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# The diagnostic X-ray exposure technique guidelines for elephants' limbs in Elephant Hospital, Thai Elephant Conservation Center, Thailand

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**ABSTRACT**

**Background:** Radiographic image is the first of choice for diagnosing complications involving elephants' limbs. The extreme thickness of their limbs causes inaccurate image quality. Therefore, an appropriate procedure is hereby investigated as a matter concerned. Because of difference of X-ray absorption in elephant tissue from human tissue, the Sante's rule cannot be directly applied.

**Objectives:** This study sought to acquire the appropriate equation by modifying the Sante's rule with a tissue factor for calculating the exposure technique for Asian elephants' limbs.

**Materials and methods:** Firstly, capacity of a mobile X-ray machine was evaluated in terms of dose rate, precision, and accuracy of radiation. The exposure techniques were then designed using the modified Sante's rule and tested with the hind limbs of 10 live elephants.

**Results:** Output of X-ray machine revealed the dose rate in milli-Rontgen per milli-Ampere-sec equal to $4\times10^{-4}$ of $kVp^2$, and the machine factor equal to 6.4. The radiographic images taken using the calculated exposure techniques showed good quality, and so, it is possible to differentiate between the medullar and the cortex of the bone.

**Conclusion:** Equations suitable for designing the exposure technique are kVp equal to two times of sample thickness in centimeter plus source image distance in inche and the tissue correcting factor 5, and mAs equal to two-fifths of the sample thickness in centimeters.

## Introduction

Elephant is the national animal of Thailand. Some elephants have an elevated position as companions to humans. The Thai Elephant Conservation Center's Elephant Hospital offers free treatment to elephants all over Thailand. The treatments are offered through mobile clinics operated by various organizations.[1] In the past decade, injury has been the cause of most Thai and Asian elephants' health problems.[2,3] When zoo animals such as elephants have a medical condition, radiological imaging is required as an important tool for diagnosis.[4] Because of their thick limbs and uncontrolled complications, exposure technique guidelines are required for good quality images. Past studies have sought to develop effective radiographic techniques for large animals such as elephants and white rhinoceroses for monitoring bone maturation, ossification, mineralization, and injury.[5-10] However, no explanation has been stated for those acquired techniques. Image quality depends on the variation of the influencing factors, such as kVp, mAs, time, source image distance (SID), and tissue absorption factor.

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In general, radiographic techniques (kVp and mAs) are calculated based on the principles of Sante's rule which includes parameters such as tissue thickness, source image distance and grid factor.[11] In fact, tissue density which is one of the important factors that affect X-ray absorption by a medium should be an factor of concern.[12] Current available known data strongly indicated only X-ray absorption on human tissue.[13,14] The radiographic technique calculated based on information on human characteristics cannot be used for elephants because of the main difference in physical characteristic of elephant skin. Lacking of knowledge has led to imprecise radiographic techniques for diagnosing elephants and is a cause for misdiagnosis. Hence, this work aims to design the equation of exposure factors (kVp and mAs) of a mobile X-ray machine for calculating the exposure technique guidelines that use for elephant limbs.

## Materials and methods

This study was approved by the Animal Ethics Committee, Faculty of Veterinary Medicine, Chiang Mai University, Thailand, in 2017 (R4/2560). Live Asian elephants residing in The National Elephant Institute, Forest Industry Organization, Lampang Province, Thailand, were joined in this experiment. A mobile X-ray machine (Hitachi, model Sirius 130HP, 250 mA, Japan) and a computed radiograph of Fuji model FCR PRIMA II (IP cassette type CC with CR imaging plate type ST-VI size 14”×17”, Japan) were used for image recording. All radiographic images were recorded using digital image plates as DICOM files. Histogram of intensity was obtained by a freeware ImageJ program[15] (version 1.51p) for image evaluation.

### Evaluation of X-ray machine

Capacity of the X-ray machine was assessed by triplicate determination of dose rate at three different mAs of each kVp (60, 80, 90, 100, 110, 120 and 130) at source image distance of 25 inch and field size of 14×14 square inches. Line voltage (kVp), mAs, and dose rate of X-ray were determined by using a solid state multisensor for diagnostic range (Radcal model AGMS-D+, CA, USA) size 35.6 mm × 20.0 mm × 11.8 mm. The machine factor (P) of the X-ray machine can be calculated from the relationship between the dose, the kVp, and mAs as the following equation: Dose (mR) = $P(kVp)^2.mAs/(SID)^2$.[16]

### Exposure technique designing

For radiographic imaging, factors affecting the exposure technique included capacity of the X-ray machine, source image distance, grid, and image acquisition system. Firstly, the estimated exposure technique was modified based on Sante's rule which includes equations for calculating the kVp and the mAs value.[17] One hind limb of a live elephant was measured for thickness and subjected to three trial exposures: (1) estimated technique, (2) lower technique, and (3) higher technique. Three images were evaluated. Exposure technique was then recalculated using the modified Sante's rule equation, and used to expose ten live elephants' hind limbs. Evaluation of the image quality was based on veterinary opinions and density plot profil. Statistical analysis was performed by authors. Microsoft Excel (2016) program was used for descriptive statistics to estimate the central tendency. All data were established as normal distributions; then, the mean and the standard deviation were calculated.

## Results

### Evaluation of X-ray machine

In order to draw the exposure technique chart, the X-ray machine was assessed for exposure properties by testing the precision and accuracy of kVp and the output of X-ray. The kVp value was evaluated by setting kVp (60, 80, 90, 100, 110, 120, and 130) for three various mAs values in each kVp. The accuracy and precision of kVp are, respectively, presented in %Error (between 1.72 and 2.59) and %CV (lower than 1 for all kVp) (Table 1). The result of the output of the X-ray machine is shown in dose rate in milli-roentgen per milli-ampere second (mR/mAs) at each kVp, as shown in Figure 1. The relation between the dose rate and kVp was defined by the equation mR/mAs $=6.4\times10^{-4}*kVp^2$, which gave the machine factor (P) as equal to 6.4.

**Table 1** Accuracy (%Error) and precision (%CV) of kVp values between 60 and 130 of X-ray machine at source image distance of 100 cm and field size of 14”×14”

| Setting kVp (mAs) | Measured kVp Mean±SD | %Error | %CV |
|---|---|---|---|
| 60 (50, 160, 200) | 61.30±0.06 | 2.17 | 0.09 |
| 80 (40, 100, 160) | 81.55±0.07 | 1.94 | 0.09 |
| 90 (40, 80, 120) | 92.28±0.04 | 2.53 | 0.05 |
| 100 (40, 80, 120) | 102.59±0.03 | 2.59 | 0.03 |
| 110 (40, 80, 100) | 112.26±0.05 | 2.05 | 0.05 |
| 120 (20, 50, 80) | 122.07±0.10 | 1.72 | 0.08 |
| 130 (20, 50, 80) | 132.57±0.16 | 1.97 | 0.12 |

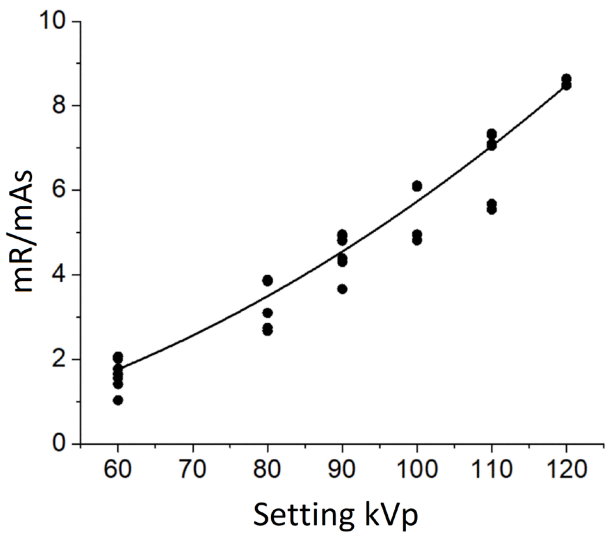


***Figure 1*** *Plot of exposure rate per mAs at various setting kVp values; the relation was fitted with the equation mR/mAs = $6.4\times10^{-4}*kVp^2$ (machine factor, P=6.4).*

**Exposure technique designing**

According to the principal of the Beer-Lambert Rule which descript the attenuation properties of X-ray in the medium as the following equation.[12]

$$I=I_0e^{-\mu X}$$

Where $\mu$ is the linear attenuation coefficient ($cm^{-1}$)

$I_0$ is the initial intensity that is related to the X-ray flux before passing through

$I$ is the transmitted intensity that passes through the medium at the measured thickness position

$X$ is the thickness of the medium that the X-ray flux passes through (cm)

For human (subscript H) $$\frac{I_{0H}}{I_H}=e^{\mu_H X} \quad (1)$$

For elephant (subscript E) $$\frac{I_{0E}}{I_E}=e^{\mu_E X} \quad (2)$$

(2)/(1) $$\frac{I_{0E}}{I_E}\frac{I_H}{I_{0H}}=\frac{e^{\mu_E X}}{e^{\mu_H X}} \quad (3)$$

$$\frac{I_{0E}}{I_E}\frac{I_H}{I_{0H}}=e^{(\mu_E X-\mu_H X)} \quad (4)$$

By the condition of transmitted intensity from human tissue and elephant tissue are the same $I_H = I_E$ and the linear attenuation coefficient of elephant tissue ($\mu_E$) which obtained by previous studies is about 1.2 time of human tissue ($\mu_E=1.2\mu_H$) so the initial intensity for elephant tissue ($I_{0E}$) at the same thickness as human tissue can be simplified as follow.

$$I_{0E}=e^{(0.2\mu_H X)}.I_{0H} \quad (5)$$

By using the equation (5), the estimated value of $e^{(0.2\mu_H X)}$ are ranging from 2-3 when the kVp value are ranging from 40-150 kVp and the thickness of subject is 20 cm. According to the machine factor of X-ray machine is in the lower range that is about 5 times lesser than the maximum value, so the first estimation of the kVp value was obtained by using Sante's rule plus the factor 10.

**Test exposure**

The capacity of the X-ray machine was such that it showed good accuracy and precision of the kVp value, and the exposure rate was found to theoretically correlate with kVp2. Because of the machine factor and the effect of the high density of the soft tissue of elephants, the radiographic image of the hind limb in the projection of the lateral view (20 cm thickness and the factor considered as 10) was taken using the estimated technique (90 kVp 8 mAs) which was modified from Sante's rule, in comparison with the lower kVp technique (70 kVp 30 mAs) and the higher kVp technique (130 kVp 8 mAs). Among the three techniques, the radiographic image obtained using 90 kVp, 8 mAs, was found to be the best (Figure 2). The plot of density along the transverse image (cross lines) showed no difference in density between the bone tissue and the soft tissue in the lower technique. Regarding the other techniques, the difference between the bone tissue and the soft tissue can be identified using the plot of density, but it lacks some details in the bone part. The new exposure technique was recalculated. The factor 5 was added for the kVp instead and the mAs value was equal to two-fifths of the subject thickness. The equation can be finalized as follows.

kVp = (2 × Tissue thickness [in cm]) + SID (in inch)+5

mAs = Tissue thickness (in cm)/2.5

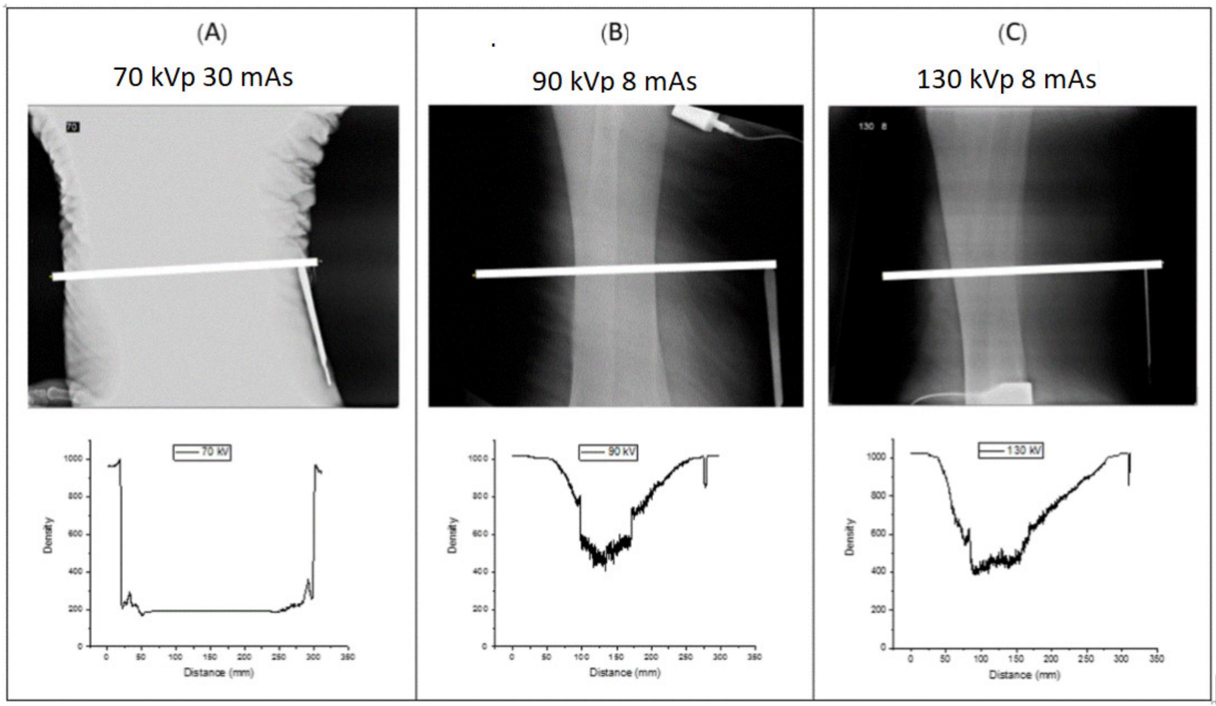


***Figure 2*** *Radiographic images of lateral view of the elephant's hind limb (upper row) and density plot profile of each image at the white level (lower row) at the lower technique (A), expected technique (B) ,and higher technique (C).*

The exposure technique was recalculated (Table 2) and used to expose the hind limbs of the 10 live elephants which consisted of five males (5, 33, 42, 59, and 67 years) and five females (4, 21, 23, 32, and 72 years) with thicknesses at the middle level of tibia in the range of 19-25 cm. The radiographic images with no post-processing were observed to have good detail in both tibia and fibula except M4 and F3 which have the thick tibia (Figure 3). The quality of the radiographic image in the density plot was extremely good, and the image revealed considerable detail with good distinction between the medullar and the cortex of the bone (Figure 4).

**Table 2** Exposure technique guidelines for Asian elephants' limb at various thicknesses (in cm) (kVp = 2 × Tissue thickness [in cm] + SID [in inch]) + 5, and mAs = Tissue thickness (in cm)/2.5, SID 40 inch, no grid, and IP cassette type CC with CR imaging plate type ST-VI size 14"x17"

| Thickness (cm) | kVp | mAs | Thickness (cm) | kVp | mAs |
|---|---|---|---|---|---|
| 16 | 77 | 6.3 | 26 | 97 | 12 |
| 17 | 79 | 6.3 | 27 | 99 | 12 |
| 18 | 81 | 8 | 28 | 101 | 12 |
| 19 | 83 | 8 | 29 | 103 | 12 |
| 20 | 85 | 8 | 30 | 105 | 12 |
| 21 | 87 | 8 | 31 | 107 | 16 |
| 22 | 89 | 10 | 32 | 109 | 16 |
| 23 | 91 | 10 | 33 | 111 | 16 |
| 24 | 93 | 10 | 34 | 113 | 16 |
| 25 | 95 | 12 | 35 | 115 | 16 |

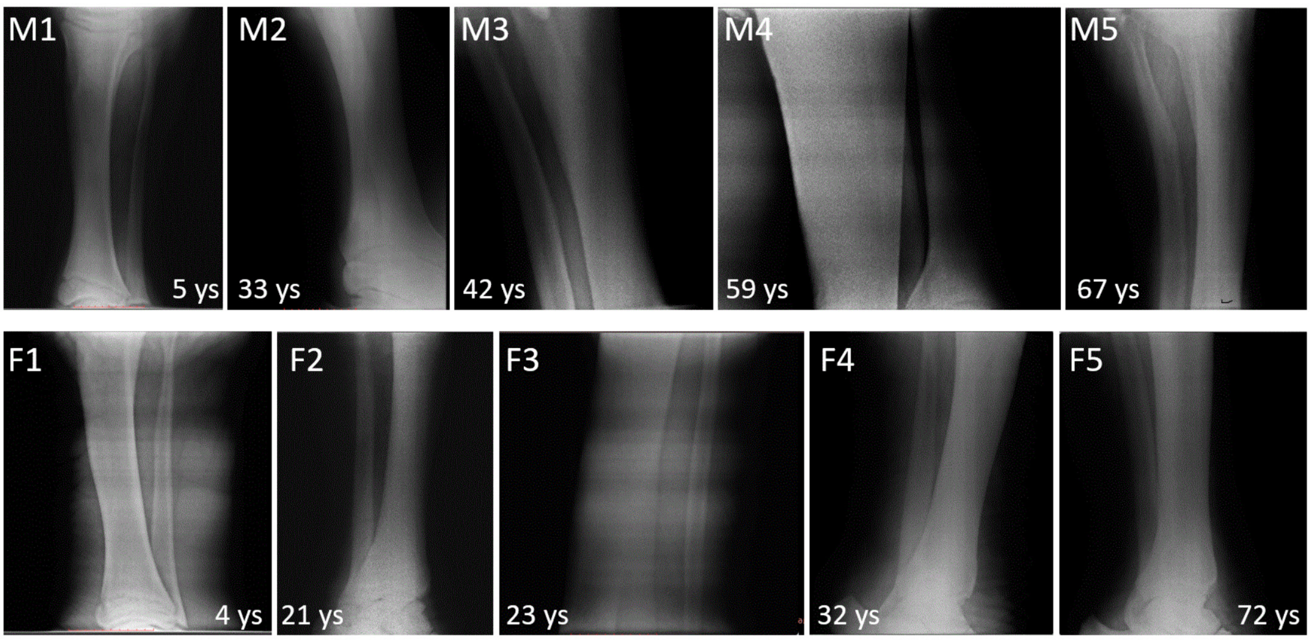


***Figure 3*** *Radiographic images of the lateral view of the hind limb from ten elephants; the upper row are images from five male elephants (M1 -M5) and the lower row from five female elephants (F1–F5). Thickness and exposure technique of each image are as follows: M1 (19 cm), 83 kVp, 8 mAs; M2 (22 cm), 89 kVp, 10 mAs; M3 (20 cm), 85 kVp, 8 mAs; M4 (22 cm), 89 kVp, 10 mAs; M5 (23 cm), 91 kVp, 10 mAs; and F1 (19 cm), 83 kVp, 8 mAs; F2 (20 cm), 85 kVp, 8 mAs; F3 (25 cm), 95 kVp, 12 mAs; F4 (21 cm), 87 kVp, 8 mAs; and F5 (21 cm), 87 kVp, 8 mAs.*

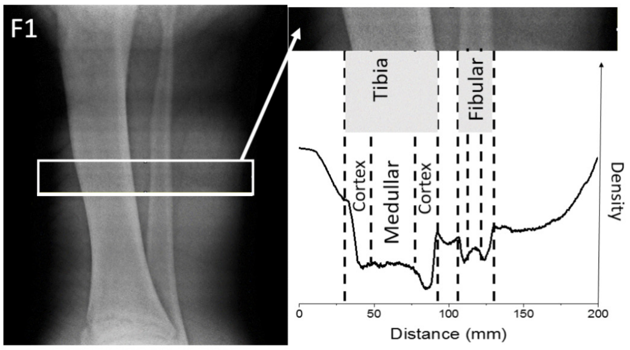


***Figure 4*** *Density plot profile of the transverse axial region (white block) (right) of the lateral view of the hind limb of an elephant (F1: age 4 years, 83 kVp, 8 mAs) (left).*

## Discussion and Conclusion

The assignment of the exposure technique for elephants' hind limb is dependent on many factors, such as output of X-ray machine, image recorder system, and tissue absorption. In general, the grid is usually applied for the X-ray image of the organ with a thickness greater than 20 cm, but in this case, the grid cutoff effect can be easily found by the movement of the animal. In this study, the output of a mobile X-ray machine was reported in terms of mR/mAs as a function of $kVp^2$ with the constant of $6.4\times10^{-4}$, which caused the machine factor (P) to be equal to 6.4. In general, the P value ranges from 5 up to 30.[18] In order to assign the exposure technique, it has to be taken into consideration that the kVp and the mAs values depend not only on the capacity of the X-ray machine but also on the absorbability of the elephant tissue. The previous study of authors on the linear attenuation coefficient of elephant soft tissue showed it to be about 1.2 times more than that of the human muscle. Results suggested that elephants required 2–3 times amount of the primary radiation exposed in order to receive the same image quality as that of human. The first trial technique for the hind limb of elephants was estimated based on Sante's rule plus a factor of 10 for the kVp value. This image was of moderate quality since it lacked bony detail because of low contrast image, which was caused by high kVp. A small adjustment was given to the kVp value for estimation, and it was used for the exposition. In practice, the limitation of the mobile X-ray machine was that the mAs setting values were fixed values such as 2, 2.5, 3.2, 4, 5, 6.3, 8, 10 up to 200 such that the mAs value had to be selected from the adjacent value of calculation. When the image showed up too light which was caused by high bone density or plaque addition, increasing the value of mAs by 30–50% or the value of kVp by 10–15% was recommended. Because of the restlessness of the elephant, the shortest exposure time is recommended, and so, increasing of kVp is the first choice. In conclusion, the exposure technique guidelines for Asian elephant limbs can be designed by using the equations of kVp = (2 × Tissue thickness [in cm]) + SID (in inches) + 5 and mAs = Tissue thickness (in cm)/2.5.

## Conflict of interest

The authors declare that they have no conflict of interest.

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