Primates (2008) 49:223–226
DOI 10.1007/s10329-008-0083-4

SHORT COMMUNICATION

Monkeys with disabilities: prevalence and severity of congenital limb malformations in *Macaca fuscata* on Awaji Island

Sarah E. Turner · Linda M. Fedigan · Hisami Nobuhara · Toshikazu Nobuhara · H. Damon Matthews · Masayuki Nakamichi

Received: 12 April 2007 / Accepted: 30 January 2008 / Published online: 3 April 2008

Abstract The Awajishima Monkey Center (AMC) free-ranging, provisioned population of Japanese macaques has included individuals with congenital limb malformations (CLMs) for at least 40 years. Including new data from this study, 16.1% of AMC infants from 1969 to 2007 (185 of 1,150) were born with CLMs. However, relatively little is known about the demographics of CLMs in the population, particularly the relationships among occurrence and severity of CLMs and age-sex demographics after infancy. In 2004, we conducted a census at AMC. Of the 199 monkeys censused, 34 individuals (17.1%) had CLMs. To estimate the severity of CLMs, we created an index that ranks individuals on a scale of 0 to 1 based on affected and absent limbs and digits. The severity of CLMs varied greatly (index range = 0.01–0.79, mean = 0.29), with similar variation in severity in each age-sex class (Student *t*-test, $P > 0.05$).

S. E. Turner (✉) · L. M. Fedigan
Department of Anthropology, University of Calgary,
2500 University Dr. N.W., Calgary, AB,
Canada T2N 1N4
e-mail: turnerse@ucalgary.ca

H. Nobuhara · T. Nobuhara
Awajishima Monkey Center, Awaji Island, Hyogo, Japan

H. D. Matthews
Department of Geography, Planning and Environment,
Concordia University, Montreal, Canada

M. Nakamichi
Laboratory of Ethological Studies, Faculty of Human Sciences,
Osaka University, Osaka, Japan

Keywords Japanese macaque · Physical impairment · Disability · Census

Introduction

Monkeys with congenital limb malformations (CLMs) have been reported in wild, provisioned, and captive groups of Japanese macaques since the mid-1950s (Yoshihiro et al. 1979). The CLMs can range from slight differences in digital structure and mobility to the absence of entire limbs (Yoshihiro et al. 1979; Homma 1980). There are many possible etiologies for CLMs and the cause of these limb malformations has never been fully established; however, some organochlorine pesticides have been implicated (Ito et al. 1988; Minezawa et al. 1990). While only a few cases of Japanese macaques with CLMs have been reported across Japan in the past two decades [e.g., a male born in 1989 without hands at Arashiyama (Ogihara et al. 2005)], CLMs have continued to occur every year at the Awajishima Monkey Center (AMC) (Nakamichi et al. 1997; Turner et al. 2005). The AMC was established in 1967, with the goal of reducing crop raiding, and promoting conservation and eco-tourism. Since then, the wild macaques have been provisioned with wheat, soy, fruit and sweet potatoes. The monkeys also forage on wild foods throughout the year, and almost exclusively in September and October, when native fruits are ripe. In 1967, there were one or two individuals at the AMC with probable CLMs (M. Nakahashi, personal communication).

The purpose of this study was to answer the following questions: (1) How many infants with CLMs are born in the Awajishima population? (2) How many individuals are living with CLMs at the AMC and what are the demographic characteristics of the disabled monkeys compared

to those of the non-disabled monkeys? and (3) What is the range of severity of CLMs, and how does severity relate to age and sex?

Methods

Birth rate and census

We used AMC records to examine birth rates of infants with CLMs. In 2004 we conducted an 8-week total count census (Ross and Reeve 2003). We combined written descriptive data and drawings with a detailed photographic record of each individual, using a Nikon CoolPix 6-megapixel digital camera with a 300 mm zoom lens. When age was not known, we estimated broad age class based on size, coloration, nipple characteristics, and presence of infant or pregnancy [age classes: infants up to 1 year, 1- to 4-year-olds, and adults 5 years and older for males and females (after Itoigawa et al. 1992)]. After collecting records on an individual, we marked the monkey with black hair dye to prevent duplication of records. We also conducted group counts several times a week during provision feeding to verify accuracy of the total count from individual identification.

We analyzed the census data using the χ^2 test for independence to assess whether differences in the frequencies (proportions) of disabled animals across age and sex categories were significantly different from what would be expected by chance.

Index

The severity of limb malformations ranged from very slight digital anomalies to complex and unique digit and limb configurations. We designed a 0–1 index in order to describe this range of severity of limb malformations within the population and to compare severity among individuals and age-sex classes: 0 corresponds to no limb malformation and 1 to the most extensively affected individual observed: a live-born infant with neither arms nor legs, who died in her first day of life. To obtain an index score for an individual monkey, we evaluated each limb, using each digit, metacarpal, metatarsal, radius/ulna, tibia/fibula, humerus, and femur bone as an index variable. We visually assessed each variable for malformation or absence, using the detailed photo records obtained during the census. Scores were cumulative, such that an individual with an absent hand received points for the absence of each digit and metacarpal involved. Variables were weighted as follows (numbers in brackets indicate the weight relative to finger digits 2, 3, 4 and 5): finger (1), thumb (2), toe (0.75), metacarpal/metatarsal (0.75), radius/ulna (2), humerus (2), tibia/fibula (2), and femur (2). Complete absence was given an additional half value over the basic malformation score for the variable.

Results

Birth rates (1996–2007)

The birth rate of infants with CLMs has remained high at AMC since the last published report, which included data up to and including the 1995 birth season (Nakamichi et al. 1997). Between 1996 and 2007, 13.7% of live-born infants had some level of limb malformation, and the number of CLM births ranged from a minimum of one in the years 2000 and 2006 to a maximum of 10 in 1996 (Fig. 1). The percentage of infants with CLMs ranged from 2.9% in 2006 to 33.3 % in 1999 (Fig. 1). When these data were considered together with those reported by Nakamichi et al. (1997) and Yoshihiro et al. (1979), the 1969 to 2007 average birth rate of CLM infants in the AMC provisioned group is 16.1% (Table 1).

Census

Including the infants born in 2004, we censused 199 monkeys. Of those 199, 34 (17.1%) had limb malformations. Additionally, four had slight digital anomalies, such as a digit that did not bend. Although these slight anomalies may have been present at birth, it is also possible that they were caused by injury; as such, these individuals were not included in the analyses of monkeys with CLMs. The 34 monkeys who were living with limb malformations included 3 live-born 2004 infants, 7 young males, 5 young females, 6 adult males, and 13 adult females (Table 2). The distribution of CLMs between the sexes, among the age

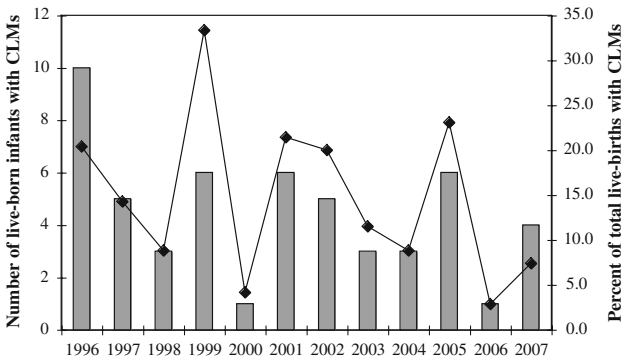

Fig. 1 Infants with congenital limb malformations (CLMs) born from 1996 to 2007 on Awajishima. The *grey bars* refer to the number of infants born with CLMs. The *black diamonds* refer to the percentage of all live born infants who were born each year with limb malformations into the Awajishima group

Table 1 Birth rates for infants with congenital limb malformations (CLMs) in the Awajishima Monkey Center (AMC) provisioned population

Years	Number of infants born with CLMs	Total number of infants born in the AMC group	Percent of infants born with CLMs (%)	Source
1969–1978	46	156	29.9	Yoshihiro et al. 1979
1979–1995	86	606	14.2	Nakamichi et al. 1997
1996–2007	53	388	13.7	This study and H. Nobuhara and T. Nobuhara (unpublished data)
1969–2007 (total)	185	1,150	16.1	

Table 2 Results from the 2004 census of the Awajishima Japanese macaques

	Infants				1–4 years			5 years and older			Total		Total: CLMs and group size
	M	F	Undetermined	Total	M	F	Total	M	F	Total	M	F	
Monkeys with CLMs	1	2	0	3	7	5	12	6	13	19	14	20	34
Monkeys without CLMs	7	11	10	28	21	40	61	22	54	76	50	105	165
Total	8	13	10	31	28	45	73	28	67	95	64	125	199

groups and between the sexes within age groups were not significantly different from what would be expected by chance (χ^2 test for independence, not shown).

Index

The severity of CLMs showed considerable variation in the AMC group (index range = 0.01–0.79, mean = 0.29, median = 0.27, standard deviation = 0.23) (Fig. 2). The spread of severity was similar between sexes, among age groups and between sexes within each age group; we found no significant sex- or censused age-class differences in the severity of CLMs (student's *t*-test, sex: df = 32, $t = 0.092$, $P = 0.927$; age: df = 29, $t = 0.563$, $P = 0.578$). For disabled monkeys of known age ($n = 31$), there was no significant relationship between age and severity (linear regression df = 30, $F = 0.529$, $P = 0.473$).

Discussion

We have presented 12 years of data on birth rates of infants with limb malformations, analyzed data from a total count census of the AMC provisioned population taken in 2004, and introduced an index for measuring the severity of limb malformations. In relation to the prevalence of CLMs in the group, incidence remains unusually high at AMC, with 17.1% of the total provisioned population affected in 2004 (census results) and 13.7% of infants born in the last 12 years (1996–2007) with malformation of the limbs. The prevalence of CLMs in this population is extremely high. Congenital limb malformations are normally rare among human and nonhuman primates, and birth rates of CLMs are expected to be a small fraction of 1% [e.g., Froster-Iskenius and Baird (1989); for a review of the CLM literature on nonhuman primates, see Brignolo et al. (2002)]. To put the prevalence at AMC into context, about 3% of live-born human infants in the United States have some type of birth defect (Canfield et al. 2006). One recent study reported a "high incidence of major malformation" when 2.6% (137 of 5,356 live-births) of human babies in a hospital in Saudi Arabia had a major congenital anomaly (Fida et al. 2007). CLMs are but one small fraction of congenital anomalies reported in these studies. Although current rates of CLMs at Awajishima are lower than the peak rates reported in the 1970s, birth rates of infants with CLMs have remained high since 1969; at least one infant with CLMs has been live-born every year and there is no evidence that CLMs are disappearing in the population. In addition, since 2004, at least three infants have been stillborn with complete absence of limbs, normally a very rare condition.

We documented a wide range of severity of CLMs in the population, comparable to variation described in other published research (e.g., Nakamichi et al. 1997), and found no significant relationship between severity of limb malformation and age. Many monkeys who have quite extensive limb malformations do survive to adulthood in this group. These individuals were cared for as infants by their mothers, with mothers often using an arm to carry the infant, even for infants slow to develop independent locomotion (Nakamichi 1986; Turner et al. 2005). Most

Fig. 2 Photographic examples of monkeys with varying CLM severity. **a** "Augusta," a female born in 1998, has digit 3 absent on her left hand, index 0.02. **b** "Nachan," a female born in 1995, has thumbs but has absent and malformed digits on both hands, index 0.13. **c** "Ran," a female born in 1991, has some malformation and absence on both hands and on her left foot, index 0.24. **d** "Fumin" a female born in 1996, has malformations on digits 1 and 5 and absence of other digits and associated metacarpals, index 0.33. **e** "Punch98," a female born in 1998, has a slight malformation on her right foot and both hands predominantly absent, index 0.38. **f** "Eric," born in 1991, has absences and malformations on all four limbs, index 0.60. **g** "Ribbon," a female born in 2001, has malformed and absent digits and metatarsals on both feet, no hands, and partial absence of radius/ulna bones. Ribbon is habitually bipedal, index 0.72. **h** "Daydrie," a male born in 1999, had extensive absence and malformation in all four limbs, index 0.74 (the highest score for a non-infant monkey living in 2004)

monkeys with physical disabilities from CLMs in this group are eventually able to develop individual modes of locomotion and other behaviors that facilitate their survival. Investigations into the potential effects and costs of physical disability, and how these may be mitigated through behavior, are ongoing at AMC.

Acknowledgments S.T. expresses sincere thanks to the Nobuhara and Nakahashi families for permission to conduct research at the Awajishima Monkey Center. Funding to S.T. was provided by the: LSB Leakey Foundation, Izaak Walton Killam Memorial Scholarship, Animal Behavior Society, Global Forest Science (GF-18–2001–169), U of C Dept. of Anthropology, Province of Alberta Graduate Scholarships, and National Science and Engineering Research Council of Canada (Postgraduate Scholarship B). L.M.F.'s research is supported by an NSERC Discovery Grant and the Canada Research Chairs Program. Sincere thanks for support of this project in Japan and Canada to Prof. F and Mrs. H. Taniguchi, the Okada family, Dr. M. Huffman, Dr. K. Shimizu, Dr. H. Tanaka, Dr. P. Asquith, Y. Kamata, G. Orban, and A. Melin.

References

Brignolo L, Tarara R, Peterson PE, Hendrickx AG (2002) Two cases of digital defects in *Macaca mulatta* infants and a survey of the literature. J Med Primatol 31:98–103

Canfield MA, Honein MA, Yuskiv N, Xing J, Mai CT, Collins JS, Devine O, Petrini J, Ramadhani TA, Hobbs CA, Kirby RS (2006) National estimates and race/ethnic-specific variation of selected birth defects in the United States, 1999–2001. Birth Defects Res A Clin Mol Teratol 76:747–756

Fida NM, Ai-Aama J, Nichols W, Algahtani M (2007) A prospective study of congenital malformations among live born neonates at a university hospital in Western Saudi Arabia. Saudi Med J 28:1367–1373

Froster-Iskenius UG, Baird PA (1989) Limb reduction defects in over one million consecutive livebirths. Teratology 39:127–135

Homma T (1980) Sequential pattern of limb anomalies in Japanese monkeys on Awajishima island. Primates 21:20–30

Ito M, Ogawa K, Sonobe T, Nakaminami G, Ishida N, Watanabe N, Inagaki H, Nigi H (1988) Relation of the congenital limb-malformation in the Japanese monkeys and organochlorin pesticides. Primate Res 4:103–133

Itoigawa N, Tanaka T, Ukai N, Fujii H, Kurokawa T, Koyama T, Ando A, Watanabe Y, Imakawa S (1992) Demography and reproductive parameters of a free-ranging group of Japanese macaques (*Macaca fuscata*) at Katsuyama. Primates 33:49–68

Minezawa M, Nozawa K, Yoshihiro S, Hamada Y, Inagaki H, Nigi H (1990) A cytogenic study of congenital limb malformations in the Japanese monkey. Primates 31:517–577

Nakamichi M (1986) Behavior of infant Japanese monkeys (*Macaca fuscata*) with congenital limb malformations during their first three months. Dev Psychobiol 19:335–341

Nakamichi M, Nobuhara H, Nobuhara T, Nakahashi M, Nigi H (1997) Birth rate and mortality rate of infants with congenital malformations of the limbs in the Awajishima free-ranging group of Japanese monkeys (*Macaca fuscata*). Am J Primatol 42:225–234

Ogihara N, Usui H, Hirasaki E, Hamada Y, Nakatsukasa M (2005) Kinematic analysis of bipedal locomotion of a Japanese macaque that lost its forearms due to congenital malformation. Primates 46:11–19

Ross C, Reeve N (2003) Survey and census methods: population distribution and density. In: Setchell JM, Curtis DJ (eds) Field and laboratory methods in primatology: a practical guide. Cambridge University Press, Cambridge, pp 90–109

Turner SE, Gould L, Duffus DA (2005) Maternal behavior and infant congenital limb malformation in a free-ranging group of *Macaca fuscata* on Awaji island, Japan. Int J Primatol 26:1435–1457

Yoshihiro S, Goto S, Minezawa M, Muramatsu M, Saito Y, Sugita H, Nigi H (1979) Frequency of occurrence, morphology, and causes of congenital malformation of limbs in the Japanese monkey. Ecotoxicol Environ Saf 3:458–470