J Med Primatol doi:10.1111/j.1600-0684.2006.00187.x

CASE HISTORY

# Quantitation of sleep and spinal curvature in an unusually longevous owl monkey (*Aotus azarae*)

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**Keywords**
aging – captive – Cebidae – kyphosis – longevity – nocturnality – radiography

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Accepted May 31, 2006.

## Abstract

*Background* A table summarizing the primary literature on 19 species of longevous non-human primates, other than owl monkey, is presented.
*Methods* We prospectively quantitated the sleep of a longevous female owl monkey (*Aotus azarae*), aged >30 years, longitudinally for 2 years and also evaluated the senility-induced change in spinal curvature.
*Results* The mean daily total sleep time (TST) of this monkey ranged between 790 and 1106 minutes, and was markedly higher in comparison with its female progeny (aged 16 years and used as a control) whose daily TST during the same experimental period ranged between 612 and 822 minutes.
*Conclusion* The calculated kyphotic index (KI) of 2.27 for this monkey, compared with the KIs 4.83 and 5.42, for its progeny and female grandprogeny (aged 1 year) respectively, confirmed the prominent spinal curvature.

## Introduction

Although the longevity quantitation of non-human primates living in the wild is susceptible to higher degree of doubt and imprecision, in the past five decades more reliable quantitation of longevity among captive non-human primates have become feasible. Based on previously published longevity reports on captive primates [6, 27, 41], longevous status among the four major non-human primate groups can be arbitrarily fixed as, >40 years for apes, >30 years for Old World monkeys, >20 years for New World monkeys and >10 years for Prosimians. Table 1 provides a select list of original reports which have appeared since 1969 on 19 species of longevous non-human primates held in captivity. As one could expect, majority of these reports were retrospective studies representing clinicopathological investigations based on the postmortem specimens of tissues and bones. Prospective studies on longevous non-human primates have been sparse at best. In addition, reports on the longevous owl monkey (*Aotus*) have been lacking.

Among the more than 230 species of non-human primates, the owl monkey is unique in being the only nocturnally adapted Anthropoidean primate [4, 39, 44]. Owl monkeys are strictly arboreal and lead a monogamous family life, with a group size of two to five members consisting of a breeding pair and young progeny. Young members emigrate from the family group when they complete the subadult stage by the end of 3 years [59]. The life span of owl monkey in the wild remains yet to be clarified [16], though 12–20 years [22] and 26–30 years [16] have been noted as plausible longevity ranges for owl monkeys under captive conditions.

As of now, the only available report on aged owl monkeys [13] relates to histopathological examination of postmortem brain tissues, as a primate representative, on a comparative scan on the neuropathology of aging in the brains of 47 vertebrate species. Unfortunately, the ages of the two owl monkeys studied for the presence of lipofuscin pigment, argyrophilic plaques, neurofibrillary tangles and corpora amylacea have not been stated.

The owl monkey colony established at the Primate Research Institute (PRI), Inuyama, Japan, in mid-1970s currently consists of 16 subjects, among which 12 belong to *Aotus azarae* species. Among these, the

 

**Table 1** A select list of studies on longevous non-human primates[1]

| Primate[2] | Number | Age range (years) | Study Focus | Ref |
|---|---|---|---|---|
| Apes | | | | |
| Chimpanzee[3] | 5 | 40–59 | Brain weight | [23] |
| Chimpanzee[3] | 7 | 40–48 | Reproductive function | [19] |
| Chimpanzee[3] | 1 | >40 | Bone mineral density | [21] |
| Chimpanzee[3] | 9 | >40 | Sociobehavioral manifestations | [25] |
| Chimpanzee[3] | 9 | 40 (mean) | Behavior | [5] |
| Lowland gorilla[4] | 1 | 44 | Senile plaques | [31] |
| Lowland gorilla[4] | 2 | *c.* 41 | Sexual behavior and estrus cycle | [2] |
| Siamang[5] | 1 | *c.* 40 | General report | [45] |
| Old World monkeys | | | | |
| Japanese macaque[6] | 1 | *c.* 40 | Skeleton | [49] |
| Crab-eating macaque[7] | 1 | >35 | Senile plaques | [40] |
| Rhesus macaque[8] | 29 | 30–37 | Age-related pathology | [52, 53] |
| Rhesus macaque[8] | 7 | 31–36 | Life span | [50] |
| Rhesus macaque[8] | 1 | 34 | Menopause | [56] |
| Rhesus macaque[8] | 2 | 31 | Hyperthyroidism | [7] |
| Rhesus macaque[8] | 3 | 31 | Behavior and pathology | [12, 35] |
| Rhesus macaque[8] | 10 | ≥30 | Serum dehydroepiandrosterone sulfate | [30] |
| Rhesus macaque[8] | 1 | >30 | Degenerative joint disease | [14] |
| Rhesus macaque[8] | 1 | >30 | Pathology | [32] |
| Assamese macaque[9] | 1 | >30 | Pathology | [32] |
| Baboon, hamadryas[10] | 5 | >30 | Aging | [33] |
| Baboon, hamadryas[10] | 7 | >30 | Pathology | [32] |
| Vervet monkey[11] | 1 | 30 | Aging | [33] |
| New World monkeys | | | | |
| Woolly monkey[12] | 2 | 30–31 | Reproductive function | [38] |
| Squirrel monkey[13] | 6 | 22–27 | β/A4 amyloid in brain | [57] |
| Squirrel monkey[13] | 1 | >20 | Cerebral tumor | [26] |
| Capuchin monkey[14] | 1 | >40 | General postmortem | [24] |
| Prosimians | | | | |
| Fat-tailed dwarf lemur[15] | 1 | 15 | Brain iron and lipofuscin | [17, 18] |
| Grey lesser mouse lemur[16] | 1 | 12 | Brain iron and lipofuscin | [17, 18] |
| Ring-tailed lemur[17] | 16 | 10–14 | Fecundity, birth seasonality | [43] |
| Ring-tailed lemur[17] | 5 | 13–22 | Hemosiderosis | [47] |
| Black lemur[18] | 6 | 11–25 | Hemosiderosis | [47] |
| Brown lemur[19] | 1 | 14 | Hemosiderosis | [47] |
| Ruffed lemur[20] | 2 | 11–13 | Hemosiderosis | [47] |
| Ruffed lemur[21] | 3 | 12–28 | Hemosiderosis | [47] |
| Potto[22] | 3 | 11–24 | Reproductivity, life span | [10, 11] |

[1]The arbitrarily fixed age levels for longevous status among non-human primate groups are, >40 yrs (apes), >30 yrs (Old World monkeys), >20 yrs (New World monkeys) and >10 years (Prosimians), based on previously reported longevity records in captivity [6, 27].
[2]Species names are as follows: [3]*Pan troglodytes*; [4]*Gorilla gorilla*; [5]*Hylobates (Symphalangus) syndactylus*; [6]*Macaca fuscata*; [7]*Macaca mulatta*; [8]*Macaca fascicularis*; [9]*Macaca assamensis*; [10]*Papio hamadryas*; [11]*Chlorocebus(Cercopithecus) aethiops*; [12]*Lagothrix lagotricha*; [13]*Saimiri sciureus*; [14]*Cebus apella*, [15]*Cheirogaleus medius*; [16]*Microcebus murinus*; [17]*Lemur catta*; [18]*Lemur macaco macaco*; [19]*Lemur fulvus*; [20]*Variecia variegata variegata*; [21]*Variecia variegata rubra*; [22]*Perodicticus potto.*

oldest member was wild born and has passed 28 years in captivity, as of September 2005. Although the owl monkey colony at our facility has been in existence for three decades, partly due to specific and focused interests of most primatologists in Japan and partly due to the labor needed to develop non-invasive protocols which satisfy the primate care protocol adopted by our Institute since 1980s, these Neotropical monkeys barely received research attention. However, the members of this owl monkey colony had received routine veterinary care and none of the living members had suffered from any maladies including pain and were not in need of specific clinical veterinary care, medications for alleviating maladies and medical interventions. Until 2002, only two short reports were published based on the genetic [29] and circadian


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activity rhythm [51] data collected from few selected members of this colony.

To remedy the then prevailing situation, we initiated our behavioral research program on this owl monkey colony in 2002. Recently, we [48] have compared the total sleep time (TST) of four members of this owl monkey colony, including the wild born oldest member Aa 23. Since in the wild, the young individuals of owl monkey disperse from the family group at the age of 3 years [59], we deduced that the oldest individual Aa 23 in our colony has already reached 30 years. According to the available published reports, and to our knowledge, this monkey thus appears to be the longest-lived owl monkey in captivity. As published data on longevous owl monkeys are scarce, our objectives for this study were (1) to prospectively quantitate the sleep of a longevous owl monkey longitudinally for 2 years, and (2) to evaluate the aging-induced change in spinal curvature.

## Materials and methods

### Animals

Three healthy female owl monkeys (*A. azarae*), sharing kinship, were used. The wild-born Aa 23 was identified as a longevous individual. Its offspring Aa 34 was used as the first control subject. At the commencement of the study in June 2003, the ages of Aa 23 and Aa 34 were $>26$ and 15 years respectively. In April 2004, Aa 34 gave birth to its ninth progeny Aa 56. Thus Aa 56 (grandprogeny of Aa 23) was also included as the second control subject, for the radiographic measurements in July 2005 towards the completion of the study. When radiographic measurements were taken, Aa 23, Aa 34 and Aa 56 weighed 1.30, 1.08 and 0.78 kg respectively. During the experimental period, while Aa 23 was housed in an individual stainless steel cage ($100 \times 70 \times 60$ cm), Aa 34 and its new-born progeny Aa 56 shared an adjacent cage of equal dimensions, since June 2005. Prior to that, Aa 34 was pair housed with its male partner and the newborn offspring, to accommodate the paternal care needs of the baby [59]. The cage dimensions in our facility for individuals and family group of four are in compliance with the required minimum space for this primate (of 1 kg mean weight) as defined by the US Animal Welfare Act 1992 [15, 16].

The colony room was maintained on a reverse, alternating 12 hours light (23:00–11:00 hours; 200 lx): 12 hours dark (11:00–23:00 hours; 0.01–0.5 lx) cycle. Lighting condition of the room was routinely checked by an illuminance meter (TopCon IM-5; Irie Seisakusho Ltd., Tokyo, Japan). Food and water were available to the monkeys *ad libitum*, and commercial pellet diet for New World monkeys (25.1 g protein and 10.6 g lipid/100 g diet) was supplemented daily with fresh fruits and twice-weekly with meal worms. Prior approval from the Research Committee of the Primate Research Institute for the reported experiments was obtained.

### Actigraphy

The sleep quantitation was carried out by an actiwatch (AW 64 model-MINIMITTER; Mini Mitter Company, Bend, OR, USA; containing 64 KB of on-board memory). Following anesthesia with ketamine HCl (10 mg/kg body wt; Sankyo, Tokyo, Japan), the AW (weighing 17 g), pre-set to collect activity–rest data of individual monkey with a sampling rate of 32 Hz and a sampling epoch of 1 minute, was suspended in an elastic band, and positioned on monkey's neck. For each subject, longitudinal data on activity pattern, TST and sleep episode length (SEL) were collected for 13 consecutive days, before removal of AW from monkey's neck. The accumulated data were retrieved into the computer, via Mini Mitter Actiwatch Reader through an RS-232 Serial Port and Activity Sleep Activity Monitoring Software, version 3.3 [37]. The definitions of the three activity–rest (sleep) parameters, as per manufacturer's instructions [37], are as follows:

**1** Activity count: an arbitrary unit quantitating primate activity, computed from any omni-directional motion made by the caged monkey with a minimal resultant force of 10 mg. The instrument tallied the activity movements with reference to degree and speed of motion and converted these parameters to produce an electrical current that varied in magnitude. This derived algorithm is referred to as AW activity count, which is instrument specific; as of now, activity counts are incompatible for comparison with AWs from different commercial suppliers [36, 37]. Though AW activity count is thus an arbitrary unit and not suitable for determining the absolute activity of the animal in concrete terms, it can be usefully employed for evaluating comparative activity patterns among the monkeys wearing the AWs from the same commercial supplier.

**2** TST: The cumulative amount of time measured in minutes in a continuous 24 hours circadian cycle (12 hours light phase:12 hours dark phase), that was scored as sleep. According to the Actiware–Sleep algorithm, based on 1 minute sampling epoch, activity counts of 40 or above were recorded as a wake epoch, and activity counts below this threshold value were recorded as a sleep epoch.

3 SEL: The mean length of blocks of continuous sleep, measured in minutes, falling between two wake bouts, in a 12 hours light phase of the 24 hours circadian cycle. The 12 hours light phase was preferred to measure this parameter, as owl monkeys predominantly rest during the light phase and not in the dark phase.

### Radiography

Radiographs of the whole body of the monkeys were taken to evaluate the alteration in spinal curvature as a consequence of aging. After anesthesia with ketamine HCl, as noted above, each subject was positioned (a) left lateral recumbently, and (b) dorso-ventrally, above the film cassette containing Fuji medical x-ray film 'RX-U' (Fujifilm Medical Co., Ltd. Tokyo, Japan). Care was taken to avoid overextension or flexion of limbs while the animals were positioned on radiographic cassette. The optimum X-ray exposure (Hitachi Medico portable X-ray machine) was 60 kV (20 mA) with exposure time set between 0.1 and 0.2 s. The distance between the film and X-ray beam source was 1 m. The films were wet processed at 20°C.

Spinal curvature of the monkeys was determined from the whole body radiographs, using kyphotic index (KI) as the criterion [34]. KI, calculated directly from the radiographs, is the ratio of AB/CD, where AB = length of the line marking the distance from seventh cervical vertebra to the sacral promontory and CD = the distance from AB to anterior border of the vertebral body that is furthest from AB [34].

## Results

### Activity–sleep quantitation

The daily activity levels, measured as mean AW activity counts, of the focal subject Aa 23 and its female offspring Aa 34 are shown in Fig. 1A. The daily mean (±SD) AW activity counts for the focal subject Aa 23 in June 2003, January 2004, January 2005 and May 2005 were 53 ± 7, 67 ± 10, 43 ± 16 and 44 ± 20 respectively. In comparison, the daily mean (±SD) AW activity counts for Aa 34 in August 2003, January 2004, June 2004 and June 2005 were 117 ± 30, 134 ± 30, 127 ± 20 and 97 ± 30 respectively. As expected, in all four data points spanning 2 years, the intensity of daily activity of aged Aa 23 monkey was almost one half or less to that of its progeny Aa 34. The AW activity count of Aa 56, the grandprogeny of Aa 23, was also determined in April 2005, when it reached 1 year. The daily mean (±SD) AW activity count of 323 ± 104 for Aa 56 (data not included in Fig. 1A) was nearly threefold higher to that of its female parent Aa 34, though it shared the same cage. We also positively ascertained from comparative individual videotape records of 24 hours duration of all

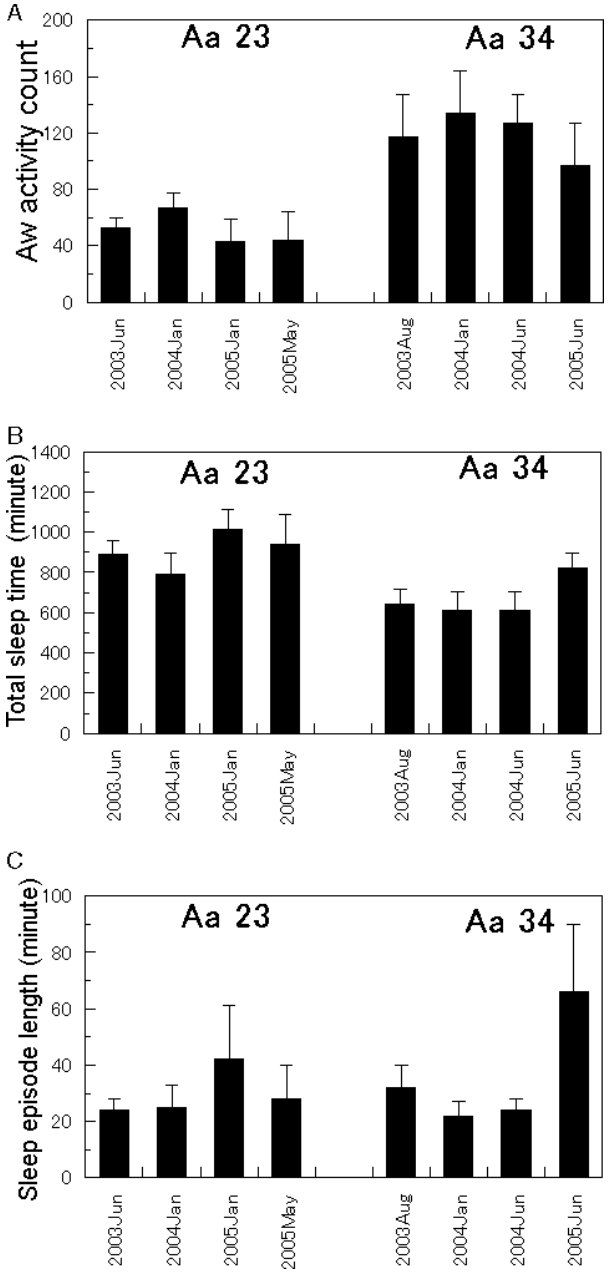


**Fig. 1** Comparison of measured activity and sleep parameters of longevous owl monkey (Aa23, aged >26 years) and its progeny (Aa 34, aged 16 years). (A) Activity counts, (B) total sleep time, and (C) sleep episode length. Each histogram represents the activity–sleep quantitation of consecutive 13 days. Results are expressed as daily mean ± SD.


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except two owl monkeys in our colony, that the activity routines of longevous monkey Aa 23 was neither hindered by any identifiable motor defects nor by arthritic development in the limb extremities. Veterinary care records also showed cataract formation in both eyes of this longevous monkey after it reached 20 years of captivity.

The daily mean (±SD) TST in the focal subject Aa 23 and its progeny Aa 34 are shown in Fig. 1B. The daily mean (±SD) TST for the focal subject Aa 23 in June 2003, January 2004, January 2005 and May 2005 were 887 ± 72, 790 ± 103, 1016 ± 94 and 937 ± 150 minutes respectively. In comparison, the daily mean (±SD) TST for Aa 34 in August 2003, January 2004, June 2004 and June 2005 were 643 ± 76, 612 ± 92, 614 ± 91 and 822 ± 71 minutes respectively. Again as expected, in all four data points spanning 2 years, the duration of TST of aged Aa 23 monkey was namely 4, 3, 6 and 2 hours longer to that of its progeny Aa 34. This indicated that the aged focal monkey slept more, especially in January 2005, compared with its progeny. The daily mean (±SD) TST of Aa 56 was determined to be 712 ± 55 minutes (data not included in Fig. 1B).

Figure 1C shows the daily mean (±SD) of SEL in the focal subject Aa 23 and its progeny Aa 34. The daily mean (±SD) SEL for the focal subject Aa 23 in June 2003, January 2004, January 2005 and May 2005 were 24±4, 25±8, 42 ± 19 and 28 ± 12 minutes respectively. In comparison, the daily mean (±SD) SEL for Aa 34 in August 2003, January 2004, June 2004 and June 2005 were 32 ± 8, 22 ± 5, 24 ± 4 and 66 ± 24 minutes respectively. As opposed to the marked difference in the TST values between that of Aa 23 and Aa 34, it appears that the variation in SEL between the focal Aa 23 monkey and its progeny Aa 34 was marginal as the daily mean values varied within a narrow window of 22–32 minutes, with overlapping SD values in six of the eight data points spanning 2 years. However, the SEL of Aa 56, sharing the same cage of Aa 34, was 43 ± 13 minutes in April 2005 (data not included in Fig. 1C).

### Aging-induced spinal curvature

Two types of spinal curvature, namely kyphosis (dorsally directed acute curvature of spine along the mid-sagittal plane) and scoliosis (laterally directed curvature of spine along the coronal plane) were examined. The extent of aging-induced spinal curvature of both these types in the longevous Aa 23 monkey was markedly visible in the radiographs taken. Photographs produced from the radiographs reveal the kyphosis (Fig. 2) and scoliosis (Fig. 3) of Aa 23 monkey's spine. Table 2 presents the KI values, calculated from the original radiographs, for the three studied monkeys. The KI of 2.27 for the Aa 23 monkey, compared with the values of 4.83 and 5.42, for Aa 34

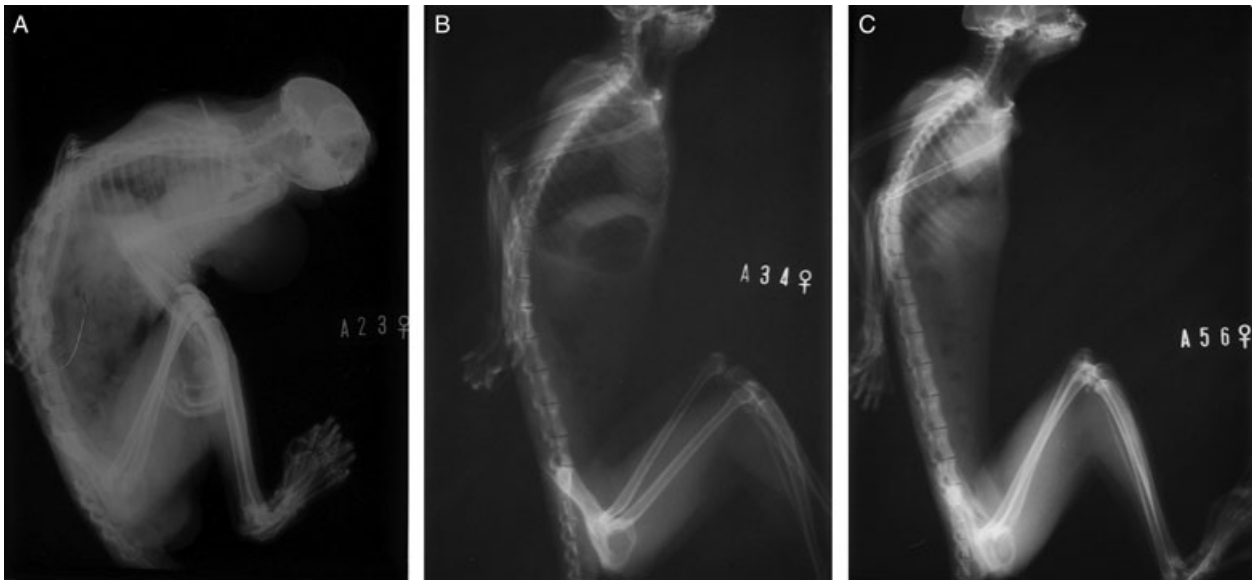


**Fig. 2** Whole body radiographs (lateral positioned) of owl monkeys, for calculation of kyphotic index. (A) Aa 23, aged >26 years; (B) Aa 34, aged 16 years; (C) Aa 56, aged 1 year. The prominent vocal sac of Aa 23, bulging externally in the ventral side, is faintly visible in (A), while it is absent in (B) and (C).

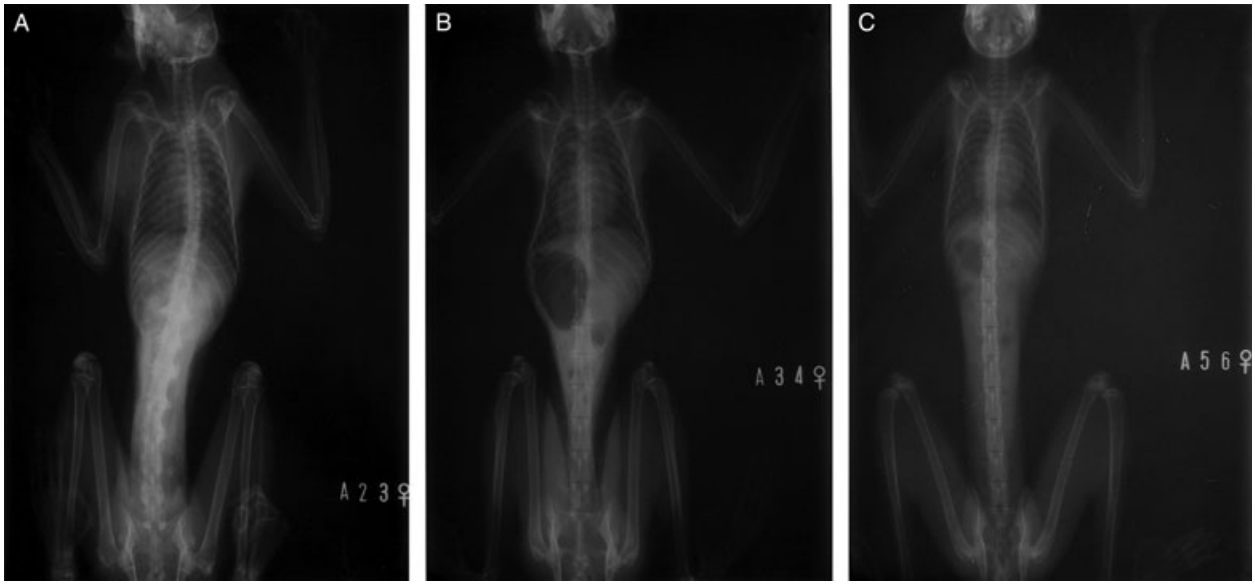


**Fig. 3** Whole body radiographs (dorso-ventral positioned) of owl monkeys. (A) Aa 23, aged >26 years; (B) Aa 34, aged 16 years; (C) Aa 56, aged 1 year. Marked lateral curvature of the spine is visible in (A), compared with those in (B) and (C).

**Table 2** Effect of age on spinal curvature in owl monkey indicated by radiography

| Owl Monkey | Age (years) | AB[1] (mm) | CD[2] (mm) | KI[3] |
|---|---|---|---|---|
| Aa 23 | >26 | 166 | 73 | 2.27 |
| Aa 34 | 16 | 198 | 41 | 4.83 |
| Aa 56 | 1 | 206 | 38 | 5.42 |

KI, kyphotic index.
[1]Length of the line marking the distance from seventh cervical vertebra to the sacral promontory. Measurement was made directly from the radiograph.
[2]The distance from AB to anterior border of the vertebral body that is furthest from AB. Measurement was made directly from the radiograph.
[3]The ratio of AB/CD.

and Aa 56 (aged 1 year) respectively, confirmed the prominent spinal curvature. Whereas the vertebral bodies of Aa 34 and Aa 56 have distinct square or rectangular shapes (Fig. 2B,C), the borders of the vertebral bodies of Aa 23 monkey appear thickened because of high degree of ossification (Fig. 2A). In addition, the intervertebral spaces of thoracic vertebrae have disappeared and those of lumbar vertebrae have diminished in Aa 23 monkey (Fig. 2A). Degeneration in the spinal vertebrae, with aging, probably have contributed to the development of marked kyphosis in Aa 23 monkey. In addition to scoliosis, disc bulge in the lumbar vertebral region of Aa 23 monkey (Fig. 3A) can also be seen, compared with those of control subjects Aa 34 and Aa 56 (Fig. 3B,C).

## Discussion

### Reports on longevous non-human primates

One stimulus for us to compile Table 1 was to update and summarize the available longevity records of captive non-human primates, strictly from the published primary literature which have reported on certain aspects of aging at organ, tissue or cellular level. This was considered of some merit, as the rigor of previous compilations and analyses on longevity [3, 41] appears diluted due to mixing of primary literature with that of standard secondary reference sources, unpublished personal communications and oral records. Table 1 presents an updated longevity record for 19 species of non-human primates. With the inclusion of the longevity information presented in this report for the owl monkey, the longevity records of 20 species of non-human primates now become updated.

What became revealed in the compilation of Table 1 was the fact that even among the few prospective studies on longevous primates, attention to the sleep behavior of senile subjects have been overlooked, because of oversight or lack of interest. At least in this report on a longevous female owl monkey, we have attempted to rectify this oversight. Now aged $>30$ years, this owl monkey appears to be an outlier to the 'Caretakers live longer' hypothesis among anthropoid primates [1], which postulated that past sexual maturity, captive owl monkey males have a strong survival advantage over females.


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### Activity–sleep quantitation

As indicated in past reviews [8, 60], sleep quantitation of agile and dexterous non-human primates has remained a challenging task for decades mainly due to inherent technical limitations involved in the highly invasive polysomnographic protocols. As a consequence, non-invasive actigraphy has gained acceptance recently as a viable and alternative sleep measurement method for non-human primates [36, 61]. Recently, in a cross-sectional study we [48] have established that the daily mean TST of four owl monkeys ranged between 9 hours 30 minutes and 12 hours 30 minutes.

The current longitudinal study extending for a 2-year period, incorporated four data points and included two (Aa 23 and its progeny Aa 34) of the four monkeys used in our previous study [48]. In the current study, the daily mean TST of the longevous Aa 23 monkey fluctuated between 13 hours 10 minutes and 16 hours 56 minutes, while that of its progeny Aa 34 monkey (aged 16 years and used as a suitable control) fluctuated between 10 hours 12 minutes and 13 hours 42 minutes. However, it should be noted that the fluctuation of daily mean TST in Aa 34 monkey during first three data points – 10 hours 43 minutes, 10 hours 12 minutes and 10 hours 14 minutes (between 2003 August, 2004 January and 2004 June) was marginal, the variation being only 31 minutes. During this period, Aa 34 monkey shared the same cage with its breeding mate. It conceived in 2004 January and gave birth to Aa 56 in 2004 April and continued to nurse its offspring in 2004 June. After Aa 56 monkey reached 1 year in 2005 April, Aa 34 monkey was separated from its breeding mate and housed with its progeny Aa 56 in a separate cage. Thus, the increase in mean daily TST of Aa 34 monkey to 13 hours 42 minutes in 2005 June may be attributed to this change in housing condition. Concurrently, the mean SEL of Aa 34 monkey also reflected this change in housing condition, where the mean SEL was 32, 22 and 24 minutes respectively in 2003 August, 2004 January and 2004 June, but increased drastically to 66 minutes in 2005 June. However, during the 2-year study period, the variation in the mean SEL among the four data points (24, 25, 42 and 28 minutes respectively) for the longevous Aa 23 monkey was not drastic. As five of the eight mean SEL data points for both Aa 23 and Aa 34 monkeys during the span of 2 years, cluster between a narrow window of 22 and 28 minutes, it could be inferred that the longevous Aa 23 monkey (a) has reduced activity and increased daily sleep time, in comparison with its progeny, but (b) retains similar SEL to that of its progeny.

We are aware of the fact that legitimate concerns do exist on using progeny and grandprogeny as controls for longevous subjects in primate studies [55, 58]. However we are of the opinion that sleep data on three generations of a family sharing the same genetic makeup and bred under identical captive conditions distinctly illuminate the effect of aging on sleep on subjects which are genetically related, and not inbred; and thus providing effective genetic control, which otherwise would be a compounding influence on the obtained data [54]. Furthermore, reports on the sleep data on three generations of primates including humans like the present study have been unusually rare in past somnology literature.

### Cataract formation and its influence on activity

Although the owl monkey has served as a popular primate model in ophthalmologic research for nearly four decades from 1941 to 1985 [42], cataract formation because of senility failed to attract the attention of researchers. Even when numerous ($n > 50$) owl monkeys were used in a couple of ophthalmologic studies [46], age details of the experimental subjects have been missing. As such, information on cataract development in aging owl monkeys is scarce at best. However, senile cataracts have not been observed in rhesus monkeys which were $< 20$ years old [28]. This finding is somewhat in agreement with the veterinary care records of the longevous Aa 23 monkey, when early signs of cataract formation in both eyes were detected after this monkey reached 20 years of captivity. Nevertheless, we doubt that impaired vision because of developed cataract could have strongly impeded the locomotory movements of this longevous monkey within its cage, to the limit of reducing its activity profile. While it may be true in wild conditions where the visually impaired monkey may hesitate to venture into unexplored space because of poor eyesight, we infer that after 20 years of captivity, omni-directional movements within its own cage would hardly be a challenging task for this longevous monkey – even with failing eye sight. Thus, the low intensity of activity (Fig. 1A) shown by the longevous monkey could more or less be directly correlated to its old age.

### Aging-induced spinal curvature

The only previous report [9] on the whole body radiography of owl monkeys featured four males aged 1, 5.5, 12 and 46 months. As the present report features three owl monkey females aged 1, 16 and $> 26$ years, direct comparisons with the previous report [9] seems less

appropriate, because of gender and age variations between the examined monkeys. However, the almost resembling patterns of the radiographic frames of Aa 56 (Fig. 3C) and its same aged male counterpart at 1 year, presented in the previous report [9], are in agreement.

Previously, an aged (>20 years) female rhesus monkey with a pronounced kyphosis and degeneration of spine has also been reported [14]. Degeneration of vertebral joints resulting in kyphosis, scoliosis, and lumbar vertebral disc bulge of the longevous owl monkey in the current study (Figs 2 and 3), in comparison with the vertebral frames of its progeny Aa 34 and grandprogeny Aa 56, appear identical with the age-related degeneration of skeletal system occurring in senile rhesus macaque [14]. The probability for spinal curvature increases with advancing age as a combined effect of decrease in bone mass, reduced spinal mineral bone density, intervertebral disk thinning and reduced muscular tone, among other factors. As revealed from the radiographic evidence, it is inevitable that the spine of Aa 23 monkey has become considerably weakened because of 28 years of captive life. However, this weakened condition of spine has not led to compression fracture of spine, as repetitively demonstrated by the (a) presence of active reflexes by the monkey, to the level that anesthesia was needed for routine noninvasive experimental procedures such as tagging and removing the AW, and (b) absence of chronic pain indication. In addition, its stable weight (1.3 kg), good appetite and lack of any detectable malady other than cataracts, also reflect a good degree of health for this longevous owl monkey's advanced age.

As owl monkeys are extremely agile and naturally have a hunched back adapted for powerful leaps among the tree branches [39], it may not be inappropriate to raise a general issue on the terminology used in spinal curvature (kyphosis, lordosis and scoliosis) with relevance to the life of non-human primates in natural habitats. Medical terms relating to spinal curvature were introduced with human frame as reference. As humans are bipedal by natural evolution, terms such as kyphosis, lordosis and scoliosis have gained negative connotation in general context. Associated with this, we agree with a previous view [20] in the context of motion economy of non-human primates within the forest canopy that primate studies are greatly distorted by questions of human evolution. Therefore, how valid is the negative connotation relating to kyphosis, lordosis and scoliosis (in medical context) for obligatory quadrupedal owl monkeys, spending their whole lives in an arboreal habitat? Nevertheless, we infer that aged owl monkeys in captivity [like the longevous Aa 23 monkey presented in this report] are susceptible to a marked degree of spinal curvature because of advanced age.

To sum up, we have prospectively quantitated the sleep time and SEL of an owl monkey which have lived in captivity for 28 years, and also have radiographically assessed its age-related change in spinal integrity, in comparison with its progeny and grandprogeny.

### Acknowledgments

We acknowledge the expert technical assistance provided by Nobuko Matsubayashi for this study.

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