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The Old School, Brewhouse Hill, Wheathampstead,
Hertfordshire AL4 8AN, UK
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Goat kids are not small calves: Species comparisons in relation to disbudding

MN Hempstead*[†‡§], JR Waas[§], M Stewart[#¥] and MA Sutherland[‡]

[†] Department of Veterinary Diagnostic and Production Animal Medicine, College of Veterinary Medicine, Iowa State University, 1809 South Riverside Drive, Ames, Iowa, USA
[‡] Animal Behaviour and Welfare, AgResearch Ltd, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand
[§] School of Science, The University of Waikato, Private Bag 3105, Hamilton, New Zealand
[#] InterAg, Ruakura Research Centre, Hamilton, New Zealand
[¥] Ministry of Primary Industries, Pipitea, Wellington 6011, New Zealand
* Contact for correspondence: mnhempstead@gmail.com

Abstract

*Limited scientific literature is available for developing 'best practice' guidelines for the management of dairy goats (*Capra hircus*), particularly goat kids. Disbudding practices for kids and calves appear to be similar; however, it is important to recognise that kids are not small calves. Disbudding causes pain and is performed on calves and kids — welfare concerns surrounding disbudding affect both industries. In this review, we evaluate literature on disbudding of kids and calves and compare methodologies across the two species. In addition, we catalogue behavioural and physiological responses to disbudding and, finally, review alternatives to disbudding (or refinements). Although there may be certain similarities between the response of goat kids and calves to cautery disbudding, it is important to highlight the differences that do exist between the species to reduce the risk of potential detrimental effects (eg brain injury). Cautery disbudding is the most common and efficacious method of disbudding kids and calves; however, kids have thinner skulls and are disbudded at a younger age, which can increase the risk of thermal injury to the brain. Kids and calves show behavioural and physiological responses indicative of pain; however, variability in these responses between studies are likely due to differences in disbudding methodologies, study design and within-species variation. Effective pain mitigation strategies may differ across species; therefore, future research is needed to optimise pain mitigation strategies for kids. Currently, alternatives to cautery disbudding including: (i) selection for polled animals; (ii) managing horned animals; or (iii) the development of novel disbudding methods (eg cryosurgery, clove oil injection) have been deemed unsuitable by the industries as the methods are either impracticable or ineffective. Therefore, if disbudding is to continue, species-appropriate pain mitigation strategies need to be refined. Establishing best practice guidelines for disbudding kids requires managers to recognise that they are not small calves.*

Keywords: *animal welfare, calves, dehorning, disbudding, goat kids, pain mitigation*

Introduction

Disbudding is a common painful husbandry procedure performed on dairy goat kids and calves. Goats (*Capra hircus*) with horns pose a risk to other goats during agonistic encounters (Tolu & Savas 2007), or to their human handlers, potentially leading to serious injuries (Waiblinger *et al* 2011, 2012; Hartnack *et al* 2018); horned goats can also damage farm facilities (Smith & Sherman 2009) and may increase the amount of handling or management required in the milking parlour. Furthermore, horns increase the amount of space required at the feed rack (Loretz *et al* 2004). Similarly, cattle (*Bos taurus*) are disbudded when they are young to reduce the risk of injury to stockpeople, horses, dogs and other cattle (Stafford & Mellor 2005). Horns can cause bruising and damage to the hides of other cattle, especially during transport and lairage (Shaw *et al* 1976; Marshall 1977). Meat quality of horned cattle (eg assessed by measuring bruise trim) is also lower than that of hornless cattle (Meischke *et al* 1974).

Goat kids (Alvarez & Gutiérrez 2010) and calves (Misch *et al* 2007; Gottardo *et al* 2011; Cozzi *et al* 2015; Winder *et al* 2016; Staněk *et al* 2018) are commonly disbudded using a hot cautery iron. Disbudding is performed on kids and calves at an age when the horn buds are easily palpable, but before they attach to the underlying skull, which is assessed both visibly and by palpating. Goat kids are generally disbudded at a much younger age than calves (discussed below). Once the horns of goats have fused with the frontal bone and a keratinised horn is clearly visible, disbudding is ineffective, and horns must be removed by amputation with either a saw or obstetrical wire (Smith & Sherman 2009; Hartnack *et al* 2018). In cattle, amputation dehorning can be performed using a number of other methods including a scoop dehorner, knife or guillotine shears (Stafford & Mellor 2005). However, dehorning causes significantly more pain than disbudding in both goats and cattle (Hague & Hooper 1997; Stafford & Mellor 2011). Furthermore, dehorning wounds of cattle take longer to heal to re-epithelialisation (98 days for dehorning [Kihurani *et al* 1989; Neely *et al* 2014] vs 62 days for disbudding [Adcock & Tucker 2018]), and dehorning can lead to complications, such as discharge or infection (eg sinusitis, meningoencephalitis), inflammation, horn regrowth, dehiscence or even death (Hague & Hooper 1997; Stafford & Mellor 2005, 2011; Smith & Sherman 2009; Hartnack *et al* 2018). For these reasons, disbudding is preferable to dehorning. Although not technically accurate, some authors use the term 'dehorning' to refer to disbudding (eg Graf & Senn 1999; Faulkner & Weary 2000; Huebner *et al* 2017). In these cases, we have carefully inspected study methodologies to differentiate amputation dehorning from disbudding and the focus of our review is disbudding, not amputation dehorning.

Current practices for disbudding goat kids and calves appear to be similar (Weaver *et al* 2005; Smith & Sherman 2009), however, in comparison with calves, the frontal bone of goat kids is thin, and the frontal sinuses are underdeveloped, increasing the risk of thermal injury to the brain (Williams 1984; Smith & Sherman 2009). Although there may be similarities between the response of goat kids and calves to cautery disbudding, it is important to highlight the differences that do exist between the species to reduce the risk of potential detrimental effects (eg brain injury). From the literature reviewed, it appears that there are similarities in physiological and behavioural responses of goat kids and calves to cautery disbudding. There is also a discrepancy in the indicators of pain used across species making direct comparisons difficult (eg ear flicking indicates pain in calves but has not been assessed in goat kids). The stress response of goat kids (based on cortisol concentrations) peaked at 10–15 min and returned to basal concentrations 1–2 h after disbudding (Alvarez *et al* 2009; Hempstead *et al* 2018a,b). Head shakes and scratches return to basal levels approximately 2 h after disbudding of goat kids (Hempstead *et al* 2018a). Cortisol concentrations of calves peak within 30 min (Stock *et al* 2013) and can remain elevated for 24 h after disbudding (Morisse *et al* 1995; Heinrich *et al* 2009); further, evoked pain or wound sensitivity can last for up to 105 days (Adcock & Tucker 2018; Casoni *et al* 2019). The wounds of goat kids can take 50 (± 8) days to heal to re-epithelialisation and remain more sensitive to pressure over this time (Alvarez *et al* 2019). There are, however, differences between the species in regards to efficacious pain mitigation strategies; a local anaesthetic block using lidocaine virtually eliminates pain associated with disbudding of calves (Stafford & Mellor 2005), but appears to be largely ineffective in goat kids (Alvarez *et al* 2009, 2015; Nfor *et al* 2016; Hempstead *et al* 2020a) and will be discussed later in more detail in *Cautery disbudding refinements: Pain mitigation strategies*. Based on these differences, we propose that best practice recommendations for goat kids should differ to those of calves.

Therefore, for both goat kids and calves, we have evaluated the scientific literature and: (i) compared the disbudding methodologies; (ii) reviewed the behavioural and physiological responses of the two species to disbudding; and (iii) identified alternatives to disbudding along with refinements of current practices (eg pain mitigation strategies). Throughout this review, we highlight the main differences (and similarities) between goat kids and calves that need to be considered when developing best practice guidelines for disbudding.

The search engines used for this review included Scopus, Web of Science, and Google Scholar. Our initial search was conducted in March 2017 and included the terms: disbudding, goat and goat kid, dairy cattle, cow and calf, pain and pain response, pain relief, mitigation or management, anaesthetic, analgesic, behaviour, physiology, cortisol, welfare, and husbandry practice. Additionally, based on the findings from the initial search, further searches were conducted and included the terms: pain sensitivity, cautery and disbudding technique, thermal burn, skull injury and damage, and brain damage. A later search was conducted in August 2019 using Scopus, which included the search terms: goat kid or kid, dairy calf or calf, disbudding or dehorning, hot-iron and cauterisation. This search included all peer-reviewed journal articles (excluding conference abstracts and surveys) from earliest to latest published date available. Studies were included if they evaluated pain, stress or injury associated with disbudding in goat kids or calves. Studies that evaluated pain associated with horn removal (ie amputation dehorning) were excluded (unless for comparison to a disbudding study). Each study was carefully screened for information on cautery disbudding methodologies, responses to cautery disbudding (eg behavioural, physiological), pain mitigation used, injuries associated with the practice and alternatives to cautery disbudding (eg caustic paste, polled animals). Only articles written in English could be included in this review due to translation expenses.

Cautery disbudding methodologies

Disbudding involves the destruction of the horn bud, and based on the literature reviewed, is commonly performed on goat kids at a mean (± SD) age of 10.6 (± 5.7) days ranging from 2–28 days (Table 1; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), and on calves aged 5.3 (± 2.0) weeks, ranging from 1–12 weeks (Table 2; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), when the horn buds are easily palpable, but before they attach to the frontal bone and are no longer mobile (goats: 1–2 months [Hull 1995], calves: 3–6 months [McMeekan *et al* 1998; Sylvester *et al* 1998]). The predominant breeds of goat kids disbudded in the studies presented include Saanen or French Alpine (12/15; 80%; Table 1;

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https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), which are commonly used in commercial dairy goat farms due to good production traits (eg large udders).

Comparatively fewer studies used other breeds (Swedish Landrace, Beetal, Nubian, Toggenburg, and LaMancha kids; Table 1; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Breed can affect horn bud development as smaller breeds, such as pygmy or dwarf kids, tend to have smaller horn buds and require disbudding at an older age than for Saanen or French Alpine kids (Smith & Sherman 2009). Similarly, there may be differences associated with breed of calves in relation to the rate of horn bud growth and also the response to pain associated with cautery disbudding. Caray *et al* (2015) reported that Holstein calves had higher rates of vocalisations and struggles than Charolais calves during cautery disbudding. The majority of calf breeds used in the studies presented in Table 2 (https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material) were Holsteins or Friesians (42/49; 86%) as they are popular dairy breeds. Sex of the animal, may also have an effect on horn bud growth as generally buck kids have larger horn buds than doe kids and should be disbudded at an earlier age (ie 2–5 days) to reduce the risk of scurs or partially re-grown horns that can be easily broken (Smith & Sherman 2009); although preventing scurs in bucks remains difficult due to the precocious nature of horn growth in these animals. The majority of research presented in Table 1 (https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material) has used both buck and doe kids, almost certainly because these studies were investigating pain and not efficacy given the difference in horn growth between buck and doe kids.

All of the kid and calf literature reviewed used a cautery disbudding iron. Electric irons were most commonly used for goat kids (11/15; 73% of studies), with gas-powered (Hempstead *et al* 2018d) and manually heated (Chandrahas *et al* 2015) irons seldom used; a further two studies omitted the iron power source (Greenwood & Shutt 1990; Chandrahas *et al* 2013). Gas-powered irons (eg butane-powered calf dehorner, Portasol®, Elmira, OR, USA) can be beneficial over electric irons as they are not limited by proximity to power sockets (Smith & Sherman 2009). Electric irons were also most commonly used for disbudding calves (33/49; 67% of studies), but a higher number of studies used gas-powered irons (16/49; 33% of studies) compared with kid studies (7%). Gas-powered irons may reach higher temperatures (700ºC; Caray *et al* 2015) than electric irons (600ºC; Tables 1 and 2; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), which may explain why they are seldom used for kids. Therefore, when using gas-powered irons on goat kids, care should be taken to minimise thermal injury to the brain by using multiple applications that are short in duration. There is considerable variability in how the technique is performed. For example, the hair covering the horn buds is removed prior to disbudding in some cases but not others (Tables 1 and 2; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Hair removal can help to identify the horn bud, reduce the risk of smoke inhalation and may decrease the amount of time needed to cause sufficient burning of the horn buds (Smith & Sherman 2009). Many studies fail to report whether the hair was removed or not (Tables 1 and 2; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material); an important omission, given that hair removal could have an impact on pain and efficacy. Almost all authors listed in Tables 1 and 2 (https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material) used cautery irons that were heated to approximately 600ºC, as initially measured by Grondahl-Nielsen *et al* (1999). However, the majority of studies did not describe how the temperature was measured and may have simply reported manufacturers' details or the temperature stated in other studies that used a similar iron. One study on disbudded goat kids (Nfor *et al* 2016) reported the temperature of the iron to be almost 300ºC less than the other studies (Table 1; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Future research is required to evaluate the effect of cautery iron temperature on pain and efficacy associated with its use on goat kids and calves.

There are two common techniques for cautery disbudding kids and calves: (i) the ring of tissue containing the horn bud cells is cut to the bone and then removed by being forcibly flicked off the head (Stewart *et al* 2009; Mintline *et al* 2013; Alvarez *et al* 2015; Huebner *et al* 2017); or (ii) the horn bud is burned but left intact (Vickers *et al* 2005; Alvarez *et al* 2009; Alvarez & Gutiérrez 2010; Stock *et al* 2015). These two approaches may be facilitated by the style of tip of the iron used (ie thin, sharp edge vs thick, blunt edge) or personal preference. The cautery iron is typically applied for 10.6 (± 5.1) s, range: 4–30 s per bud in kids (Table 1; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material) and 19.8 (± 16.8) s, range: 3–60 s in calves (Table 2; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Shorter application times are necessary for goat kids to reduce the risk of heat transference to the brain through the frontal bone; the frontal bone is thinner and the sinus underdeveloped in kids at the typical age of disbudding (Bowen 1977; Mobini 1991; Smith & Sherman 2009; Hartnack *et al* 2018), relative to that of calves (Wright *et al* 1983; Sanford 1989).

Meningoencephalitis can result after cautery disbudding in goat kids (Thompson *et al* 2005), moreover, post mortem examination revealed necrosis of the skull (1/70 kids [Hempstead *et al* 2018d]) and brain beneath the horn buds (4/12 kids [Thompson *et al* 2005], 1/243 kids [Hempstead *et al* 2018e]), brain lesions under the disbudding sites (five kids that died after disbudding [Wright *et al* 1983], 3/139 kids [Allen *et al* 2013a], one kid presented for severely reduced condition after disbudding [Dennler *et al* 2014]) and congested meninges (2/40 kids [Sanford 1989]). There appears to be no scientific reports of brain injury associated with cautery disbudding of calves. At worst, cautery disbudding can lead to kid mortality (eg 12/150 goat kids died three days after disbudding [Thompson *et al* 2005]); this may be associated with improper practice, for example, overly long periods of iron application or excessive force/pressure while the iron is pressed onto the horn bud. Goat kids may have an increased risk of disbudding-related injuries and mortality compared to calves, as cautery disbudding was originally designed for use in calves, which are disbudded at an older age (5.3 [± 2.0] weeks vs 10.6 [± 5.7] days for kids; Tables 1 and 2; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Due to differences in skull development in kids, penetration into the sinus by a cautery iron occurs more easily in comparison with calves, leading to open cavities that increase the risk of infection (Smith & Sherman 2009; Hartnack *et al* 2018).

Efficacy of cautery disbudding methodologies

When disbudding is not effective and the germinal epithelium has not been completely destroyed, animals can develop scurs. In contrast, horns have a hard, keratinised outer shell that has fused with the underlying frontal bone (Dove 1935). There is little research evaluating the efficacy of disbudding in kids or calves to prevent scurs; however, as part of on-farm welfare assessments in England, Portugal and Italy, scurs were reported in 6.4, 10.8 and 12.7% of goats assessed, respectively (Anzuino *et al* 2010; Battini *et al* 2016; Can *et al* 2016).

A recent study showed that disbudding goat kids using an iron to cauterise and remove the horn bud resulted in a greater probability of success in preventing scurs or horns (77%) than leaving the bud intact (20%) (Hempstead *et al* 2018e). When the bud was removed, there were 25% scurs (with no horns), whereas an intact bud resulted in 30% scurs, 2% horns and 41% scorns (Hempstead *et al* 2018e). 'Scorns' were unusual growths (neither scurs nor horns) that resembled a lump of fibrous tissue and were only observed when the bud was left intact (Hempstead *et al* 2018e). Similarly, in calves, cautery disbudding by removing the horn bud was 100% successful at preventing horn growth, whereas not removing the horn bud reduced efficacy to 91% success (Sutherland *et al* 2019a). Moreover, not removing the horn bud was associated with more infection at the site of disbudding (Sutherland *et al* 2019a). Therefore, for both kids and calves, cauterising the horn bud and subsequently removing the horn bud appears to be the most efficacious method to prevent further horn development.

Response to cautery disbudding

Behavioural responses

Behavioural responses of goat kids and calves *during* disbudding are compared in Table 3 (see supplementary material to papers published in *Animal Welfare*; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Goat kids that were disbudded (with or without local anaesthetic), struggled more frequently and vocalised more intensely than handled controls (Alvarez *et al* 2009, 2015; Nfor *et al* 2016). Calves have also been reported to struggle during disbudding (Table 3; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Both cautery disbudded kids (Alvarez & Gutiérrez 2010; Chandrahas *et al* 2013; Nfor *et al* 2016) and calves (Grondahl-Nielsen *et al* 1999; Stewart *et al* 2008) performed more leg movements (eg kicking) during disbudding. Tail shaking has been reported to change in response to disbudding in a single calf study (Graf & Senn 1999), but not in goat kids (Alvarez *et al* 2015; Table 3; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material); this may be due to the small size and rapid movement of the goat kid tail making quantification difficult. Calves attempt to escape by rearing up, crouching down or may trip and fall down and perform frequent head jerks, which may be an attempt to escape from negative stimuli (Graf & Senn 1999; Stewart *et al* 2008); these behaviours have not been evaluated in goat kids (Table 3; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Escape behaviour may not be expressed in goat kids due to the comparative ease of fully restraining smaller animals.

Behavioural comparisons of goat kids and calves *following* disbudding are presented in Table 4 (see supplementary material to papers published in *Animal Welfare*; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Head shaking and rubbing, and body shaking, were more frequently performed in cautery disbudded kids than in sham-handled controls; kids also scratched their heads for longer periods of time (Greenwood & Shutt 1990; Hempstead *et al* 2017, 2018a; Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Similarly, calves shook and scratched their heads more often, and were generally more active, in comparison to handled controls or calves provided pain relief following disbudding (Morisse *et al* 1995; Grondahl-Nielsen *et al* 1999; Heinrich *et al* 2010; Stilwell *et al* 2010; Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Head-directed behaviours, such as head rubbing, or scratching may represent an attempt to reduce pain and irritation associated with a cautery burn (ie by activating low-threshold mechanoreceptors). In humans, a sharp pain can also be reduced by vigorously rubbing the site of injury (Purves *et al* 2001). Calves disbudded without pain relief performed more ear flicks than calves disbudded with pain relief for up to 44 h post-treatment (Faulkner & Weary 2000; Heinrich *et al* 2010). Ear flicking appears to be a useful indicator of pain in calves (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material) (Grondahl-Nielsen *et al* 1999; Faulkner & Weary 2000; Heinrich *et al* 2010; Stilwell *et al* 2010), but has not yet been assessed as an estimator of pain in goat kids; this may be the result of the relatively rapid and inconsistent ear movement of kids and even with the use of video recordings, reliable quantification of this behaviour is difficult (Hempstead *et al* 2017).

Our research group found that cautery disbudded goat kids spent more time lying than handled controls during the 24-h post-treatment period (Hempstead *et al* 2018c).

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Another study reported that the number of standing bouts were higher in disbudded kids than those disbudded and given meloxicam (Chandrahas *et al* 2013; Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Differences in study design may explain the conflicting results: Hempstead *et al* (2018c) used accelerometers strapped to the kids' legs, which continuously recorded lying behaviour over 24 h, while Chandrahas *et al* (2013) used a manual counting technique. Additionally, no handled control group was used by Chandrahas *et al* (2013). Further study is required to clarify whether lying or standing behaviour reflects pain associated with disbudding in goat kids. Calves disbudded with either caustic paste or a cautery iron showed no difference in the ratio of standing to lying 24 h before or after disbudding, indicating no long-term changes in behaviour; however, up to 3 h after disbudding, calves had a higher number of transitions between standing up and lying down than before disbudding, which may reflect restlessness (Morisse *et al* 1995). Interpreting changes in lying behaviour can be difficult as the changes can reflect pain in some species but not others; for example, cautery disbudded calves administered local anaesthetic spent more time lying than calves disbudded without anaesthetic (Sutherland *et al* 2018a,b). Additionally, cryosurgically disbudded calves (with and without pain relief) spent more time lying than cautery disbudded calves (without pain relief), suggesting less discomfort, although this interpretation was not supported by the calves' physiological response (Sutherland *et al* 2019b). In comparison, castrated piglets spent more time lying than uncastrated piglets (McGlone *et al* 1993), which may be an attempt to reduce movement-related stimulation of the affected area. However, it does appear as though increased time spent lying can reflect comfort in cows (Norring *et al* 2008; Tucker *et al* 2009) and calves (Worth *et al* 2015).

A reduction in play behaviour in the home pen for up to 3 h after the procedure, including kicking and bucking, has been reported in disbudded calves (Mintline *et al* 2013) but not goat kids (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Similarly, play behaviour was reduced in calves that were disbudded with caustic paste compared to control animals a day after the procedure (Rushen & de Passillé 2012). Moreover, cautery disbudded calves performed less play behaviour (eg running, bucking, head-to-head contact) in an arena test than handled controls 3 h after disbudding (Mintline *et al* 2013) — similar studies have not been performed for goat kids. To our knowledge, no studies have recorded play behaviour in kids in the home pen or an arena test. A potential explanation why play behaviour has not been measured in goat kids, to date, is that these behaviours are difficult to assess reliably because of the small size and rapid movement of goat kids (Hempstead *et al* 2017); to the authors' knowledge, there are no ethograms of goat kid play behaviour in the current literature.

A visual analogue scale (VAS), a rating scale for pain based on the behavioural response (eg vocalisations, head shakes, scratches) of animals to a painful situation, was used by Ingvast-Larsson *et al* (2011) to rank kids disbudded with and without analgesia (ie meloxicam) on a scale of 1 (no signs of pain) to 10 (severe signs of pain). The VAS scores were lower for kids that received meloxicam, suggesting less pain was experienced than those that did not receive meloxicam (Ingvast-Larsson *et al* 2011). However, the same authors reported that individual differences in behaviour were large and there were no differences in specific behaviours between groups (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Other studies have also reported large individual differences in both kid (Greenwood & Shutt 1990; Hempstead *et al* 2017) and calf behaviour (Graf & Senn 1999; Theurer *et al* 2012; Neave *et al* 2013; Bates *et al* 2019). These results may reflect the variable nature of behaviour across young animals; to provide the most accurate assessment of pain, the use of a variety of techniques (ie physiological and behavioural measures) may be required (Broom 1988).

Apparent differences in the behavioural responses between goat kids and calves exist due to differences in the behaviours that have been monitored across studies (Tables 3 and 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). For example, goat kids that were cautery disbudded in the absence of pain mitigation strategies (eg analgesics), have been reported to perform higher rates of exploring/biting structures within their pen, in comparison to kids disbudded and provided with meloxicam (Chandrahas *et al* 2013); disbudded kids also displayed more body shakes than handled controls (Hempstead *et al* 2017, 2018a). These behaviours have not been reported in the calf literature. Furthermore, the number of calf studies far outweighs the number of kid studies conducted (Tables 1 and 2; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), and therefore, the opportunity to investigate a wider variety of indicators of pain is greater.

The behavioural response to cautery disbudding appears to vary within species; there are differences in how calves respond during cautery disbudding for frequencies of struggling, vocalising and head movement (Table 3; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material) and following disbudding for head shaking, rubbing and scratching, lying bouts, feeding and ear flicking (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Similarly, for goat kids, there seems to be variation in the frequencies of head shaking and scratching, lying bouts, feeding and mouth movements following disbudding (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), although goat kids appear to be more consistent in their response during the procedure (Table 3; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). These within-species differences may be associated with differences in study methodology. The ethograms used across studies may differ; for example, Faulkner and Weary (2000) define head rubbing as using the hind leg or sides of the pen, whereas Morisse *et al* (1995) defined head rubbing as using the sides/edges of feeders (and not the hind leg). For the purpose of this review, the behaviours were used as they were named by the authors of the studies. The ethogram we used in goat kid studies defined head rubbing as using the pen walls, whereas using the hind leg was defined as scratching (Hempstead *et al* 2017, 2018a,c); these behaviours were differentiated due to the rapid and at times inconsistent movements of goat kids (Hempstead *et al* 2017).

Differences within species may also be associated with individual differences in personality, temperament, identity profile or coping styles. Moreover, goats show a clear hierarchical system of dominant and subordinate animals (Miranda-de la Lama *et al* 2011), which may affect how they respond to cautery disbudding. In dairy calves, those that are more exploratory or active, consume starter feed at an earlier age and eat more grain throughout the weaning period (Neave *et al* 2018). However, little is known as regards to the effect of individual differences or hierarchy of goat kids on their responsiveness to painful procedures.

Pressure algometry has been used to assess pain associated with inflammation or soft tissue injury in cows (Dyer *et al* 2007; Fitzpatrick *et al* 2013), horses (Varcoe-Cocks *et al* 2006) and humans (Pelfort *et al* 2015). Pressure algometry measures the amount of pressure tolerated by an animal before it withdraws from the algometer; this is called the mechanical nociceptive threshold (MNT). Goat kids showed increased sensitivity (ie lower MNT) of the tissues surrounding the horn buds after cautery disbudding compared with pre-disbudding MNT (Hempstead *et al* 2018d) until the wounds had healed to re-epithelialisation approximately 50 days after the procedure (Alvarez *et al* 2019). Similarly, disbudded calves had lower MNT values and therefore were more sensitive to pressure after cautery disbudding than handled controls (Heinrich *et al* 2010; Allen *et al* 2013b; Stock *et al* 2015). Additionally, the wounds took approximately 60 days to heal to re-epithelialisation (Adcock & Tucker 2018). Increased pain sensitivity was also found in disbudded calves for up to 105 days using Von Frey monofilaments (Espinoza *et al* 2013; Mintline *et al* 2013) together with pressure algometry (Casoni *et al* 2019); Von Frey monofilaments assessed evoked behavioural responses (ie limb withdrawal) after the application of a stimulus (ie Von Frey hairs of differing stiffness) (Lewin *et al* 1993; Chaplan *et al* 1994). Therefore, devices that measure pain sensitivity (ie pressure algometry, Von Frey monofilaments) can be useful for evaluating pain in kids and calves, although further research is required to validate their use on kids following disbudding.

In summary, it appears that cautery disbudding causes acute pain to both calves and goat kids based on similar behavioural responses during the practice. Useful behavioural indicators of pain associated with cautery disbudding, for both kids and calves, include vocalisations, struggling, leg movement during and head-directed behaviour patterns (head shaking, scratching and rubbing) following disbudding. However, some behaviours have been evaluated in one species but not the other (eg mouth movements, body shakes, ear flicks and bucks/kicks), making direct comparisons of these behaviours to estimate pain associated with disbudding difficult. Additionally, these behaviours may have been measured differently (eg differences in ethograms, duration of monitoring). Careful analysis of behavioural responses to pain are required when evaluating the efficacy of pain mitigation for kids and calves.

Physiological responses

Physiological changes, such as increases in cortisol concentrations have been frequently measured to assess pain experienced by cautery disbudded goat kids (Greenwood & Shutt 1990; Alvarez *et al* 2009; Ingvast-Larsson *et al* 2011; Nfor *et al* 2016; Hempstead *et al* 2018a,b) and calves (Graf & Senn 1999; Grondahl-Nielsen *et al* 1999; Faulkner & Weary 2000; Allen *et al* 2013b). The hypothalamic pituitary adrenal axis can be activated by stressful experiences such as pain (Mellor *et al* 2000). Cortisol is the main glucocorticoid hormone released in ruminants and can be measured in saliva, hair, faeces, plasma or serum (Landa 2012). Cortisol concentrations of disbudded goat kids were elevated relative to handled controls (by approximately 40 nmol l^{-1}) for up to 2 h after disbudding, reaching a maximum of 190 nmol l^{-1} (Greenwood & Shutt 1990; Alvarez *et al* 2009; Alvarez & Gutiérrez 2010; Nfor *et al* 2016). We also found that cortisol concentrations of disbudded kids were higher than sham-handled kids over the 2 h post-treatment period and, for all kids, cortisol concentrations at 15 min, peaked at nearly 300 nmol l^{-1} (Hempstead *et al* 2018a). Differences in methodology may account for differences in the magnitude of the cortisol response across studies, such as the age of kids used (10–20 day old kids in Alvarez *et al* [2015] vs 4 day old kids in Hempstead *et al* [2018a]). There were no significant differences in cortisol concentrations found between cautery disbudded and handled control kids for up to three days post-treatment (Ingvast-Larsson *et al* 2011). Cortisol can be highly variable depending on the stage of development of goat kids (Chen *et al* 1999). To determine cortisol from blood samples, animal restraint is often required, which may add to the stressful and painful experience, further increasing cortisol concentrations (Goonewardene *et al* 1999; Graf & Senn 1999). Therefore, the stress caused by restraint alone may confound our ability to accurately measure responses to pain. It is important to note the 'ceiling effect' on cortisol responses where maximal cortisol secretion is reached at low levels of noxiousness and thus the degree of stress or pain may be underestimated (Mellor *et al* 2000).

β-endorphin is an opioid peptide that is released in response to stresses including pain (Guillemin *et al* 1977). Greenwood & Shutt (1990) reported that immunoreactive β-endorphin concentrations of cautery disbudded kids peaked 5 min post-disbudding; however, no comparisons with handled controls were made (Greenwood & Shutt 1990). β-endorphin concentrations also increased in response to the

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mulesing of lambs (Paull *et al* 2008), but the same trend was not observed in amputation-dehorned cattle (Cooper *et al* 1995). Higher β-endorphin concentrations were found in calves disbudded at one week of age than those disbudded at four weeks of age (Mirra *et al* 2018). β-endorphins act to suppress the flow of noxious stimuli and can dampen the experience of pain (Derbyshire 1999); β-endorphin changes should be further explored as an indicator of pain in disbudded goat kids.

Lactate and glucose concentrations have not been shown to increase in response to cautery disbudding of goat kids for up to 72 h (Ingvast-Larsson *et al* 2011; Hempstead *et al* 2018a). Lactate is utilised during gluconeogenesis in the liver, and once converted to glucose, is transported to the muscles, where glucose is reduced to lactate (Exton & Park 1967). Lactate has been shown to increase in response to cortisol secretion in pigs, as stress causes mobilisation of glycogen stores (Brown *et al* 1998; Hambrecht *et al* 2004). Prunier *et al* (2005) reported an increase in lactate in response to castration of piglets for 30 min, but the response was not observed in disbudded goat kids over the same period (Hempstead *et al* 2018a, 2020b). Glucose is synthesised by gluconeogenesis, which is stimulated by cortisol and other glucocorticoids (Khani & Tayek 2001). Glucose did not increase in response to castration of piglets (Prunier *et al* 2005) or cautery disbudding of goat kids (Ingvast-Larsson *et al* 2011; Hempstead *et al* 2018a, 2020b). These results may reflect low glycogen stores in young animals (Heymann & Modic 1939), or the maintenance of constant blood glucose by insulin (Steffens 1970). To our knowledge, neither lactate nor glucose change in response to cautery disbudding in calves. It appears that changes in lactate and glucose concentrations may not be adequately sensitive to detect acute or longer-term stress or pain in goat kids.

Haptoglobin is an acute phase protein that acts as an inflammatory biomarker, as it increases in response to inflammation either from disease or non-infectious causes, such as tissue injury (ie surgery and burns, chemical injury) (Dobryszycka 1997; Heller & Johns 2015). Increases in haptoglobin have been reported in severely burned compared with healthy human patients (Miskulin *et al* 1978; Mallet *et al* 1987). Increases in haptoglobin concentrations associated with cautery disbudding have not been observed in goat kids (Hempstead *et al* 2018b) or calves (Allen *et al* 2013b; Ballou *et al* 2013); however, Ballou *et al* reported that calves that were surgically castrated (or surgically castrated and dehorned) showed an increase in haptoglobin 24 h after the procedure. This is in agreement with other research that reported haptoglobin to be at peak concentration 24 h after induction of inflammation in mice (Wang *et al* 2001). Elevated cortisol concentrations in response to disbudding indicate that kids and calves experience acute pain in response to disbudding, however, as there is no concurrent increase in haptoglobin concentrations then it is likely that surgical castration causes a greater inflammatory response than cautery disbudding.

Elevations in skin temperature, measured by infra-red thermography, can indicate inflammation of the procedural site in cautery disbudded goat kids (Hempstead *et al* 2018b; Alvarez *et al* 2019) and hot-iron branded cattle (Schwartzkopf-Genswein & Stookey 1997). However, others reported that infra-red thermography failed to detect any changes in skin temperature (Adcock & Tucker 2018; Mirra *et al* 2018). Cautery disbudded kids had skin temperatures around the horn bud that were similar to controls at 24 and 48 h post-treatment, but increased above controls at 72 h post-treatment (Hempstead *et al* 2018b), indicating the increase in temperature was associated with an inflammatory response and not contact of the iron on the skin. Cattle that were hot-iron branded showed higher skin temperatures around the site of branding than unbranded control sites (between 24 and 168 h after treatment) (Schwartzkopf-Genswein & Stookey 1997). Therefore, infra-red thermography appears to detect inflammation in both goat kids and cattle and may be a more sensitive measure of inflammation than acute phase proteins in relation to disbudding.

The sympathetic nervous system regulates heart and respiration rates and body temperature, which can change in response to stressors, such as painful stimuli (Porges 1995); changes in these parameters have either not been investigated (eg eye temperature) or not been observed in response to cautery disbudding of goat kids (Alvarez *et al* 2009; Alvarez & Gutiérrez 2010; Nfor *et al* 2016). Fluctuations in body temperature can indicate stress or pain in disbudded calves and can be detected from images of the eye taken by an infra-red thermography camera (Stewart *et al* 2008, 2009; Ijichi *et al* 2020). Immediately following disbudding of calves, eye temperature rapidly decreased, relative to disbudded calves administered a local anaesthetic (Stewart *et al* 2009). Infra-red thermography may be useful for detecting pain in goat kids as it can non-invasively measure stress (Stewart *et al* 2009) and inflammation (Hempstead *et al* 2018b). Heart rate increased and heart rate variability decreased in calves after cautery disbudding (Grondahl-Nielsen *et al* 1999; Stewart *et al* 2008, 2009) as measured using continuous heart rate monitors and electrocardiogram recordings; in comparison, existing goat kid studies used a stethoscope, a manual method of measuring heart rate, which requires handling that can affect heart rate (Alvarez *et al* 2009; Alvarez & Gutiérrez 2010; Nfor *et al* 2016), and may explain the lack of differences in heart rate between disbudded and non-disbudded kids. Automated heart or respiration rate monitors attached to disbudded animals and controls may more accurately detect differences in heart or respiration rate in future goat kid studies.

Other physiological parameters that have been reported to change in response to cautery disbudding and have been used to indicate pain in calves (but not yet in kids), include adrenocorticotropic hormone (ACTH), vasopressin (Graf & Senn 1999), substance P (Coetzee *et al* 2012; Allen *et al* 2013b) and prostaglandins (Allen *et al* 2013b; Stock *et al* 2015). Similar to cortisol (as discussed previously), ACTH is released in response to stressors and elevated levels can indicate stress or pain in surgically castrated piglets (Keita *et al* 2010), bull calves (Fisher *et al* 1997) and tail-docked lambs (using a rubber ring; Peers *et al* 2002). Cautery disbudded calves had elevated ACTH concentrations above those that were disbudded without pain relief relative to those provided with pain relief, thus indicating that pain was experienced (Graf & Senn 1999). An increase in vasopressin is often observed in response to a painful or stressful event (Anderson & Muir 2005) and was elevated in cautery disbudded calves immediately following the procedure (Graf & Senn 1999). Substance P is a "neuropeptide that regulates the excitability of dorsal horn nociceptive neurons and is present in areas of the neuroaxis involved in the integration of pain, stress, and anxiety" (Coetzee 2011; p 200). Substance P was higher in castrated calves than uncastrated controls over 4 h, which contrasted with cortisol concentrations that did not differ between groups; thus indicating substance P may be a more sensitive measure of nociceptive responses of calves to castration than cortisol (Coetzee *et al* 2008). There are contrasting reports of changes in substance P concentrations in response to cautery disbudding of calves: Stock *et al* (2015) reported no difference in substance P between cautery disbudded and control calves; however, at 120 h after disbudding, substance P was lower in calves administered with meloxicam than those that were not (Allen *et al* 2013b). Prostaglandin E2 was also lower in calves disbudded with pain relief than in controls disbudded without pain relief (Allen *et al* 2013b; Stock *et al* 2015). Whether these estimators of pain would be practical for assessing goat kid welfare is unclear, as blood constituents can be highly variable in young kids (Chen *et al* 1999). It is important to recognise the limitations of using blood constituents to indicate pain as they can be affected by other stresses in addition to pain. For example, cortisol can increase in response to sexual stimulation (Colborn *et al* 1991) or be affected by circadian rhythms (Andersson *et al* 2000).

Based on the review of the literature, blood sampling to assess plasma cortisol and β-endorphin concentrations appear to be useful for evaluating pain in calves and goat kids; however, blood sampling itself causes stress. Therefore, non-invasive measures, such as using infra-red thermography to assess skin and eye temperature or less invasive measures, such as automated heart rate monitors, which have been shown to be useful methods for evaluating pain in calves, should be evaluated in future goat kid studies.

Changes in production measures associated with disbudding

There was no difference in weight gain between goat kids that served as handled controls or were disbudded using a cautery iron, cryosurgery, caustic paste or clove oil over the two weeks that followed disbudding (Hempstead *et al* 2018b,d). Similarly, there were no differences in growth rate or feed intake between disbudded and control calves (Grondahl-Nielsen *et al* 1999; Stock *et al* 2015). However, Bates *et al* (2015) reported that calves disbudded without pain relief had lower weight gains than calves disbudded with pain relief. Generally, changes in bodyweight are associated with changes in feeding motivation and feed intake (Morton & Griffiths 1985). Pain associated with castration of piglets can increase feeding behaviour as the process of suckling can have analgesic effects, which may impact weight gain (Noonan *et al* 1994). In addition to feed intake and impaired growth associated with acute pain, chronic pain can have negative effects on measures such as immune function, milk yield and fertility (Anil *et al* 2005).

Alternatives to cautery disbudding

Raising horned adults

Adult goats with horns can be problematic for farmers (eg due to injuries to goats and handlers, and increased space requirements), explaining why kids are commonly disbudded. Nevertheless, one alternative to cautery disbudding, that can eliminate pain associated with the practice, is to raise goats with horns. Not only would this save producers time and money (eg eliminating the need to disbud and employ contractors to perform disbudding) at a very stressful time (ie kidding season), it would eliminate pain and tissue damage associated with disbudding. However, raising horned goats would require farmers to adapt facilities and management systems. Appropriately designed facilities can reduce the risk of aggressive encounters between goats, reducing horn-related injuries (Andersen & Boe 2007; Waiblinger *et al* 2011). For example, in commercial dairy goat systems, greater space allowances in lying areas within barns (or lower stocking densities), and the provision of outdoor space would allow goats to move away from instigators of conflict. Having longer horizontal feed racks (or a wider palisade, or vertical feed spaces) to accommodate horned goats, may also reduce the risk of injury. Although farms that manage herds of horned goats can have a higher incidence of horn-inflicted udder injuries, injuries can be reduced if farms have lower numbers of milking does and if these does are mixed less often during lactation (Waiblinger *et al* 2011). Other research has reported that horned goats display more avoidance behaviour as well as lower threat rates (involving no physical contact) than hornless animals (Aschwanden *et al* 2008; Hillmann *et al* 2014); furthermore, hornless animals attacked other goats more frequently (Aschwanden *et al* 2008; Hillmann *et al* 2014). Horned cattle appear to be a danger to other cattle and stockpersons, not only due to injuries, but to the facilitation of aggressive responses (Stafford & Mellor 2005, 2011). However, literature on the social behaviour of horned compared with hornless cattle is limited (Knierim *et al* 2015). Cattle with horns can be managed to reduce the risk of agonistic behaviour and injury, for example, by habituating new cows to the herd over an extended period of time (Menke *et al* 1999). Cattle that were dehorned or were polled (considered below) behaved similarly during routine management practices (Goonewardene *et al* 1999). Overall, it seems that goats and cattle can be managed with horns, but a horned herd may not be practical for all operations without considerable management change, and this can also be affected by breed and management practices on different farms. Until practices are changed in order to manage horned goats and cattle, other alternatives are required.

Artificial selection for polled animals

Another alternative to disbudding is to breed animals that do not grow horns. The polled trait is common in beef cattle, but rare in dairy breeds (Spurlock *et al* 2014; Cozzi *et al* 2015; Thompson *et al* 2017). However, the utilisation of polled goats is uncommon due to developmental abnormalities. Polled intersex syndrome (PIS) occurs frequently in goats (Szatkowska *et al* 2014); the PIS mutation links polledness and intersexuality or hermaphrodism (Pailhoux *et al* 2001), which affects fertility of both does and bucks. Naturally occurring polled goats tend to have bony 'knobs' in place of horn buds, which can occasionally be mistaken as horns and disbudded unnecessarily (Dove 1935). New genetic techniques or selective breeding to establish a polled line of goats may prevent the need for disbudding. Horn growth is a genetically heritable autosomal recessive trait, and polled cattle result from an autosomal dominant pattern of inheritance (Spurlock *et al* 2014). In the US beef industry, the number of calves born with horns decreased from 27.8% in 1997 to only 12.4% in 2007, which was likely due to the Beef Quality Assurance programme recommending that the industry use polled genetics (United States Department of Agriculture [USDA] 2009). However, in comparison with the beef industry, 94% of US dairy operations still dehorned calves in 2014 (USDA 2018), indicating less pressure from assurance programmes to utilise polled genetics in this industry. Farmers appear concerned about sire quality, which may explain why the polled line is rarely used for dairy cattle (Winder *et al* 2016). However, there does appear to be a reduction in some production traits, which are associated with homozygous polled cattle compared with horned cattle, but careful selection of heterozygous polled cattle can improve these deficits (Spurlock *et al* 2014). Additionally, the production of polled animals may be more expensive than simply disbudding and providing pain mitigation; as a result, farmers may prefer the latter (Thompson *et al* 2017). However, the effect of consumer perception of painful farming practices, such as disbudding, on economics should not be overlooked (Thompson *et al* 2017). Polled lines for both cattle and goats appear to be the best possible approach for eliminating the need for horn removal, but further research is required to better understand links between polled animals, production and fertility.

Caustic paste disbudding

The second most common method of disbudding kids and calves involves applying an alkali (typically one with a sodium or calcium hydroxide base) to the horn bud region as a paste (Stafford & Mellor 2011); this paste causes a chemical burn that destroys the germinal tissue of the horn bud (Winder *et al* 2017). The corrosive action of caustic paste generally lasts for as long as it is in contact with the skin (Palao *et al* 2010). Best practice recommendations are to shave the horn bud region and apply a ring of petroleum jelly around the base of the horn bud to reduce the risk of the paste spreading and causing injury to the surrounding tissues and the eyes.

In goat kids, caustic paste disbudding caused elevations in: (i) cortisol concentrations; (ii) skin temperatures surrounding the horn buds; and (iii) the frequencies of head shaking and scratching (Hempstead *et al* 2018b,c): these changes were greater than those of cautery disbudded kids, suggesting more pain was associated with caustic paste disbudding. Moreover, caustic paste disbudding appeared to cause pain in calves for at least 4 h as evidenced by higher cortisol concentrations, head rubs and shakes, heart rates and sensitivity of the horn buds in comparison to sham-disbudded controls (Vickers *et al* 2005; Stilwell *et al* 2009; Winder *et al* 2017). However, in comparison to cautery disbudding, caustic paste has been suggested to cause less pain in calves, evidenced by less head shaking, post-treatment (Vickers *et al* 2005). Conversely, Morisse *et al* (1995) suggested that cautery disbudding resulted in less pain than caustic paste disbudding, evidenced by lower cortisol concentrations in cautery disbudded calves; however, by the authors' own admission, comparisons were questionable due to differences in age between treatment groups. Caustic paste disbudding can have further negative consequences: Winder *et al* (2017) observed the paste running into the eyes of calves or being transferred by the animal's own legs to other areas of the body or rubbed onto other animals or pen structures. However, calves could be housed individually to prevent transference of caustic paste to other animals (Vickers *et al* 2005).

A study evaluating the efficacy of caustic paste (a novel formulation containing caustic paste, lidocaine and prilocaine) disbudding of calves reported that 30% of treated animals (6/32 calves) grew scurs (Winder *et al* 2017). In comparison, 60% (6/10) of kids that were disbudded with caustic paste alone had scurs three weeks after disbudding (Hempstead *et al* 2018b). Therefore, caustic paste disbudding does not appear to be a suitable alternative to cautery disbudding, especially for kids, which may require disbudding a second time.

Cryosurgical disbudding

Cryosurgical disbudding involves directing a pressurised spray of liquid nitrogen (or applying a liquid nitrogen cooled probe) onto the horn bud region (Bengtsson *et al* 1996; Hempstead *et al* 2018b,c; Sutherland *et al* 2019a,b). Cryosurgery is commonly used in human medicine to remove cutaneous skin lesions, and does not generally require local anaesthesia, has a low risk of infection as well as reduced healing times (Zimmerman & Crawford 2012; Krunic & Marini 2015). In human studies, participants that received cryosurgery reported experiencing tolerable, mild to moderate pain (Bonnez *et al* 1995). Low temperatures (≤ –20°C) freeze tissue and, with a slow thaw (up to 10°C per min), kill the horn bud cells (Krunic & Marini 2015). Cryosurgically disbudded goat kids showed higher cortisol concentrations, skin temperatures (surrounding the horn buds), and frequencies of head scratching than cautery disbudded kids (Hempstead *et al* 2018b,c). Hempstead *et al* (2018b) initially found there was no skin damage associated with cryosurgical disbudding; however, 24 h after cryosurgery, ulcerations or vesicles were observed, resulting in open wounds and delayed healing (Hempstead *et al* 2018b). For calves, cryosurgery also appeared to cause more pain as cortisol concentrations were elevated for 90 min post-treatment, above concentrations of cautery disbudded and control calves (Sutherland *et al* 2019b); the technique in calves has also been found to cause open wounds and delayed healing (Bengtsson *et al* 1996).

Cryosurgical disbudding was ineffective at preventing scurs in kids, as only 20% (2/10 kids) of cryosurgically disbudded kids did not develop scurs (Hempstead *et al* 2018b). At six months of age, calves that were cryosurgically disbudded using a liquid nitrogen-cooled probe resulted in a success rate (ie horn buds without scurs or horns) of only 1.5% (2/134) of horn buds (Sutherland *et al* 2019a). However, cryosurgery accomplished by spraying liquid nitrogen onto the horn region of calves had an overall success rate (ie animals with no scurs or horns) of 26% (Sutherland *et al* 2019b). Additionally, the spray technique was effective in preventing horn growth in 56% (9/16 horns) of cases (Bengtsson *et al* 1996). Using methodologies described in the current literature (Bengtsson *et al* 1996; Krunic & Marini 2015; Hempstead *et al* 2018b; Sutherland *et al* 2019b), cryosurgery appears to cause more pain than cautery disbudding in kids and calves, and does not appear to be as efficacious at preventing horn development. Moreover, there are impracticalities associated with using liquid nitrogen on-farm, such as the need to store liquid nitrogen, the expense (and maintenance) of the spray applicator(s) and the requirements of additional training and safety equipment.

Clove oil disbudding

Clove oil has been injected subcutaneously into the horn bud region to prevent horn growth in goat kids (Molaei *et al* 2015; Still-Brooks *et al* 2017; Hempstead *et al* 2018b,e) and calves (Molaei *et al* 2014; Sutherland *et al* 2018a,b,c). Clove oil is derived from clove spice and has complex properties. Clove oil is a well-established fish anaesthetic (Sladky *et al* 2001; Javahery *et al* 2012), displays anaesthetic effects in humans (Markowitz *et al* 1992), and has antibacterial (Briozzo *et al* 1989), cytotoxic (Babich *et al* 1993; Prashar *et al* 2006) and anti-carcinogenic properties (Zheng *et al* 1992). The main constituent of clove oil is eugenol which, at high concentrations, causes cellular necrosis of the oral mucosa of rats (Kozam & Mantell 1978) and isolated human skin cells (Prashar *et al* 2006). The exact mechanisms of action of clove oil on horn buds are not well understood, but cytotoxicity of clove oil may be associated with membrane damage and subsequent cell lysis or cell apoptosis (Prashar *et al* 2006); clove oil can also inhibit cellular enzymes involved in cell transport, which may cause cell death (Kreydiyyeh *et al* 2000). Goat kids receiving clove oil injections to horn buds had a similar cortisol response as sham-handled controls; they also displayed a similar change in skin temperature and frequency of head shakes and scratches as cautery disbudded kids, suggesting a similar experience of pain (Hempstead *et al* 2018b,c). Furthermore, clove oil disbudding may result in faster healing than cautery disbudding due to less tissue damage during the procedure (Hempstead *et al* 2018b), which largely occurred beneath the dermis. However, haptoglobin concentrations were elevated above those of cautery disbudded kids at 24 h post-treatment, indicating pain associated with inflammation was caused by the clove oil injection (Hempstead *et al* 2018b). Calves injected with clove oil initially experienced less pain, and in the 48 h after treatment, appeared to experience reduced pain compared to cautery disbudded calves (Sutherland *et al* 2018b). Earlier studies, investigating the efficacy of clove oil disbudding in goat kids (Molaei *et al* 2015) and calves (Molaei *et al* 2014), did not assess pain responses associated with clove oil disbudding, but assumed that the analgesic properties of eugenol would reduce the need for pain relief. In a recent efficacy study, Hempstead *et al* (2018e) found clove oil to be an ineffective disbudding agent in kids: the probability of scurs and horns post-injection was 72% (95% confidence intervals; 63–80%) and 21% (15–29%), respectively, when animals were treated at approximately four days of age. However, clove oil was reported to prevent horn growth in five day old kids, but sample sizes were low (16 animals; Molaei *et al* 2015). Differences in the methodologies used to inject clove oil may account for the corresponding difference in clove oil disbudding efficacy between these two studies; however, there was insufficient detail provided by Molaei *et al* (2015) to directly compare with the methodologies used by Hempstead *et al* (2018e). Injecting clove oil under the horn bud of four day old calves prevented horn growth in 87% of animals at six months of age (Sutherland *et al* 2019a). However, when treated calves were re-examined at 16 months of age, clove oil was only effective at preventing horn growth in 32% of animals (4% developed horns and 61% developed scurs; 3% missing data; Sutherland *et al* 2019c), suggesting that clove oil only delayed horn development. In contrast, Molaei *et al* (2014) found that injection of clove oil prevented horn growth in 100% of treated animals (12 animals) over an eight-month observation period, which likely contributed to the higher rates of success than those of Sutherland *et al* (2019c). Differences in clove oil composition and administration procedures, including source and percentage of eugenol in the clove oil, breed of goat or cattle, number of animals assessed and the length of time the animals were examined may account for differences in efficacy across studies. The two clear benefits of clove oil disbudding are that: (i) it does not involve tissue removal; and (ii) it poses no risk of thermal damage to the brain. However, further research is required to evaluate tissue damage over longer time-frames, and pain associated with clove oil injection; the technique will need to be refined to improve efficacy.

Cautery disbudding refinements: Pain mitigation strategies

A large hurdle to providing pain mitigation for cautery disbudding in both goat kids and dairy calves, is that there are currently no compounds specifically approved for pain relief in livestock in the United States (Coetzee

2011). However, there are a range of drugs that have been evaluated for extra-label use for pain relief and are required to be administered by (or under the supervision of) a veterinarian (Coetzee 2011).

Local anaesthesia

A common pain mitigation strategy for cautery disbudding of calves is the administration of local anaesthesia (eg lidocaine), which causes a lack of sensation to a localised area (Dugdale 2011). Lidocaine can reduce pain associated with cautery disbudding of calves, evidenced by the absence of behavioural responses associated with pain during disbudding; for example, treated calves perform fewer head shakes and also have lower cortisol concentrations for up to 2 h post-treatment compared with calves disbudded without pain relief (Graf & Senn 1999; Grondahl-Nielsen *et al* 1999; Stafford & Mellor 2005). The advantages of using local anaesthetics are that they: (i) are not cost prohibitive; (ii) require less equipment than a general anaesthetic; and (iii) are able to be administered (with training) by farm personnel (Dugdale 2011).

Interestingly, when administered to the horn buds of goat kids prior to cautery disbudding (using either a ring or nerve block), lidocaine does not appear to consistently eliminate or reduce acute pain; kids disbudded with lidocaine had similar frequencies of vocalisations and leg shakes, and similar cortisol concentrations as kids disbudded without lidocaine (Alvarez *et al* 2009, 2015; Nfor *et al* 2016; Ajuda *et al* 2020; Hempstead *et al* 2020a). There are multiple explanations for the apparent difference in efficacy between calves and kids. Goat kids have two nerves innervating each horn bud (the lacrimal and infratrochlear nerves; Dugdale 2011), whereas calves have only the one nerve (the lacrimal) supplying each horn bud (Vitums 1954; Dugdale 2011). This means that two injections per bud are required to achieve a successful block (Dugdale 2011), and it may be more difficult to consistently block both nerves as each injection site requires a lower volume to be injected due to lidocaine toxicity issues. Consequently, injection placement must be more precise to ensure that it is close to the nerve. Additionally, dairy goat kids are commonly disbudded at one week of age (Smith & Sherman 2009); at this age the nerves are likely smaller than those of calves, which are commonly disbudded at approximately 4–8 weeks old (Stafford & Mellor 2005) and hence may be more difficult to consistently block.

Perhaps, disbudding goat kids at an older age may improve lidocaine efficacy, however, goat kid horn growth is more precocious than that of calves (ie 1–2 vs 3–6 months until horns attach to the skull). Therefore, a later disbudding age for goat kids may result in reduced efficacy (ie scurs). Due to goat kids being younger and having lower weights than calves at the time of disbudding, dosage may also affect the success of the block; in previous studies, kids were administered 2 ml of 2% lidocaine per horn bud (Alvarez *et al* 2009, 2015), 2 ml of 1% lidocaine per horn bud (Hempstead *et al* 2020a) and 1 ml of 1% lidocaine per horn bud (Nfor *et al* 2016) whereas calves typically receive 4–5 ml of 2% lidocaine per horn bud (Morisse *et al* 1995; Graf & Senn 1999). In addition, goat kids can have an increased risk of receiving a toxic overdose compared to other ruminants, once again due to their young age and small size when they are disbudded (Smith & Sherman 2009; Dugdale 2011). Therefore, the dose required to reduce sensitivity of the horn bud area may be above the levels that goat kids can tolerate. The toxic dose of lidocaine for young kids and lambs is approximately 4–10 mg kg^{-1}, with a suggested concentration of 4 mg kg^{-1} (Dugdale 2011). However, more recent research suggested that 1 ml of 1% lidocaine per horn bud did not result in convulsions and hence was safe to use in goat kids (Venkatachalam *et al* 2018); the authors stated that this dosage was effective, however, specific measures of lidocaine efficacy (eg a pin prick test, vocalisations, struggling) were not evaluated. Considering that kids are more tolerant to lidocaine than initially thought (Venkatachalam *et al* 2018), further research evaluating lidocaine or other forms of local anaesthesia (eg articaine) as a method of providing pain relief in the context of disbudding is needed; alternatives to injected lidocaine, such as topical formulations, should also be evaluated in future research.

General anaesthesia

General anaesthesia produces a state of unconsciousness that is a "controlled and reversible intoxication of the central nervous system, whereby the patient neither perceives nor recalls noxious (or other) stimuli" (Dugdale 2011). Under deep general anaesthesia, patients may respond to noxious stimuli from surgical procedures at the level of the spinal cord and brain, in the absence of clinical responses; this may be abolished by administration of local anaesthesia. However, it is not well understood whether this has any adverse effects on patient outcomes (Lichtner *et al* 2018). General anaesthesia is not commonly used as a method of pain relief for disbudding calves (almost certainly associated with the success of lidocaine at reducing or eliminating pain), but it has been evaluated in goat kids as an alternative to local anaesthesia (Hempstead *et al* 2018a, 2020b). Goat kids that were administered isoflurane during disbudding performed fewer head shakes and displayed lower cortisol concentrations for up to 2 h post-treatment compared to kids disbudded without pain relief (Hempstead *et al* 2018a). It is possible, however, that isoflurane may have reduced the goat kids' ability to respond to the procedure, meaning they may still have perceived pain, but were unable to show it (Hempstead *et al* 2018a, 2020b): a reduced behavioural response was observed in calves under isoflurane anaesthesia for up to 2 h after umbilical surgery (Offlinger *et al* 2012). In future studies, a control group that is not disbudded but administered isoflurane should be included (Hempstead *et al* 2018a). Practically, isoflurane can be administered on farms, as portable units have now been developed. The benefits of isoflurane include the ability to rapidly adjust anaesthetic depth (Dugdale 2011); recovery is also faster than other inhalation anaesthetics (eg halothane or sevoflurane). Furthermore, a reduction in struggling allows disbudding practices to be carried out more efficiently (Hempstead *et al* 2018a). Limitations of using isoflurane include the requirement that the drug is administered by a veterinary surgeon (increasing costs associated with the practice); furthermore, complications associated with the use of anaesthetics include regurgitation, aspiration pneumonia, hypoventilation and hypotension (Dugdale 2011). While general anaesthesia can block the perception of pain associated with cautery disbudding of goat kids (Hempstead *et al* 2018a, 2020b), more practical pain mitigation strategies that can be easily administered by farm personnel at a minimal cost to the farmer should be investigated.

Adrenergic alpha-2 agonists

Adrenergic alpha-2 agonists (eg xylazine, dexmedetomidine) are able to produce sedation in ruminants by stimulating alpha-2 adrenergic receptors in the central and peripheral nervous systems (Riebold 2015), inhibiting noradrenalin release and impeding transmission of further nerve impulses; this can provide the dual effect of sedation and analgesia (Dugdale 2011). Xylazine alone does not produce adequate anaesthesia and therefore should be used in combination with an analgesic or anaesthetic. Xylazine (approximately 0.2 mg kg^{-1}) used in combination with lidocaine, can effectively reduce pain in disbudded calves as evidenced by lower frequencies of head jerks, leg movements and struggles, and lower cortisol concentrations, than disbudded controls (Grondahl-Nielsen *et al* 1999; Stilwell *et al* 2010). Xylazine has a short withholding period and produces dose-dependent sedation but may cause cardiovascular depression (Khan *et al* 1999). Xylazine (0.2 mg kg^{-1}) and ketamine at a dose of 8.8 mg kg^{-1}, have been used in combination to sedate goat kids prior to disbudding (Ingvast-Larsson *et al* 2011); however, the effect of these drugs on pain was not assessed. Goat kids that were disbudded under sedation using dexmedetomidine (0.1 mg kg^{-1}) had lower cortisol concentrations than those disbudded without sedation for up to 30 min post-treatment (Nfor *et al* 2016). Sedatives such as xylazine and dexmedetomidine show promise for pain mitigation when disbudding goat kids. However, sedatives can have negative cardiovascular effects in goat kids (eg bradycardia and central suppression of thermoregulation; Dugdale 2011; Nfor *et al* 2016) as well as respiratory effects on small ruminants (eg pulmonary oedema, hypoxaemia; Dugdale 2011). Therefore, the appropriate dosage to induce sedation, but prevent deleterious effects, should be investigated.

Non-steroidal anti-inflammatory drugs

Non-steroidal anti-inflammatory drugs (NSAIDs) block cyclooxygenase activity to inhibit synthesis of prostaglandins that mediate inflammation and associated pain (Dahl & Kehlet 1991; Del Tacca *et al* 2002). Meloxicam has been suggested to reduce inflammatory pain associated with disbudding of goat kids as the VAS score was lower in kids disbudded with meloxicam 24 h post-treatment (Ingvast-Larsson *et al* 2011). Meloxicam, whether given to calves 12 h prior to or at the time of disbudding, reduced cortisol, substance P and prostaglandin E2 concentrations compared to control calves (Allen *et al* 2013b). Additionally, meloxicam-treated calves were less active and had lower tissue sensitivity than control calves (cautery disbudded only) for up to 5 h post-treatment (Heinrich *et al* 2010). Intravenously administered meloxicam was still bioavailable 52 h after administration, indicating an extended half-life in calves, producing long-lasting effects from a single application (Coetzee *et al* 2012). An oral formulation has been suggested as a practical alternative to injections on-farm, as ketoprofen (an NSAID) can be added to milk prior to disbudding (in calves; Faulkner & Weary 2000); however, the dose per animal would be difficult to control in group-housed animals. In summary, accumulated evidence suggests that NSAIDs may reduce post-operative pain associated with cautery disbudding of goat kids and calves and are practical for use on-farm. Future research should investigate the optimal time to administer NSAIDs prior to disbudding for effective pain mitigation.

Multimodal pain management

We have focused on the effect of pain mitigation strategies used singularly. However, to reduce pain, including acute (during disbudding), acute post-operative (following disbudding) and longer-term pain until re-epithelialisation (Adcock & Tucker 2018), a single pain mitigation strategy may be ineffective. Acute pain in the disbudding context is generally associated with tissue damage caused by a noxious stimulus that can resolve in a number of days, whereas inflammatory pain, which contributes to acute post-operative pain, can occur throughout the entire healing phase (McKune *et al* 2015). In order to mitigate the effects of different types of pain, a multimodal approach to pain management should be employed. General or local anaesthesia used in conjunction with NSAIDs can provide pain mitigation for the initial nociceptive damage caused by the cautery iron and, also, relief from inflammatory pain associated with thermal burns (for days after the procedure), which has been demonstrated in calves (Faulkner & Weary 2000; Heinrich *et al* 2009; Stewart *et al* 2009; Allen *et al* 2013b) and kids (Ingvast-Larsson *et al* 2011; Hempstead *et al* 2018a). However, further research is necessary to investigate longer-lasting pain mitigation solutions for not only acute post-operative pain, but throughout the wound healing period and beyond. Additionally, further research is required on more cost-effective pain management strategies for goat kids that are effective, do not require veterinary administration and can be easily adopted by farmers.

Animal welfare implications

Cautery disbudding is the most common method of terminating horn bud growth in goat kids and calves; it also appears to be the most efficacious method of preventing scur and horn growth, especially when the horn bud is fully removed. However, cautery disbudding, if performed by unskilled operators, can cause thermal damage to the brains of goat kids; therefore, care is required when disbudding kids. Additionally, there is a need to develop best practice guidelines for disbudding that are goat kid-specific. Disbudding without pain relief causes behavioural and physiological changes in kids and calves indicative of pain.

Therefore, until alternative management practices are adopted that cause minimal or no pain (eg managing horned goats, polled genetics), there is need to provide pain mitigation strategies when disbudding kids and calves. Combining local anaesthesia with NSAIDs appears to provide effective pain mitigation for calves; however, general anaesthesia (eg isoflurane) or sedation (dexmedetomidine) in combination with NSAIDs appear to be more appropriate for kids. Nevertheless, further research is needed to evaluate more practical and economical pain mitigation strategies for goat kids experiencing cautery disbudding.

Conclusion

Cautery disbudding of goat kids not only causes pain, but the practice can cause thermal injury and necrosis of the brain (and meningoencephalitis), which significantly impacts welfare. Disbudding practices for kids and calves appear to be similar; however, in comparison with calves, there are differences in anatomy, reports of thermal injury to the brain, measures of pain associated with disbudding and efficacious pain mitigation strategies. Cautery disbudding methodologies, such as age at disbudding, iron application time and whether the horn bud was removed, varied considerably across the scientific literature we reviewed; differences in methodologies could potentially affect characteristics of pain, injury and efficacy associated with the practice. In future, researchers should more clearly describe disbudding methodologies to improve our ability to make comparisons across studies. In addition, future research should establish optimal cautery disbudding methods and then standardise the training that disbudding operators receive. The effect of iron temperature and application protocols (eg how long the iron is applied, and how much pressure should be applied to remove the horn bud) deserve special consideration to reduce pain and injury, and to increase efficacy.

Pain and injury associated with disbudding could be eliminated by: (i) changing herd management strategies (including facility design) to allow for horned goats; or (ii) breeding and farming polled animals. Based on the literature reviewed here, it appears that alternative disbudding methods, including caustic paste and cryosurgical disbudding, are more painful than cautery disbudding and may not be useful alternatives. Although clove oil injection appears to cause a similar experience of acute pain as cautery disbudding, the method (as currently applied) may cause longer-term inflammatory pain, is ineffective at preventing horns and scurs and may not be a viable alternative to cautery disbudding.

Lidocaine, as currently applied, does not appear to reliably reduce pain associated with disbudding in goat kids; therefore, the effect of dosage, formulation and/or method of application (eg injected vs topical) should be investigated. General anaesthesia and NSAIDs can reduce pain during and following cautery disbudding of goat kids. Pain relief that is affordable, practical (eg easy to administer) and safe for both humans and the goats they manage is most likely to be adopted by farmers.

Bath (1998) suggested that the minimisation of pain caused by a husbandry procedure requires that it is done for the right reasons, by the best method, using the correct equipment, at the right time, with correct follow-up and with proper training. Until a less painful and efficacious alternative is realised, it appears that adapting cautery disbudding methods using pain mitigation is the best option currently available for farmed dairy goats. In order for the industry to establish best practice guidelines for disbudding goat kids, managers must recognise that goat kids are not small calves.

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