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ORIGINAL RESEARCH

Radiation from the equine perineal region is low compared with the elbow and head 24 hours after bone scintigraphic examination

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Abstract

The timing of follow-up radiography and ultrasound in horses that undergo skeletal scintigraphy for lameness investigation varies internationally and between equine hospitals. The prospective, one-group, pretest, posttest study aimed to estimate radiation levels from horses three and 24 h after injection of hydroxydiphosphonate labeled with metastable technetium (^{99m}Tc-HDP) and investigate which anatomical locations of the horse had higher radiation levels. Included were 46 horses referred for lameness investigation between June and December 2021. Radiation levels from the horse surface were measured using an electronic device from six anatomical locations (head, elbow, dorsum, ventrum, stifle, and perineum) at two time points and adjusted to three and 24 h after injection of ^{99m}Tc-HDP using the radioactive decay law. The radiation measured was significantly different in the various locations of the horses for both time points. At 3 h after injection of ^{99m}Tc-HDP, the ventrum had the highest radiation dose. At 24 h, the radiation emitted from the perineal region was significantly lower ($P < .0001$) than from the elbow and head, which had the highest values. There was a negative correlation between age and the radiation detected at 24 h postinjection ($P = .02$). Radiation from the perineal region was low compared with other regions of the horse 24 h postscintigraphy. Additional care should be taken around the ventrum area during the scintigraphy examination and around the elbow and head at 24 h postscintigraphy to minimize radiation to personnel.

KEYWORDS

ALARA, nuclear medicine, radiation safety, radiopharmaceutical

1 | INTRODUCTION

Bone scintigraphy is a popular imaging modality in horses because of its sensitive and noninvasive nature in imaging the physiologic status of bone.[1] Its high sensitivity for detecting early disease, and the ease of evaluation of a large region makes it an ideal tool for screening cases of lameness or poor performance.[2,3] However, it has been demonstrated that scintigraphy is unlikely to result in a full and correct diagnosis of lameness or poor performance in sports horses when used as an indiscriminate tool.[4] In the past decades, scintigraphy has attained widespread use, with many equine referral hospitals and universities having gamma cameras.[3] However, the inherent spatial resolution of scintigraphy is poor, images are planar, and thus small anatomical structures may not be possible to clearly define.[3] Skeletal scintigraphy is used to locate areas of increased radiopharmaceutical uptake that may reflect injury or disease and direct further imaging.[5]

Since horses often travel to referral centers to undergo lameness investigation and skeletal scintigraphy, follow-up radiography and ultrasound examinations are often requested to be performed as soon as possible to obtain a final diagnosis and potential treatment in one single visit. The timing of follow-up radiography and ultrasound in horses that undergo skeletal scintigraphy varies internationally and between equine hospitals. This timing is governed by local radiation regulators but the question arises if the guidelines are clearly a result of evidence-based information. Scintigraphy represents an ionizing radiation safety hazard for the veterinary staff both on the day of the examination and in cases where further diagnostic imaging procedures are done during the following days. A particular concern arises when the veterinary staff are in close contact with the horse for a prolonged time during ultrasonographic examinations and while performing radiography. Transrectal ultrasonographic examination is now routinely used in the diagnosis and documentation of lumbosacroiliac injuries,[6] and ultrasound is an extremely useful tool for the characterization of musculoskeletal diseases such as suspensory ligament injury.[7,8] In these circumstances, distance from the source of radiation cannot be effectively practiced as a safety measure.

This study primarily aimed to investigate what anatomical regions of the horse had the highest radiation levels 24 h after skeletal scintigraphy and secondly to estimate radiation levels from those regions. Hydroxyethylene diphosphonate acid labeled with metastable technetium (^{99m}Tc-HDP) is primarily excreted in urine.[9] We hypothesized the radiation levels would be generally low but that the perineal region would have the highest levels of radiation, particularly in females due to urine contamination.

2 | MATERIALS AND METHODS

2.1 | Selection and description of subjects

The study had a prospective one-group pretest, posttest design. Inclusion criteria included horses referred to the Diagnostic Imaging Department of the University Animal Hospital of the Swedish University of Agricultural Sciences for a bone phase scintigraphy for lameness or poor performance investigation, between June and December 2021. Data were collected as part of the routine internal radiation safety monitoring procedures at our institution, therefore no institutional animal care and use approval was required. Exclusion criteria included uncooperative horses not allowing measurements to be made the day after skeletal scintigraphy; failed intravenous administration of radiopharmaceutical and unavailability of the first author (L.M.) to perform the measurements.

2.2 | Data recording and analysis

Hydroxyethylene diphosphonate acid labeled with metastable technetium was administered intravenously via intravenous catheter placed in the jugular vein. The mean amount of technetium administered was 5022 Bq/horse (range 4000–6500 Bq), with the variation depending on the size and age of the horses. This method of standardizing the dose of radiopharmaceutical is used to shorten the amount of time the staff are manipulating the radiopharmaceutical. The exact amount of radioisotope administered was registered in each horse's clinical file. Three of the horses were sedated prior to the administration of intravenous radiopharmaceutical: two of them received intramuscular acepromazine (2 mL; Plegicil 10 mg/mL, Pharmaxim AB) due to fractious behavior and one horse received detomidine per os (3 mL; Domosedan 7.6 mg/mL, Orion Pharma AB Animal Health) due to fear of needles. For the scintigraphy examinations, the horses were intravenously sedated to effect using butorphanol (Butomidor 10 mg/mL, Salfarm Scandinavia AB) and detomidine (Domosedan 10mg/mL, Orion Pharma AB Animal Health).

Horses subjected to scintigraphy examinations which included the pelvis were administered furosemide at a dose of 15 mL/horse (Furix 10 mg/mL, Orifarm Generics AB), 1 h before the scintigraphy examination. For the radiation measurements, a portable dose rate monitor for measurement of ambient dose rate equivalent was used (UMO LB123 Universal Monitor, LB 1236-H10 probe, Berthold technologies). The device expresses radiation levels in dose equivalent with 10 mm tissue depth (Hp(10)) in micro-Sievert per hour (μSv/h). The dose rate probe is a proportional counter with a detection range between 0.05 μSv/h and 10 mSv/h and an energy range from 30 keV to 1.3 MeV. The manual probe was placed in direct contact with the horses' skin surface. This measuring instrument was compared with calibrated personal dosimeters at the Nuclear Medicine Department of the University Teaching Hospital of Uppsala University, and deemed accurate, with a 10% variation in its readings.

All the measurements were performed by one single operator (second year ECVDI resident, L.M.) to avoid variations in technique between operators, aided by a horse handler. The horse handler, gamma camera operator, and operator recording the measurements wore protective aprons and thyroid shields with 0.35 mm lead thickness. The horse handler practiced, whenever feasible, distancing from the horse, with a minimum distance of 30 cm. The operator recording the measurements wore disposable gloves and placed a disposable glove protecting the probe of the measuring device from urine and fecal contamination.

Six anatomical points of the horse's skin surface were measured (Figure 1) in the following order: the head, at the level of the temporomandibular joint; the elbow at the level of the olecranon tuber; the dorsum, at the level of the kidneys; the stifle at the level of the patella; the caudal ventrum, at the level of the urinary bladder and the perineal region. For each anatomical point, three consecutive measurements were performed. The measurements were obtained at two separate time points: immediately after the scintigraphy examination and the

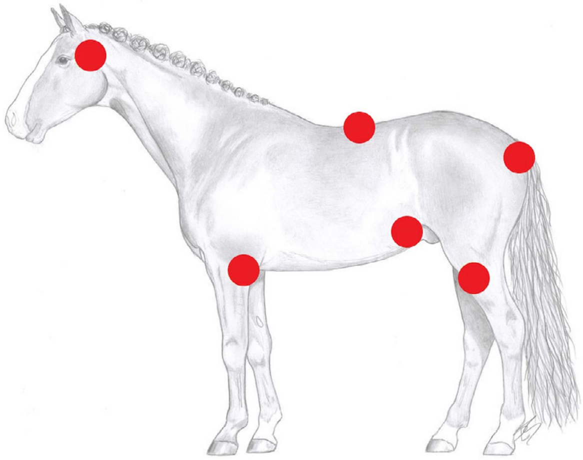

FIGURE 1 Illustration of the six anatomical sites that were measured for each horse, with sites represented by dots. [Color figure can be viewed at wileyonlinelibrary.com]

day following the examination. For the patients undergoing follow-up examinations the day after the scintigraphy (radiographs and/or ultrasound), the measurements were recorded in the examination room immediately after the exam. For the horses not undergoing a follow-up diagnostic imaging study, the measurements postscintigraphy day were recorded in the designated scintigraphy stable hallway, at least 5 m away from other stabled horses, or in the scintigraphy examination room. The radiation levels were not measured at set times due to the variation in scintigraphy scans' duration and the clinical setting of the study which conditioned the timings of the measurements. The duration of examinations and the time elapsed between the injection of radiopharmaceutical and the first and second measurements are presented in Supporting information S1.

Three consecutive background radiation measurements of the room where each horse was measured were recorded. The background radiation was measured after the horse had left the room or at least 2 m away from the horse with the detector probe orientated away from the horse. The radiation levels measured were registered using an Excel spreadsheet (Microsoft), and the mean for each of the three consecutive measurements was calculated. The mean values of background radiation were then subtracted from the mean values of radiation levels measured for both days.

To compare radiation levels between the different horses and different anatomical locations, and since the measurements could not be recorded at the same times for all the horses, they were retrospectively adjusted to two specific time points (3 and 24 h after administration of radiopharmaceutical), using the radioactive decay law to estimate activity.[10] The decay law ($A = A_0 e^{-\lambda t}$) was used to estimate activity so that A_0 was the measured radiation value with subtracted background radiation. λ was calculated as (0.693/half-life for ^{99m}Tc) with half-life ($T1/2$) for ^{99m}Tc = 6.02 h. t was calculated as the time in hours from the actual time of measurement to the adjusted time points 3 and 24 h after injection of radiopharmaceutical.

All bone scintigraphy images were reviewed for diagnostic purposes by a board-certified veterinary radiologist (Dip ECVDI; C.L. or M.U.).

TABLE 1 Age, weight, mean dose of HDP^{99m}Tc, furosemide administration, and gender for horses ($n = 46$) included in the study.

Mean age (years ± SD)	10 ± 4
Mean weight (kg ± SD)	496 ± 115
Mean dose of HDP99mTc (Bq/kg ± SD)	10.8 ± 3.4
Furosemide (number of horses)	
Yes	30
No	16
Gender (number of horses)	
Mare	19
Gelding	26
Stallion	1

Note: Age, weight, and dose are presented as mean ± standard deviation (SD).

2.3 | Statistics

Statistical analyses were performed by a statistician (J.R.) using open source software environment R.[11] Mixed-effect models were employed to assess the age, sex, horse's weight (measured using a calibrated weight scale), the dose of radioisotope, furosemide administration, the different body parts and radiation levels measured. The implementation in the R package lme4 was used.[12] Multiple comparisons were carried out by Tukey's method (R package emmeans).[13] The significance level was set at .05. The correlation was computed by Pearson's correlation coefficient. The statistical analyses were performed for both time points: 3- and 24-h postadministration of the radiopharmaceutical, respectively.

3 | RESULTS

Fifty-four horses met the inclusion criteria. Seven horses were uncooperative the following day of the scintigraphy examination and one horse had subcutaneous infiltration of ^{99m}Tc-HDP therefore being excluded from the study. The study sample consisted of forty-six horses. The mean age was 10 years old (ranging from 4 to 22). There were 19 mares, 26 geldings, and 1 stallion. The included breeds were: 12 Swedish Warmbloods, nine Icelandic Horses, six Halfbloods, three Oldenburgers, two Connemara, two Dutch Warmbloods, two Warmblood Trotters, and one each of the following, Arabian Thoroughbred, Crossbreed horse, Crossbreed pony, English Thoroughbred, Gotland Russ, Hanoverian, Holsteiner, New Forest pony, Shetlands pony, and Swedish Riding pony. The mean weight, age, and dose of radiopharmaceutical administered are presented in Table 1.

3.1 | Radiation levels

The mean estimated radiation levels for both time points are presented in Table 2. At 3 h after the administration of radiopharmaceutical, the

TABLE 2 Mean estimated radiation levels (μSv/h) at different anatomical locations at 3 and 24 h postinjection of HDP^{99m}Tc in a sample of 46 horses.

	Radiation levels at 3 h			Radiation levels at 24 h		
Anatomical location	***Mean ± SD***	***Max***	***Min***	***Mean ± SD***	***Max***	***Min***
Head	45.2 ± 19.8	133.2	20.8	3.2 ± 1.1	6.7	1.3
Elbow	54.5 ± 15.8	100.2	28.6	3.4 ± 1.0	5.4	1.3
Dorsum	35.4 ± 9.4	58.4	20.0	2.6 ± 0.8	4.2	1.1
Ventrum	91.7 ± 92.6	537.9	28.0	2.3 ± 0.9	4.3	0.7
Stifle	52.9 ± 39.4	235.5	17.3	1.8 ± 0.7	3.2	0.6
Perineum	47.1 ± 20.2	102.8	21.6	2.5 ± 1.0	6.2	0.7

Note: Estimated radiation levels are presented as mean ± standard deviation (SD), maximum (Max), and minimum (Min) values.

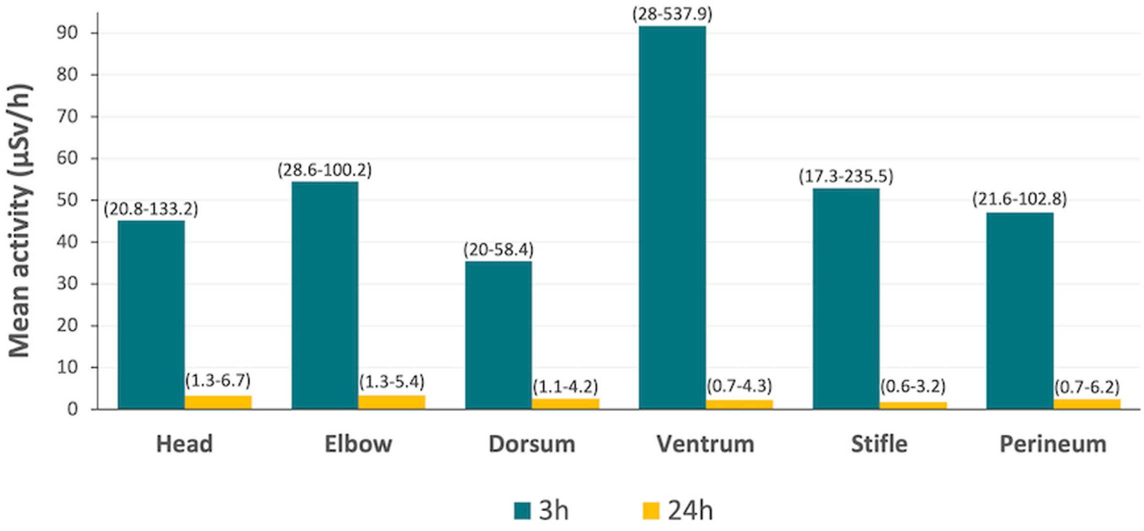

FIGURE 2 Mean estimated activity at the six anatomical locations at three and 24 h postinjection of radiopharmaceutical in 46 horses. The range of estimated values is shown in brackets. [Color figure can be viewed at wileyonlinelibrary.com]

ventrum was the anatomical point of the horses with the highest radiation levels measured (mean 91.7 μSv/h). The lowest radiation levels were obtained at the dorsum (mean 35.4 μSv/h).

Twenty-four hours after the radiopharmaceutical was administered, the radiation levels decreased between 92% and 96%. The greatest decrease was in the ventrum region (Figure 2). At this time point, the anatomic location with the highest radiation levels was the elbow followed closely by the head. The head was the anatomical point with the highest estimated activity (6.7 μSv/h). The body part with the lowest mean estimated radiation levels was the stifle, followed by the ventrum and perineum.

In the measurements of the ventrum, a few observations deviated considerably (Figure 3). Hence, from a statistical perspective, the ventrum was omitted from the statistical inference based on 3 h estimated levels of radiation. For the second time point 24 h postinjection of radiopharmaceutical, ventrum was included in the mixed model analysis (Figure 4).

The estimated radiation levels from the different body parts of the horses were analyzed using mixed-effect models and resulted in significantly different mean levels at both 3- and 24-h time points after injection of radioisotope ($P < .001$ for both time points).

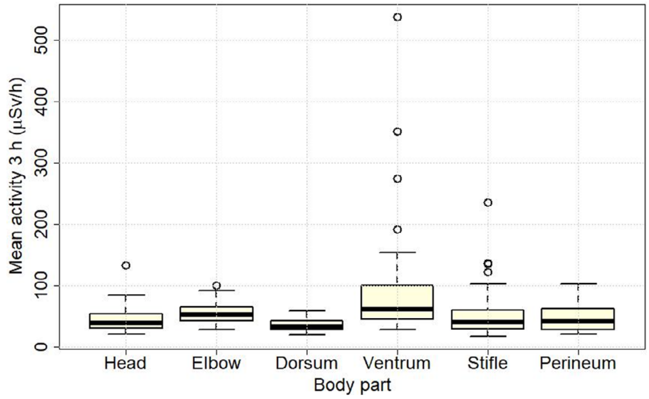

FIGURE 3 Boxplots representing the estimated mean radiation levels for six anatomical locations in 46 horses, 3 h after injection of HDP^{99m}Tc. [Color figure can be viewed at wileyonlinelibrary.com]

There was no significant association between the sex of the horses and the estimated radiation levels nor between the administration of furosemide and the amount of estimated radiation for either of the time points (three and 24 h postadministration of radioisotope). The

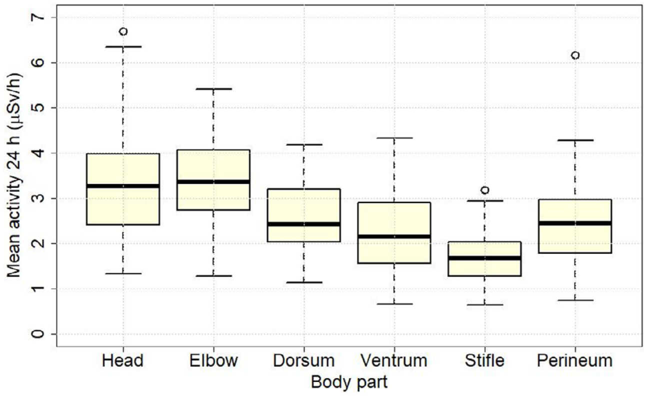

FIGURE 4 Boxplots representing the estimated mean radiation levels for six anatomical locations in 46 horses, 24 h after injection of HDP^{99m}Tc. [Color figure can be viewed at wileyonlinelibrary.com]

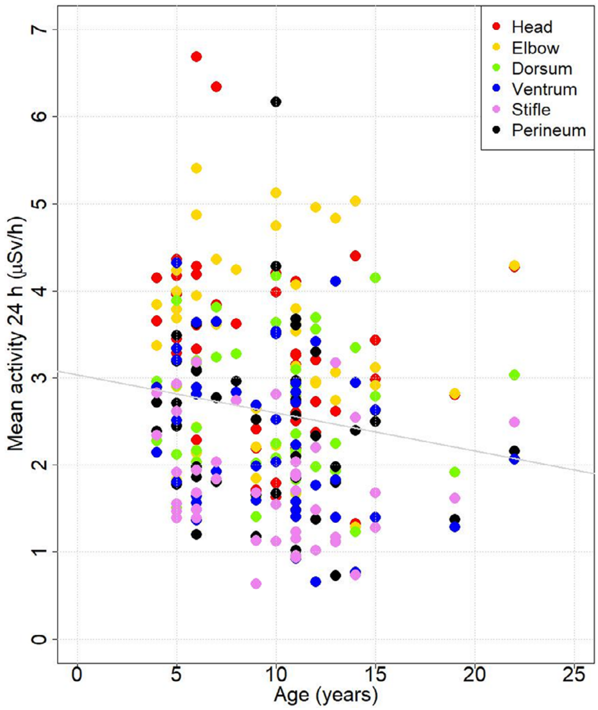

FIGURE 5 Plot of the estimated mean activity 24 h after injection of radiopharmaceutical from six different anatomical sites and the age of the 46 horses. The line represents the weak negative correlation between the two variates ($r = -0.16$, $P = .008$). P represents statistical differences, and its' significance level is .05. The different coloured dots represent the six different anatomical sites measured in the horses. [Color figure can be viewed at wileyonlinelibrary.com]

estimated level of radiation was significantly associated with the dose of radiopharmaceutical administered (in Bq/kg) for both time points ($P = .001$ at 3 h and $P = .05$ at 24 h postinjection). There was a significant association between the age of the individuals and the amount of estimated radiation 24 h after injection ($P = .02$). There was a weak negative correlation between age and estimated amount of radiation 24 h after injection of radiopharmaceutical ($r = -0.16$, $P = .008$, Figure 5).

TABLE 3 Summary of multiple comparisons (Tukey's method) between the estimated radiation levels 24 h after injection of radiopharmaceutical and the different anatomical sites, their mean differences, and corresponding *P* values.

Comparison between anatomical sites	Mean differences	*P* value
Head—Elbow	−0. 16	.90
Head—Dorsum	0. 62	.0013*
Head—Perineum	0.80	<.0001*
Head—Ventrum	0.92	<.0001*
Head—Stifle	1.45	<.0001*
Elbow—Dorsum	0.78	<.0001*
Elbow—Perineum	0.96	<.0001*
Elbow—Ventrum	1.08	<.0001*
Elbow—Stifle	1.61	<.0001*
Dorsum—Perineum	0.18	.85
Dorsum—Ventrum	0.30	.38
Dorsum—Stifle	0.84	<.0001*
Ventrum—Stifle	0.54	.008*
Perineum—Ventrum	0.12	.97
Perineum—Stifle	0.66	.0005*

Note: *P* values represent statistical differences and the asterisk indicates statistically significant difference between the pairwise comparison (significance level .05).

Multiple comparisons were carried out between estimated radiation levels from the different body parts at both time points, respectively. At 3 h, only two pairwise comparisons were significant, namely, elbow and dorsum ($P = .0002$) and dorsum and stifle ($P = .0005$). However, it was noted that at the stifle, a few outliers may have influenced the mean estimated radiation levels upwards (see Figure 3).

At 24 h, the summary of multiple comparisons is depicted in Table 3. It was observed that the head and elbow do not differ from each other, but both differ significantly from every other anatomical part. Moreover, the stifle differs significantly from all other anatomical parts. Considering the perineum, there was a significant difference when compared with the head, elbow, and stifle, but not the dorsum and ventrum.

4 | DISCUSSION

This study primarily aimed to investigate which anatomic regions of the horse had the highest estimated radiation levels the day after scintigraphic examinations. We hypothesized the estimated radiation levels in the perineal region could be higher compared with other regions, particularly in females due to urine contamination. The results rejected this hypothesis, as the perineal region had lower estimated radiation compared with the elbow and head, and no difference in estimated radiation levels was found in females compared with male horses. We also hypothesized the overall estimated radiation levels would be low the day after the bone scan. The results supported this, with a decrease in estimated radiation the day after scintigraphy between 92% and 96% compared with the estimated radiation levels 3 h after injection of the radiopharmaceutical.

Three hours after the injection of the radiopharmaceutical, the ventrum was the region of the horse with the highest estimated radiation levels. After intravenous administration, the plasma clearance of bisphosphonates is biexponential and a function of skeletal uptake and urinary elimination, with a maximum urinary concentration of radiopharmaceutical after 2 h.[14,15] Therefore, this result is most likely explained by the proximity to the urinary bladder, where the radioisotope accumulates.[15] At our institution, furosemide is administered only to horses undergoing examinations of the pelvis and/or proximal hindlimbs where superimposition of the urinary bladder containing radiopharmaceutical is expected to degrade the image quality and diagnostic value, as described recently.[16] At this time point, the estimated mean radiation levels from the stifle presented a few outliers which are most likely explained by the proximity of the stifle with the urinary bladder, where the radioisotope accumulates, therefore depending on how the probe of the measuring device was angled, it may have contributed to abnormally high readings. This may have contributed to the significant difference found in the pairwise comparison between the radiation estimates of the dorsum and the stifle ($p = .0005$). The level of radiation estimated in the head of the horses on the day of the scintigraphy was the second lowest, with only the dorsum region having lower mean radiation levels. This result was unexpected since the skull of the horse is composed of large osseous structures, has a relatively low amount of soft tissues, and the measuring site was in the proximity of the parotid salivary glands. It should be considered that a staff member stands close to a horse's head during scintigraphy and according to Gatherer et al.,[17] this member of staff receives approximately twice the amount of radiation than the one operating the scintigraphy equipment during image acquisition. Mageed et al.[16] have recently demonstrated that the head is a significant source of radiation to the staff during the examination and that a distance of at least 30 cm should be practiced to significantly reduce the amount of radiation to the personnel.

Estimated radiation levels from the horses' skin surface 24 h postadministration of radiolabeled pharmaceutical decreased greatly (more than 92% in all the body parts) to levels less than 3.4 μSv/h (dose equivalent). This is well below the 7.5 μSv/h limit dose rate (average over a working day) of a controlled radiation area.[18,19] The main radiation hazard occurs during the scintigraphic examinations. Therefore, all the possible radiation protection measures should be adopted to minimize staff exposure during that time.

The estimated radiation emitted from the perineal region was significantly lower compared with other regions of the horse 24 h postscintigraphy, particularly the head and elbow regions. These radiation estimates do not reflect the true clinical conditions of rectal ultrasound as internal radiation from the rectum was not measured. However, there are several factors to consider. First, radioisotope elimination via the gastrointestinal tract is very low given the predominantly urinary route of elimination and according to several authors, considered negligible.[9,14,15,20,21] Dose limits to the hand and arm are higher compared with the torso due to the sensitivity of internal organs to ionizing radiation, which in turn is monitored by personal dosimeters. Despite the radiologists' arm being near skeletal structures (such as the pelvis) during rectal and/or limb ultrasound examinations, the radiation exposure to the torso is more relevant. Our method of measuring radiation levels is therefore adequate to estimate exposures to the torso.

The amount of radiation estimated from the ventrum had the greatest decrease of all measured anatomical points the day after injection of the radiopharmaceutical, reaching 96%. This result simply reflects the evacuation of all urine containing radioisotope during the elapsed 24 h. Additionally, this result suggests that most of the radiation estimated from the perineal region 24 h after the radiopharmaceutical injection is due to pelvic and lumbosacral skeletal structures rather than urine.

The estimated radiation from the stifle was lower compared with the elbow 24 h after administration of the radiopharmaceutical. A possible explanation for this is the greater amount of soft tissues surrounding the bones of the pelvic limb which attenuate more radiation compared with the thoracic limb. On the other hand, the patella is a rather superficial structure and therefore this result has an uncertain explanation.

In the results of this study, a weak negative correlation between the age of the horses and the amount of estimated radiation 24 h postradiopharmaceutical was noted. The injected radiolabeled bisphosphonates adsorb to the surface of hydroxyapatite crystals in proportion to local bone vascularization and osteoblastic activity.[14] In horses, a decrease in bone metabolism with increasing age has been reported as well as a gradual decrease in bone-to-soft-tissue contrast beyond 3 years of age.[22,23] Therefore, we speculate this decrease in radiation in older horses is due to decreased osteoblastic activity of the bone, where the radiopharmaceutical attaches. At 3 h postinjection of radioisotope, the radiopharmaceutical can be found in circulation, as an unbound fraction and also fixed in the skeleton,[14] which explains why there was no significant difference in estimated radiation levels at this time point between the ages of horses.

Measurements were acquired at anatomical landmarks chosen based on previous studies[16,24] but also adding new anatomic points of interest where the veterinary staff are likely to be in proximity to the day after the scintigraphic examination when performing follow-up examinations for lameness diagnosis, namely the elbow, stifle and perineum. To the best of authors' knowledge, the radiation doses of the stifle and perineum have not been previously investigated and the radiation levels immediately caudal to the elbow have been investigated in a very small sample of horses by Riddolls et al.[15]

This study has several limitations. Laterality (left vs right side) and location of increased areas of uptake of radiopharmaceutical were not recorded, which may have contributed to differences in radiation dose rates measured. The choice to perform radiation dose rate measurements in such a blinded way aimed to mimic a clinical setting as much as possible, where the staff is performing follow-up examinations focused around the increased radiopharmaceutical uptake. The measurements were not performed nor compared on both sides of the horses but only on the side that was more accessible to the operator at the time, to allow for quicker performance and avoid longer exposure to radiation. Horses did not receive a dose of radiopharmaceutical and furosemide based on body weight, instead, they received a rather standardized dose. This is due to our institution's protocols that were not changed for the purpose of the study; however, it is a limitation as horses should receive a dose based on body weight. A power calculation was not performed, which is a limitation of the statistical design of this study. The radiation levels measured were adjusted to two specific time points (3 and 24 h postinjection of radioisotope) using the radiation decay law but without accounting for biological half-time. This may have caused a slight overestimation of radiation levels. Furthermore, the radiation levels in the study were only measured in two time points and these time points were tailored to the specific workflow of our institution. Therefore, our conclusions are only valid for three and 24 h postinjection of radiopharmaceutical which represents a weakness of the study as other institutions will have different protocols and may perform follow-up examinations before 24 h have elapsed. Another limitation of this study is the large standard deviations observed in the estimated radiation levels 3 h postinjection of radiopharmaceutical. They are the result of a very large variation in the amount of radiation measured particularly in the area of the urinary bladder of the horses at this time point. Some horses would have a filled bladder at the time of measurement and several mares were in heat at the time of examination which led to a changed behavior with increased urination but decreased amount of voided urine. In some instances, the horses would be taken to the stable to urinate, and in some instances not, when the examination time had been longer and further exposure to radiation was avoided. Therefore, it led to the radiation estimates from the ventrum 3 h postinjection of radiopharmaceutical being omitted from the statistical analysis only at that time point. However, no difference was found between the sex of the horses and the radiation estimates. The second largest standard deviation in mean estimated radiation was in the stifle which was interpreted to be due to the proximity with the urinary bladder when a horse is standing. The relatively large variation in mean estimated radiation from the perineum is most likely due to variable amounts of urine contamination in different horses. The variation in the mean radiation estimates from the head and elbow 3 h after injection is of uncertain explanation. One of the hypotheses is individual variation. No difference was identified in the mean estimated radiation levels between the horses who received furosemide and those that did not, which is in accordance with the recent study by Mageed et al.[16] According to one study, 24 h was considered an appropriate radioisolation time for mature horses.[15] The results of our study support the 24-h radioisolation time. The exact risk of harmful effects from chronic exposure of populations to low doses of radiation is largely unknown. Establishment of a "safe" or "lowest permissible dose" of ionizing radiation has remained open to question. This reflects the importance of continual adherence to the as low as reasonably achievable principle whenever a decision is made to irradiate a patient because the exact effect of radiation is not fully understood and predictable.[25]

In conclusion, to minimize radiation to staff, additional care should be taken around the horses' ventrum area during the day of scintigraphy and the elbow and head 24 h postscintigraphy.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and design: Marcelino, Uhlhorn, Ley
(b) Acquisition of data: Marcelino, Johansson
(c) Analysis and interpretation of data: Marcelino, Falk, Rydén, Uhlhorn, Ley

Category 2

(a) Drafting the article: Marcelino
(b) Revising article for intellectual content: Marcelino, Falk, Johansson, Rydén, Uhlhorn, Ley

Category 3

(a) Final approval of the completed article: Marcelino, Falk, Johansson, Rydén, Uhlhorn, Ley

Category 4

(a) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Marcelino, Falk, Johansson, Rydén, Uhlhorn, Ley

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

5PREVIOUS PRESENTATION OR PUBLICATION DISCLOSURE

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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