change associated with a drug treatment (**Tables 1–3**). The numerical values

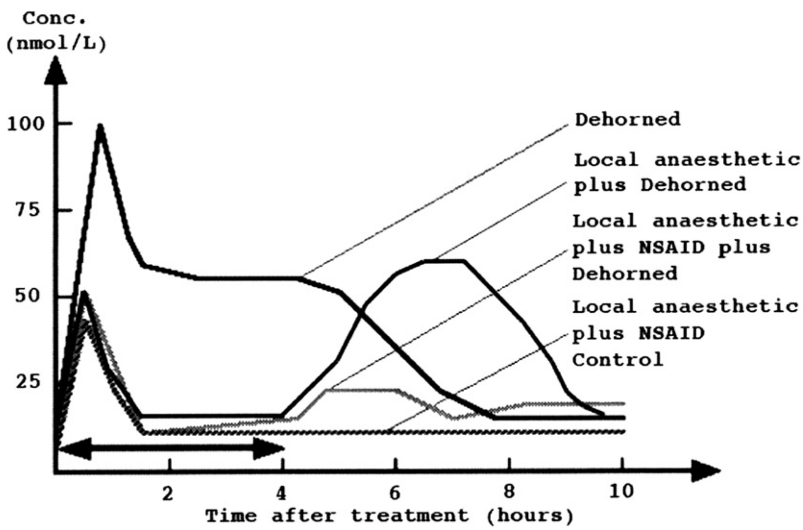

Fig. 1. Cortisol change over time in cattle following amputation (scoop) dehorning. Local anesthesia (bupivacaine) with administration of nonsteroidal anti-inflammatory drug (NSAID; ketoprofen) provides a reduction in measured cortisol concentrations, although a delayed cortisol response is evident without the addition of an anti-inflammatory. The double-headed arrow along the x-axis represents the duration of the local anesthesia provided by bupivacaine. (*Data from* Stafford KJ, Mellor DJ. Dehorning and disbudding distress and its alleviation in calves. Vet J 2005;169(3):337–49.)

Table 1
Summary of the scientific literature examining the effect of analgesic drug administration on plasma cortisol response in dehorned calves

Reference	Procedure	Study Population	Analgesic Regimen	Outcome Parameter	Change in Cortisol (%)	Significance (*P* Value)
Boandl et al,[36] 1989	Cautery (electric) dehorning	7–16 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL/horn), 5 min before dehorning	Cortisol (30 min)	−13.41	NS
Morisse et al,[26] 1995	Chemical paste dehorning	4 wk Dairy	Lidocaine local anesthesia (cornual nerve, 4 mL/horn), 15 min before dehorning	Cortisol (1 h)	−19.34	NR
				Cortisol (4 h)	−57.26	NR
				Cortisol (24 h)	−6.45	NR
	Cautery (electric) dehorning	8 wk Dairy	Lidocaine local anesthesia (cornual nerve, 4 mL/horn), 15 min before dehorning	Cortisol (1 h)	−18.03	NR
				Cortisol (4 h)	234.48	NR
				Cortisol (24 h)	101.56	NR
Petrie et al,[17] 1996	Amputation (scoop) dehorning	6–8 wk Dairy	Lidocaine local anesthesia (cornual nerve, 3 mL/horn), 20 min before dehorning	Cortisol (AUEC: 0–2 h)	−53.64	<.05
				Cortisol (AUEC: 2–9.5 h)	53.94	NS
				Cortisol (AUEC: 0–9.5 h)	10.92	NS
	Cautery (gas) dehorning		Lidocaine local anesthesia (cornual nerve, 3 mL/horn), 20 min before dehorning	Cortisol (AUEC:0–2 h)	−23.37	NS
				Cortisol (AUEC: 2–9.5 h)	22.78	NS
				Cortisol (AUEC: 0–9.5 h)	2.28	NS
McMeekan et al,[18] 1998	Amputation (scoop) dehorning	12–16 wk Dairy	Bupivacaine local anesthesia (cornual nerve, 6 mL/horn), 20 min before dehorning	Cortisol (AUEC: 0–3.83 h)	−61.00	<.05
				Cortisol (AUEC: 3.84–9.33 h)	109.71	NS
				Cortisol (AUEC: 0–9.33 h)	−10.24	NS
			Bupivacaine local anesthesia (cornual nerve, 6 mL/horn), immediately before dehorning	Cortisol (AUEC: 0–3.83 h)	−72.82	<.05
				Cortisol (AUEC: 3.84–9.33 h)	47.35	NS
				Cortisol (AUEC: 0–9.33 h)	−37.07	NS
			Bupivacaine local anesthesia (cornual nerve, 6 mL/horn), 20 min before dehorning and 4 h later	Cortisol (AUEC: 0–3.83 h)	−80.69	<.05
				Cortisol (AUEC: 3.84–9.33 h)	31.97	<.05
				Cortisol (AUEC: 0–9.33 h)	−47.18	<.05

McMeekan et al,[20] 1998[a]	Amputation (scoop) dehorning	12–16 wk Dairy	Ketoprofen 3 mg/kg IV, 20 min before dehorning	Cortisol (C_{max}: 0–3.83 h)	−21.43	NS
				Cortisol (C_{max}: 3.83–9.33 h)	−93.33	<.05
			Bupivacaine local anesthesia (cornual nerve, 6 mL/horn), 20 min before dehorning	Cortisol (C_{max}: 0–3.83 h)	−46.43	NS
				Cortisol (C_{max}: 3.83–9.33 h)	3.33	NS
			Ketoprofen 3 mg/kg IV, bupivacaine local anesthesia (cornual nerve, 6 mL/horn), 20 min before dehorning	Cortisol (C_{max}: 0–3.83 h)	−50.00	<.01
				Cortisol (C_{max}: 3.83–9.33 h)	−46.67	NS
			Ketoprofen 3 mg/kg IV, lidocaine local anesthesia (cornual nerve, 6 mL/horn), 20 min before dehorning	Cortisol (C_{max}: 0–3.83 h)	−82.14	<.01
				Cortisol (C_{max}: 3.83–9.33 h)	−66.67	NS
Sylvester et al,[54] 1998	Amputation (scoop) dehorning	20–24 wk Dairy	Lidocaine local anesthesia (cornual nerve, 6 mL/horn), 30 min before dehorning	Cortisol AUEC	−50.48	<.05
			Lidocaine local anesthesia (cornual nerve, 6 mL/horn), 30 min before dehorning, cauterize wound following amputation	Cortisol AUEC	−75.24	<.05
Graf and Senn,[7] 1999[a]	Cautery (electric) dehorner	4–6 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL; caudal horn bud SQ, 5 mL; medial horn bud, 3 mL), 20 min	Cortisol (C_{max}: 0–4 h)	−38.78	<.05
			Saline injection (cornual nerve, 5 mL; caudal horn bud SQ, 5 mL; medial horn bud, 3 mL), 20 min	Cortisol (C_{max}: 0–4 h)	59.18	<.05
Grøndahl-Nielsen et al,[8] 1999[a]	Cautery (electric) dehorner	4–6 wk Dairy	Lidocaine local anesthesia (cornual nerve, unknown amount), 20 min before dehorning	Cortisol (C_{max}: 0–30 min)	−84.00	<.01
				Cortisol (C_{max}: 30–60 min)	−77.78	NS
				Cortisol (C_{max}: 60–150 min)	−90.91	NS
				Cortisol (C_{max}: 15–240 min)	−33.33	NS
			Xylazine 0.2 mg/kg and butorphanol 0.1 mg/kg, IM, 20 min before dehorning	Cortisol (C_{max}: 0–30 min)	−76.00	<.01
				Cortisol (C_{max}: 30–60 min)	−77.78	NS
				Cortisol (C_{max}: 60–150 min)	36.36	NS
				Cortisol (C_{max}: 150–240 min)	8.33	NS
			Xylazine 0.2 mg/kg and butorphanol 0.1 mg/kg, IM, 20 min before dehorning; lidocaine local anesthesia (cornual nerve, unknown amount), 15 min before dehorning	Cortisol (C_{max}: 0–30 min)	−60.00	<.05
				Cortisol (C_{max}: 30–60 min)	−92.59	NS
				Cortisol (C_{max}: 60–150 min)	−45.45	NS
				Cortisol (C_{max}: 150–240 min)	−91.67	NS

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Table 1
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Reference	Procedure	Study Population	Analgesic Regimen	Outcome Parameter	Change in Cortisol (%)	Significance (*P* Value)
Sutherland et al,[55] 2002[a]	Amputation (scoop) dehorning	12–16 wk Dairy	Lidocaine local anesthesia (cornual nerve, 6 mL/horn) 15 min before dehorning; bupivacaine (cornual nerve, 6 mL/horn) 2 h following lidocaine injection	Cortisol (C_{max}: 0–5 h)	−70.06	<.05
				Cortisol (C_{max}: 5–10 h)	82.93	<.05
				Cortisol (C_{max}: 10–24 h)	10.00	NS
			Lidocaine local anesthesia (cornual nerve, 6 mL/horn) 15 min before dehorning followed by cautery; bupivacaine (cornual nerve, 6 mL/horn) 2 h following lidocaine injection	Cortisol (C_{max}: 0–5 h)	−56.69	<.05
				Cortisol (C_{max}: 5–10 h)	−12.20	NS
				Cortsiol (C_{max}: 10–24 h)	10.00	NS
Sutherland et al,[19] 2002[a]	Amputation (scoop) dehorning	12–16 wk Dairy	Lidocaine local anesthesia (cornual nerve, 6 mL/horn) 15 min before dehorning; bupivacaine (cornual nerve, 6 mL/horn) 2 h following lidocaine injection	Cortisol AUEC (0–24 h)	−13.14	NS
				Cortisol (C_{max}: 0–5 h)	−70.06	<.05
				Cortisol (C_{max}: 5–10 h)	82.93	<.05
				Cortisol (C_{max}: 10–24 h)	10.00	NS
			Lidocaine local anesthesia (cornual nerve, 6 mL/horn), phenylbutazone 4.0–5.3 mg/kg, IV 15 min before dehorning; bupivacaine (cornual nerve, 6 mL/horn) 2 h following initial lidocaine injection	Cortisol AUEC (0–24 h)	−8.89	NS
				Cortisol (C_{max}: 0–5 h)	−54.74	<.05
				Cortisol (C_{max}: 5–10 h)	80.49	<.05
				Cortisol (C_{max}: 10–24 h)	2.50	NS
			Lidocaine local anesthesia (cornual nerve, 6 mL/horn), ketoprofen 3.0–3.75 mg/kg, IV 15 min before dehorning; bupivacaine (cornual nerve, 6 mL/horn) 2 h following initial lidocaine injection	Cortisol AUEC (0–24 h)	−21.41	NS
				Cortisol (C_{max}: 0–5 h)	−61.31	<.05
				Cortisol (C_{max}: 5–10 h)	−20.73	NS
				Cortisol (C_{max}: 10–24 h)	5.00	NS
Mellor et al,[45] 2002[a]	Amputation (scoop) dehorning	10 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL/horn) 20 min before dehorning	Cortisol (C_{max}: 0–2.5 h)	−47.83	<.05
				Cortisol (C_{max}: 2.5–8 h)	53.64	<.05

Stafford et al,[23] 2003[a]	Amputation (scoop) dehorning	12 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL/horn) and ketoprofen 3 mg/kg IV, 15 min before dehorning	Cortisol AUEC	−55.17	NS
				Cortisol (C_{max}: 0–4 h)	−76.32	<.05
				Cortisol (C_{max}: 4–8 h)	−47.37	NS
			Xylazine 0.1 mg/kg IV, 20 min before castration	Cortisol AUEC	3.45	NS
				Cortisol (C_{max}: 0–4 h)	−44.74	<.05
				Cortisol (C_{max}: 4–8 h)	57.89	NS
			Xylazine 0.1 mg/kg IV, 20 min before dehorning and lidocaine local anesthesia (cornual nerve, 5 mL/horn) 15 min before dehorning	Cortisol AUEC	6.90	NS
				Cortisol (C_{max}: 0–4 h)	−73.68	<.05
				Cortisol (C_{max}: 4–8 h)	78.95	<.05
			Xylazine 0.1 mg/kg IV, 20 min before dehorning and lidocaine local anesthesia (cornual nerve, 5 mL/horn) 15 min before dehorning; tolazoline 2 mg/kg 5 min after dehorning	Cortisol AUEC	81.03	NS
				Cortisol (C_{max}: 0–4 h)	31.58	<.05
				Cortisol (C_{max}: 4–8 h)	136.84	<.05
Doherty et al,[30] 2007[a]	Cautery (electric) dehorning	10–12 wk Dairy	Lidocaine (2%) local anesthesia (cornual branch of zygomatic-temporal nerve, 3 mL/horn; cornual branch of infatrochlear nerve; 4 mL/horn rostral to horn base)	Cortisol (C_{max})	−25.00	<.05
			Lidocaine (5%) local anesthesia (cornual branch of zygomatic-temporal nerve, 3 mL/horn; cornual branch of infatrochlear nerve; 4 mL/ horn rostral to horn base)	Cortisol (C_{max})	−56.25	<.05
Stilwell et al,[37] 2008	Chemical paste dehorning	1.5–6 wk Dairy	Flunixin meglumine 2 mg/kg IV, 5 min before dehorning	Cortisol (1 h)	0.37	NS
				Cortisol (3 h)	−58.47	NS
				Cortisol (6 h)	−52.08	NS
				Cortisol (24 h)	37.70	NS
			Flunixin meglumine 2 mg/kg IV, 60 min before dehorning	Cortisol (1 h)	−8.08	NS
				Cortisol (3 h)	−2.18	NS
				Cortisol (6 h)	21.83	NS
				Cortisol (24 h)	96.48	NS

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Reference	Procedure	Study Population	Analgesic Regimen	Outcome Parameter	Change in Cortisol (%)	Significance (*P* Value)
Stilwell et al,[21] 2009	Chemical paste dehorning	3–5 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL/horn) 5 min before dehorning	Cortisol (10 min)	−25.18	NS
				Cortisol (30 min)	−59.63	<.05
				Cortisol (50 min)	−65.19	<.05
				Cortisol (1 h)	−47.51	<.05
				Cortisol (3 h)	−5.50	NS
				Cortisol (6 h)	7.89	NS
				Cortisol (24 h)	34.68	NS
			Flunixin meglumine 2.2 mg/kg IV and lidocaine local anesthesia (cornual nerve, 5 mL/horn), 5 min before dehorning	Cortisol (10 min)	−9.40	NS
				Cortisol (30 min)	−50.06	<.05
				Cortisol (50 min)	−53.21	<.05
				Cortisol (1 h)	−77.68	<.05
				Cortisol (3 h)	−67.85	<.05
				Cortisol (6 h)	−24.64	NS
				Cortisol (24 h)	−25.61	NS
			Lidocaine local anesthesia (cornual nerve, 5 mL/horn) 5 min before dehorning	Cortisol (90 min)	−42.47	<.05
				Cortisol (120 min)	−51.26	NS
				Cortisol (150 min)	39.80	NS
				Cortisol (180 min)	59.19	<.05

Baldridge et al,[32] 2011	Amputation (scoop) dehorning followed by surgical castration	2–4 mo Dairy	Sodium salicylate at 2.5–5 mg/mL in the drinking water (13.62–151.99 mg of salicylate/kg body weight)	Cortisol (C_{max}) Cortisol AUEC (0–1 h) Cortisol AUEC (1–6 h) Cortisol AUEC (6–24 h)	1.60 −9.27 −36.90 −22.83	NS NS *P*<.05 NS
			0.025 mg/kg butorphanol, 0.05 mg/kg xylazine, 0.1 mg/kg ketamine coadministered IM immediately before castration	Cortisol (C_{max}) Cortisol AUEC (0–1 h) Cortisol AUEC (1–6 h) Cortisol AUEC (6–24 h)	−12.00 −28.90 −5.82 −0.01	NS *P*<.05 NS NS
			Sodium salicylate at 2.5–5 mg/mL in the drinking water (13.62–151.99 mg of salicylate/kg body weight) and 0.025 mg/kg butorphanol, 0.05 mg/kg xylazine, 0.1 mg/kg ketamine coadministered IM immediately before castration	Cortisol (C_{max}) Cortisol AUEC (0–1 h) Cortisol AUEC (1–6 h) Cortisol AUEC (6–24 h)	−3.46 −20.89 −24.19 −15.69	NS NS NS NS
Coetzee et al,[42] 2012	Amputation (scoop) followed by cautery (electric) dehorning	16–20 wk Dairy	Meloxicam 0.5 mg/kg IV immediately before dehorning	Cortisol AUEC Cortisol (C_{max})	−7.95 3.66	NS NS

Percent change in cortisol was calculated using the formula [(Mean of analgesic group/Mean of dehorned control group) − 1] × 100.

Abbreviations: AUEC, area under the effect curve for cortisol; C_{max}, maximum plasma concentration; IM, intramuscular; IV, intravenous; NR, values not reported; NS, not significant; SQ, subcutaneous.

[a] Values were estimated from included published figures.

Table 2
Summary of the scientific literature examining the effect of analgesic drug administration on plasma cortisol response in dehorned calves using local anesthesia in the control group

Reference	Procedure	Study Population	Control Analgesic Regimen	Analgesic Regimen	Outcome Parameter	Change in Cortisol (%)	Significance (*P* Value)
Milligan et al,[22] 2004	Cautery (gas) dehorning	2 d–2 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL) 10 min before dehorning	Ketoprofen 3 mg/kg IM, 10 min before dehorning	Cortisol (3 h)	−24.91	NS
					Cortisol (0–3 h)	−224.02	<.05
					Cortisol (6 h)	14.55	NS
					Cortisol (3–6 h)	336.79	NS
Heinrich et al,[40] 2009	Cautery (electric) dehorning	6–12 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL) 10 min before dehorning	Meloxicam 0.5 mg/kg IM, 10 min before dehorning	Cortisol (0–6 h)	−80.88	<.01
					Cortisol (24 h)	0.86	NS
Duffield et al,[31] 2010	Cautery (electric) dehorning	4–8 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL) 10 min before dehorning	Ketoprofen 3 mg/kg IM, 10 min before dehorning	Cortisol (3 h)	4.62	NS
					Cortisol (6 h)	10.45	NS
Stilwell et al,[24] 2010	Cautery (gas) dehorning	5–6 wk Dairy	Xylazine 0.2 mg/kg IM, 10 min before dehorning	Lidocaine local anesthesia (cornual nerve, 5 mL) 8 min before dehorning	Cortisol (10 min)	−8.94	NS
					Cortisol (25 min)	5.07	NS
					Cortisol (40 min)	17.41	NS
					Cortisol (60 min)	53.65	NS

Percent change in cortisol was calculated using the formula [(Mean of analgesic group/Mean of dehorned control group) − 1] × 100.

Table 3
Summary of scientific literature examining the effect of analgesic drug administration on other outcomes in dehorned calves

Reference	Procedure	Study Population	Analgesic Regiment	Outcome Parameter	Percent Change (%)	Significance (*P* Value)
Morisse et al,[26] 1995	Chemical paste dehorning	4 wk Dairy	Lidocaine local anesthesia (cornual nerve, 4 mL/horn), 15 min before dehorning	Lying time	3.50	NS
	Cautery (electric) dehorning	8 wk Dairy	Lidocaine local anesthesia (cornual nerve, 4 mL/horn), 15 min before dehorning	Lying time	7.88	NS
Graf and Senn,[7] 1999[a]	Cautery (electric) dehorner	4–6 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL; caudal horn bud SQ, 5 mL; medial horn bud, 3 mL), 20 min	Vasopressin (C_{max})	−90.00	<.05
				ACTH (C_{max})	−72.50	<.05
			Saline injection (cornual nerve, 5 mL; caudal horn bud SQ, 5 mL; medial horn bud, 3 mL), 20 min	Vasopressin (C_{max})	125.00	NS
				ACTH (C_{max})	62.50	NS
Grøndahl-Nielsen et al,[8] 1999[a]	Cautery (electric) dehorner	4–6 wk Dairy	Lidocaine local anesthesia (cornual nerve, unknown amount), 20 min before dehorning	ADG (0–7 d)	NR	NS
				Feed intake (0–7 d)	NR	NS
				Heart rate (0–4 h)	NR	NS
				Rumination (0–4 h)	NR	NS
				Rumination latency	−58.33	<.05
			Xylazine 0.2 mg/kg and butorphanol 0.1 mg/kg, IM, 20 min before dehorning	ADG (0–7 d)	NR	NS
				Feed intake (0–7 d)	NR	NS
				Heart rate (0–4 h)	NR	NS
				Rumination (0–4 h)	NR	NS
				Rumination latency	−37.50	<.05
			Xylazine 0.2 mg/kg and butorphanol 0.1 mg/kg, IM, 20 min before dehorning; lidocaine local anesthesia (cornual nerve, unknown amount), 15 min before dehorning	ADG (0–7 d)	NR	NS
				Feed intake (0–7 d)	NR	NS
				Heart rate (0–4 h)	NR	NS
				Rumination (0–4 h)	NR	NS
				Rumination latency	−46.67	<.05

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Table 3
(*continued*)

Reference	Procedure	Study Population	Analgesic Regiment	Outcome Parameter	Percent Change (%)	Significance (*P* Value)
Faulkner and Weary,[27] 2000	Cautery (electric) dehorner	4–8 wk Dairy	Ketoprofen 3 mg/kg PO 2 h before dehorning, 2 h post dehorning, and 7 h after dehorning (Analgesic control: xylazine 0.2 mg/kg IM 20 min before dehorning and lidocaine local anesthesia [cornual nerve and ring block 4.5 mL/side] 10 min before dehorning)	Weight gain (0–24 h)	500.00	NS (*P* = .07)
Mellor et al,[45] 2002[a]	Amputation (scoop) dehorning	10 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL/horn) 20 min before dehorning	Noradrenaline (C_{max})	−16.00	NS
				Adrenaline (C_{max})	−9.09	NS
Doherty et al,[30] 2007	Cautery (electric) dehorning	10–12 wk Dairy	Lidocaine (2%) local anesthesia (cornual branch of zygomatic-temporal nerve, 3 mL/horn; cornual branch of infatrochlear nerve; 4 mL/horn rostral to horn base)	Neutrophil %	9.53	NS
				Lymphocyte %	−10.04	NS
				N:L %	−19.83	NS
				Fibrinogen	NA	NS
				α_1-acid glycoprotein	NA	NS
			Lidocaine (5%) local anesthesia (cornual branch of zygomatic-temporal nerve, 3 mL/horn; cornual branch of infratrochlear nerve; 4 mL/horn rostral to horn base)	Neutrophil %	0.23	NS
				Lymphocyte %	1.70	NS
				N:L %	−21.49	NS
				Fibrinogen	NA	NS
				α_1-acid glycoprotein	NA	NS

Heinrich et al,[40] 2009	Cautery (electric) dehorning	6–12 wk Dairy	Meloxicam 0.5 mg/kg IM given 10 min before dehorning; analgesic control: lidocaine local anesthesia (cornual nerve, 5 mL/horn)	Heart Rate	−20.43	<.05
				Respiratory rate	−100.00	<.05
Stewart et al,[41] 2009[a]	Cautery (gas) dehorning	4–5 wk Dairy	Lidocaine local anesthesia (cornual nerve, 5 mL/horn and ring block, 3–4 mL/horn) 10 min before dehorning	Eye temperature (2–3 h post dehorning difference)	−610.00	<.001
				Heart Rate (0–5 min)	−22.22	<.05
				HRV: LF Power (2–3 h)	13.16	<.05
				HRV: HF power (2–3 h)	−35.90	<.05
				HRV: LF:HF ratio (2–3 h)	500.00	<.05
			Meloxicam 0.5 mg/kg IV, 55 min before dehorning and lidocaine local anesthesia (cornual nerve, 5 mL/horn and ring block, 3–4 mL/horn) 10 min before dehorning	Eye temperature (2–3 h post dehorning difference)	No change	NS
				Heart rate (0–5 min)	−26.98	<.05
				HRV: LF Power (2–3 h)	7.89	<.05
				HRV: HF power (2–3 h)	−15.38	<.05
				HRV: LF:HF ratio (2–3 h)	166.67	NS
Heinrich et al,[29] 2010	Cautery (electric) dehorning	6–12 wk Dairy	Meloxicam 0.5 mg/kg IM given 10 min before dehorning; analgesic control: lidocaine local anesthesia (cornual nerve, 5 mL/horn)	Accelerometer (0–5 h)	−10.26	<.05
				Pressure algometry	31.48	<.05
				Feed consumption	300.00	NS (*P* = .09)

(*continued on next page*)

Table 3
(*continued*)

Reference	Procedure	Study Population	Analgesic Regiment	Outcome Parameter	Percent Change (%)	Significance (*P* Value)
Baldridge et al,[32] 2011	Amputation (scoop) dehorning after surgical castration	2–4 mo Dairy	Sodium salicylate at 2.5–5 mg/mL in the drinking water (13.62–151.99 mg of salicylate/kg body weight)	ADG (0–13 d)	−1111.22	<.05
				Chute exit speed	0.97	NS
			0.025 mg/kg butorphanol, 0.05 mg/kg xylazine, 0.1 mg/kg ketamine coadministered IM immediately before castration	ADG (0–13 d)	−729.98	NS
				Chute exit speed	−77.81	<.05
			Sodium salicylate at 2.5–5 mg/mL in the drinking water (13.62–151.99 mg of salicylate/kg body weight) and 0.025 mg/kg butorphanol, 0.05 mg/kg xylazine, 0.1 mg/kg ketamine coadministered IM immediately before castration	ADG (0–13 d)	−1095.92	<.05
				Chute exit speed	−94.97	<.05
Theurer et al,[33] 2012[a]	Cautery (electric) dehorning	10 wk Dairy	Meloxicam 0.5 mg/kg PO immediately after dehorning	Lying down % (1–4 d)	20.13	<.05
				Hay feeder % (0–1 d)	−40.86	<.05
				Grain feeder % (0–1 d)	−50.00	<.05
				Grain feeder % (1–2 d)	80.00	<.05
Coetzee et al,[42] 2012	Amputation (scoop) followed by cautery (electric) dehorning	16–20 wk Dairy	Meloxicam 0.5 mg/kg IV, immediately before the start of dehorning	Substance P	−37.79	<.05
				Lying time %	−97.06	<.01
				Heart rate (8 and 10 h)	NR	<.05
				ADG (0–10 d)	162.50	<.05

Percent change in cortisol was calculated using the formula [(Mean of analgesic group/Mean of dehorned control group) − 1] × 100.

Abbreviations: ACTH, adrenocorticotropic hormone; ADG, average daily gain in body weight; HRV, heart-rate variability; LF, low frequency; HF, high frequency; NA, data not available; NR, values not reported; PO, by mouth.

[a] Values were estimated from included published figures.

of the biomarker used for comparison included: maximum concentration (C_{max}), area under the effect curve (AUEC), and concentration at specific time points. In addition, these values were further summarized following categorization by analgesic regimen when applicable (**Tables 4** and **5**). Following this summary analysis, a multimodal approach using local anesthetics, nonsteroidal anti-inflammatories and, when possible, sedative analgesics is recommended for the most effective reduction of pain response in cattle following dehorning. These recommendations are similar to those of other reviews concerning the management of pain in cattle following dehorning.[16]

This review on the pain associated with dehorning is meant to both be independent of and mirror the article assessing pain following castration. For a more detailed examination of similar themed topics including pain assessment, challenges associated with providing analgesia in food animals, and a pharmacology review, the reader is referred to the article on castration by Coetzee elsewhere in this issue.

ASSESSMENT TOOLS USED TO DETERMINE THE EFFICACY OF ANALGESIC DRUGS IN CATTLE FOLLOWING DEHORNING

Assessment of Behavioral Changes After Dehorning

Behavioral changes are often monitored and recorded in studies involving pain. The observed changes have been suggested as a more sensitive marker for pain in comparison with other physiologic markers such as cortisol.[25] Behavior indices have been recorded using videography,[7,22,26–31] chute behavior,[32] accelerometers,[33] and remote triangulation devices.[33] Head shaking, ear flicking, head rubbing, transition between standing and lying, inert lying, vocalization, and grooming are all behavioral changes frequently recorded in an ethological evaluation of cattle following dehorning.[8,21,26–28]

Behavioral responses are subject to interpretation. In the case of dehorning, reliable indicators of pain are difficult to assess in cattle following dehorning with and without analgesia.[27,29,31] For example, it has been suggested that head rubbing may be a result of increased nociception or may indicate irritation, itching, or healing.[31] However, correlation between behavioral responses and changes to cortisol concentrations has been reviewed.[2] For a more thorough evaluation of behavioral responses following dehorning, see the excellent reviews by Stafford and Mellor[2,16] detailing these behavioral changes.

Recently, Heinrich and colleagues[29] evaluated changes in behavior following cautery dehorning. Based on behavioral changes, the investigators determined that pain may be present for up to 44 hours following the procedure. Other studies have indicated a continuation of painful or decreased normal behaviors for up to 72 hours after dehorning.[16,27] The duration of pain observed in these studies beyond other physiologic or neuroendocrine parameters further supports the necessity to provide long-lasting effective analgesia for cattle during and after common procedures presumed to be painful, such as dehorning. Additional research is needed to investigate chronic pain responses associated with dehorning.

Assessment of Physiologic Changes After Dehorning

Changes to the physiology of cattle following dehorning are frequently observed biomarkers in pain assessment. Serum cortisol, heart rate, feed intake, and average daily weight gain (ADG) are often used in studies evaluating the efficacy of analgesics in painful or stressful procedures such as dehorning. Cortisol concentrations should be interpreted with caution because of the variations in cortisol response following a stressor, as well as a wide variety of inciting causes that can activate the

Table 4
Summary of the mean (range) percent change in peak plasma cortisol concentrations (C_{max}) and cortisol concentrations recorded at specific time points in analgesic-treated calves compared with untreated dehorned control calves in the published literature

Analgesia	Mean Percent Change in Cortisol (0–5 h)	Range (%)	Mean Percent Change in Cortisol (4–9.3 h)	Range (%)	Mean Percent Change in Cortisol (6–24 h)	Range (%)	Mean Percent Change in Cortisol (0–24 h)	Range (%)
Local	−25.98 (9)	−90.91–234.48	14.70 (5)	47.37–82.93	29.96 (4)	−6.45–101.56	−40.01 (2)	56.25 to −25.00
NSAID	−17.96 (2)	−58.47–0.37	−41.20 (2)	−93.33–21.83	67.09 (1)	NA	1.03 (2)	−1.60–3.66
NSAID + local	−63.40 (3)	−82.14–50.00	−15.64 (3)	−66.67–80.49	−6.04 (2)	−25.61–5.00	NA	NA
Sedative-analgesia	−28.12 (2)	−76.00–36.36	57.89 (1)	NA	NA	NA	−12.00 (1)	NA
Sedative-analgesia + NSAID	NA	NA	NA	NA	NA	NA	−3.46 (1)	NA
Sedative-analgesia + local	−59.71 (2)	−73.68 to −45.45	78.95 (1)	NA	NA	NA	NA	NA

Estimated cortisol concentrations were categorized according to the following time categories to best fit the pattern observed in the published literature. The number of treatment groups evaluated is indicated in parentheses. Percent change in cortisol was calculated using the formula [(Mean of analgesic group/Mean of dehorned control group) − 1] × 100.

Abbreviation: NSAID, nonsteroidal anti-inflammatory drug.

Table 5
Summary of the mean (range) percent change in area under the plasma cortisol concentration over time curve (AUEC) in analgesic-treated calves compared with untreated dehorned control calves in the published literature

Analgesia	Mean Percent Change in Cortisol (0–5 h)	Range (%)	Mean Percent Change in Cortisol (4–9.3 h)	Range (%)	Mean Percent Change in Cortisol (6–24 h)	Range (%)	Mean Percent Change in Cortisol (0–24 h)	Range (%)
Local	−58.30 (2)	−80.69–23.37	53.15 (2)	22.78–109.71	NA	NA	−30.59 (5)	−75.24–10.92
NSAID	−9.27 (1)	NA	36.90 (1)	NA	−22.83 (1)	NA	−7.95 (1)	NA
NSAID + Local	NA	NA	NA	NA	NA	NA	−15.15 (1)	NA
Sedative-analgesia	−28.90 (1)	NA	−5.82 (1)	NA	0.01 (1)	NA	3.45 (1)	NA
Sedative-analgesia + NSAID	−20.89 (1)	NA	24.19 (1)	NA	−15.69 (1)	NA	NA	NA
Sedative-analgesia + local	NA	NA	NA	NA	NA	NA	6.90 (1)	NA

Estimated cortisol concentrations were categorized according to the following times to best fit the pattern observed in the published literature. The number of treatment groups evaluated is indicated in parentheses. Percent change in cortisol was calculated using the formula [(Mean of analgesic group/Mean of dehorned control group) − 1] × 100.

hypothalamus-pituitary-adrenal (HPA) system responsible for cortisol release.[34,35] However, cortisol changes over time have been used frequently as a parameter assessing stress in cattle following dehorning.[7,17,19,36,37]

In cattle dehorned without analgesia, most studies indicate an initial peak in cortisol observed within the first 30 minutes that subsequently plateaus at an elevated concentration, until returning to baseline approximately 7 to 8 hours following the procedure.[16] It has been hypothesized that the initial peak in cortisol is a result of a significant noxious nociception owing to the removal of the horn tissue, whereas the observed plateau results from pain associated with inflammation.[20] The anti-inflammatory potential of cortisol has been suggested to result in the attenuation of the inflammatory-mediated pain response.[18,19]

Schwartzkopf-Genswein and colleagues[38] evaluated the cortisol response to dehorning over a period of 3 consecutive days in 26- to 59-day-old Holstein calves. Cortisol response was measured in calves that were not dehorned, sham dehorned, and then dehorned by hot iron without the addition of analgesia or anesthesia. The study found that elevations in cortisol were significantly higher from 0 to 30 minutes after dehorning, compared with between both 60 to 240 minutes and 24 to 48 hours. In addition, from 0 to 60 minutes the cortisol response was greater for calves dehorned in comparison with sham dehorning or no dehorning. Another study investigated the effects of electric dehorning on cortisol response in 18 Holstein calves at 8 weeks of age.[39] The study found calves dehorned at 8 weeks of age had significantly higher cortisol response at 5, 15, 30, and 60 minutes after dehorning compared with calves not dehorned.

In dehorning studies, cortisol responses can vary with age. As a covariate in one study, serum cortisol concentrations before dehorning and then at 3 and 6 hours after dehorning were adjusted based on calf age (range of 2 days to 2 weeks old).[22] It was determined that older calves had significantly lower serum cortisol concentrations immediately before ($P<.01$), 3 hours after ($P<.05$), and 6 hours after ($P<.01$) dehorning. These changes should be considered when evaluating different studies using subjects of different age.

Heart rate has been monitored and recorded in dehorning studies as an indicator of physiologic stress.[8,40–43] Compared with calves that were sham dehorned, heart rate remained elevated for up to 3 hours in dehorned calves receiving no analgesia.[8,41–43] Additional studies have indicated an acutely decreased heart rate following treatment with an analgesic, compared with placebo-treated controls.[40–42]

The cost of analgesics is often cited as one of the major influencing factors that motivate producers to not use analgesics in painful procedures.[12–15] If economic gains could balance the costs, the routine use of analgesic compounds at the time of dehorning might be adopted more readily by producers. The economics of pain management is reviewed by Newton and O'Connor elsewhere in this issue. Previous literature has not provided a reliable amount of supportive data for an increased ADG following dehorning with analgesia; however, more recent studies have indicated its beneficial use. Studies have indicated an increased time spent at the grain feeder and an increased ADG following the use of a nonsteroidal anti-inflammatory drug (NSAID) at the time of dehorning in comparison with cattle not treated with any analgesia.[27,32,33,42] Although Grøndahl-Nielsen and colleagues[8] did not observe any difference in ADG or feed intake in the 7 days following dehorning, there was a significant difference in animals treated with analgesics at the time of dehorning, initiating rumination more quickly than those without analgesics provided. This improved rumination has also been reported in other studies with extended observation periods.[16,44]

Other physiologic parameters have been evaluated in cattle following dehorning, indicating a pain response (see **Table 3**). Plasma adrenocorticotropic hormone,[7] vasopressin,[7] noradrenaline,[45] and adrenaline[45] concentrations increased acutely following dehorning and remained elevated for up to 1 hour.

Assessment of Neuroendocrine Changes After Dehorning

Neuroendocrine changes have been assessed in many studies evaluating nociception following dehorning, including substance P,[42] electrodermal activity,[32] infrared thermography,[41] heart-rate variability,[41] and electroencephalography (EEG).[46]

Substance P is a neuropeptide expressed within portions of the neuraxis, involved with pain, stress, and anxiety.[47] Increased concentrations are found in cattle following castration when compared with those sham castrated, thus potentially validating its use as biomarker of pain.[48] A recent study investigated concentrations of substance P following dehorning in 16- to 20-week-old calves treated with an anti-inflammatory at the time of dehorning.[42] Animals treated with meloxicam had a significant reduction in mean concentrations of substance P compared with the placebo-treated controls. In addition, there were no significant differences observed in cortisol concentrations between the 2 groups, thereby suggesting an improved sensitivity of using substance P as a biomarker of pain and determinant of drug efficacy in comparison with cortisol.

Heart-rate variability has been suggested to reflect a measurement of the autonomic nervous system through the assessment of sympathetic and parasympathetic activity, thus providing an evaluation of pain.[49] Using heart-rate variation, the control of the intervals between consecutive beats is increased through vagal tone (increased heart-rate variation, high-frequency power) or sympathetic (decreased heart-rate variation, low-frequency power). In 4- to 5-week-old calves dehorned using a cautery dehorning unit, changes in heart-rate variation illustrated a sympathovagal imbalance coinciding with reported pain associated with dehorning.[41]

In addition, a decreased eye temperature as determined by infrared thermography has been suggested as a neuroendocrine response mediated by sympathetic vasoconstriction on the induction of pain.[43] Stewart and colleagues[41] investigated eye temperature concurrently with heart-rate variability, and reported a decrease in eye temperature during the same time period as the changes in heart-rate variations, further supporting the sympathovagal imbalance.

Analysis of EEG following a painful procedure has been validated for the detection of acute pain in both dehorning and castration studies.[46,50] Acute noxious sensory stimuli produce changes within EEG frequencies, reflecting the cerebral cortical electrical activity perceiving the nociception.[46] A desynchronization occurs, which has been interpreted as perceived nociception. Mean EEG frequencies were evaluated in calves 24 to 36 weeks of age following amputation via scoop dehorning. EEG frequencies were recorded following the induction of minimal anesthesia in the calves using intravenous ketamine (3.4 mg/kg) and propofol (4.1 mg/kg). Although this minimal anesthesia model may have confounded the results, specific wavelengths were significantly altered following dehorning, indicating noxious nociception. Animals in which a local nerve block was administered had significantly fewer changes in EEG frequencies, providing supportive evidence of decreased nociception following dehorning in comparison with calves dehorned without analgesia.[46]

ANALGESIC STRATEGIES FOR DEHORNING AND THEIR EFFECTS ON PAIN BIOMARKERS

Dehorning Methods

Several studies have evaluated the different dehorning techniques on relative changes in biomarkers for pain. Sylvester and colleagues[6] compared the differences in cortisol concentrations in calves dehorned by 4 different methods of dehorning: Barnes scoop dehorning, guillotine shears, a butcher's saw, and embryotomy wire. This study found no differences among treatment groups during the 36 hours after dehorning for cortisol, except that calves dehorned by guillotine shears had a significantly lower cortisol at 2 to 2.5 hours after the procedure. The cortisol C_{max} and integrated cortisol response were not statistically different among treatment groups. Another study investigated differences in cortisol response to variations in performing the technique of scoop dehorning.[51] Shallow-scoop dehorning and deep-scoop dehorning were compared in 30 Friesian calves 14 to 16 weeks old, and no significant difference was found between increases in cortisol concentrations or the integrated cortisol response from 0.25 to 5 hours after dehorning. The only difference noted was that cortisol concentrations in calves undergoing shallow-scoop dehorning returned to control values by 8 hours, whereas deep-scoop dehorned calves returned to baseline by 6 hours.

Several studies have investigated cautery dehorning. In lambs, an attenuated cortisol response was observed following tail docking using a thermocautery device in comparison with a knife.[52] It was suggested that the tissue damage caused by the heat from the hot iron destroyed the nociceptors adjacent to the wound, thus mitigating the cortisol response.[2] This reported cortisol variation was also observed while comparing cautery dehorning with amputation. A study using scoop versus cautery dehorning by Petrie and colleagues[17] in 6- to 8-week-old Friesian calves found that scoop dehorning without the provision of anesthesia or analgesia produced a significantly higher cortisol area under the curve (AUC) from −70 minutes to 2 hours postprocedure, compared with cautery dehorning. The examination of 2 cautery dehorning methods using 3- to 4-week-old Holstein calves indicated no significant difference in C_{max} between Buddex (57.1 nmol/L) and cautery (60.4 nmol/L) methods.[53]

Chemical dehorning methods have also been recently evaluated.[26,28,37] Using behaviors such as head shaking, head rubbing, and lying to standing transitions, Vickers and colleagues[28] determined that caustic paste with a sedative was less painful than the use of a hot iron with a sedative and a local anesthetic in calves 10 to 35 days old. However, in an earlier study, 4-week-old calves dehorned with caustic paste had increased plasma cortisol concentrations in comparison with 8-week-old calves dehorned using a hot iron.[26] It is reported that the application of the caustic paste is not painful; however, within an hour both cortisol and behavioral changes indicate a pain or stress response, returning to pretreatment levels up to 24 hours following dehorning.

Without the provision of analgesics, it has been recommended to dehorn cattle using cautery rather than amputation or chemical methods.[16] This conclusion was reached as a result of an extensive review of the published literature indicating a decreased cortisol response in cautery dehorning; however, it was suggested that more research comparing the cautery and chemical dehorning methods should be completed.[16]

Local Anesthetics

Local anesthetics provided to cattle before dehorning have been shown to aid in the mitigation of the initial acute cortisol response.[7,17,18,21,30,54,55] Local anesthetics act at the sodium channel to prevent generation and propagation of nerve impulses or action potentials.[56] Most commonly, performed nerve blocks consist of infiltrating the perineural space surrounding the cornual nerve, a branch of the zygomaticotemporal portion of the ophthalmic division of the trigeminal nerve, with a local anesthetic; however, other local nerve blocks, such as ring blocks or caudal horn blocks, have been used in dehorning studies in efforts to increase the likelihood the effective anesthesia (**Fig. 2**).[7,27,30,57]

The cornual nerve block has been described by several studies and textbooks. In brief, a 2.5-cm 18- or 20-gauge needle is inserted lateral to the palpable temporal ridge of the frontal bone and 2.5 cm rostral to the base of the horn (see **Fig. 2**). Following a negative aspiration confirming the needle is placed subcutaneously, 5 to 10 mL of 2% lidocaine is injected, directing the needle toward the horn for desensitization of the area.[57] In cattle with larger horns, cutaneous branches of the second cervical nerve will need to be desensitized using a local anesthetic infiltration caudal to the horn.[57] Proper restraint is necessary to deliver the local anesthetic to the correct location for complete cessation of nociception (**Fig. 3**). This procedure can be performed using plastic disposable syringes or automatic syringes for multiple animals (see **Fig. 3**).

A recent study using 2-month-old dairy calves examined the efficacy of lidocaine with epinephrine using 4 local-anesthetic delivery techniques: cornual nerve block, ring block, percutaneous injection via a needle-free drug delivery system (JET), and a topical eutectic mixture of local anesthetics containing 2.5% lidocaine and 2.5% prilocaine (EMLA).[58] Although the calves in the study were not dehorned, a peripheral variable-output nerve stimulator was used to evaluate anesthetic efficacy. Consistent local anesthetic was achieved using the cornual nerve block (87.5%; 7 of 8 calves) and ring block (100%; 8 of 8 calves). In addition, there was no difference in onset time between the 2 techniques (cornual nerve: 2 minutes vs ring block: 3.25 minutes); however, the mean duration of the cornual nerve block was approximately 2.5 hours longer than that of the ring block (304 minutes vs 147 minutes, respectively). Both the JET delivery system and the EMLA cream failed to provide consistent, effective local anesthesia.

Sufficient evidence supports a delayed cortisol response that occurs following the return of sensitivity to an area once anesthetized.[17–19,54] As mentioned previously, local anesthetics mitigate the cortisol response for their respective duration of action (ie, lidocaine: 2 hours; bupivacaine: 4 hours) following the dehorning procedure, but a delayed cortisol response is observed, presumably once sensitivity returns to the anesthetized area. In addition, among dehorning studies with only local anesthesia provided, there is an initial reduction of the cortisol response; however, following this reduction an increased cortisol response is observed (see **Tables 4** and **5**).

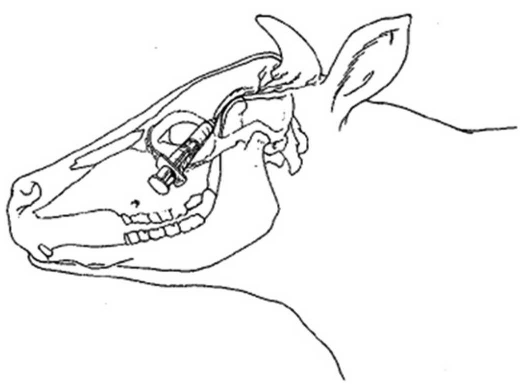

Fig. 2. Diagram of cornual nerve anatomy including approximate locations for local anesthetic injection. (*From* Skarda RT. Techniques of local analgesia in ruminants and swine. Vet Clin Food Anim Pract 1986;2:627; with permission.)

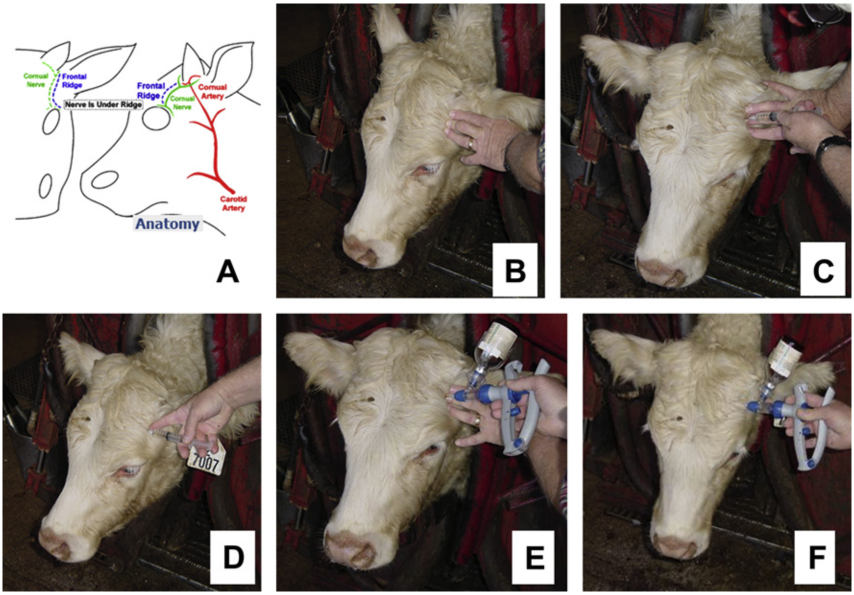

Fig. 3. Steps for providing local anesthetic for dehorning using a cornual nerve block. (*A*) Anatomy of the cornual innervation. (*B*) Palpation of the temporal ridge. (*C*) Insertion of the needle below the ridge and aspirate. (*D*) Injection of 5 to 10 mL of lidocaine. (*E*) Palpation of the frontal ridge and insertion of needle attached to automatic syringe. (*F*) Injection of 5 to 10 mL of lidocaine using an automatic syringe.

Lidocaine

Lidocaine 2% is the most commonly used analgesic in dehorning studies (see **Tables 1–3**). Pharmacokinetics studies following an inverted-L nerve block using a local lidocaine infusion in mature cattle indicated a serum elimination half-life of 4.19 ± 1.69 hours.[59] Clinically, studies assessing the analgesic duration of lidocaine report an approximate duration of 2 hours, based on both behavioral and physiologic changes.[2] Although integrated cortisol concentrations are typically not significantly different between cattle dehorned using local anesthesia and nontreated controls, consistent cortisol changes are significantly reduced or eliminated during the acute phase of the pain response.[7,17,18,54,55] In general, once the desensitization associated with local infusion of lidocaine has diminished, cortisol concentrations significantly increase in comparison with animals dehorned without lidocaine.[7,17,18,54,55]

Many studies look at the effects of nerve blocks on cortisol response to dehorning (see **Tables 1–3**). Although a few studies have indicated no difference in the pain or stress response following the provision of a local anesthetic before dehorning, most studies support its use because of a near elimination of the acute behavior and physiologic changes that are typically observed.[16,36] Graf and Senn[7] found that a cornual nerve block with 2% lidocaine significantly diminished the cortisol response in 4- to 6-week-old calves when compared with those injected with saline from 20 to 90 minutes after dehorning. A study investigated the use of cautery following amputation dehorning and local lidocaine anesthesia in 20- to 24-week-old calves.[54] The integrated cortisol response over a 9-hour period indicated a significant reduction using lidocaine local anesthesia before amputation dehorning. In addition to the use of lidocaine anesthesia, cautery following amputation dehorning significantly diminished the cortisol response by 75% (see **Table 1**).

The effects of scoop dehorning versus scoop dehorning with cautery, both with and without the addition of local anesthesia, have been evaluated.[55] This study found that calves undergoing dehorning had significant elevations in cortisol compared with control calves from 0.5 hours to 6 hours and then again at 13 to 15 hours. It is of interest that on administering local anesthesia with lidocaine and bupivacaine 15 minutes before the procedure and then again at 1 hour 45 minutes postprocedure, an increase in cortisol concentrations from 0 to 5 hours was abolished, and calves experienced a significant increase in cortisol response that was greater than that in calves dehorned without anesthesia at 6 and 7 hours. Calves receiving local anesthesia plus cautery in addition to scoop dehorning had almost no change in cortisol concentrations throughout the 24-hour period measured.

Doherty and colleagues[30] found that 10- to 12-week-old Holstein calves experienced a significantly lower cortisol response 30 and 60 minutes after dehorning after a cornual nerve block of either 10 mL of 5% lidocaine or 10 mL of 2% lidocaine administered 30 minutes before dehorning, compared with untreated, dehorned calves. No significant difference was noted between the 5% and 2% lidocaine solutions on cortisol response.

Of note, studies involving chemical dehorning indicated a decreased duration of analgesia efficacy using local lidocaine anesthesia alone.[21,28] Following dehorning using a caustic paste and local lidocaine anesthesia in 3- to 5-week-old calves, behavioral signs of distress were attenuated for the first hour but then became evident over the next 5 hours.[21] It was hypothesized that the alkalotic paste may have increased the pH of the surrounding tissue, thus affecting the equilibrium of the anesthetic solution and disrupting its function.[28]

Bupivacaine

In addition to lidocaine, bupivacaine has been used in several dehorning studies, mostly because of its prolonged clinical analgesic effect in comparison with lidocaine.[18,19,55] Clinical analgesic efficacy in one study was reported to be approximately 4 hours, as confirmed by a lack of behavioral reaction to a needle-prick of the skin adjacent to the horn.[18]

McMeekan and colleagues[18] evaluated the effect of timing of cornual nerve block administration using 0.25% bupivacaine on cortisol response in 3- to 4-month-old calves. Calves administered a cornual nerve block at 20 minutes before dehorning and then again 4 hours after dehorning experienced a significantly lower cortisol AUC than control calves dehorned without analgesia, calves administered the cornual nerve block only at 20 minutes prior, and calves administered the cornual nerve block immediately prior. Another study by McMeekan and colleagues[20] found that calves undergoing scoop dehorning with a cornual nerve block using bupivacaine administered 20 minutes prior and 4 hours after had a significantly lower AUC from 0 to 9.33 hours for cortisol, compared with the calves dehorned with only a cornual nerve block 20 minutes prior, immediately prior, or with no analgesia. However, for the first 3.83 hours, all calves receiving a cornual nerve block experienced a significantly lower AUC cortisol response than those undergoing scoop dehorning without treatment.

Nonsteroidal Anti-Inflammatory Drugs

As previously mentioned, following the acute pain associated with dehorning, a suggested inflammatory-mediated pain response exists,[20] which is evident in both continued distressful behaviors and increased cortisol concentrations following the initial cortisol response. In addition, among dehorning studies with only NSAIDs provided, there is a mild initial attenuation of the cortisol response, which continues past the initial acute phase and provides prolonged anesthesia (see **Tables 4** and **5**). The following NSAIDs have been studied for their role in the attenuation of the cortisol response both alone and in combination with a local anesthetic.

Ketoprofen

Several studies have evaluated the analgesic efficacy of ketoprofen following dehorning (see **Tables 1–3**).[19,20,22,23,27,31,60] Although the use of ketoprofen alone does not completely diminish the initial acute cortisol response following dehorning, evidence supports its use to aid in the decrease of the inflammatory component.[20] In combination with local anesthesia, cortisol AUC was significantly ameliorated for up to 5 hours after dehorning.[19,20] Another study in 4- to 8-week-old calves treated with local anesthesia, xylazine, and ketoprofen given 2 hours before and 2 and 7 hours after dehorning resulted in a tendency of weight gain over a 24-hour period following cautery dehorning ($P = .07$).[27] Because of the short elimination half-life of ketoprofen of 0.42 hours, administrations must be repeated to sustain analgesic concentrations.[61]

Calves treated with a cornual nerve block of 5 mL of 2% lidocaine and 0.03 mL/kg of 10% ketoprofen given intramuscularly 10 minutes before procedures experienced significantly lower cortisol concentrations from 0 to 3 hours compared with calves given only a cornual nerve block.[22] However, another study found there to be no difference in cortisol response at 3 and 6 hours after electrocautery dehorning in 4- to 8-week-old calves treated with 3 mg/kg ketoprofen intramuscularly plus a cornual nerve block in comparison with calves given an intramuscular injection of sterile saline plus a cornual nerve block.[31]

Phenylbutazone

Although phenylbutazone is not approved for cattle in the United States, historically it has been a commonly used analgesic in cattle.[62] One study has evaluated the benefit of phenylbutazone in providing analgesia to cattle following dehorning.[19] In combination with a 5-hour local anesthesia regimen using both lidocaine and bupivacaine, calves treated with phenylbutazone (4.0–5.3 mg/kg) did not show a significant attenuation of the delayed cortisol response following return of sensitivity to the anesthetized area. This finding is consistent with those of previous literature suggesting that phenylbutazone is known to have anti-inflammatory actions weaker than those of ketoprofen in calves.[63,64] Based on the lack of efficacy data and concerns regarding the potential toxicity to consumers of phenylbutazone tissue residues, the use of phenylbutazone at the time of dehorning is not recommended.

Meloxicam

The benefits of meloxicam, a potentially longer-acting NSAID, have been detailed in several dehorning studies.[29,33,40–42] A study by Heinrich and colleagues[40] found that 6- to 12-week-old calves treated with a cornual nerve block with 5 mL of 2% lidocaine given 10 minutes before cautery dehorning experienced significantly higher serum cortisol concentrations from 0 to 6 hours after dehorning when compared with calves administered the cornual nerve block plus a single intramuscular dose of 0.5 mg/kg meloxicam; however, no differences in cortisol concentrations were noted at 24 hours after dehorning. In addition, heart rate and respiratory rates were decreased for those animals treated with meloxicam. A decrease in heart rate was also observed in another study at 8 and 10 hours after administration of intravenous meloxicam (0.5 mg/kg) at the time of dehorning, indicating a continued reduction of stress without the effects of local anesthesia (**Fig. 4**).[42] Furthermore, pressure tolerance as measured by pressure algometry was significantly improved following meloxicam administration, indicating a reduced pain-associated nociception.[29]

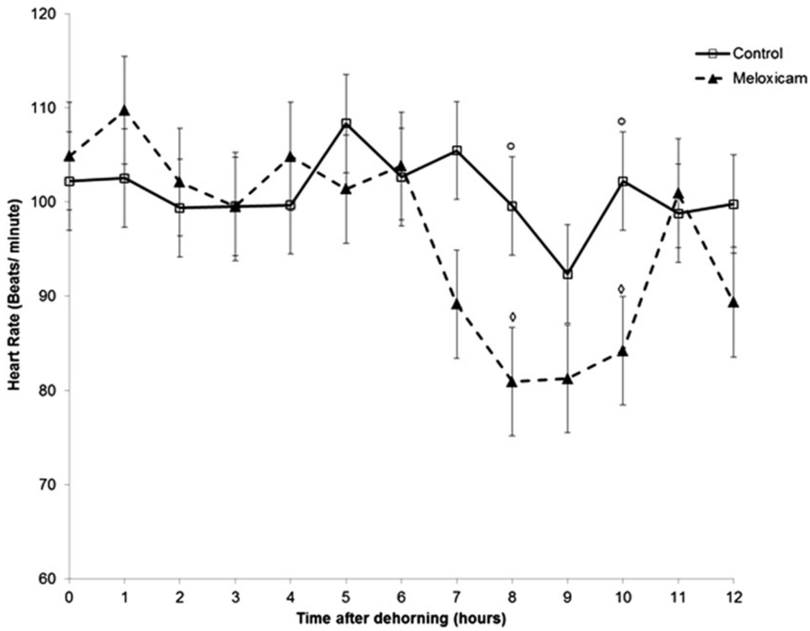

Fig. 4. Mean (±SEM) heart rate (beats/min) in dehorned calves collected after receiving 0.5 mg/kg intravenous meloxicam (*closed triangles*) or placebo (*open squares*) immediately before dehorning. Columns not connected by a symbol of the same shape and color are significantly different ($P<.05$). Heart rate was collected every 15 seconds over 12 hours. Significant reduction in heart rate is observed at 8 and 10 hours for meloxicam-treated calves compared with placebo-treated controls, indicating a prolonged effect of meloxicam administered at the time of dehorning without the effects of a local anesthetic. (*From* Coetzee JF, Mosher RA, KuKanich B, et al. Pharmacokinetics and effect of intravenous meloxicam in weaned Holstein calves following scoop dehorning without local anesthesia. BMC Vet Res 2012;8:153. http://dx.doi.org/10.1186/1746-6148-8-153; with permission.)

Theurer and colleagues[33] determined that 10-week-old calves treated with oral meloxicam (0.5 mg/kg) at the time of dehorning spent more time at the grain feeder on days 2 and 6 than those without treatment. In addition, Coetzee and colleagues[42] treated 16- to 20-week-old calves with intravenous meloxicam (0.5 mg/kg) at the time of dehorning, which resulted in a significant weight gain over a 10-day period compared with those dehorned without analgesia. The difference in ADG observed in this study was suggested to have been a result of the increased time at the grain feeder.

Flunixin meglumine

The analgesic effects of flunixin meglumine following dehorning are not well studied in the literature. Only 2 studies have investigated the use of flunixin meglumine and its effects on cortisol response in calves following only chemical dehorning (see **Tables 1** and **3**).[21,37] The effects of flunixin meglumine (2.2 mg/kg) administered intravenously and injected either 1 hour or 5 minutes before chemical dehorning were investigated in 10- to 40-day-old calves.[37] This study determined that no acute treatment effect was observed by providing preemptive analgesia, as all groups experienced significantly higher cortisol concentrations 1 hour after dehorning procedures; however, by 3 hours calves treated with flunixin meglumine were not significantly different from non-dehorned animals, whereas cortisol concentrations in placebo-treated animals were significantly higher. Cortisol concentrations in placebo-treated calves and calves treated with flunixin meglumine were not significantly different from each other, and by 6 to 24 hours all groups experienced similar cortisol concentrations.

In another study, local anesthesia was used during chemical dehorning procedures in a study of 3- to 5-week-old calves.[21] Calves administered 2.2 mg/kg intravenous flunixin in combination with a cornual nerve block had decreased cortisol concentrations at 3 hours postprocedure, compared with those calves administered only a cornual nerve block and untreated control calves. However, by 6 hours and beyond, no significant difference in cortisol concentrations among treatment groups were observed.

Salicylic acid derivatives

Baldridge and colleagues[32] investigated the effects of 2.5 to 5 mg/mL sodium salicylate administered in water 72 hours prior and 48 hours following a simultaneous surgical castration and amputation dehorning. An increased ADG was observed for 13 days in calves treated with an analgesic perioperatively. In addition, calves receiving sodium salicylate also had a significantly lower AUEC for cortisol 1 to 6 hours after dehorning-castration.

Sedative-Analgesic Drugs

Pharmaceutical agents such as α2-agonists, opioids, and *N*-methyl-D-aspartate (NMDA) receptor antagonists have all been investigated to determine the potential effects on pain biomarkers following dehorning. Potential benefits of these analgesics include the attenuation of the acute cortisol response, which can aid in the reduction of prolonged handling stress associated with dehorning; however, there is no evidence of continued analgesia following this initial period (see **Tables 4** and **5**).[8,23,24]

α2-Adrenergic agonists and opioids

Xylazine, a common α2-agonist, has been studied alone and in combination with opioids such as butorphanol, NMDA receptor antagonists (ketamine), and local anesthesia.[8,23,24,32] Grøndahl-Nielsen and colleagues[8] evaluated the effects of treatment with a cornual nerve block, xylazine (0.2 mg/kg), and butorphanol (0.1 mg/kg) intramuscularly, or no treatment on cortisol response in 4- to 6-week-old calves. This study found that cortisol increased significantly for calves in the untreated and dehorned group immediately after dehorning in comparison with the other treatment groups. However, after 10 minutes there was no significant difference among treatment groups.

The use of an α2-antagonist to reverse the sedative effects of an α2-agonist was studied to determine the effect on cortisol response following dehorning.[23] Tolazoline given to calves 5 minutes following dehorning resulted in a significant increase in cortisol concentrations greater than concentrations of those animals dehorned without analgesia. This effect was significantly prolonged for the 8 hours during which cortisol concentrations were measured; however, the AUEC was not significantly different.

Another study by Stilwell and colleagues[24] examined the effects of 0.2 mg/kg xylazine administered intramuscularly 10 minutes before dehorning, alone or in combination with 5 mL 2% lidocaine administered as a cornual nerve block on the cortisol response of calves dehorned by a hot iron. These treatments did not mitigate the cortisol response to dehorning, as both treatment groups had values significantly higher than those of control calves from 10 to 60 minutes after dehorning.

Tramadol

Tramadol ((1RS,2RS)-2[(dimethylamino-methyl]-1-(3-methoxyphenyl)-cyclohexanol) is a centrally acting analgesic primarily used in humans and companion animals to treat mild to moderate pain.[65,66] Analgesia is suggested to be a result of a dual mechanism involving both opioid-receptor activation and increased serotonin and norepinephrine transmission.[65] Although pharmacokinetic and pharmacodynamics values have not been determined in cattle, one study evaluated its antinociceptive potential following chemical dehorning in 3-week-old dairy calves using an intravenous dose of 4 mg/kg or a rectal dose of 200 mg.[67] Following an evaluation of pain-associated behaviors while using a numerical rating scale to determine pain levels, tramadol administered at the investigated doses and routes did not provide adequate analgesia for controlling pain related to chemical dehorning.

FUTURE PROSPECTS FOR TREATING PAIN ASSOCIATED WITH DEHORNING

A multimodal approach is necessary for the continued treatment and management of pain associated with dehorning. Education is paramount to the successful delivery of analgesia to cattle following common noxious procedures. This aspect is best evidenced in a Canadian survey concerning analgesia associated with dehorning, which found that clinicians in geographic areas with aggressive education in pain management were more likely to provide analgesia at the time of noxious procedures.[15] In addition, research needs to continue to determine better biomarkers of pain to improve the assessment of an appropriate analgesic therapy. Finally, artificial selection by breeding polled sires will aid in decreasing the population of horned animals.

SUMMARY

The literature focusing on pain management in cattle during dehorning is plentiful. As demonstrated, there have been several studies looking at the effects of dehorning on concentrations of plasma cortisol. In addition, several analgesic regimens have been used in efforts to relieve pain during these procedures, with varying results. Following this review, the authors suggest a multimodal approach using local anesthetics, NSAIDs and, when possible, sedatives with analgesic properties to best provide analgesia to cattle following dehorning (see **Tables 4** and **5**). Local anesthetics and sedative-analgesics aid in the attenuation of the acute cortisol response, and NSAIDs mitigate the observed inflammation-associated pain. As with all pharmaceutical agents administered to food-producing species, especially for the treatment of pain, valid veterinary client-patient relationships must be maintained and appropriate withdrawal times must be followed. Further research should be implemented to determine safe, long-lasting, and cost-effective analgesics for food animals following noxious procedures.

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