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In vivo femoral strains in swimming turtles: Influence of locomotor medium on limb bone loading

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Abstract: The transition from aquatic to terrestrial habitats was an event in vertebrate evolution that preceded a sudden radiation of species. Subsequently some vertebrate lineages have returned to their ancestral aquatic habitats. It is known that vertebrate bone structure can vary depending on habitat. An evolutionary explanation for this is that loads on the skeleton vary depending on the environment organisms inhabit. Terrestrial vertebrates would be expected to experience greater loads on their bones versus aquatic vertebrates due to body support demands, but there are no experimental data to test this hypothesis or quantify the difference. We tested how loads differed on the appendicular skeleton between use in terrestrial and aquatic habitats by recording *in vivo* femoral strains during swimming and walking in turtles. We predicted that since swimming exerts less force on the limbs, peak load magnitudes would be lower during swimming versus walking, but that load peaks would be nearly equal during the thrust and recovery phases of the swimming limb cycle. Our data support our first prediction, with average peak strain magnitudes of swimming being half those of walking. Loading regimes were similar between both swimming and walking with compressive axial strains experienced dorsally on the femur. However, our second prediction was not supported, because peak strains were much higher during the thrust phase. Our results indicate that even when environmental forces are lessened, limb muscles play a large role in the production of bone loads.

Hypotheses:

1) While swimming, femoral strains will be equal in thrust and recovery, but in opposite directions.
2) Peak magnitudes for walking will be greater than swimming.

Methods:

- Axial strains recorded at 5000 Hz from multiple femur locations during flow-tank swimming and treadmill walking to peak exertion
- Simultaneous bi-planar high-speed video (100 Hz) used to demarcate cycle phases (thrust vs. recovery, and stance vs. swing).

Results:

- Thrust showed greater strains than recovery, but directions were not opposite (**Table 1, Figure 1**).
- Peak magnitudes are greater in walking than in swimming (**Table 2, Figure 2**).

Animal	Location	N	Thrust	Recovery	*F*	*P*
TS01	Anterior	52	-169.8 ±100.2	-119.6 ±84.7	7.75	0.0064*
TS01	Ventral	11	-176.6 ±72.9	-128.9 ±60.9	3.02	0.0962
TS01	Posterior	52	-118.5 ±55.3	-126.4 ±83.6	0.33	0.5694
TS03	Anterior	129	98.2 ±74.6	48.2 ±32.6	49.00	<0.0001*
TS03	Posterior	129	102.9 ±53.5	48.8 ±36.0	91.31	<0.0001*
TS04	Anterior	71	124.7 ±120.6	51.2 ±45.3	23.39	<0.0001*
TS04	Posterior	71	135.7 ±85.8	76.5 ±42.8	27.39	<0.0001*

Table 1. ANOVA results for thrust vs. recovery during swimming. * Significant at α=0.05.

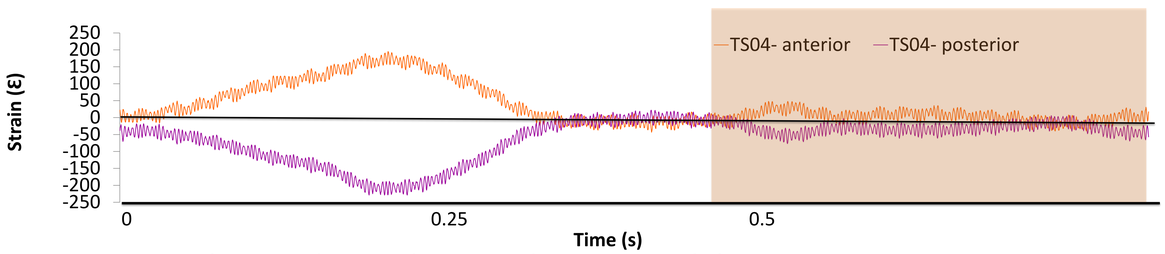

Figure 1. Femoral strain during thrust and recovery while swimming.

Location	Phase	Swimming (N=129)	Walking (N=49)	*F*	*P*
Anterior	Thrust/ Stance	98.2 ±74.6	188.4 ±122.8	35.93	<0.0001*
Anterior	Recovery/ Swing	48.2 ±32.6	145.9 ±115.2	78.05	<0.0001*
Posterior	Thrust/ Stance	102.9 ±53.5	185.1 ±84.7	60.30	<0.0001*
Posterior	Recovery/ Swing	48.8 ±36.0	150.1 ±74.8	149.25	<0.0001*

Table 2. ANOVA results for thrust and recovery, TS03 walking vs. swimming. *Significant at α=0.05

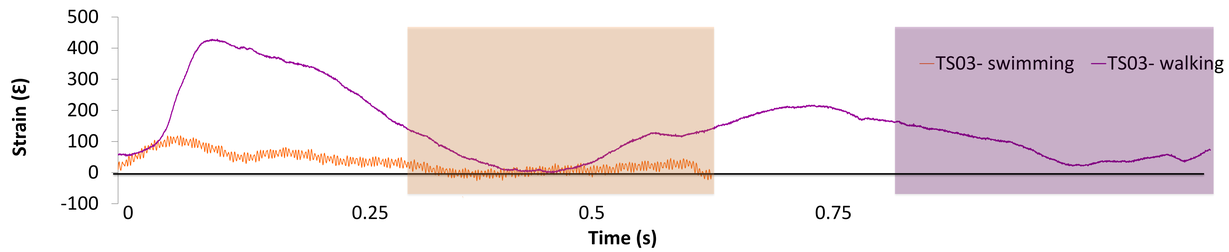

Figure 2. Representative femoral strains during walking and swimming cycles for anterior gauge site of TS03

Discussion:

- Strains are smaller when the environment reduces body support demands.
- Variance in strain patterns between individuals may be due to placement of gauges.
- During swimming, strains during recovery are significantly lower than during thrust.
- Presence of the same direction of strain during recovery and thrust may be due to femoral rotation.

Future Work:

- Studies of strains in the forelimb (humerus) are in progress.
- Phylogenetic analysis of limb bone shape differences between terrestrial turtles and aquatic rowers.

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