% Testing hypotheses for the function of the Carnivoran baculum using finite element analysis

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% Baculum groove model maths

close all

clear all

% Radius and area of non-grooved baculum

R\_original = 5;

A\_original = pi\*R\_original^2;

% Groove radii

r = 0.5:0.5:4.5;

% run loop for each groove radius

for r\_loop = 1:length(r)

% use optimisation routine (fminbnd) on groove mathematics to calculate the new outer radius

% of grooved baculum so that its cross sectional area matches ungrooved baculum

% ('groove\_math' and calc\_area\_difference' functions are at bottom of script)

[R\_new(r\_loop)] = fminbnd(@(R) calc\_area\_difference(R,R\_original,r(r\_loop)),R\_original,2\*R\_original);

% calculate area of new grooved baculum as double check to ensure it matches ungrooved model

A(r\_loop) = groove\_maths(R\_new(r\_loop),r(r\_loop));

% calculate area of a range of potential outer radii (these are used for plotting purposes only)

R\_loop = linspace(R\_original,1.2\*R\_original);

for i = 1:length(R\_loop)

A\_loop(r\_loop,i) = groove\_maths(R\_loop(i),r(r\_loop));

end

% plot the results

figure('color','w')

subplot(2,1,1)

plot(R\_loop,A\_loop(r\_loop,:),'k')

hold on

h = refline(0,A\_original);

set(h,'color','k','linestyle','--')

plot(R\_new(r\_loop),A,'ro')

box off

xlabel('Radius (mm)')

ylabel('Area (mm^2)')

axis([xlim 50 120])

angle = 0:0.01:2\*pi;

circle\_x = sin(angle);

circle\_y = cos(angle);

subplot(2,1,2)

h(1) = patch(R\_original\*circle\_x,R\_original\*circle\_y,'k');

h(2) = patch(R\_new(r\_loop)\*circle\_x+3.5\*R\_original,R\_new(r\_loop)\*circle\_y,'k');

axis equal

h(3) = patch(r(r\_loop)\*circle\_x+3.5\*R\_original,r(r\_loop)\*circle\_y+R\_new(r\_loop),'w');

set(h,'linestyle','none')

axis([-9 27 -6 6])

axis off

% write out figures to file

if ~isdir('groove\_maths\_figures')

mkdir('groove\_maths\_figures')

end

print('-djpeg',fullfile('groove\_maths\_figures',['baculum\_' num2str(R\_new(r\_loop)) '\_groove\_' num2str(r(r\_loop)) '.jpeg']))

close all

end

% output results to csv file

% create matrix to ouput

MMM = zeros(length(r)+1,2);

MMM(1,:) = [0 R\_original];

MMM(2:end,:) = [r' R\_new'];

% write file

fid = fopen('groove\_model\_dimension.csv','w');

fprintf(fid,'%s\n','Groove radius,Baculum radius');

fclose(fid);

dlmwrite('groove\_model\_dimension.csv',MMM,'-append')

% function to produce variable (area\_difference) that is to be minimised by

% the optimiser 'fminbnd' above (i.e. optimiser tends variable towards zero).

% 'area\_difference' is calculated as the difference between cross sectional

% area of original non-grooved baculum and the current grooved baculum.

function area\_difference = calc\_area\_difference(R,R\_original,r)

area\_difference = abs(pi\*R\_original^2 - groove\_maths(R,r));

end

% function to calculate the cross sectional area of the grooved baculum

% (see paper for figures and equations associated with the maths)

function A1 = groove\_maths(R,r)

theta = 2\*acos((r^2)/(2\*r\*R));

alpha = 2\*acos(1-(r^2)/(2\*(R^2)));

A2 = ((r^2)/2)\*(theta - sin(theta));

A3 = ((R^2)/2)\*(alpha - sin(alpha));

A1 = pi\*R^2 - A2 - A3;

end