

Monday, October 6, Noon–1:00 PM, 1997.

Please write all answers in the space provided. If you need additional space, write on the back sides. Indicate your answer as clearly as possible for each question. *Write your name at the top of each page as indicated.*

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**1. (30 points total) Forces and Moments, Stability**

**(i) [15 points]** Show, with the aid of a free-body diagram, how increasing abdominal pressure can reduce the force in the erector spinae muscles (the extensors of the spine) when lifting heavy objects with outstretched hands.

**(ii) [15 points]** For a bow-legged individual whose knee joints are displaced laterally from the normal anatomic position (of being directly over the foot), would you expect the contact force on the medial tibial condyle during gait to be higher or lower compared to the case of normal bone alignment? Use a free-body diagram to support your answer.

**2. (30 points total) Dynamic Analysis**

A dumbbell is held in the hand during a curl exercise, and quickly raised toward the shoulder in a circular motion (angular acceleration  $\mathbf{a}$  and angular velocity  $\mathbf{w}$ ) about the elbow joint. The wrist is fully rigid during this motion and the elbow does not move. At some instant before the forearm reaches the horizontal position, it is at an angle  $\mathbf{q}$  to the vertical and is still accelerating. Treating this as a two-dimensional planar rigid body problem, do the following.

**(i) [10 points]** Draw a fully labeled free body diagram, including all accelerations, of the forearm/hand/dumbbell system. Assume that only one muscle is acting about the elbow joint and that all other soft tissue forces (from ligaments etc.) are negligible.

**(ii) [15 points]** Write out the equation of translational motion in the vertical direction. Explain any nomenclature not evident from your free-body diagram.

**(iii) [5 points]** If this exercise was done with the individual standing on a weighing scale, would the scale reading at this instant be greater than, less than, or equal to the combined body-weight and the dumbbell? Provide a brief explanation.

### 3. (40 points total) Design and Analysis of Hip Prostheses

(i) [10 points] Write out an expression for the resultant bending moment  $M$  at the center  $c$  of the cross-section X-X for the two-dimensional model of a cemented bone-prosthesis system shown in Figure 1. Assume that the joint contact force  $J$  and the abductor force  $A$  act at angles  $\mathbf{a}$  and  $\mathbf{b}$ , respectively, as shown. The  $(x, y)$  coordinates of the points  $a$  (the femoral head center),  $b$  (the assumed single attachment point of the abductors), and  $c$  (the center of the cross-section at X-X) are  $(a_x, a_y)$ ,  $(b_x, b_y)$ , and  $(c_x, c_y)$ , respectively.

**Figure 1:** Two-dimensional model of a cemented titanium-alloy hip prosthesis, showing the cross-section at the mid diaphysis ( $D$  = outside diameter;  $E$  = Young's modulus; subscripts  $b$ ,  $c$ , and  $s$  refer to the bone, cement, and stem, respectively).

**(ii) [20 points]** Write out the expression for the maximum tensile bending stress of the cemented stem at the cross-section X–X of Figure 1 for the following two cases. Include explicit expressions for all second moment of area terms (*i.e.* give these parameters in terms of diameters etc.).

**(a)** A fully fixed device with ideal load sharing.

**(b)** A proximally loosened device, where it is assumed as a worst case scenario that there is no load sharing between bone and prosthesis at section X–X.

**(iii) [10 points]** If the primary design objective for this device was to minimize tensile stresses on the surface of the stem, suggest how this might be achieved in terms of material selection (CoCr vs. Ti-alloy) and sizing of the prosthesis diameter.

**ME 176 Mid-Term Exam, Fall 1997**

*Name:* \_\_\_\_\_

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