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TECHNICAL NOTE

Radiographic measurement of the cardiothoracic ratio in a feral population of long-tailed macaques (*Macaca fascicularis*)

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Abstract The cardiothoracic ratio is often used as a proxy measure of cardiovascular pathophysiology in humans but less frequently in nonhuman primates, for whom little published data are available to establish normal values. The present study is the first to examine relative cardiac size in a feral population of primates. This report presents estimates of the cardiothoracic ratio in long-tailed macaques (*Macaca fascicularis*) from Bali, Indonesia. The mean cardiothoracic ratio for the study sample was 0.55, above the commonly used threshold of 0.50 for identifying an enlarged heart in human medicine. Future research on wild populations of macaques is needed and should include multiple assessments of cardiac function including both radiography and echocardiography.

Introduction

The cardiothoracic ratio (CtR) is often used as a proxy measure of cardiovascular pathophysiology in humans.[1–3] The CtR is a simple, though imperfect, measure in widespread clinical use that correlates with left ventricular mass and systolic dysfunction in humans, and is a predictor of

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mortality from coronary heart disease.[3] The cardiothoracic ratio may also have diagnostic value for identifying tuberculous pericarditis.[4,5] The use of the cardiothoracic ratio in nonhuman primate (NHP) veterinary medicine has been poorly documented, with only a few reports in the published literature. e.g.[6,7] To date, there have not been any studies of the CtR in a natural primate population. The following report presents the results from a radiographic study of the CtR in a natural population of macaques from Indonesia.

Methods

During the summers of 2001 and 2002 a sample of long-tailed macaques (*Macaca fascicularis*) were darted opportunistically at seven Hindu temples in Bali, Indonesia in conjunction with a project examining the serological prevalence of various NHP and human viruses. Darts were loaded with 15 mg of Telazol® (Fort Dodge Laboratories, Fort Dodge, IA, 50501, USA). Body weight and body length (crown-rump length [CRL]) were recorded prior to radiography. Chronological age was estimated using the dental eruption ages for males and females presented elsewhere.[8]

The protocol for field radiography has been described in detail elsewhere,[7,9] and is only summarized here. Films were exposed at 60 kVp/30 mA, with an approximate film-to-tube distance of 1 m. Exposure times were no greater than 0.1 s resulting in 3.0 milliamp seconds of exposure (30 mA $\times$ 0.1 sec = 3.0 milliamp s [mAs]). Subjects were positioned vertically, seated on a box, facing the X-ray unit with arms extended laterally. Film cassettes were labeled using lead tape and placed directly behind the subject. Films were exposed during the inspiratory phase of respiration.

Two breadth measurements were taken directly from radiographs using digital sliding calipers: 1) maximum breadth of the cardiac silhouette (CBr), and 2) maximum interior thoracic breadth (TBr) (Fig. 1). Because the thorax is separated from the abdomen by the diaphragm, the maximum thoracic breadth was measured as the linear distance between the internal margins of the ribs near the superior margin of the hemi-diaphragm.[10,11] The CtR was calculated as CBr/TBr. Because the CtR a ratio of two measurements—both taken on structures positioned in roughly the same anatomical plane—error stemming from magnification should be minimal. Measurement was not possible on all radiographs due to poor image quality or animal orientation. Similarly, because the lead tape identification labels were not visible on many of the exposed films, those films could not be matched with data on age, sex, body length and body weight.

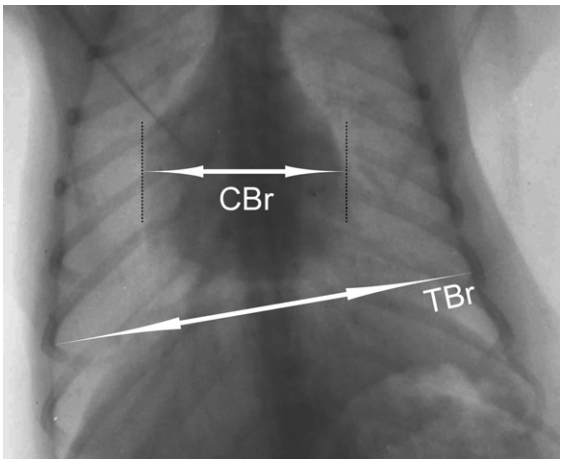

Figure 1 Radiograph illustrating cardiothoracic measurement variables. Radiograph taken of 01B3 from Sangeh monkey temple.

For the purposes of assessing the potential for inter-observer error in the measurement of the CtR, measurements on each radiograph were taken by two different observers on different days. Only those films that were deemed measurable by both observers were included in the study. A paired *t*-test was used to assess the significance of inter-observer error. The mean of both observers was used for subsequent statistical analyses. Pair-wise differences in means and standard deviations for the CtR were tested using a two sample *t*-test and a simple *F*-test. All films were visually assessed for pericarditis by one of the authors trained in human thoracic radiology. Pericarditis was provisionally identified by a globular cardiac silhouette with loss of motion artifact over the apex of the left ventricle. Data on the cardiothoracic ratio from other macaque species were gathered from the literature.[6,7]

Results

Data on location, sex, age, body weight and length, average of the two observers' measurements of the CtR, as well as findings from the qualitative assessment of cardiac shape are presented in the Table 1. Sample statistics for the CtR along with comparative data from the literature are presented in Table 2. The results of the test of inter-observer error indicated there was not a significant difference between observers ($t = 0.446$, $p = 0.658$) in their measurement of the CtR. The average difference between observers was minimal (mean = 0.026, median = 0.013), and was less than 4.8% of the mean CtR (mean = 0.550).

The distribution of CtR values (Fig. 2) did not deviate significantly from normality (Shapiro-Wilk $W = 0.981$, $p = 0.716$). The CtR was not correlated with age ($r = 0.026$, $p = 0.909$, $n = 21$), body weight ($r = 0.390$, $p = 0.059$, $n = 24$), or body length ($r = 0.236$, $p = 0.302$, $n = 21$). There was not a significant difference between males and females in CtR estimates ($t = 1.822$, $p = 0.082$). Significant pair-wise *t*-test comparisons among species in mean CtR was confined to one species, *Macaca tonkeana*. The CtR of *M. tonkeana* differed significantly from *Macaca cyclopis* ($p = 0.001$), *Macaca nigra* ($p = 0.007$), and *M. fascicularis* ($p = 0.016$). There were no significant differences among species in standard deviation values for the CtR.

The qualitative assessment of the cardiac silhouette revealed 5 possible cases of pericarditis. Only 7 of 41 (17.1%) animals exhibited a CtR of less than 0.50. Only 20 of 41 animals (48.8%) exhibited a CtR of less than 0.55. The mean CtR for those exhibiting a cardiac silhouette consistent with pericarditis (mean = 0.5942, SD = 0.045, $n = 5$), though larger, was not significantly different ($t = 1.851$, $p = 0.076$) from those with an apparently normal cardiac silhouette (mean = 0.5519, SD = 0.046, $n = 23$). It seems reasonable to