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Brief communication: Hip joint mobility in free-ranging rhesus macaques

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Abstract

Objectives—We aimed to test for differences in hip joint range of motion (ROM) between captive and free-ranging rhesus macaques (*Macaca mulatta*), particularly for hip joint abduction, which previous studies of captive macaques have found to be lower than predicted.

Materials and Methods—Hip ROM was assessed following standard joint measurement methodology in anesthetized adult free-ranging rhesus macaques (n=39) from Cayo Santiago, and compared to published ROM data from captive rhesus macaques (n=16) (Hammond 2014a, *American Journal of Physical Anthropology*). Significant differences between populations were detected using one-way analysis of variance ($p < 0.05$).

Results—In a sample of pooled sexes and ages, free-ranging macaques are capable of increased hip abduction, flexion, and internal rotation compared to captive individuals. These differences in joint excursion resulted in free-ranging individuals having significantly increased ROM for hip adduction-abduction, rotation, flexion-extension, and the distance spanned by the knee during hip abduction. When looking at data for a smaller sample of age-matched males, fewer ROM differences are significant, but free-ranging males have significantly increased hip abduction, internal rotation, range of flexion-extension, and distance spanned by the knee during hip abduction compared to captive males of similar age.

Discussion—Our results suggest that a spatially restrictive environment results in decreased hip mobility in cage-confined animals and ultimately limits the potential limb postures in captive macaques. These results have implications for selection of animal samples in model validation studies, as well as laboratory animal husbandry practices.

Keywords

hip abduction; nonhuman primate captive care; caging; Cayo Santiago; *Macaca mulatta*

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Introduction

A key element of primate functional morphology is hip joint range of motion (ROM), with increased ROM proposed to confer distinct advantages when navigating the arboreal environment. Specifically, it has been widely assumed that high levels of hip mobility should be particularly important for more acrobatic animals because they must reach for distantly and erratically positioned arboreal supports during bridging behaviors (Jenkins, 1972; Walker, 1974; Jenkins and Camazine, 1977; Ruff, 1988; Swartz, 1989; MacLatchy, 1995; 1996; 1998). Passive hip joint excursion data were recently collected for a broad sample of anthropoid primates in order to test this assumption (Hammond, 2013; 2014a; b). These data showed that hip abduction and external rotation are significantly larger in more acrobatic arboreal species compared to monkeys that use primarily parasagittal limb postures (e.g., *Macaca, Papio*) (Hammond, 2013; 2014a; b).

In vivo data for hip abduction in *Macaca* underestimate simulations of hip abduction, however. A comparative digital model of hip abduction based on bony morphology (Hammond et al., 2016) indicates that macaque bony hip morphology predicts a larger range of hip abduction than is found empirically (i.e., when measured *in vivo*; Hammond, 2013; Hammond, 2014a). One possible explanation for this is that prior measurements of macaques were made on captive individuals, who might exhibit a reduced range of hip abduction due to long-term caging, whereas model predictions are based on wild-shot animals. The laboratory macaques (*M. mulatta* and *M. fascicularis*) tested against the Hammond et al. (2016) model of hip abduction lacked access to climbing structures in their enclosures and lived in cages that limited the range of limb movements (see Materials and Methods). The caged macaques differed from the other live animals in the study, which were primates living in larger and/or more naturalistic enclosures with access to climbing structures.

Data suggest that caging does indeed influence primate joint mobility. Turnquist (1983) found that caging, especially from an early age, influences joint mobility in patas monkeys, although caged monkeys in this study actually displayed a greater ROM than free-ranging individuals. In a follow-up study, Turnquist (1985) demonstrated that normal ranges of motion in caged patas monkeys can be restored if given access to a free-ranging environment. Available data on ROM for free-ranging rhesus macaques do not allow a test of comparative ROM models, because all necessary variables were either not collected or not provided in publications (Turnquist and Kessler, 1989), or because the data provided were not specific enough (DeRousseau et al., 1983).

The possibility that hip joint abduction is significantly reduced in captive compared to free-ranging macaques has remained untested because comparable data on hip abduction from the latter have not been available. We aimed to test for differences in hip abduction between captive and free-ranging rhesus macaques (*Macaca mulatta*), in order to supplement published data on the effects of caging on ROM (DeRousseau et al., 1983; Turnquist, 1983; 1985; Turnquist and Kessler, 1989; Wells and Turnquist, 2001), and to determine whether data from free-ranging macaques better fit comparative models of hip abduction (Hammond et al., 2016).

Materials and Methods

Study sample and environment

We sampled 39 Indian-derived rhesus macaques (37 males, 4.2–15.8 years; 2 females, 9.2–11 years) on Cayo Santiago, Puerto Rico (See Supplemental Table 1). The captive sample consisted of published data for 16 rhesus macaques (8 males, 8.8–9.3 years; 8 females, 8.6–9.5 years) from the Wisconsin National Primate Research Center (WNPC) (Hammond, 2013; 2014a). All macaques sampled in this study are believed to be skeletally adult based on known epiphyseal fusion ages for the pelvis and proximal femur for both Cayo Santiago (Cheverud, 1981) and laboratory-housed (Van Wagenen and Asling, 1958) rhesus macaques (see Supplemental Table 2, Supplemental Figure 1). Male Cayo Santiago macaques were being trapped for another project and were opportunistically measured, resulting in disproportionately more males than females in the free-ranging sample. None of the female macaques from WNPC or Cayo Santiago were lactating or pregnant. All individuals in this study were healthy and selected in consultation with veterinary staff. All free-ranging macaques were handled in compliance with the CPRC Institutional Animal Care and Use Committee protocols, and their handling and use was authorized by the Institutional Animal Care and Use Committee of the University of Puerto Rico (protocol #A0100108) and NYU's University Animal Welfare Committee (protocol # 14-1439). Captive macaque handling and use was approved by the University of Missouri's Animal Care and Use Committee (protocol #6862) and the WPRC Institutional Animal Care and Use Committee.

Cayo Santiago is a 15.2-ha island located 1 km off the south-east coast of Puerto Rico. Rhesus macaques were released on the island in 1938, from which the current animals are descended with no further introductions (Rawlins and Kessler, 1986). This descendent population shows no genetic evidence of inbreeding (Widdig et al., in press). Cayo Santiago's vegetation has changed over the years. Currently, the island features a mix of flat mangroves and grassland, combined with steep and craggy cliffs, dispersed woodland, and tall (>30 ft) palm trees. Animals spend much of the day travelling terrestrially, which includes walking on flat and gently inclined surfaces, but often also includes travel up and down steep inclines and rocky cliffs. They regularly climb relatively low ($\approx$ 10–15 ft) trees, and occasionally climb the island's much taller palm trees (JPH, personal observations).

All sampled captive rhesus macaques were captive-born at the Wisconsin National Primate Research Center, and reared in conditions standardized for optimal nutrition and health in laboratory animals. Detailed caging histories for each captive macaque were not available. Most of the macaques (12 of 16) were caged with another macaque(s), with the remaining 4 males housed individually (see Supplemental Table 3). It is possible that some animals were housed in larger pens or runs at some point during their life, but all animals were housed in cages at time of measurement. Minimum cage size is based on the federal Animal Welfare Act guidelines based on body weight. Macaques that were less than 10 kg are required to be housed in cages with a minimum of 0.40 m² floor area and 0.76 m vertical height, and macaques over 10 kg are required to be housed in cages with a minimum of 0.56 m² floor area and 0.81 m vertical height (see Supplemental Table 3). Each WNPC macaque had access to a horizontal perch that ran the length of the cage, and all animals could climb the

vertical extent of the interior cage walls. WNPC macaques were observed climbing on cage mesh walls at times (personal observation, ASH).

Methods

Free-ranging macaques were trapped on Cayo Santiago in October-December 2015 between 8:00 and 11:00. Trained staff of the Caribbean Primate Research Center captured monkeys in a 100 m² feeding corral provisioned with monkey chow. Subjects were netted in the corral, transferred to a holding cage (0.62 × 0.42 × 0.62 m), and moved to a field laboratory. Veterinary technicians anesthetized the monkeys with ketamine hydrochloride at 10 mg/kg via intramuscular injection. Captive macaques were cage-confined animals housed at the Wisconsin National Primate Research Center, and were measured in September 2012. Individuals were anesthetized with up to 7 mg/kg of ketamine and up to 0.03 mg/kg of dexmedetomidine.

After the animals were anesthetized, passive joint excursion data and morphometric data were collected on each animal. All methods and measures are as described briefly here, and more extensively as previously reported in Hammond (2014a), unless otherwise specified. Free-ranging macaques were measured by a single observer (VPJ), following instruction on the measurement protocol used by ASH on the captive sample. The most relevant measurements for the objectives of this study are those of hip joint adduction and abduction, but additional joint ROM data were collected for internal and external rotation, flexion, and extension. All range of motion data were collected with each individual laying supine on an examination table and using disposable double-armed goniometers.

Briefly, the femur was oriented perpendicular to the horizontal surface of the examination table, in the transverse plane of the body passing through the hip joints. Measures of adduction, abduction, internal rotation, and external rotation were all measured starting from this posture, which acts as a neutral position for all measurements. The femoral diaphysis was positioned perpendicular to the examination table and subsequently moved from this neutral position to the maximum positions of adduction and abduction in the transverse plane of the body. Maximum abduction and adduction were measured as angles formed between the femoral diaphysis and the midsagittal plane (i.e., midline) of the body, with the vertex of the angle being the hip joint (Figure 1a). Total range of movement from adduction to abduction was calculated for each individual by adding the adduction and abduction values (Figure 1a).

Internal and external rotation of the hip were measured utilizing tibial movement, which reflects the longitudinal rotation of the femur at the hip joint (see Hammond, 2014a). Internal and external rotation of the femur were measured with the femur oriented perpendicular to the examination table and the knee flexed (i.e., in neutral position) (Figure 1b). In this position, tibial movement in the plane parallel to the table reflects femoral rotation in the sagittal plane. Total range of movement from internal to external rotation was calculated for each individual by adding the two values together (Figure 1b).

Hip extension and flexion were measured in the supine position from lateral view, measuring the angle formed between the femoral diaphysis and the iliac blade (Figure 1c). Total range

of movement from flexion to extension was calculated for each individual by subtracting the value for flexion from the extension value (Figure 1c).

Linear measures of body size were collected using a disposable soft tape measure, and approximated to the nearest cm. Linear measures include thigh circumference at the level of mid-thigh, thigh length, and the distance between the knees when both thighs are fully abducted. Body weight was measured in kg using a digital scale (captive animals) and in lbs and converted into kg using a standard scale (Cayo Santiago animals).

Analysis

We performed quantitative analyses using R (version 3.0.1, R Development Core Team, 2012). Data for free-ranging and captive macaques were compared first across the entire sample (“pooled”) and then in a subset of male individuals that were of similar age (“age-matched”). Cercopithecoid joint mobility is sensitive to aging (DeRousseau et al., 1983; Turnquist, 1983; DeRousseau, 1985; Turnquist, 1986; DeRousseau, 1988), and the age-matched sample maximizes the comparability between our free-ranging and captive individuals (see age distribution in Supplemental Figure 1). The age-matched sample included all male macaques between 8.0–9.9 years of age. The small number of free-ranging females in our sample precluded a similar statistical comparison for age-matched females. One-way analysis of variance (ANOVA) was used to compare captive and free-ranging values for all variables. Significance was assessed at $p < 0.05$.

Outliers were removed from the dataset prior to analyses due to uncertainty about the effects of using solely ketamine without dexmedetomidine on the free-ranging macaques. Ketamine-based anesthesia can result in some muscle tone that would not be present when also using inhaled isoflurane gas or an injected sedative (e.g., Ramsden et al., 1976; White and Cummings, 1979), and muscle tone was indeed present in some free-ranging individuals during measurement (VPJ, personal observation). Thus, ranges of joint motion may actually be larger in the free-ranging macaques than is revealed by our data due to the effects ketamine-based anesthesia (i.e. our comparison is likely to be conservative). Individual data points for the free-ranging macaques that were more than 2 standard deviations from the free-ranging mean were discarded from the sample prior to statistical analysis. The majority of the individual data points that met this exclusion criterion were among the first 8 free-ranging individuals measured by VPJ, which may also reflect the observer’s measurement learning curve. For individuals with an outlier measurement, we elected to include those other data points that were within 2 SDs of the mean of the whole dataset. This approach allows us to maximize the sample size given that such live animal datasets are rare and difficult to obtain. However, we cannot be sure that the effects of ketamine did not influence other measurements collected on these individuals. The full dataset, including outliers discarded prior to analysis (with these discarded data points indicated), is provided in Supplemental Table 1.

Results

Descriptive and test statistics for hip joint ROM are provided for the pooled male and female sample in Table 1, and for age-matched males in Table 2. Data for the pooled male and female sample are plotted in Figure 2.

Free-ranging macaques (pooled males and females) have significantly increased hip abduction ($p<0.001$), range of adduction-abduction ($p=0.02$), flexion ($p<0.001$), internal rotation ($p<0.01$), and range of flexion-extension ($p<0.001$) when compared to captive counterparts (Table 1). There was no difference between captive and free-ranging macaques in adduction ($p=0.94$), extension ($p=0.92$), external rotation ($p=0.12$). Range of internal-external rotation ($p=0.05$) is significantly larger in free-ranging individuals, although data for both groups substantially overlap (Figure 3). Body weight ($p=0.68$) and thigh circumference ($p=0.29$) were not significantly different between the captive and free-ranging individuals. Thigh length, the third variable related to body size, was significantly larger in the free-ranging macaques ($p<0.001$). The distance spanned between the knees during abduction, which is the functional outcome of hip abduction and body size, was significantly larger in free-ranging macaques ($p<0.001$).

When looking at data from an age-matched subset of males, the results are similar, although with fewer measures significantly different. Free-ranging male macaques (aged 8.0–9.9 years) have significantly increased hip abduction ($p<0.001$), internal rotation ($p=0.01$), and range of flexion-extension ($p<0.001$) when compared to captive males of the same age (Table 2). There was no difference between captive and free-ranging age-matched male macaques in other angular measures of hip mobility, including those measures found to be significantly different across the entire pooled sample (i.e., range of adduction-abduction, flexion, and range of flexion-extension). Body weight ($p=0.28$) and thigh length ($p=0.94$) were not different in the captive and free-ranging male subset but thigh circumference was significantly larger in the free-ranging males ($p=0.01$). The distance spanned between the knees during abduction was significantly larger in free-ranging males ($p=0.04$).

Discussion

Our results suggest that animals living in spatially-restrictive environments and without access to climbing structures are likely to show a reduced hip joint range of motion compared to free-ranging counterparts. Our pooled sample of free-ranging macaques displayed increased hip abduction, flexion, internal rotation, range of adduction-abduction, and range of flexion-extension compared to captive animals. Our age-matched male subset, which should maximize comparability between individuals in the sample, displayed an increase in hip abduction, internal rotation, and range of flexion-extension in the free-ranging males. Macaques are versatile arboreal quadrupeds (e.g., Rodman, 1979; Fleagle, 1980; Cant, 1988; Wells and Turnquist, 2001), and navigating the diversity of environments on Cayo Santiago, which includes open grassland, trees, and cliffs (Wells and Turnquist, 2001), seems likely to involve the use of non-stereotyped hip postures. These hip postures likely include abduction during scrambling and climbing, tightly flexed hip postures at take-off during propulsive leaping (e.g., Fleagle and Anapol, 1992), and internal rotation during

general arboreal quadrupedalism (e.g., Grand, 1968). Overall, our results suggest that a spatially-restrictive environment limits the potential limb postures in captive macaques and add to past work that has shown long-term caging influences somatic variables such as growth (e.g., Van Wagenen and Asling, 1958; Cheverud, 1981) and joint mobility (e.g., Turnquist, 1983; 1985). These results have implications for laboratory animal welfare and husbandry practices.

External rotation and hip abduction have been previously identified as key movements associated with arboreal versatility (Hammond, 2013; 2014a; b). Our data does not find a significant difference in external rotation between captive and free-ranging macaques, supporting earlier work which found that captive macaques do not achieve external rotation as large as more acrobatic taxa such as hominoids and spider monkeys (Hammond, 2014a). However, as already noted, hip abduction was significantly larger in free-ranging individuals (in both pooled and age-matched analyses), although there is overlap between the free-ranging and captive groups (Tables 1–2, Figure 2).

The distance spanned by the knees during abduction was significantly larger in the free-ranging macaques, and this result was present in both the pooled and age-matched sample. A larger span at the knee should reflect a greater hindlimb envelope (i.e., a greater reach of the hindlimb), allowing an animal to reach further for more distantly placed arboreal supports (see also Hammond, 2014a; b; Hammond et al., 2016; Preuschoft et al., 2016). Because an increased limb envelope increases arboreal competency, and is also increased by higher levels of abduction, this suggests to us that the observed increase in hip abduction in free-ranging animals is likely to be biologically meaningful. Larger animals should have a larger reach, but nutritional or growth differences are unlikely to fully explain our results because the sample of free-ranging age-matched males did not exhibit increased weight or thigh length and yet showed significantly increased distance spanned by the knee during abduction.

Previous studies have found differences in joint mobility in male and female macaques. DeRousseau et al. (1983) found a significant increase in abduction in free-ranging male macaques compared to females, with no differences in hip flexion, extension, and adduction, though the sex-specific values were not published. Turnquist and Kessler (1989) found male-female differences in mobility that they attributed to sex-specific differences in the age of puberty and maturation. Our female free-ranging sample was too small to test for differences between sexes. In this study, free-ranging females fell toward the lower range of values for male hip extension, but at the higher range for flexion and external rotation (Figure 2). It is possible that a larger sample of free-ranging females would have demonstrated significant differences between free-ranging males and females, as previously reported by DeRousseau et al. (1983) and Turnquist and Kessler (1989).

It is also possible that some of the differences between captive and free-ranging macaques may result from two different observers collecting the datasets (ASH vs VPJ). Regrettably, it was not possible for us to perform an error study on the same individuals given our animal access protocols. However, our data are similar to the joint excursion data of other workers, which suggests that joint mobility data are being collected fairly consistently between

observers. For instance, extension was not significantly different between the two observers in this study, and our values are overlapping and similar in range to those published by Turnquist and Kessler (1989). In that study, macaque extension was typically about 150°, ranging from 129° in older individuals to 158° in younger individuals (versus our 131–168°, with a mean of 151°). Thus, we are reasonably confident that some of the differences we observe here are genuine differences between our captive and free-ranging samples, and unrelated to interobserver error.

Another possibility is that some of the differences between captive and free-ranging macaques may result from different anesthetic agents. Ketamine hydrochloride, or ketamine, is a dissociative anesthetic that interferes with neuronal activity that is widely and safely used for primate anesthesia (Cohen and Bree, 1978). It is difficult to assess level of sedation when relying on ketamine to anesthetize animals (Haas and Harper, 1992), and individuals anesthetized with just ketamine sometimes display increased muscle tone, or hypertonicity (Morgan et al., 1971; White and Cummings, 1979; Mayrand et al., 1994; Hammond, 2014a; Lima et al., 2016). Monkeys showing increased muscle tone due to the administration of ketamine tend to clench their limbs towards the trunk (i.e., fetal position), making extension, abduction, and rotation challenging to measure (ASH, personal observation). Range of motion is ideally measured on completely passive joints (i.e., with no muscle tone or rigor), which can be better achieved with a combination of ketamine *and* a secondary sedative or isoflurane gas (e.g., Ramsden et al., 1976; White and Cummings, 1979). Given that the captive animals were anesthetized with the sedative dexmedetomidine in combination with ketamine, we would expect that the joint mobility in the captive animals would represent the maximum joint excursions to each individual's capacity, whereas the free-ranging sample may not display their full joint excursion capacity due to residual muscle tone. Since any anesthetization bias seems likely to have reduced the differences between the free-ranging individuals and the captive individuals, the differences we report in the present study may therefore actually be conservative.

Lastly, the passive excursion data for the free-ranging rhesus macaque (*M. mulatta*) hip joint are more consistent with simulations of hip abduction based on wild-shot macaques. Simulations based on long-tailed (*M. fascicularis*) and pig-tailed (*M. nemestrina*) macaques predicted that hip abduction should be about 47° (range of 39–57°) (Hammond et al., 2016), which is significantly higher than that observed in captive rhesus (mean 25°, range 10–37°) and long-tailed macaques (mean 26°, range 20–36°) (Hammond, 2014a). The range of abduction (i.e., 20–62°) in the free-ranging rhesus macaques measured here overlaps with the simulation data, suggesting that the Hammond et al. (2016) model of hip abduction predicts joint excursions in *Macaca* better than previously realized. This study highlights the discrepancy between measures of hip abduction in captive and free-ranging rhesus macaques and underscores the need for caution when selecting *in vivo* samples for locomotor studies, as small cage-confinement can impact joint mobility in monkeys.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Measurements

The full measurement protocol can be found elsewhere (Hammond (2014a)). All measures are demonstrated here on a left hip of a captive macaque. (a) Measurements of hip abduction and adduction and (b) internal and external rotation are taken with the thigh oriented to 90° (i.e., perpendicular to examination table). (c) Measurements of hip flexion and extension are taken in lateral view. Note that smaller numerical values for flexion indicates a greater joint excursion.

Figure 2. Passive joint excursion in captive and free-ranging rhesus macaques

Data are shown for adduction and abduction (above), internal and external rotation (middle), and flexion and extension (bottom). Note that smaller numerical values for flexion indicate a greater joint excursion, whereas in all other movements a larger angular excursion represents higher mobility. Figure does not include outlier data points that were not included in analyses.

Figure 3. Ranges of motion in captive and free-ranging rhesus macaques

Data are shown for adduction-abduction (above), internal rotation-external rotation (middle), and flexion-extension (bottom). Figure does not include outlier data points that were not included in analyses.

Table 1
Descriptive statistics and test statistics for hip joint mobility for the pooled macaque sample

	all free-ranging individuals				all captive individuals			Test statistics*	
	n	mean	SD	min, max	n	mean	SD	min, max	P value
age (yrs)	39	8.4	2.6	4.2, 15.8	16	9.1	0.2	8.6, 9.5	0.97
weight (kg)	39	10.5	2.4	5.5, 16.8	16	10.2	2.5	7.0, 14.1	0.17
adduction	38	54.6	13.9	18, 81	16	54.3	8.4	36, 67	0.01
abduction	36	35.4	8.4	20, 62	16	25.4	7.8	10, 37	16.29
internal rotation	37	48.0	12.2	20, 72	16	37.1	6.8	28, 54	11.28
external rotation	36	50.7	11.3	19, 67	16	55.9	10.3	40, 81	2.46
flexion	37	14.6	9.3	2, 36	16	32.6	3.6	28, 41	56.26
extension	37	151.2	10.0	131, 168	16	150.9	9.5	131, 167	0.01
range of adduction-abduction	36	89.3	14.4	63, 123	16	79.6	9.8	54, 91	5.90
range of internal-external rotation	34	101.7	15.2	76, 134	16	92.9	11.8	72, 114	4.10
range of flexion-extension	37	137.3	13.4	109, 163	16	118.3	10.5	98, 139	27.78
thigh circumference (cm)	36	25.4	2.0	21, 30	16	26.1	2.7	23, 31	1.14
thigh length (cm)	36	20.6	1.3	18, 24	16	18.9	2.0	15, 22	12.65
distance between knees (cm)	36	35.8	4.0	25, 43	16	29.7	3.7	24, 36	27.39

All values are shown in degrees unless otherwise indicated. Bolded P values are significant. Degrees of freedom = 1 for all comparisons.

Table 2

Descriptive statistics and test statistics for hip joint mobility within age-matched male macaques

	free-ranging males (8.0–9.9 yrs)				captive males (8.0–9.9 yrs)				Test statistics*	
	n	mean	SD	min, max	n	mean	SD	min, max	F value	P value
age (yrs)	11	8.6	0.5	8.0, 9.1	8	9.0	0.2	8.8, 9.3	3.89	0.07
weight (kg)	11	11.2	1.6	8.9, 14.5	8	12.1	1.9	9.1, 14.1	1.25	0.28
adduction	11	55.7	11.4	38, 69	8	56.8	7.9	47, 67	0.05	0.83
abduction	11	35.5	5.4	25, 44	8	23.9	5.3	19, 35	21.65	<0.001
internal rotation	11	53.2	12.7	27, 72	8	34.8	4.6	28, 40	15.15	<0.01
external rotation	11	49.4	10.4	32, 65	8	48.8	6.6	40, 59	0.23	0.64
flexion	9	15.2	9.6	3, 30	8	32.0	2.2	29, 35	23.00	<0.001
extension	11	148.6	10.1	131, 164	8	144.4	7.6	131, 153	1.00	0.33
range of adduction-abduction	11	91.2	13.4	63, 106	8	80.6	7.6	67, 90	4.01	0.06
range of internal-external rotation	11	99.3	23.8	40, 134	8	83.5	5.7	72, 90	3.33	0.09
range of flexion-extension	9	136.0	13.5	116, 152	8	112.4	8.5	98, 121	18.11	<0.001
thigh circumference (cm)	11	26.2	1.6	24, 39	8	28.3	1.7	26, 31	7.90	0.01
thigh length (cm)	11	20.5	0.8	19, 22	8	20.5	1.4	18, 22	0.01	0.94
distance between knees (cm)	11	37.1	3.7	31, 43	8	31.3	3.6	26, 36	4.97	0.04

All values are shown in degrees unless otherwise indicated. Bolded P values are significant. Degrees of freedom = 1 for all comparisons.