EFFECT OF CHANGE IN PELVIC MORPHOLOGY ON ENERGETIC COST OF BIPEDAL WALKING
IN THE JAPANESE MACAQUE

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SUMMARY
We estimated energetic cost of bipedal walking in the
Japanese macaque based on inverse dynamic calculation and
evaluated how change in pelvic morphology affects the cost of
locomotion. An anatomically-based musculoskeletal model of
the Japanese macaque was constructed and joint motions and
ground-reaction-forces from experiments on human walking
were input to the model to calculate muscular force. The
energetic cost of locomotion was then estimated based on the
calculation of mechanical energy generated by muscles. Our
results demonstrated that the cost of transport of bipedal
walking was lowered when the pelvis was replaced with that
of humans because the change in pelvic morphology altered
paths of the muscles around the hip joint.

INTRODUCTION
Japanese macaques (Macaca fuscata) that have been trained
for bipedal performance exhibit a remarkable ability to walk
bipedally. However, energetic cost of bipedal walking in the
Japanese macaque is presumably much higher than that of
humans because the morphology of the locomotor apparatus is
not as adapted to bipedalism as that of humans in inherently
quadrupedal primate. In this study, we estimated energetic
cost of bipedal walking in the Japanese macaque based on
inverse dynamic calculation and evaluated how change in
pelvic morphology affects the cost of bipedal locomotion.

METHODS
We constructed a 3D musculoskeletal model of the Japanese
macaque. The skeleton was modeled as a chain of 7 rigid body
segments representing HAT (head, arms and torso), thighs,
shanks and feet. The path of each muscle was defined by a line
segment connecting origin to insertion through an
intermediary point if necessary. The maximum force
generated by the muscle was determined based on the
measured physiological cross-sectional area of the muscle [1].
This anatomically accurate model of the Japanese macaque
was then loaded into the simulation software, AnyBody
Modeling System (AnyBody Technology, Denmark) for
inverse dynamic analysis of the model.

In order to obtain input data to the model, bipedal walking of
two adult human subjects were measured using a motion
capture system and force plates. To match the macaque
musculoskeletal model to the temporal history of joint marker
coordinates, the marker coordinates were firstly scaled to the
size of the macaque model based on segment lengths. The
model was then registered to the time history of the marker
coordinate. The ground reaction forces were scaled by body
mass. These normalized motion data were substituted into the
model to compute muscular forces based on inverse dynamic
calculation. The sum of the cubes of muscle stresses was used
as the objective function to solve for the muscle recruitment
problem [2]. The metabolic energetic cost of the locomotion
was estimated based on the calculation of mechanical energy
of the muscles, assuming that the efficiency of conversion
from metabolic to positive and negative mechanical work are
0.25 and -1.2, respectively.

There are substantial differences in pelvic morphology
between macaques and humans. In this study, therefore, the
pelvis of the macaque musculoskeletal model was replaced
with that of human to evaluate the effect of change in pelvic
morphology on energetic cost of bipedal walking in the
Japanese macaque.

RESULTS AND DISCUSSION
The calculated costs of transport were 16.4 and 18.3 J/(kg.m)
for the motion data of the subject 1 and 2, respectively, based
on the macaque pelvis model, whereas those based on the
human pelvis model were 11.5 and 14.5 J/(kg.m), respectively,
indicating that the cost of transport of bipedal walking
decreased when the pelvis was replaced with that of humans.
The lower cost of transport in the human pelvis model could
be attributed to the fact that the change in pelvic morphology
altered paths of the muscles spanning the hip joint and the
more force must have been generated by the hip muscles. The
present finding implies that the human pelvic morphology
may have evolved to improve efficiency of bipedal walking.

REFERENCES
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Figure 1: Walking pattern of the human pelvis model.