A Pressure-Sensitive Glove for Standardization of the Force Applied During Distal Forelimb Flexion Tests in Horses

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A b s t r a c t

The force applied by the surgeon, during a flexion test, has a strong influence on the outcome of the test. The objective of this study was to verify if a commercially available pressure-sensitive glove could be used to standardize the force applied in the equine distal forelimb flexion test. Three experienced veterinary surgeons and three final-year students performed bilateral distal forelimb flexion tests on cadaver limbs and on live horses with a pressure-sensitive glove. All participants were asked to apply a constant force for 60 seconds using the indicator on the glove display while a camera recorded the value on the glove display. The videos were reviewed and the percentage of time for which the correct force was applied was measured. No significant differences were found between the percentages of time of application of the standard force between experienced and nonexperienced operators (P ¼.802). No statistical difference was found between experienced and inexperienced operator either in live horses (P ¼ .591) or in the cadaver model (P ¼ .797). In conclusion, the pressure-sensitive glove could become an essential and affordable tool for the equine practitioner, facilitating standardization of the test.

1. Introduction

Lameness evaluations with flexion tests are a routine procedure for equine practitioners and are commonly used in both lame and sound horses [1–6]. Positive or also negative results in these evaluations may help the clinician to understand the origin and the severity of the lameness. Previous studies have investigated factors that may influence the outcome of flexion tests [1–6] and divided them into three categories: examiner-related factors, physiological horse-related factors, and pathologic horse-related factors [6]. Examiner-related factors (force and time) have a strong influence on the outcome of the test, and several studies [2,3,5] have shown low interexaminer repeatability of the applied force. All the author cited recommended strict standardization of the force applied on the horse’s limbs and the time of application. For this purpose, various force-measuring devices have been developed [3,4]. These devices are not widely used in practice, possibly because they are not commercially available and self-manufacturing may not be possible for everybody.

The hypothesis of this study was that a commercially available pressure-sensitive glove, which was initially designed to measure the pressure applied by the fingers on a golf club, could be successfully used as a tool to standardize the force applied by the operator in the equine distal forelimb flexion test. The purpose of the study was to verify if a commercially available pressure-sensitive glove allows operators with different levels of experience to consistently apply a constant force for a standardized time during the distal limb flexion test in horses.

2. Materials and Methods

2.1. Instrumentation Description

The commercially available pressure-sensitive glove (SensoGlove, Senso Solutions GmbH, Aachen, Germany) is made of leather and contains one pressure sensor in each finger; each pressure sensor is made with a small balloon filled with air. This balloon when compressed send to a small computer placed on the dorsum of the glove the degree of compression of which it has been subjected which is then transformed by the software with a specific algorithm in a measure of pressure applied (Fig. 1). The computer has a small display that allows continuous monitoring of the pressure applied by each finger with instant visual and audio feedback. Once established the proper “grip” pressure, the glove will beeps at the precise point when the pressure violation is occurred. The pressure setting can be easily changed by means of dedicated buttons. If the glove becomes worn or if the operators use gloves of a different size, the computer can be removed and transferred to another glove with a simple move.

The SensoGlove is easily accessible to anyone and, at the time of writing, costs approximately $89 (80.68 V) for the complete glove and $22 (19.29 V) for the glove without the computer (excluding shipping cost), and it can be purchased easily trough the mainWebsite of the manufacturer (www.sensoglove.com). The computer has a scale (inner scale provided by the manufacturer) (Fig. 1) ranging from 1 (low sensitivity) to 18 (high sensitivity) that allows the operator to increase or decrease the sensor sensitivity depending of the need. Decreasing the number reduces the sensitivity, thus increasing the maximal force that may be applied on the sensors and vice versa. A visual force scale (Fig. 1) allows monitoring of changes in the pressure, and an acoustic warning indicates that the maximal value has been exceeded. For the perfect application of the set force, the operator must remain in the middle of the visual scale (Fig. 1). To increase the registered value on the visual force scale, it is sufficient to apply pressure on one finger at a time because the device can differentiate on which finger is applied the main force or in which finger the grip is too tight or too soft. If the force is applied to more than one finger, the display shows the fingers on which the force is applied and the computer registers the maximal force exerted by all the fingers involved, reporting which finger is overcoming or not the set force.

Because the leather of the glove was too thin to withstand continual contact with a horse hoof, we applied a more robust working glove onto the pressure-sensitive glove. This adjunct was proved by previous testing conducted by the author not to modify the sensitivity of the pressure-sensitive glove. Because the glove is designed to measure the pressure exerted by each finger on a golf club during the swing phase, it is not originally set to measure pressures as high as 100 N. For this reason, we asked the producer to modify the software of the glove by decreasing the sensitivity to the air pressure generated by the compression of the balloons. This way, while before end scale was achieved with a pressure of say approximately 10 N, after this modification, the glove can detect pressures up to 200 N before reaching end scale.

2.2. Calibration of the Glove

The glove was calibrated using a dynamometer (HCB200K100, Kern&Sohn, Balingen, Germany) connected to a handle. The pressure was increased until the value on the visual scale of the glove (left part of the display) was at the midscale point, which resulted in the audio warning. In accordance with the suggestions provided by Verschooten and Veerbeck [4], we have chosen a force of 100 N that corresponds to the midscale value on the glove display when sensitivity was set at 16 (sensitivity inner scale of the glove) (Fig. 1).

2.3. Study Population

Three inexperienced (fifth-year veterinary students), two males and one female mean age of 24.6 years, and three experienced (i.e., more than 3 years of experience in equine lameness evaluations) clinicians, two males and one female, mean age 35 years, participated in the study. Before starting the tests, each volunteer was asked to report the leading arm. They were then asked to perform the distal limb flexion test in a cadaver model and on live horses using the pressure-sensitive glove. For the cadaver model, a complete left and right limb distal was obtained from regularly slaughtered horses at a local abattoir. For the live horses, informed consent was obtained from the owners.

2.4. Performance of the Flexion Test

The flexion test of the distal limb was performed as described by Busschers and Van Weeren [6] and Keg et al [3] (Fig. 2); the examiner exerted a force on the dorsal surface of the hoof-wall with the glove, while maintaining the metacarpus in a vertical position. The upper arm of the examiner exerted a contrapressure on the distal radius of the horse [3,6]. After receiving brief training from an experienced clinician, the inexperienced participants carried out the flexion test under supervision. All the examiners first performed a series of six tests each on both forelimbs of a cadaver (cadaver limb model). Then, they all performed the tests on six standard-bred horses (live horse model).

2.5. Cadaver Limb Model

To estimate the ability of the operators to maintain the desired constant force for 60 seconds, a preliminary experiment was carried out on complete (from foot to shoulder) left and right horse fresh cadaver limbs, test was performed within 4 hours after death. The limbs were held in the same position as in a live horse, with the operator performing the flexion test in the same position as in the clinical setting. The limb was pinned by the scapula on a wooden wall. Pinning of the muscles and skin and not of the scapula allowed slight abduction of the limb and permitted the operators to perform the test in the correct position.

2.6. Live Horse Model

Six standard-bred horses (age, 3–6 years; weight, 450–530 kg; three females, three males) that resulted sound at a preliminary lameness investigation performed separately by all the experienced clinicians were used for the study. All the operators performed bilateral distal forelimb flexion tests on each horse. Each horse underwent only one bilateral flexion test per day, and the tests were performed at least 24 hours apart.

2.7. Force–Time Evaluations

On both models, participants were asked to apply a constant force so as to reach and not overcome the midscale indicator on the glove and hold it for 60 seconds. Operators had a clear view of the glove display while performing the test, which allowed them to accordingly correct the application of the force. An operator with a camera recorded the visual scale value on the glove display for each attempt. A blind observer then reviewed the videos to evaluate whether a constant force of 100 N was applied throughout the 60-second period. The total time for which the appropriate force was applied was expressed as a percentage over 60 seconds in which the display indicator on the glove was on the desired spot.

2.8. Statistical Analysis

For each assessment, we obtained the median, maximum, and minimum values of the total time during which the appropriate force was applied. Normality of data was determined with the Shapiro–Wilk test. Data were divided into four different categories (experienced with left and right limbs and nonexperienced with left and right limbs). To evaluate the extent to which the data were consistent with the null hypothesis (i.e., that there is no difference among the different four categories), Kruskal–Wallis test was performed. As post hoc test, Wilcoxon signed rank test (paired), or Wilcoxon rank sum test (unpaired) were used to compare flexion test time percentage obtained from left and right limbs and from experienced and nonexperienced operators both in the cadaver model and in the live horse model. Furthermore, coefficients of variation were calculated for each left and right limb overall, experienced and inexperienced operators, left and right limbs of experienced and inexperienced operators, experienced and inexperienced operators overall, and both in the cadaver limb test and in the live horse test. Statistical analysis was performed using Graphpad Prism 6.0 (Graphpad, La Jolla, CA), and significance was set at P <.05.

3. Results

Descriptive statistics of the total time for which the appropriate force was applied are reported in Table 1. No significant differences were found between the percentages of time of application of the standard force between experienced and inexperienced operators (P ¼ .802) and between left and right limb flexion (P ¼.99) in the cadaver limb test. Similarly, in the live horse test, no significant difference was found between experienced and inexperienced operators (P ¼ .59) and between left and right limb flexion (P ¼ .218).

When analyzing differences in the right limb flexion test, significant difference was found between the live and cadaver models (P ¼ .006). The same comparison was not significant for the left limb (P ¼ .12).

No statistical difference was found between experienced and inexperienced operator either in live horses (P ¼ .591) and in the cadaver model (P ¼.797) (the difference in the overall percentage between flexion tests performed in the cadaver or live horse model was significant [P ¼.0032]).

The coefficients of variation are reported in Table 2. The coefficient of variation was higher for every variable in the live horse model.

4. Discussion

During lameness investigations, flexion tests are an important tool, but there are many variables that influence the outcome of this procedure. The force used for the flexion test is individually determined and affects the outcome of the test. It is particularly important to try to eliminate any factor that would lead to systematic bias and the use of the glove allows application of a constant force.

As determined by the results, the glove allows experienced and nonexperienced operators to apply a 100 N force with very little variation on both forelimbs during a flexion test. In clinical practice, the use of the glove could allow standardization of the force applied in flexion tests in horses, making them a reliable tool even when used by inexperienced operators.

By watching the visual scale on the display, the clinician can adjust the force exerted and thus achieve a high degree of consistency during and between flexion tests. From our data, four factors appear to mainly influence the ability of the operator to maintain a constant force for 60 seconds.

The first factor is the horse itself, as reflected by the difference in percentages and by the generally lower coefficients of variation between flexion tests performed in the live or cadaver models. The difference between live and cadaver limbs is due to the spontaneous movements of horses that can cause momentary loss of control and result in variations in the pressure applied. Evaluating the inconsistent pressure application on sound or lame horses was beyond the purposes of this study, but we could speculate that in horses with positive flexion tests, this factor may be even more influential. Nevertheless, the loss of pressure can occur when performing the tests without the pressure-sensitive glove, and this factor cannot be completely controlled. However, the presence of the glove allows the operator to immediately correct the variations in force as soon as the horse movement subsides.

The second factor is the operator’s familiarity with using the glove, as reflected by the higher percentages of application in the live horse model. While one would expect to see the opposite trend, the fact that all volunteers performed the tests on the cadaver first may have helped them gain familiarity with the correct positioning of the glove.

The third factor is related to variations among operator ability, as reflected by the values recorded in the cadaver limb model. While we could expect each operator to apply the 100 N force 100% of the time in each test in the cadaver model, this was not the case. We think that this could be attributed to muscle fatigue, the concentration levels of the operator, and to their coordination, that is their ability to quickly react to variations in the values displayed.

The fourth factor influencing the findings is the leading arm of the operator, as reflected by differences in coefficients of variation between left and right limbs, both in the cadaver and live horse models and the higher total coefficient of variation in the right limb in the live horse model. The clinicians in our study were all right handed, and this could have resulted in a different direction of application of the force when it was applied to the right forelimb, compared with the left, despite the fact that all operators were asked to standardize their position as much as possible while performing the test. It is reported in literature that the two arms often demonstrate differences in sensorimotor ability, preferred hands being more reliant on the use of visual information during targeted movement, whereas nonpreferred hands are believed to be more reliant on proprioceptive feedback [7]. Nevertheless in bimanual tasks, as the flexion test is, it is important to report that the preferred hand usually performs the fine movement and the nonpreferred hand has the stabilizing role [8]. Therefore, the whole operation of forelimb flexion test in horses may rely on visual information for fine tuning.

The coefficient of variation in live horses ranged between 2.79% and 6.1%. Thus, the maximum time for which the correct force was not applied ranged between 1.7 and 3.7 seconds.We can speculate that this period could not be clinically relevant. In fact, previous studies observed values between 5 and 60 seconds, which is a wide range. In a clinical setting, it will be very difficult to consistently apply the 100 N force for 100% of the 60-second period in the 100% of live horses examined, regardless of the method used to standardize the force.

Previous studies found that there was a clear and statistically significant difference between the forces applied by experienced and inexperienced examiners with different outcomes of the test in the same horse [3]. The flexion test is a useful tool in the hands of experienced clinicians who can apply a relatively standardized force, but the results of this procedure can be questionable due to large variations between individuals [3]. However, the pressure-sensitive glove could be also useful for experienced clinicians to standardize the force during different lameness examinations of the same horse.

Relative to the device described by Keg et al [2] and Verschooten and Veerbeck [4], the glove used in this study is more portable, is commercially available, and relatively inexpensive. The little computer on the back of the glove may be kept while replacing the glove itself. This glove may be particularly useful in the case of a prepurchase examination where a false-positive result of the flexion test may influence the results, the glove will not give the idea if the flexion test is positive or not but at least it will exclude one of the variables. Flexion tests performed on a single horse by different veterinarians may have different results, and the force applied by each individual is an important factor that affects the outcome. Only when both the force and the time are standardized in a consistent way does the flexion test become an objective tool for examination of the locomotor system of the horse without operator-related confounding factors. Our glove could standardize the force for forelimb flexion test, and the low cost of the device makes it particularly affordable for all veterinarians. One potential limitation of the glove is that it only indicates whether a preset force is applied; thus, proper setting is mandatory. This can be easily achieved by wearing the glove and pushing with one finger at a time on a weight scale, by changing the setting on the glove's display, one can precisely define the corresponding force applied.

Because of the shape of the small balloons, we noticed that forces not applied in a perpendicular direction relative to their surface will not be correctly measured. While this could be regarded as a limit, it is actually a merit. By forcing the operator to apply the force in a correct direction, the glove forces the operator to perform the flexion test correctly and with a consistent method. Furthermore, each clinician has to be aware of the limitations caused by the four factors that may influence the time of application of the force. Familiarity with using the glove, proper coordination, and correct positioning during the flexion tests may reduce the effects of these limitations.

Another limitation is that the glove is not waterproof, and the participants have reported some doubts about the easy usury of the glove. However, these problems could be overcome because, thanks to the characteristics of the sensors (air balloons instead of pressure-sensitive electronics), it is possible to put a more robust glove above, without reducing the effectiveness.

Further study may also evaluate hysteresis of the pressure and the curve over time applied on the glove during the procedure, which in this studywas beyond the purpose.

5. Conclusions

In conclusion, the pressure-sensitive glovewas effective in standardizing the force applied during the distal forelimb flexion tests and could become an essential and affordable tool for the equine practitioner, allowing standardization of the test and an objective assessment during equine lameness investigation.

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Table 1:

Percentages (median-min/max) of time in which the force of 100 N was applied over a 60-second period by inexperienced (tot: 3; inexp) and experienced (tot: 3; exp) examiners, in a cadaver model on six live horses.

Group	Left	95% CI	Right	95% CI	Total	95% CI
Cadaver study						
Total inexp	95 (92–98)	93.99–96.34	94.5 (93–100)	93.84–96.49	95 (90–100)	94.1–96.15
Total exp	95 (90–100)	93.2–96.97	95 (93–100)	94.45–96.89	95 (93–100)	94.58–96.25
Total	95 (90–100)	94.1–96.15	95 (93–100)	94.58–96.25	95 (90–100)	94.63–95.91
Live horse						
Total inexp	98 (90–100)	95.46–99.94	97.5 (92–100)	94.87–98.73	97.5 (80–100)	94–98.20
Total exp	97 (90–100)	91.69–99.11	97.5 (92–100)	91.21–99.59	98 (82–100)	94.52–98.58
Total	97 (80–100)	92.88–97.92	98 (90–100)	95.9–98.6	98 (80–100)	94.93–97.72

Abbreviation: CI, confidence interval.

Table 2:

Coefficient of variation of the percentages of inexperienced (inexp) and experienced (exp).

Group	Left	Right	Total
Cadaver study			
Total inexp	1.94	2.19	2.54
Total exp	2.01	3.12	2.07
Total	2.54	2.07	2.3
Live horse study			
Total inexp	2.79	3.2	4.68
Total exp	5.44	6.14	4.49
Total	2.96	5.64	4.53