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Validity and repeatability of goniometry in normal horses

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Keywords
Horse, joint, goniometry

Summary

Purpose: To assess validity and inter- and intra-tester reliability of equine goniometry and to establish values for carpal, metacarpophalangeal, tarsal, and metatarsophalangeal flexion and extension in horses.
Subjects: Seventeen healthy equine subjects of varied breeds were used.
Methods: Three investigators blindly and independently measured in triplicate the extension and flexion of carpal, metacarpophalangeal, tarsal, and metatarsophalangeal joints of 17 horses after sedation. Radiographs of these joints in flexion and extension were acquired while under sedation. Goniometric and radiographic measurements were compared statistically and were correlated. A Bland-Altman plot was constructed. Inter- and intra-tester repeatability of goniometry were evaluated by calculating intraclass correlation coefficients (ICC). Mean flexion and extension of carpal, metacarpophalangeal, tarsal, and metatarsophalangeal joints were calculated.
Results: Goniometric and radiographic measurements did not differ statistically and were significantly correlated (correlation coefficients ranged from 0.59 - 0.89). The mean difference between goniometric and radiographic measurements was 0.4°. Triplicate measurements collected by the three raters did not differ significantly within raters (ICC ranging from 0.950 - 0.995) and between raters (ICC ranging from 0.942 - 0.989).
Conclusion: Goniometry is a valid and repeatable tool for evaluation of the range of motion of carpal, metacarpophalangeal, tarsal, and metatarsophalangeal joints in standing, sedated healthy horses.

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Introduction

Goniometry is the measurement of joint angles performed with a goniometer. It is a relatively simple, affordable, and non-invasive method to quantitatively measure joint motion. In humans, the accuracy and reproducibility of goniometry have been documented and various goniometric methods have been compared (1-4). Orthopaedic surgeons and physical therapists commonly use goniometry to objectively measure the range of motion (ROM) of joints. These objective measures aid in decisions on therapeutic interventions and allow documentation of progress after intervention (5, 6). Goniometry has also been used in dogs, cats, and calves. Reliability and validity of goniometry have been established in healthy Labrador Retrievers and German Shepherd dogs (7, 8). Goniometry has also been used to evaluate diseased carpal, elbow, shoulder, stifle, and hip joints in dogs (9-22). Similarly, goniometry has been validated in healthy cats and used in cats with osteoarthritis (23, 24). The repeatability of goniometry in calves has been reported (25). In horses, the flexion of metacarpophalangeal joints of healthy and injured horses have been reported and repeatability of goniometry for measuring passive flexion of the carpal, metacarpophalangeal, tarsal, and metatarsophalangeal joints has been reported (26-28). However, extension of these joints has not been evaluated and goniometric measurements have not been validated by statistically comparing goniometric measurements to radiographic measurements.

The objectives of this study were to evaluate validity, intra-tester repeatability, and inter-tester repeatability of goniometric measurements of the carpal, metacarpophalangeal, tarsal, and metatarsophalangeal joints in horses free of orthopaedic disease. It was also intended to calculate the mean and confidence intervals for flexion and extension in normal joints. The hypothesis was that goniometry is a valid and a repeatable instrument that allows for quantifiable evaluation of flexion and extension of selected equine joints.

Materials and methods

The institutional animal care and use committee of the University of Tennessee (Knoxville, TN, USA) approved the experimental protocol. Horses belonging to the College of Veterinary Medicine at the University of Tennessee (Knoxville) that measured 132 cm (13 hands) to 163 cm (16 hands), had no history of injury or trauma and no evident lameness, and had no radiographic signs of osteoarthritis were eligible for inclusion in the study. Horses were part of a teaching herd that was composed of Quarter horses, Thoroughbreds, and Tennessee Walking Horses. All were housed on pasture. Horses were initially assessed by a board certified veterinary surgeon (HSA) using an orthopaedic examination protocol that consisted of a movement examination, flexion tests, and ROM assessment. The movement examination was performed while trotting in a straight line in hand on a hard surface. Standard flexion tests were performed by flexing the metacarpophalangeal and metatarsophalangeal joints for 30 seconds and the hock or carpus for one minute and then trotting in hand in a straight line on a hard surface (29). Joints were passively moved through the complete passive ROM in the standing non-sedated horse to determine if there was restricted joint motion or a pain response to manipulation. Horses that were determined to be lame, had restricted joint motion, or showed signs of pain in response to joint manipulation were excluded from the study. All remaining horses had a standard series of radiographs acquired for all joints to be studied. Those with evidence of osteoarthritis were excluded from the study.

Horses were sedated with detomidine HCl[a] (0.2 to 0.4 µg/kg IV). The side of the evaluation was randomly selected before data collection (e.g., if 'left' was selected, goniometric and radiographic measurements were collected from left limbs). Four joints were evaluated: the carpus, metacarpophalangeal joints, tarsus, and metatarsophalangeal joints. Three investigators (CAD, MAH, EKL) evaluated two positions for each joint: standing extension and maximal passive flexion. The investigators underwent a training session in which the measurement protocols were reviewed and practised, and two horses were measured as a group. Plastic goniometers[b] with 25 cm long arms were modified. For carpal and tarsal measurements, the arms of the goniometer were extended to 37 cm. For metacarpophalangeal and metatarsophalangeal measurements, one arm was shortened to 10 cm. The goniometers had one-degree graduations. All measurements were collected using a validated method (7). The investigators could see the arms of the goniometers, but were blinded to the graduations and measurements. Following measurement, the goniometer was turned so that an additional investigator read and recorded the numeric value of each measurement. Measurements by each investigator were collected in triplicate. To assess intra-rater repeatability, one investigator performed three sets of goniometric measurements for each joint position with an interval of approximately four hours between each set. Goniometric measurements of extension were collected in a standard pose with the horse standing squarely, bearing full weight, and with both forelimbs and hindlimbs in a vertical position (30). The limb was then lifted, joints were maximally flexed manually, and passive flexion was measured.

Prior to determining the joint angle, the joint to be measured was carried through its full ROM to determine the axis of rotation (28). The axis of rotation for the carpus is dorsal to the joint and for the tarsus is plantar to the joint, as previously described (28). Other landmarks were chosen based on the fact that they were easily palpable or had been used in other conformational studies (30-32). For carpal joint extension and flexion, the goniometer disc was placed at the previously determined axis of rotation. The proximal arm of the goniometer was aligned with the cranial to caudal midpoint of the lateral aspect of the antebrachium and extended proximally to the palpable lateral tuberosity of the radius. The distal arm of the goniometer was aligned with the long axis of the lateral aspect of the third metacarpal bone and extended distally to the centre of the palpable lateral condylar fossa of the third metacarpal bone. For metacarpophalangeal joint extension and flexion, the goniometer disc was placed at the previously determined axis of rotation. The proximal arm of the goniometer was aligned with the long axis of the lateral aspect of the third metacarpal bone and extended proximally to the dorsal aspect of the palpable proximal fourth metacarpal bone. The distal arm of the goniometer was aligned with the long axis of the lateral aspect of the proximal phalanx and extended distally to the palpable lateral eminence of the middle phalanx. For tarsal extension and flexion, the goniometer disc was placed at the previously determined axis of rotation. The proximal arm of the goniometer was aligned with the long axis of the tibial shaft and extended proximally to the palpable lateral tibial condyle. The distal arm of the goniometer was aligned with the long axis of the lateral aspect of the third metatarsal bone and extended distally to the centre of the palpable lateral condylar fossa of the third metatarsal bone. For metacarpophalangeal joint extension and flexion, the goniometer disc was placed at the previously determined axis of rotation. The proximal arm of the goniometer was aligned with the long axis of the lateral aspect of the third metatarsal bone and extended proximally to the dorsal aspect of the palpable proximal fourth metatarsal bone. The distal arm of the goniometer was aligned with the long axis of the lateral aspect of the proximal phalanx and extended distally to the palpable lateral eminence of the middle phalanx.

The joints were digitally radiographed using an imaging plate[c] measuring 27.5 by 35 cm. Standard lateromedial radiographs of the joint of interest were acquired with the horse standing squarely and bearing full weight on all four limbs. When the limb was lifted and the joint of interest was maximally flexed, the horse was standing squarely and the flexed limb was maintained in a vertical line with the upper portion of the limb. Digital goniometric measurements were collected on radiographs by use of an image processing software[d] application.

Carpal extension was the angle formed by the cranial aspect of the cortex of the distal portion of the radius and the dorsal aspect of the cortex of the proximal portion of the third metacarpal bone (measured using the *dynamic angle* software function). Carpal flexion was measured by drawing the long axes of the distal portion on the antebrachial and

a Dormosedan®: Zoetis United States, Florham Park, NJ, USA
b Plastic 360 ISOM Goniometer: DJO Global, Vista, CA, USA
c MyRad Standard: Universal Imaging, Bedford Hills, NY, USA
d OsiriX Imaging Software, version 4.1.32: Pixmeo SARL, Bernex, Switzerland; Available at: http://www.osirix-viewer.com/

Table 1 Mean measurement values of various joints as obtained by three observers by use of a plastic goniometer and from radiographs in 17 healthy horses.

Joint position	Goniometric measurements (mean ± SD; degrees)	Radiographic measurements (mean ± SD; degrees)	Correlation	p-value*	95% CI of goniometric measurements (degrees)
Carpus flexion	31 ± 4	31 ± 4	0.78	<0.001	29 to 35
Carpus extension	183 ± 3	183 ± 3	0.63	0.007	181 to 186
Metacarpophalangeal flexion	120 ± 4	120 ± 6	0.70	0.002	118 to 123
Metacarpophalangeal extension	210 ± 6	212 ± 4	0.59	0.013	208 to 216
Tarsus flexion	40 ± 7	42 ± 4	0.83	<0.001	37 to 47
Tarsal extension	159 ± 5	158 ± 5	0.89	<0.001	156 to 164
Metatarsophalangeal flexion	95 ± 5	97 ± 6	0.68	0.003	93 to 101
Metatarsophalangeal extension	206 ± 7	205 ± 4	0.69	0.002	203 to 213

Correlation = Pearson's correlation coefficient. *For each joint position, p-values <0.05 indicate a statistically significant correlation between goniometric and radiographic measurements. 95%CI = 95% confidence interval.

metacarpal limb segments using the *axis* function of the image analysis software, and measuring the angle formed by two 20 cm long lines joining the long axes of the antebrachium and metacarpal limb segments and intersecting on the dorsal to palmar midpoint of the distal aspect of the carpus. Metacarpophalangeal extension was the angle formed by the long axes of the third metacarpal bone and proximal phalanx (measured using the *axis* function). Metacarpophalangeal flexion was the angle formed by the dorsal aspect of the third metacarpal bone and the palmar aspect of the proximal phalanx (measured using the *dynamic angle* function). Tarsal extension was the angle formed by the cranial aspects of the cortex of the tibia and dorsal aspect of the cortex of the third metatarsal bone (measured using the *dynamic angle* function). Tarsal flexion was the angle formed by the caudal aspect of the skin surface of the crus and the dorsal aspect of the third metatarsal bone (measured using the *dynamic angle* function). Metatarsophalangeal extension was the angle formed by the long axes of the third metatarsal bone and proximal phalanx. Metatarsophalangeal flexion was the angle formed by the dorsal aspect of the third metatarsal bone and the plantar aspect of the proximal phalanx (measured using the *dynamic angle* function).

A priori power analyses with a power of 0.80 and a p-value <0.05 were performed using pilot data from three horses to determine the number of subjects needed to detect differences between goniometric measurements collected by different observers, and to detect differences between the goniometric and radiographic measurements. Sample sizes ranged from four to nine subjects.

Goniometric and radiographic measurements were compared using two-tailed paired t-tests[e]. Pearson correlation coefficients for goniometric and radiographic measurements were calculated. Interclass correlation coefficients of multiple goniometric measurements were calculated within and between raters. A Bland-Altman plot of goniometric and radiographic measurements was charted. Significance was set at p <0.05.

Results

Twenty-six horses of various breeds were screened for inclusion. Nine horses were excluded because of lameness, restricted joint motion, or showed signs of pain in response to joint manipulation. Seventeen horses were included. Horses ranged in height between 139.7 cm (13.3 hands) and 157.5 cm. (15.2 hands). The horses were four to 19 years of age. Measurements were collected from the right limbs in 12 horses and the left limbs in five horses. Mean ± SD goniometric and radiographic measurements and confidence intervals for each joint position are reported in ▶Table 1. Goniometric and radiographic measurements did not differ statistically (p ranging from 0.107 to 0.941). The mean difference between goniometric and radiographic measurements was 0.4° and is presented on a Bland-Altman plot (▶Figure 1). Correlation coefficients between goniometric and radiographic measurements for each joint position ranged from 0.59 to 0.89, and were statistically significant (all p <0.013). Measurements collected by the three raters did not differ significantly within raters (ICC ranging from 0.950 to 0.995, p <0.001, ▶Table 2) and between raters (ICC ranging from 0.942 to 0.989, p <0.001).

Discussion

We accepted our hypotheses that equine goniometry of normal joints is valid and reliable within and between observers. The flexion and extension angles obtained from

e SPSS version 21 for Mac: IBM Corporation, Armonk, NY, USA manual goniometric measurements of the carpal, metacarpophalangeal, tarsal, and metatarsophalangeal joints are comparable to those obtained radiographically. The primary benefit of this is related to therapeutic monitoring. When treating or monitoring a condition that affects joint motion, the examiner has the ability to serially monitor improvement or worsening of the condition. This will allow for an early change in the treatment protocol if indicated. Additionally, radiographic equipment may not always be available, or in the case of non-digital radiographs, may take a prolonged time to get measurements. Having a technique comparable to radiographs that allows for the rapid collection of joint angles is desirable. In addition, there is a decreased expense of not having to obtain radiographs and a decreased radiation exposure to personnel.

Liljebrink and colleagues examined the intra- and inter-tester reliability of goniometric measurements of joint flexion in horses, including differences between two investigators and differences in flexion measurements collected in standing and anaesthetized horses (28). In that study, intra-tester reliability was high to excellent (ICC ranging from 0.8 to 1) and inter-tester reliability was low to average (ICC ranging from 0.1 to 0.5). The authors concluded that goniometry was a promising tool in documenting passive joint motion when used by a single investigator. That study, however, only assessed reliability of passive flexion of the carpal, metacarpophalangeal, tarsal, and metatarsophalangeal joints. In contrast, the current study examined both flexion and extension of these four joints. The current study shows excellent intra- and inter-tester reliability. The improved inter-observer repeatability may be due to the fact that each investigator underwent a training session prior to collecting measurements, thus enhancing their understanding of preselected landmarks used for the placement of the goniometer. The modifications of the arms of the goniometer to more closely fit the limb may also have improved the repeatability of measurements. The maximum passive flexion values obtained in the current study are similar to those obtained by Liljebrink and colleagues (28). However, due to differences in recording methods, a direct comparison of the values cannot be made. In the current study, the interior angle was always in the direction of joint flexion, as it is done in goniometric measurements in dogs and cats (7). Joint angles were greatest when joints were in extension and as the joints were flexed, angles decreased. Measurements in the previous study were collected using a different method (28). Subtracting 180° from these measurements yields values that are comparable to the values reported in the current study. Mean carpal and tarsal flexions, for example, were 24° and 49° respectively in the Liljebrink study compared to 31° and 40° in the current study. Similarly, metacarpophalangeal flexion was 125° in that same study and was 120° in the current study (28).

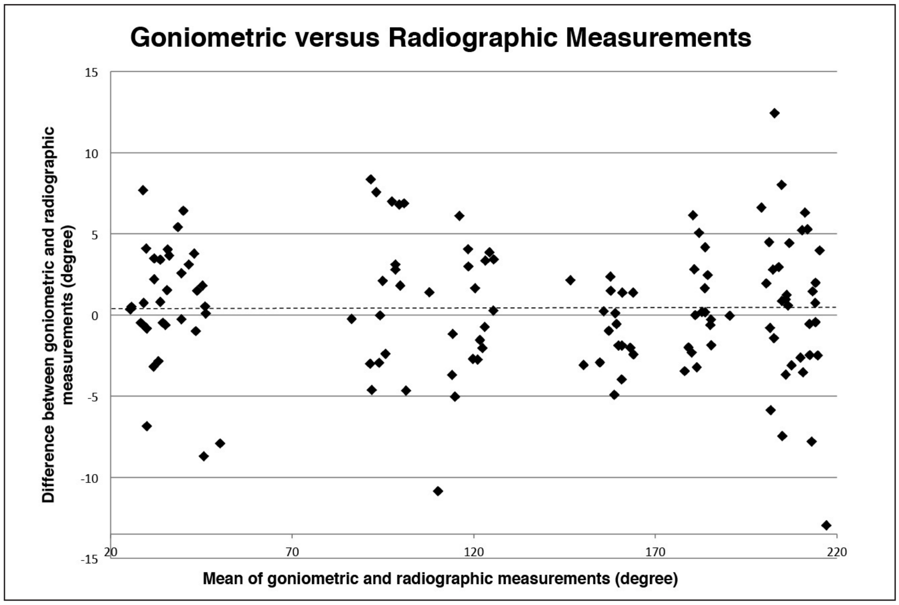

Figure 1 Bland-Altman plot of goniometric versus radiographic measurements of flexion and extension of four joints in 17 horses (n = 136 paired measurements). The dashed line represents the mean difference between goniometric and radiographic measurements (0.4°).

Table 2 Inter-rater and intra-rater repeatability of goniometric measurements of various joints as obtained by three observers by use of a plastic goniometer in 17 healthy horses.

Joint position	Inter-rater ICC*	Intra-rater ICC*		
		Rater A	Rater B	Rater C
Carpus flexion	0.965*	0.960	0.950	0.971
Carpus extension†	0.974	0.979	0.985	0.975
Carpometacarpal flexion	0.942	0.969	0.958	0.978
Carpometacarpal extension	0.980	0.976	0.983	0.979
Tarsus flexion	0.989	0.991	0.993	0.995
Tarsal extension	0.980	0.974	0.975	0.974
Tarsometatarsal flexion	0.964	0.985	0.989	0.987
Tarsometatarsal extension	0.986	0.981	0.992	0.985

ICC = Interclass correlation coefficient. * All ICC had p-values <0.001.
† Extension measurements were collected with horses standing.

The standing goniometric extension angles determined in this study were similar to those determined by photography, kinematics, and three-dimensional motion analysis in previous studies (30-34). In the current study, the standing carpal extension angle was 183° ± 3°; previous studies have reported angles ranging from 176° to 194° (33, 34). The standing tarsal extension angle in the current study was 159° ± 5°; previous studies have reported angles ranging from 147° to 169° (30, 31, 34). Previous studies of standing metacarpophalangeal and metatarsophalangeal angles measured angles that were supplementary to the angles measured in the current study. After conversion, the standing metacarpophalangeal angle in the current study was 210° ± 6° while previous studies reported angles ranging from 195° to 212° (31, 34). The standing metatarsophalangeal angle in the current study was 206° ± 7°. Previous studies reported angles ranging from 195° to 228°.

Goniometry is designed to be easily and rapidly performed by clinicians. Goniometry of large limb joints usually relies on aligning the wheel of the goniometer with the centres of rotation and on aligning the arm of the goniometer with anatomic landmarks that are readily palpable from the skin surface or on centring the arm of the goniometer on a limb segment. The landmarks used in the current study were similar to the landmarks used in the validation studies in dogs and cats. These landmarks had to be modified because in dogs and cats, goniometry of the carpus relies on the lateral humeral epicondyle and goniometry of the tarsus relies on the midpoint between the tibial tuberosity and the fibular head. For practical reasons, the radiographs of the carpus acquired in the current study did not include the elbow joint and the radiographs of the tarsus did not include the stifle joint. To measure carpal extension, the cranial aspect of the cortex of the distal portion of the radius was used, and to measure tarsal extension, the cranial aspect of the cortex of the distal portion of the tibia was used. The landmarks used for carpal flexion in the current study differed from landmarks used to measure carpal extension in dogs and cats because the length of the carpal bones in horses is such that, when the carpus is flexed, the cranial aspect of the cortex of the distal portion of the radius and the cranial aspect of the cortex of the proximal portion of the metacarpal bone are 15 to 20 cm apart. Using the long axes of the radius and metacarpal bones to measure carpal flexion would require a goniometer with arms that would be approximately 10 cm wide and a wheel that would be 15 to 20 cm wide. This is larger than goniometers that are commercially available. The goniometers used in the study were adapted from goniometers that are commercially available and are used to measure human hip and knee joints. With that type of goniometer, with arms and a wheel that are narrower than what would be needed to measure carpal flexion using a method identical to the method used in dogs and cats, measuring carpal flexion based on the dorsal aspect of the distal portion of the radius and the proximal portion of the metacarpal bone would have been very impractical because the wheel would have had to be located distal to the carpus, requiring excessively long arms. The goniometric method used to measure the carpus centred the wheel on the carpus. The radiographic method used for measurement of carpal flexion was deemed to be the best estimation of the method used for goniometric measurement. To measure tarsal flexion on radiographs, we subjectively felt that the orientation of the crus was best estimated by the skin surface of the caudal aspect of the crus because the cranial aspect of the cortex of the tibia appeared to be curved, and because the skin surface of the caudal aspect of the crus more closely matched the proximal arm of the goniometer than the cranial aspect of the cortex of the distal portion of the tibia. To measure metacarpophalangeal (metatarsophalangeal) extension on radiographs, we compared the orientation of the long axes of the third metacarpal (third metatarsal) bone and proximal phalanx. This method best approximated the goniometric method. To measure metacarpophalangeal (metatarsophalangeal) flexion on radiographs, the palmar (plantar) surface of the cortex of the proximal phalanx was used because, we subjectively felt that when the metacarpophalangeal (metatarsophalangeal) joint was flexed, the shape of the pastern changed as a consequence of soft tissues being tight on its dorsal aspect and loose on its palmar (plantar) aspect. Subjectively, the radiographic measurement methods used in this study were considered rapid, repeatable and closest to goniometric measurements. These methods, however, were not compared to other radiographic measurements methods, such as the method reported by Strand and colleagues that consisted of drawing lines in the centre of the long axis of the distal portion of the third metacarpal bone and the proximal portion of the proximal phalanx (26, 27). Other methods could potentially correlate more closely with goniometric measurements, but the comparison of several radiographic or goniometric methods to each other was deemed to be beyond the scope of this project.

For the horses enrolled in this study, extending the length of the arms of the goniometer from 25 cm to 37 cm improved the ability to repeatedly obtain consistent measurements of the carpal and tarsal joints. Measurements of metacarpo/metatarsophalangeal joint angles can be more challenging using a standard length goniometer due to the shorter length of the distal limb segments and the flare of the hoof. Measurements were more easily and consistently obtained by shortening the arm of the goniometer to 10 cm and using the easily palpable lateral eminence of the middle phalanx as the distal landmark. Goniometer arm lengths may need to be adjusted to accommodate horses whose sizes differ from the horses used in this study. A shortcoming of this method is the number of individuals required to accurately perform the measurements. While extension measurements are easily collected by two people – one holding the horse and the other collecting the measurement – flexion measurements are best performed by three individuals. For safety and accuracy, one individual is needed to hold the horse, a second individual is needed to maximally flex the joint, and a third performs the measurement.

When determining the initial state of an articular or periarticular disease, as well as evaluating response to therapy and rehabilitation, it is valuable to be able to assess ROM in the standing horse and to be able to objectively quantify the degree of extension and flexion of affected joints. One must be able to assess improvement or degradation of the condition over time in order to adjust therapy. While subjective evaluation may be useful, it may under- or overestimate improvement. Having an accurate, repeatable and quantifiable method that is easily applied is desirable. Goniometry provides an objective quantifiable method of evaluation of ROM instead of a subjective evaluation.

The study reported here was performed on a normal population of sedated light breed horses. As such, the results may not apply to all breeds. Additionally, some horses may have chronic restriction of passive ROM that does not affect performance. Measurement of contralateral limb angles is important to determine if measurements are normal for a particular horse. Pain originating in articular or periarticular structures probably influences ROM and may interfere with the assessment of joint motion. Similarly, periarticular swelling or joint effusion may affect ROM (26).

This study validates goniometric measurements of the carpal, metacarpophalangeal, tarsal, and metatarsophalangeal joints in standing, sedated, healthy horses by comparing manually measured angles to those obtained upon measuring angles obtained from radiographs. Breed specific studies are needed to assess the effects of breed and conformation on normal ROM of these joints. The influence of specific orthopaedic problems on joint motion should also be evaluated in the future.

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Conflict of interest

There are no conflicts of interest to declare.

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