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Pressure Measurements from Five Different Nosebands at Rest, and During Riding at Walk, a Collected Gait, Backing up and a Full Stop

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Abstract

Background: Scientific procedures for addressing noseband fit and tightness, eliminating the risk of excessive and painful tightening, as well as quantitative measurements of pressures under the noseband while riding are either scarce or lacking. **Purpose/Aim:** To assess simple means of measuring pressure under different nosebands with a view to their adoption as scientific methodology. **Method:** Horses (n = 7) were fitted with five different bridles (A-E). Pressure distribution and intensity were measured using colour sensitive film (Fujifilm LLLW), assessing the level of pressure and distribution across the surface of the nosebands, as assessed and ranked by independent assessors. A CURO system was also used to measure pressure in real-time under nosebands whilst riding. **Results:** The colour-sensitive film for D & B were ranked 1st and 2nd, respectively. Regularity of pressure overall showed a statistical difference between nosebands (A & B significantly more unregular than the others). Pressure measurements revealed significantly different means (all $P < 0.0001$, except for B vs D and C vs E which were not significant; A (24.14 kPa), B (33.99 kPa), C (29.46 kPa), D (25.33 kPa) and E (30.26 kPa). **Conclusions:** Pressures under nosebands can reach levels that appear capable of inflicting tissue damage, hence bridles and nosebands should be assessed using scientific methodology and not based on arbitrary and subjective criteria, as is currently the case.

Keywords

Noseband, Welfare, Pain, Bridle Fit, Riding, Tölt, FEI

1. Introduction

There is currently no evidential background for the procedure of addressing noseband tightness, nor an objective way to eliminate excessive tightening of the noseband. Furthermore, the process of approving bridles under the governmental body of FEI is not based on quantitative measurements. Written confirmation to this effect from the FEI's spokesperson in Lausanne, Switzerland by e-mail (7th February 2023) stated that "*The FEI does not hold a certification process for individual pieces of equipment* [..]*..in other words, there is no mechanism where a manufacturer* [..] *would be able to submit a piece of tack and/or equipment for review by a panel, and get a "stamp of approval" by the FEI*". Instead, the FEI "*..merely interprets the applicable FEI Rules and Regulations when it comes to individual tack and equipment*", and reaches a decision that is not grounded in scientific quantifiable measurements.

A noseband is considered to be an important part of controlling the horse during riding [1] [2] [3]. Indeed, a study from 2013 showed that the noseband can increase the sensitivity towards the bit, enabling the rider greater control when the noseband is tightened to a certain level [4]. It should also be noted that the second most frequent reason for using a noseband under competition is that Fédération Équestre Internationale (FEI) requires it as part of their rules and regulations [2] [5]. However, one international study found great variance and significant difference in the tightness of the noseband within different FEI competition disciplines, where only 7% were found to meet the two finger FEI standard, equivalent to 1.5 cm, when measured objectively, and 44% were found to be tightened to 0 fingers, equivalent to 0 cm [1]. Such findings indicate a clear need for a better protocol for the control of equipment during FEI competitions, especially noseband tightness [1]. The obligate use of a noseband within the FEI regimen combined with the desire for aesthetic riding (e.g. neck frame, closed mouth), has over the past decade been of increasing academic concern, as the noseband can inhibit and restrict oral behaviour and jaw movements that potentially masks symptoms of conflict behaviour in the horse [6] [7].

The lack of scientific quantifiable assessment of horse tack, such as noseband fit and comfort by the FEI is surprising since horse welfare in general and the fit of tack to avoid pain and injury is part of their policy and code of conduct, and I quote "*The FEI requires all those involved in international equestrian sport to adhere to the FEI Code of Conduct and to acknowledge and accept that at all times the welfare of the Horse must be paramount. Welfare of the horse must never be subordinated to competitive or commercial influences*" [8].

Of course lack of an objective certification procedure for tack might be simply due to the fact that no current real-time scientific methodology exists, or has been adapted for the purpose of assessing comfort or pain in horses fitted with different bridles and nosebands. A couple of data logger studies have been performed though [9] [10]. Murray and colleagues measured bridle peak pressure and found it to be different between those bridles tested [9]. These authors were also able to show that greater carpal flexion, tarsal flexion and forelimb protraction were found with bridles that had a lower peak pressure, leading them to conclude that there may be an association between reduced peak bridle pressures and improved gait [9]. Robinson and Bye reported that pressures exerted by a side pull bitless bridle were capable of causing tissue damage if sustained for long periods of time. They furthermore attributed their observed pressure increase to be associated with the transfer of rein tension in a concentrated fashion on to the frontal nasal plane, instead of it being evenly distributed across the head [10]. Robinson and Bye also found that excess pressure from the bridle had an adverse effect on performance, which they attributed to avoidance behavior due to bridle design [10].

Defining what constitutes comfort or for that matter dis-comfort or pain is not an easy field to research. In humans we have the advantage of asking the subject involved as to whether a particular piece of equipment or clothing fits comfortably, we can even use such equipment as the DoloCuff [11] to provide quantifiable data about pressure and perceived pain—albeit still assessed by a Visual Analogue Scale evaluation [12]. However, in horses we must rely on what we can measure, or on body language and behavior during tacking and riding [13] [14] [15]. In a study from 2016, Fenner and colleagues found a significant correlation between a noseband tightened to 0 cm and increased heart rate, decreased heart variability and increased eye temperature indicating a physiological stress response [16]. Furthermore, these authors found an increased post inhibitory rebound effect where the horses increased their inhibited oral behavior such as licking, swallowing, chewing and yawning [16]. Moreover, an increase in eye temperature is correlated with an increase in the level of blood cortisol which is an indirect indicator of "*pain, stress and fear*" [6, 16]. Already as early as 2012 McGreevy and colleagues found a tendency towards an association of an increase in eye temperature with a decrease in facial skin temperature when the noseband was tightened [6].

Pressure sensitive film and pressure sensors are already commercially available, so it should be feasible to measure the amount of pressure exerted on regions of a horse's body by bridles, saddles, etc. Fujifilm Prescale pressure sensitive film has previously been used to accurately test pressure [17], whilst Acoustic Myography CURO units, designed to detect and record pressure waves from active tissue, a technique that has been tried and tested over the past decade [18]-[23], were modified for this study to record from linear thin film pressure sensors. Of course, one still needs to know how specific levels of pressure can be correlated with discomfort and pain. Pressure and the pain associated with an excess of the same, can be both administered as well as sensed. It is generally accepted that in terms of sensory pressure, hearing involving sound pressure waves in air above 110 decibels constitutes a threshold of discomfort, and that sounds of 130 decibels and above become painful [24]. Administered pressure to body tissues also has a pain threshold, the DoloCuff and similar mechanical test devices indicate that pressures of 250 mmHg (33 kPa or 3.3 N/cm^2) and above are painful, although there is individual variability as to what constitutes pain and likewise there are anatomical differences (e.g. skin thickness, subcutaneous tissue composition and depth). In an article aimed at determining the discomfort of the use of a tourniquet on human subjects, it was found that when the tourniquet was inflated to 250 mmHg over the upper arm, 60% of the subjects complained of moderate pain and 14% of severe pain, in other words, discomfort for almost 75% of those subjects tested (96 healthy individuals) [25]. Furthermore, a study comparing human skin against that of the horse, in which the gluteal region was analyzed, counted the number of nociceptors and the thickness of the epidermal layer of the skin and found no statistical difference, only a significant difference in the thickness of the dermal layer, which does not comprise pain sensitive free nerve endings [26].

With these issues in mind, the present study has chosen to focus on the measurement of pressure under five different nosebands by means of available scientific methodology (pressure sensitive film and sensors). The hypotheses tested are: i) Fujifilm LLLW and SEN0299 linear thin film pressure sensors in connection with specialized pressure CURO MkII units form a quantifiable means of monitoring pressure under the noseband of horses during exercise, and ii) FEI approved bridles exert less pressure under the noseband than one that has been recently banned by the FEI.

2. Materials and Methods

2.1. Animals

The measurements presented in this manuscript were carried out in accordance with the Helsinki Declaration. The owners of the horses used, gave their informed consent prior to the start of this study. In addition, this study was entirely non-invasive in its nature, and full ethical approval was gained from Copenhagen University Department of Pathobiological Sciences, Faculty of Health & Medical Sciences (protocol ID 2018-15-0201-01462; measurement dates 6 - 7th March 2023). The inclusion criteria were that animals were educated riding horses (> 7 years of experience), accustomed to bitted bridles. All the horses were evaluated through manual palpation as well as a complete physical evaluation by a qualified and experienced veterinary student (Emilie Gertz) and any horses exhibiting any pain responses were excluded from the study.

2.2. Bridle and Noseband Fitting

Before each horse was fitted with a bridle, the bridle was adjusted to the shape of the horse's head, so that the noseband sat as high as possible on the *Planum nasale*, but with at least one centimeter distance from the *Crista facialis*. The noseband was tightened to 1.5 cm as measured on the mid-plane of the bridge of *Planum nasale* using an ISES taper gauge (ISES Taper Gauge, International Society for Equitation Science, England) (see **Figure 1**). Measurements were made for seven horses and against four different FEI approved bridles (A, B, C and E) as well as one bridle that was not FEI approved (D), at rest and during a period of walk and collected gait (tölt) as well as during a full stop and backing up. The bridles were assessed in random order for the horses in this trial. The

Figure 1. Shows, from top left, the ISES taper gauge in use, which ensures a distance of at least 1.5 cm between the noseband and the Planum nasale. To the right is bridle A with an anatomical noseband, bridle B with a crank-type noseband, below far left is bridle C with an anatomical noseband, bridle D with an English noseband and bridle E with an anatomical noseband. Bridles A, B, C and E are all FEI approved, whilst bridle D was not.

horses were fitted with the same snaffle (KK ultra, 14 mm, Herman Sprenger, DE) and were ridden following the same riding sequence, using their own saddles and by the same experienced rider (Emilie Gertz). Bridles and bits were fitted by professional bit and bridle fitters Gill Batt and Jill Hick. It should be noted that pauses of a few seconds were made in between each of the exercises listed above. This, combined with the same riding sequence (walk, collected gait etc.) meant that pressure data for each of these activities could be reliably identified and measured subsequently.

2.3. Pressure Film (Fujifilm LLW)

Pressure under the noseband was assessed using Fujifilm LLLW—ultra super low-pressure film (0.2 - 0.6 MPa) which was cut as two strips that were gently placed together, inserted, and taped into the noseband of each of the bridles used in this study (see Figure 2). This two-sheet system is composed of two plastic films which are respectively coated with colour-forming material and colour-developing material. Microcapsules in the colour-forming layer are broken by pressure, and the colourless dye is absorbed into the developer, causing a chemical reaction producing a red colour. The microcapsules containing the colour-forming material are constructed to varying sizes and strengths, and are coated uniformly, producing a colour density that corresponds to the amount of pressure applied to the film.

Figure 2. Shows how the FujiFilm correlates with the amount of pressure exerted on the film. Note how this film can detect not only intensity of colouration but also whether it is a dense or diffuse colouration.

The time taken to measure pressure in this way requires a continuous pressure on the ultra-super low-pressure film (LLLW) of 5 seconds, and the measurement maintenance time is 2 minutes. Samples were removed immediately from the bridle after each test, and very carefully transferred to a light box (Folding Mini USB Lightbox 40 cm Photo Studio, CN) set to its maximum light setting (1200 lumens) to be photographed within minutes of completing each ride.

2.4. Pressure Sensor and Acoustic Myography

SEN0299 flat sensors (linear thin film pressure sensors; RP-L-400, DFRobot Inc, Mouser, DK) which are flexible and thin with a length of 400 mm were used to detect pressure. This sensor is durable and designed to sense static and dynamic pressure with a high response rate. SEN0299 sensors comprise a pressure sensitive layer and a thin conductive circuit. When outside pressure is applied to the active upper layer, the disconnected circuit of the lower layer becomes connected through the pressure sensitive layer and in this way converts pressure into resistance, which can be measured and recorded. The output resistance decreases as pressure increases.

Acoustic myography (AMG) is a biomechanical method capable of recording pressure waves generated in the equine tissue or in connection with equine equipment (stirrups, bridles etc.) [19]-[23]. For this study, modified CURO units (MkII) were used that were capable of handling pressure data from SEN0299 flat sensors (CURO-Diagnostics ApS, DK).

Using this setup, it was possible to see actual pressure measurements while the horses were physically active. A sampling rate of 1 kHz was used and recorded data were stored using the CURO App before being subsequently analyzed. Data from SEN0299 thin film sensors were collated and tested for statistical significance (see Table 3).

2.5. Pressure Film (Fujifilm LLLW) and Pressure Sensor Trace Interpretation

Both pressure films and pressure sensor traces were ranked by thirteen independent individuals. The method of selection of independent individuals asked to rank the pressure film and pressure sensor traces was one based on purposive sampling. Individuals were chosen based on their knowledge of horses and horse equipment, their knowledge of the scientific approach as well as their ability to read, understand and follow the guidelines provided. Individuals were excluded if it was deemed that they might be imprecise or biased in some way, although the identity of each piece of equipment was never revealed.

The pressure films were ranked based on the intensity of their colouration (correlated to the pressure applied) and the extent of coverage (area of film coloured). Higher ranking scores (4 or 5) were awarded to those strips with very intense colouration and a large area of the strip affected (see Table 1 and Figure 3).

The pressure sensor traces were ranked based on the level of pressure (the lower the trace the more pressure exerted) the regularity of the trace throughout the exercise period (dips indicate periods of high pressure) and any positive change in the trace during exercise. Low ranking scores (1 or 2) were awarded to those traces with a high, stable and even trace, especially if the trace increased during exercise. The independent individuals ranked these films and traces once, and did so in a blinded fashion, since they did not know which bridle represented which pressure film or pressure trace. They were told though to rank based on the aforementioned parameters. For an example of one such ranking scale adopted by an independent individual, see Figure 3.

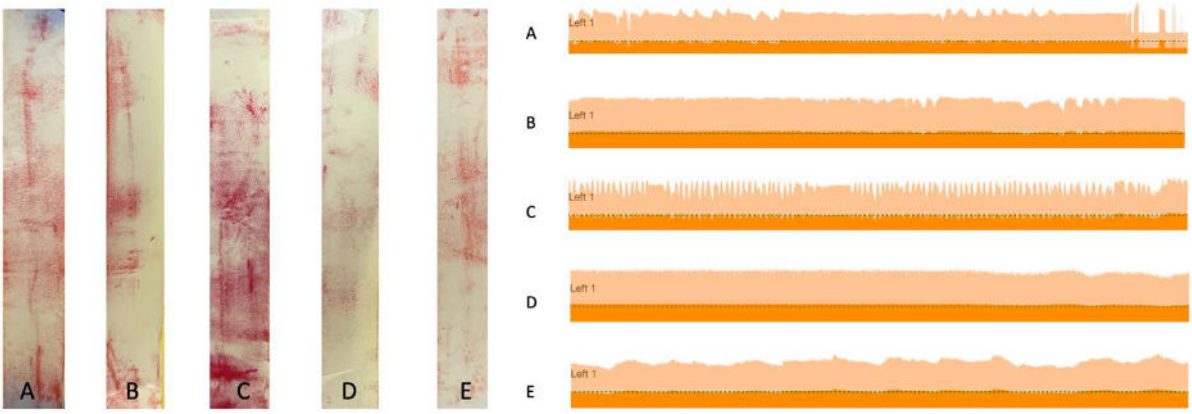

Figure 3. A typical Fujifilm LLLW strip can be seen on the left and a CURO pressure trace on the right for one of the horses tested using bridles A, B, C, D and E, where D was not an FEI approved bridle. The ranked assessment in this particular case, identified D as having the rank score of 1 based on how little colouration bridle D presented with, and the diffuse nature of the coloration, whilst C received the rank score of 5 (E = 2; B = 3; A = 4). The regularity of the pressure trace for this particular horse was also ranked, as was the degree of deflection from a resting position (top of the trace) such that D was ranked with a score of 1 and C was ranked with a score of 5 (B = 2; A = 3; E = 4).

2.6. Data Assessment and Statistics

Data were tested for normal distribution and normality using a Shapiro-Wilk test, and found to pass. Data for the Fujifilm LLLW strips and the CURO pressure sensor traces were ranked by thirteen independent individuals based on the aformentioned predefined parameters, before being tested for statistical significance using a Mann Whitney U test as well as a Tukey's Multiple Comparison test. Source of variation assessment between rows, assessing inter-observer variation was performed using a two-way ANOVA which provided not only the percentage of total variation, but also the level of any significance (Prism 10; Version 10.1.1; GraphPad Prism LLC, USA). The SEN0299 pressure sensor data were tested for statistical significance using an adjusted ANOVA for multiple comparisons and post hoc Tukey's test (Prism 10; Version 10.1.1; GraphPad Prism LLC, USA). Data are presented as means ± SD, as well as the median value where relevant.

3. Results

The results of this study are divided into three categories, two that are subjective and address the assessment of noseband pressure using the pressure sensitive film and the pressure sensor traces using acoustic myography, and then a third and final objective measurement of noseband pressure examining the actual pressure recordings.

3.1. Pressure Film (Fujifilm LLLW)

Table 1. Differences in the rank score assessment of the colouration of the Fujifilm LLLW pressure film for the five bridles tested. This rank score is based on 13 independent individual assessments (91 data values), using predefined parameters, and tested for statistical significance using a Mann Whitney U (MWU) test, as well as a Tukey's Multiple Comparison (TMC) test. Source of Variation assessment between rows and between columns found Observer variation to be 0% whilst Bridle variation was 72.9% ($P < 0.0001$). Moreover a Bartlett´s test found the SD's to be not significantly different.

Bridle	Rank Score		
	Mean ± SD	Median	Significance
A	4.30 ± 0.81	4.00	MWU: A vs. B; vs. C; vs. D; Vs. E = all $P < 0.00001$ TMC: A vs. B; A vs. D both $P < 0.0001$
B	1.79 ± 0.70	2.00	MWU: B vs. C; vs. D; vs. E = $P < 0.00001$; 0.0019; <0.00001 TMC: B vs. C; B vs. E both $P < 0.001$
C	3.71 ± 0.70	4.00	MWU: C vs. D; vs. E = $P < 0.00001$ and NS TMC: C vs. D = $P < 0.0001$
D- not FEI approved	1.45 ± 0.63	1.00	MWU: D vs. E = $P < 0.00001$ TMC: D vs. E = $P < 0.0001$
E	3.75 ± 1.16	4.00	See above

The first subjective assessment of noseband pressure involved the use of pressure film strips, the results of which can be seen in Figure 3. The left-hand panel of Figure 3 shows five typical pressure film strips, labelled A-E for each of the bridles. Note that the intensity of the colouration as well as the area distribution of colour differs between the five strips.

As described in the methods, the pressure films were ranked. It was found that bridle D had the best rank score of 1, with bridle B having the second best ranking, both of which were statistically significantly different from bridles A, C and E. In Table 1 you can see the results of the statistical analyses which reveal the results for the Mann Whitney U (MWU) test, as well as a Tukey's Multiple Comparison (TMC) test. The results indicate which bridle comparison was found to be significantly different; bridle A versus B for example.

3.2. Pressure Sensor Traces

The second subjective assessment of noseband pressure involved the use of SEN0299 pressure sensitive sensors connected to a CURO unit for visual assessment, the results of which can be seen in Figure 3. The right-hand panel of Figure 3 shows five typical pressure sensitive sensor traces, labelled A-E for each of the bridles. Note that the regularity of the trace (more regular in D) and the deflections from the resting position (end of A) vary considerably between the five traces.

Table 2. Differences in the rank score assessment of the regularity of the CURO pressure sensor trace measurements for the five bridles tested. This rank score is based on 13 independent individual assessments (91 data values), using predefined parameters, and tested for statistical significance using a Mann Whitney U (MWU) test, as well as a Tukey's Multiple Comparison (TMC) test. Where there is no TMC values, this test found no significant difference. Source of Variation assessment between rows and between columns found Observer variation to be 2.6% ($P < 0.0001$) whilst Bridle variation was 96.4% ($P < 0.0001$). Moreover a Bartlett's test found the SD's to be significantly different.

Bridle	Rank Score		
	Mean ± SD	Median	Significance
A	4.36 ± 0.96	5.00	MWU: A vs. B; vs. C; vs. D; Vs. E = all P < 0.00001 TMC: A vs. C P = 0.01; A vs. D P = 0.02; A vs. E P < 0.01
B	3.49 ± 1.28	4.00	MWU: B vs. C; vs. D; vs. E = all P < 0.00001
C	2.44 ± 1.14	2.00 NS	MWU: C vs. D; vs. E = both
D- not FEI approved	2.52 ± 1.16	3.00	MWU: D vs. E = NS
E	2.19 ± 1.22	2.00	See above

As described in the methods, the pressure sensitive sensor traces were ranked. It was found that bridles C, D and E received the best rank score, being not statistically different from each other, but significantly better ranked than bridles A and B. In Table 2 you can see the results of the statistical analyses which reveal the results for the Mann Whitney U (MWU) test, as well as a Tukey's Multiple Comparison (TMC) test. The results indicate which bridle comparison was found to be significantly different; bridle A *versus* B for example.

3.3. SEN0299 Pressure Sensors

The third measurement in this study was the only true objective assessment of noseband pressure and it was made by a detailed analysis of the CURO recordings obtained with the SEN0299 pressure sensors. The data were analyzed following the procedure outlined in the methods. All the bridles were compared against each other for significant difference between values (See Table 3).

Statistical significance using an ANOVA revealed the difference between pressure values, for each of the five bridles measured to be as follows; A vs. B $P < 0.0001$; A vs. C $P < 0.0001$; A vs. D $P < 0.0001$; A vs. E $P < 0.0001$; B vs. C $P < 0.0001$; B vs. D NS; B vs. E $P < 0.0001$; C vs. D $P < 0.0001$; C vs. E NS; D vs. E $P < 0.0001$.

It was found that bridle D had a significantly lower pressure exerted under the noseband than at least three of the FEI approved bridles tested.

The highest values (mmHg) were found during such activities as full stop and backing up, where pressures around 287 mmHg (38 kPa) were recorded. However, when one considers the SD values, actual maximum pressure recordings of 316 mmHg (42 kPa) were noted.

Table 3. Differences in the noseband pressures (mmHg with comparisons; kPa and N/cm2) for the five bridles tested in this study during periods of rest, backing up, during a collected gait—both minimum and maximum values, during a period of walk—both minimum and maximum values, with a full stop and overall mean values for all activities. Values are mean SD of 7 horses and underlined values (mmHg) represent the min and max for each bridle noseband. Statistical significance with ANOVA; A vs. B $P < 0.0001$; A vs. C $P < 0.0001$; A vs. D $P < 0.0001$; A vs. E $P < 0.0001$; B vs. C $P < 0.0001$; B vs. D NS; B vs. E $P < 0.0001$; C vs. D $P < 0.0001$; C vs. E NS; D vs. E $P < 0.0001$.

Bridle	*Mean*	*Rest*	*Backing up*	*Collected gait (Min)*	*Collected gait (Max)*	*Walk (Min)*	*Walk (Max)*	*Full stop*
A	181 ± 31 [24.14 kPa 2.41 N/cm^2]	145 ± 30 [19.33 kPa 1.93 N/cm^2]	236 ± 39 [31.46 kPa 3.14 N/cm^2]	157 ± 27 [20.93 kPa 2.09 N/cm^2]	212 ± 50 [28.26 kPa 2.82 N/cm^2]	162 ± 35 [21.59 kPa 2.15 N/cm^2]	207 ± 45 [27.59 kPa 2.75 N/cm^2]	231 ± 45 [30.79 kPa 3.07 N/cm^2]
B	255 ± 27 [33.99 kPa 3.39 N/cm^2]	244 ± 37 [32.53 kPa 3.25 N/cm^2]	284 ± 33 [37.86 kPa 3.78 N/cm^2]	253 ± 30 [33.73 kPa 3.37 N/cm^2]	282 ± 23 [37.59 kPa 3.75 N/cm^2]	259 ± 27 [34.53 kPa 3.45 N/cm^2]	276 ± 30 [36.79 kPa 3.67 N/cm^2]	287 ± 21 [38.26 kPa 3.82 N/cm^2]
C	221 ± 35 [29.46 kPa 2.94 N/cm^2]	202 ± 41 [26.93 kPa 2.69 N/cm^2]	252 ± 25 [33.59 kPa 3.35 N/cm^2]	205 ± 42 [27.33 kPa 2.73 N/cm^2]	231 ± 38 [30.79 kPa 3.07 N/cm^2]	211 ± 35 [28.13 kPa 2.81 N/cm^2]	234 ± 37 [31.19 kPa 3.11 N/cm^2]	252 ± 19 [33.59 kPa 3.35 N/cm^2]
D - not FEI approved	190 ± 05 [25.33 kPa 2.53 N/cm^2]	165 ± 08 [21.99 kPa 2.19 N/cm^2]	209 ± 09 [27.86 kPa 2.78 N/cm^2]	170 ± 08 [22.66 kPa 2.26 N/cm^2]	202 ± 09 [26.93 kPa 2.69 N/cm^2]	182 ± 05 [24.26 kPa 2.42 N/cm^2]	212 ± 07 [28.26 kPa 2.82 N/cm^2]	211 ± 09 [28.13 kPa 2.81 N/cm^2]
E	227 ± 02 [30.26 kPa 3.02 N/cm^2]	211 ± 03 [28.13 kPa 2.81 N/cm^2]	252 ± 16 [33.59 kPa 3.35 N/cm^2]	216 ± 06 [28.79 kPa 2.87 N/cm^2]	242 ± 02 [32.26 kPa 3.22 N/cm^2]	218 ± 05 [29.06 kPa 2.90 N/cm^2]	242 ± 07 [32.26 kPa 3.22 N/cm^2]	249 ± 10 [33.19 kPa 3.31 N/cm^2]

It is worth noting that each noseband had a different surface area. Measurements of the entire length and width (*i.e.* those regions covering the dorsal and ventral aspects of the *Os nasale*) of each of the 5 nosebands revealed areas of A = 43.2 cm^2; B = 134.4 cm^2; C = 30.0 cm^2; D = 82.5 cm^2; and E = 28.1 cm^2.

4. Discussion

To the best of the author's knowledge, this is one of the first scientific studies to measure the pressure under the dorsal region of nosebands, comparing four approved and one non-approved FEI bridle noseband whilst at rest, when backing up, during periods of walk and collected gait as well under a full stop. This study reveals that both Fujifilm LLLW and SEN0299 linear thin film pressure sensors form a quick, easy, non-invasive yet reliable, precise, and quantifiable measure of pressure under the noseband of horses during periods of physical activity as well as at rest. Furthermore, it has been demonstrated that the four FEI approved bridles do not offer less pressure under the noseband than one recently banned by the FEI.

Whilst this is a small study in terms of the number of horses measured, it does serve to illustrate the accuracy and repeatability of the techniques adopted. It should be noted though, that this study was undertaken outdoors, under prevailing weather conditions on two following days, and that as a result of a change in the weather on the second day an 8th horse was dropped from this study at the owners request. It is also worth noting that the rider was not blinded during the experiment, although they did not participate in fitting the bridles to the horses, since the rider remained seated on the same horse during each bridle change. However, emphasis was placed on not looking, but simply riding and following the exact same riding sequence each time. Each ride was also monitored and filmed, to ensure that it was the same procedure followed every time. It is accepted that horses learn by repetition [27], so it is not unthinkable that the horses in this study could have learnt the riding program and over the number of repeats, present the rider with a decreasing need to give signals along the way. This in turn could indirectly be anticipated to have an effect on the pressure under the noseband (reduced). In terms of discussing fatigue, the riding sequence lasted about 2.5 minutes and was repeated five times in total for each horse. Each horse had a pause between every riding sequence according to the time it took to change from one bridle to another, approximately 3 - 5 minutes. In total each horse was ridden for 12.5 minutes with a pause of 2.5 minutes in between each subsequent ride. It is not suspected that fatigue influenced the data, as all the participating horses were well trained and in good condition. Had fatigue been seen, then harder stop and start signals would have been noted from the rider for each horse, and such a change would have been noticeable as an increase in the pressure at these points in the recordings. However, it should be considered that the rider knew all the horses, was a very experienced rider, and would have noticed if any of the horses began to show signs of fatigue. Rider bias was eliminated as much as possible by randomly assigning the order of the bridles used, and using the same rider, with knowledge of each horse.

Results for the FujiFilm pressure film revealed a statistically significant difference between the bridles tested. FujiFilm was assessed both based on colour intensity and the area that was coloured, and results lend weight to the fact that both bridles B and D exerted the lowest pressure under the noseband of all the bridles tested. In support of which Clayton & MacKechnie-Guire [28] state that the criterion for a bridle having a pressure-reducing effect is met by increasing the surface area, combined with the noseband being padded with a shock-absorbing material that feels soft and yielding when lightly pressed.

The result for the CURO Pressure sensor trace revealed a significant difference between the bridles. Bridles C, D and E were found to have the best rank score, and they were not significantly different from one another. However, bridles A and B, which are both FEI approved, were found to produce traces with more irregular pressure than the other three bridles.

In terms of pressure measurements under nosebands of ridden horses, Murray and colleagues, used a data logger and a pressure mat fitted to the dorsal region (*Planum nasale)* of ten horses under a cavesson crank noseband adjusted to the usual tightness used by the rider [9]. Using this approach they were able to measure pressures under the nosebands during three straight line passes at a sitting trot, obtained over a 10 meter course, pressures they found to range from 30 - 53 kPa [9]. Whilst these values are very comparable with the present study if taken at the lower end of their range, the higher values of 53 kPa were never observed even when measured during backing up or with a full stop, a difference that could be due to the tightness of the noseband in their study compared with the present study. Recently, Robinson and Bye noted that noseband pressures in five horses had a mean of 2.67 - 4.42 N/cm^2 with peak values ranging 3.26 - 8.06 N/cm^2 measured at a rising trot in an arena [10]. Like the present study, Robinson and Bye measured from the dorsal region (*Planum nasale)* of horses, and used three different bridles; a cross under, a side pull and a snaffle with cavesson noseband [10]. Whilst Robinson and Bye typically recorded higher pressures with their trot and bridles than found in the present study, vales are most comparable with their snaffle and cavesson data [10]. The reason for their higher pressures is not immediately apparent as they also used a "two-finger" gauge to fit their nosebands, however, pressures of up to 6.82 N/cm^2 for the cross under and 8.06 N/cm^2 for the side pull bridles constitute values of 511 and 604 mmHg, respectively [10], values which are far in excess of painful pressures in man [25].

Casey and colleagues investigated where the pressure over the *Os nasalis* was greatest and found it to be on the lateral border [29]. In extension of which, a noseband with a smaller area might be expected to exert a higher pressure per square centimeter, which would likewise result in a stronger intensity in the red colouration when using the FujiFilm. Whilst pressure distribution over the *Os nasalis* can be expected to be greatest on the lateral edges, pressure will also be distributed *via* the soft tissue laterally in the cheek and caudal to this under the mandible [29]. It is perhaps not surprising then, that bridle D exerts less pressure than bridles A, C and E, since bridle D has an English noseband with pressure relieving design properties. Bridle B is, interestingly enough, also designed with similar pressure relieving properties, but this bridle exerted the most pressure under the noseband (284 ± 33 mmHg; see **Table 3**) of all the bridles tested, and one might perhaps assume this to be the result of its crank type design [6] [16] [29]. Pressures distributed over the *Planum nasale* and mandibles will of course be subject to anatomical structures, individual differences and bridle design, all of which should now be the focus of further study. One final point to note whilst discussing this topic is that even though bridle B exerted the highest pressure measured in this study, the outcome from the Fuji-Film ranking indicates that it was able to distribute this pressure more evenly when compared to the three other FEI approved bridles (A, C and E), perhaps this is related to the fact that bridle B had the largest surface area of all five nosebands in this study (162% greater than the next largest which was D).

Recently, MacKechnie-Guire and colleagues evaluated the pressure exerted on the nasal bones and the mandibular rami of four noseband types [30]. Their study used small pressure mats to assess noseband pressure and they adjusted tightness with the help of an ISES taper gauge with 0 to 2 fingers gap. Pressures were measured for 10 strides only in a straight line at the trot and revealed that with the noseband adjusted to 0 finger tightness, mean pressures were 6.7 kPa (50 mmHg) for the drop, 10.8 kPa (81 mmHg) for the cavesson, 14.4 kPa (108 mmHg) for the flash and 14.4 kPa (108 mmHg) for the crank nosebands, respectively [30]. However, what remains unknown from this study is how the pressure was distributed over the nosebands or indeed, whether the values reported by MacKechnie-Guire and colleagues represent the mean or min/max pressures recorded or are simply an average [30]. Likewise, one could argue that trotting for just 10 strides in a straight line cannot be compared to a full exercise program, and indeed one that includes among its exercises the sort of collection or tension that could be expected under competition. It remains clear, however, that the pressures measured by Mackechnie-Guire and colleagues are not dissimilar to those recorded in the present study using the SEN0299 thin film pressure sensors and modified CURO units [30], but how are these values to be understood?

Several groups, using indirect measurements of pressure under the noseband, have demonstrated that pressure affects a horse's physical stress response, all associated with the use of a tight noseband [6] [16], changes that may indicate perception of pain by horses. Whilst the present study has not measured pain, nor has it assessed potential tissue damage, it is well documented that prolonged periods of pressure on soft tissues adjacent to bony prominences lead to degeneration of underlying tissue, so called "pressure-related deep tissue injury", and more recently research indicates that tissue deformation *per se* may well be another candidate for initiating pressure-induced deep tissue injury [31]. Pressure related tissue injury has four acknowledged stages: 1) intact skin with persistent reddening "non-blanching erythema", 2) abrasion or blistering without bruising, 3) full thickness skin loss with superficial tissue exposure, and 4) full thickness skin loss with damage to underlying structures (*i.e.* nerves, tendon, bone). Stage 1 on this scale of pressure-induced injury is achieved with applied pressures of 1.9 N/cm^2 whilst pressures of 0.9 N/cm^2 if applied over a period of two hours can result in tissue death [32]. Furthermore, pressures of 0.40 N/cm^2 have been shown to limit axonal transport in nerves, whilst a pressure of 0.67 N/cm^2 results in an altered structure of myelin sheaths [33]. It is therefore proposed that future studies should examine precise pressures under and around the noseband of ridden horses and include the duration of application of tack into the experimental design.

Tissue damage aside, discomfort and pain have been described in horses in comparison to horse behaviour and facial expressions observed during box rest in response to invasive procedures or acute medical conditions [34] [35]. Recently an article entitled "An Equine Painface" was published, in which the results of an experimental trial were used to make an objective pain assessment of any given horse at rest, utilizing a point based system of the horse's mimicry, posture and behaviour [13], although this system may be biased or affected by the presence of people known to the horse. Dyson and colleagues [36] undertook a behavioural research study and then went on to develop a "Ridden Horse pain Ethogram" [14] which aims to be able to determine whether a horse has signs of musculoskeletal pain by assessing the horse's facial expression and behaviour whilst being ridden. A horse that expresses more than 8 of the 24 behaviour patterns most likely has an underlying painful issue [36]. Furthermore, Dyson and colleagues [15] concluded that there may be a connection between poorly adapted equipment and conflicting behaviour.

In summary, therefore, it is the opinion of the author that equine welfare, whether it be for competition or recreation, should be a major priority when designing, fitting and especially approving equipment such as bridles and nosebands. The time has come to use the science available to rethink the use of nosebands and to find an objective golden standard protocol for approving any piece of tack allowed by the FEI.

5. Conclusion

This study has demonstrated that scientific methodology can be used relatively quickly and easily to quantify the pressure under nosebands of different bridles, even whilst they are in use in real-time. It is therefore proposed that the procedure by which a bridle is approved or rejected by the FEI, which currently has no scientific basis, since the FEI has no official process or description of how they reach their decisions, as outlined by the FEI themselves, be modernized and quantified using such techniques, or similar, to those outlined in this study. Future studies should examine other potential techniques of measuring pressure under the noseband, as well as other locations (*i.e.* under the mandibular branches), as well as in connection with the pressure-distributing properties of other pieces of horse equipment.

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Conflicts of Interest

AH is in the process of establishing a company to produce and market the Acoustic MyoGraphy system (CURO-Diagnostics ApS).

Institutional Review Board Statement

Although this research was non-invasive in its nature ethical approval for the techniques used was sought and granted by The Research Ethics Committee of the University of Copenhagen—2023-09-PAS-014A.

Informed Consent Statement

Informed consent was obtained from all horse owners involved in the study.

Data Availability Statement

The author is happy to share data and to collaborate with those who find this research of interest, as well as to disclose the identity of each of the five bridles used in this study.

Disclaimer

This trial has been performed as an independent randomized and semi-blinded test without external influence. It has not been funded or paid for by any bridle manufacturers and nor has AH received any form of payment for these measurements.

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