STRUCTURAL PROPERTIES OF FOURTH-GENERATION COMPOSITE FEMURS AND TIBIAS

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INTRODUCTION

Composite replicate femurs and tibias (Sawbones, Pacific Research Laboratories, Inc., Vashon, WA) are widely used in orthopaedic research, and have undergone several design changes since their introduction in 1987. Fourth-generation composite bones, the latest design, have the same geometries as the third-generation bones, but the cortical bone analogue material was changed to increase fracture and fatigue resistance, tensile and compressive properties, thermal stability, and moisture resistance (Pacific Research Laboratories, Inc., 2007). The purpose of this study was to measure the structural properties of this latest design of composite femurs and tibias from Pacific Research Laboratories, Inc. This was done to confirm that these composite bones still had structural properties that were in the range of those for natural human bones.

METHODS AND PROCEDURES

Six medium fourth-generation composite femurs (model 3403) and six medium fourth-generation composite tibias (model 3401) were tested under bending, axial, and torsional loading in an MTS 858 Bionix materials testing machine (MTS Systems Corp., Eden Prairie, MN). The research design is described in detail in earlier studies by the author (Heiner and Brown, 2001; Heiner and Brown, 2003) and is outlined only briefly here. Bending was applied through a 4-point bending fixture, with 62 mm between successive contact points. Each bone was bent in two directions, anterior surface in tension and lateral surface in tension. Loading was between 50 N and 500 N at 0.025 mm/sec. For axial testing, the femurs and tibias were distally potted to depths of approximately 8 cm and 6 cm, respectively. The composite bones were aligned using a rigid, centrally-located rod, which went up into the bones' intramedullary shaft. The femurs were oriented in 11° of adduction from the vertical, and the tibias were oriented vertically. The bones were loaded through a platen that conformed to the femoral head or tibial condyles, and connected to the MTS machine through a ball joint and x-y table in series. The ball joint location utilized on the load platen was that for which axial stiffness was the highest. Compression was between 60 N and 600 N, at 60 N/sec. Strain distribution along the proximal-medial diaphysis was measured for three of the femurs with five unidirectional strain gages (Measurements Group, Inc., Raleigh, NC). For torsional testing, the femurs and tibias were proximally and distally potted with Cerrobend to depths of approximately 8 cm and 6 cm, respectively. The bones were oriented vertically, and otherwise aligned as described for axial testing. The bones were constrained in all other degrees of freedom except for axial motion, which was allowed to float during the testing. Torsional loading was applied such that the proximal ends of the bones rotated internally. Loading was between 0.5 Nm and 7.5 Nm at 0.25 deg/sec. Setup variability was determined by completely disassembling the set-up then retesting one bone for each loading mode.

RESULTS

Property	Bone Type	Femur	Tibia	Units
Flexural	Natural	317 (23%)	233 (30%)	Nm^2
Rigidity,	3rd gen	210 (7.2%)	209 (7.2%)	
AT	4th gen	241 (4.5%)	199 (5.0%)	
Flexural	Natural	290 (42%)	205 (23%)	Nm^2
Rigidity,	3rd gen	239 (5.6%)	131 (2.0%)	
LT	4th gen	273 (5.8%)	146 (3.5%)	
Axial	Natural	2.48 (25%)	NA	N/µm
Stiffness	3rd gen	1.47 (12%)	7.80 (5.6%)	
	4th gen	1.86 (7.5%)	7.48 (9.3%)	
Torsional	Natural	4.41 (37%)	2.42 (33%)	Nm^2/
Rigidity	3rd gen	2.15 (10%)	1.69 (7.9%)	deg
	4th gen	3.21 (2.6%)	1.93 (3.6%)	

Table 1. Structural properties of natural (Heiner and Brown, 2003), medium third-generation (3rd gen) composite, and medium fourth-generation (4th gen) composite femurs and tibias (average and coefficient of variation, n=6). AT = anterior surface in tension; LT = lateral surface in tension.

Strain gage location	Natural	3rd gen	4th gen
Highest	633 (28%)	1193 (2%)	708 (10%)
2nd highest	454 (38%)	930 (8%)	703 (8%)
Middle	376 (38%)	582 (13%)	504 (7%)
2nd lowest	182 (32%)	248 (22%)	259 (17%)
Lowest	36 (213%)	-61 (62%)	44 (88%)

Table 2. Compressive strain ($\mu\varepsilon$) on natural (Heiner and Brown, 2003), medium third-generation (3rd gen) composite, and medium fourth-generation (4th gen) composite femoral proximal-medial shafts (average and coefficient of variation, n=3), at 600 N of compression. Strain gages were equally spaced from the level of the lesser trochanter (“Highest”) to the middle of the shaft (“Lowest”).

DISCUSSION

The fourth-generation composite bones had average stiffnesses and strains that were for the most part closer to those values measured for the natural bones, than were the third-generation composite bones in comparison to natural bones (all measurements by the same author). (Natural tibia axial stiffness results were not reported, because of unacceptably high setup variability indicating exceptional difficulty in obtaining proper bone alignment (Heiner and Brown, 2003); this complication was also reported by Cristofolini and Viceconti (2000).) For the stiffness tests, variability between the specimens was less than 10% for all cases, and setup variability, calculated as the percent change between a test and re-test on the same specimen (with re-potting, when applicable), was less than 6% for all cases. The inter-specimen variability of the fourth-generation composite bones was much less than that of the natural bones; other studies have reported this as well (Cristofolini et al., 1996; Cristofolini and Viceconti, 2000; Heiner and Brown, 2001; Heiner and Brown, 2003).

SUMMARY

The structural properties of Pacific Research Laboratory’s fourth-generation composite femurs and tibias are in the range of those for natural human bones.

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ACKNOWLEDGEMENTS

Pacific Research Laboratories, Inc., provided the funding.