APPENDIX 1: DISC GRADING WORKSHEET

Disc Grading Worksheet

Date:___/___/_____ **Assessor:**_____

ID:_____ **Age:**_____ **Grade:** 1 ☐ 2 ☐ 3 ☐ 4 ☐

- **Dimensions**

Height: _____mm Width: _____mm Depth: _____mm

- **Exterior**

Comments:_____

Osteophytes

Present		Position(s)		Sup Rim	Inf Rim	Centre	Size		
		Anterior Centre	☐	☐	☐	☐	S☐	M☐	L☐
Total Number:	_____	Anterolateral Left	☐	☐	☐	☐	S☐	M☐	L☐
		Anterolateral Right	☐	☐	☐	☐	S☐	M☐	L☐
	Comment:	Lateral Left	☐	☐	☐	☐	S☐	M☐	L☐
	_____	Lateral Right	☐	☐	☐	☐	S☐	M☐	L☐
	_____	Posterior Centre	☐	☐	☐	☐	S☐	M☐	L☐
		Posterolateral Left	☐	☐	☐	☐	S☐	M☐	L☐
		Posterolateral Right	☐	☐	☐	☐	S☐	M☐	L☐

- **Transverse Faces**

Comments:_____

Rim Lesions

Present		Position		Size		
Superior Face	☐	Anterior Centre	☐	S☐	M☐	L☐
		Anterolateral Left	☐	S☐	M☐	L☐
	Comment:	Anterolateral Right	☐	S☐	M☐	L☐
	_____	Lateral Left	☐	S☐	M☐	L☐
	_____	Lateral Right	☐	S☐	M☐	L☐
		Posterior Centre	☐	S☐	M☐	L☐
		Posterolateral Left	☐	S☐	M☐	L☐
		Posterolateral Right	☐	S☐	M☐	L☐
Inferior Face	☐	Anterior Centre	☐	S☐	M☐	L☐
		Anterolateral Left	☐	S☐	M☐	L☐
	Comment:	Anterolateral Right	☐	S☐	M☐	L☐
	_____	Lateral Left	☐	S☐	M☐	L☐
	_____	Lateral Right	☐	S☐	M☐	L☐
		Posterior Centre	☐	S☐	M☐	L☐
		Posterolateral Left	☐	S☐	M☐	L☐
		Posterolateral Right	☐	S☐	M☐	L☐

End Plate Condition

Superior: _____

Inferior: _____

- **Interior Sagittal Faces**

Comments:_____

Nucleus	L	R	Anulus	L	R
Bulging gel	☐	☐	Discrete fibrous lamellae	☐	☐
White fibrous tissue peripherally	☐	☐	Delamination	☐	☐
Consolidated fibrous tissue	☐	☐	Focal lamellar thickening	☐	☐
Nuclear Clefts	☐	☐	Loss of anular-nuclear demarcation	☐	☐
			Radial Tears	☐	☐
			Circumferential Tears	☐	☐

APPENDIX 2: IMAGE PROCESSING CODE

```
tic;                                                                    %Start timing
read_direc = uigetdir('C:\Images', 'Select READ Directory');            %Prompt for selection of a "read" directory
read_direc = [read_direc '\'];                                          %append a '\' character
dir_info = dir(read_direc);                                             %Get directory name
fname = char(dir_info.name);                                            %Set file names
fname = fname(3:end, :);                                                %Exclude directories
[number_of_files, nlen] = size(fname);                                  %Set number of files and length of file names

wb = waitbar(0, 'Processing, Please Wait...');                          %Set wait bar parameters
set(wb, 'Name', 'Elastic Fibre Analysis');

figure(1);
image = imread([read_direc fname(3,:)]);                                %Open an image from the dataset
imshow(image);                                                          %Display image
map = colormap;                                                         %Extract colormap from image
close(figure(1));                                                       %Close image

for i = 1:number_of_files,                                              %Loop through each image in the stack
    hand = deblank(fname(i,:));                                         %Strip trailing blank characters from file name
    if strcmp(lower(hand(1, end-2:end)), 'bmp'),                        %Only proceed if file is a bitmap
        image = imcomplement(imread([read_direc fname(i,:)]));          %Read grey image and invert
        se = strel('diamond',3);                                        %Define structuring element
        tophatFiltered = imtophat(image,se);                            %Identify elastic fibres
        contrastAdjusted = imadjust(tophatFiltered);                    %Adjust image contrast
        bw = im2bw(contrastAdjusted, 0.8);                              %Convert image to binary
        bw = bwmorph(bw, 'clean');                                      %Remove isolated pixels
        bw = bwareaopen(bw,100);                                        %Remove all objects containing fewer than 100 pixels
        se = strel('disk',2);                                           %Define structuring element
        bw = imclose(bw,se);                                            %Smooth fibre morphology
        bw = imfill(bw,'holes');                                        %Fill background holes
        bw = bw .* 255;                                                 %Scale image
        bmphead([read_direc 'B_' deblank(fname(i,1:end-4)) '.bmp'], bw, map);   %Write new image to file
```

```
    end

    waitbar(i/number_of_files,wb);                                  %Display wait bar during computation
end

disp(['Images from directory: '  read_direc ' converted to binary.']);  %Notify completion
disp(['Time taken (Minutes): ' num2str(toc / 60)]);                     %Display time taken

close(wb);
```

APPENDIX 3: HISTOLOGY DATA

The tables presented in this appendix contain the comprehensive data aquired for quantitation of intralamellar elastic fibre density. For each of the seven specimens analysed, there are two tables – the first for anterolateral regions (inner, middle and outer) and the second for posterolateral regions, as labelled. The value in each cell is the number of elastic fibres intercepted by each horizontal or vertical line of the overlaid six by six grid. Data in the left hand blocks are the raw numbers and those in the right hand blocks have been normalised as the number of fibres per 100 microns.

16 YO

Anterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	11	13	16	18	15	12	3	1	4	2	0	2
CL_AL_Outer_2	4	6	7	9	10	8	4	1	4	0	6	6
CL_AL_Outer_3	15	8	8	11	12	12	2	0	1	0	1	2
CL_AL_Outer_4	8	12	8	9	10	10	2	5	2	3	5	4
CL_AL_Outer_5	21	16	13	12	9	11	3	0	0	0	2	1
CL_AL_Outer_6	26	23	25	27	29	28	4	0	2	4	0	-

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
9	10	13	14	12	9	3	1	4	2	0	2
3	5	6	7	8	6	4	1	4	0	6	6
12	6	6	9	9	9	2	0	1	0	1	2
6	9	6	7	8	8	2	5	2	3	5	4
17	13	10	9	7	9	3	0	0	0	2	1
20	18	20	21	23	22	4	0	2	4	0	-

Anterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	19	14	9	11	8	7	1	1	2	0	1	0
CL_AL_Mid_2	5	8	7	9	11	16	1	4	0	2	2	0
CL_AL_Mid_3	13	10	11	11	11	10	2	3	1	6	0	5
CL_AL_Mid_4	8	7	7	5	3	3	2	1	2	0	2	-
CL_AL_Mid_5	0	2	4	8	10	8	1	1	3	1	1	0
CL_AL_Mid_6	8	4	9	9	5	8	2	1	1	0	0	2

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
15	11	7	9	6	6	1	1	2	0	1	0
4	6	6	7	9	13	1	4	0	2	2	0
10	8	9	9	9	8	2	3	1	6	0	5
6	6	6	4	2	2	2	1	2	0	2	-
0	2	3	6	8	6	1	1	3	1	1	0
6	3	7	7	4	6	2	1	1	0	0	2

Anterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	4	5	3	0	2	1	2	4	3	1	0	2
CL_AL_Inner_2	1	0	0	1	0	0	1	6	0	0	1	3
CL_AL_Inner_3	1	1	2	2	2	3	3	2	0	1	2	1
CL_AL_Inner_4	10	7	5	7	5	0	1	4	3	6	2	1
CL_AL_Inner_5	1	1	5	3	3	2	3	4	3	3	1	3
CL_AL_Inner_6	1	1	2	2	0	1	0	1	0	0	3	2

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
3	4	2	0	2	1	2	4	3	1	0	2
1	0	0	1	0	0	1	6	0	0	1	3
1	1	2	2	2	2	3	2	0	1	2	1
8	6	4	6	4	0	1	4	3	6	2	1
1	1	4	2	2	2	3	4	3	3	1	3
1	1	2	2	0	1	0	1	0	0	3	2

16 YO

Posterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	26	30	25	17	13	11	11	13	16	18	15	8
CL_AL_Outer_2	25	21	20	13	8	13	5	10	14	13	6	6
CL_AL_Outer_3	16	22	20	21	22	25	18	14	11	19	20	19
CL_AL_Outer_4	22	21	24	24	20	19	21	23	21	25	25	21
CL_AL_Outer_5	19	24	23	27	21	19	7	15	21	23	25	24
CL_AL_Outer_6	14	10	15	15	14	11	14	10	11	18	17	9

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
20	24	20	13	10	9	11	13	16	18	15	8
20	17	16	10	6	10	5	10	14	13	6	6
13	17	16	17	17	20	18	14	11	19	20	19
17	17	19	19	16	15	21	23	21	25	25	21
15	19	18	21	17	15	7	15	21	23	25	24
11	8	12	12	11	9	14	10	11	18	17	9

Posterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	5	3	5	3	1	0	3	2	3	5	4	2
CL_AL_Mid_2	12	11	12	6	3	2	16	21	21	18	22	16
CL_AL_Mid_3	1	3	3	0	1	1	5	5	6	6	4	4
CL_AL_Mid_4	5	5	7	3	3	6	23	17	20	18	10	13
CL_AL_Mid_5	4	4	2	1	3	4	8	6	6	4	5	1
CL_AL_Mid_6	13	13	9	14	11	6	7	5	14	8	5	3

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
4	2	4	2	1	0	3	2	3	5	4	2
9	9	9	5	2	2	16	21	21	18	22	16
1	2	2	0	1	1	5	5	6	6	4	4
4	4	6	2	2	5	23	17	20	18	10	13
3	3	2	1	2	3	8	6	6	4	5	1
10	10	7	11	9	5	7	5	14	8	5	3

Posterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	4	4	7	6	4	5	2	4	5	6	4	4
CL_AL_Inner_2	6	6	5	4	2	2	5	8	3	6	7	8
CL_AL_Inner_3	7	6	7	7	9	7	4	4	5	4	5	2
CL_AL_Inner_4	7	7	3	1	0	0	6	7	3	6	1	1
CL_AL_Inner_5	12	7	7	5	12	12	1	1	2	2	0	1
CL_AL_Inner_6	6	9	4	6	5	8	8	8	3	7	2	3

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
3	3	6	5	3	4	2	4	5	6	4	4
5	5	4	3	2	2	5	8	3	6	7	8
6	5	6	6	7	6	4	4	5	4	5	2
6	6	2	1	0	0	6	7	3	6	1	1
9	6	6	4	9	9	1	1	2	2	0	1
5	7	3	5	4	6	8	8	3	7	2	3

28 YO

Anterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	14	9	10	12	12	9	15	16	15	10	6	6
CL_AL_Outer_2	11	11	12	15	13	14	13	13	12	11	10	7
CL_AL_Outer_3	34	41	35	33	30	29	15	24	17	15	14	18
CL_AL_Outer_4	16	16	18	20	18	17	9	5	8	7	6	6
CL_AL_Outer_5	18	22	22	16	17	16	10	7	3	3	2	6
CL_AL_Outer_6	36	34	39	29	32	27	17	11	15	14	8	8

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
11	7	8	9	9	7	15	16	15	10	6	6
9	9	9	12	10	11	13	13	12	11	10	7
27	32	28	26	24	23	15	24	17	15	14	18
13	13	14	16	14	13	9	5	8	7	6	6
14	17	17	13	13	13	10	7	3	3	2	6
28	27	31	23	25	21	17	11	15	14	8	8

Anterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	18	14	17	12	11	10	5	11	3	5	3	4
CL_AL_Mid_2	22	21	21	12	18	15	8	6	5	5	4	2
CL_AL_Mid_3	4	7	9	4	2	5	5	6	8	8	7	4
CL_AL_Mid_4	10	9	8	8	10	10	7	6	5	4	6	2
CL_AL_Mid_5	13	13	16	13	8	9	10	10	12	13	11	7
CL_AL_Mid_6	11	10	10	12	9	9	5	7	4	7	4	4

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
14	11	13	9	9	8	5	11	3	5	3	4
17	17	17	9	14	12	8	6	5	5	4	2
3	6	7	3	2	4	5	6	8	8	7	4
8	7	6	6	8	8	7	6	5	4	6	2
10	10	13	10	6	7	10	10	12	13	11	7
9	8	8	9	7	7	5	7	4	7	4	4

Anterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	12	12	12	12	12	9	4	4	6	5	6	3
CL_AL_Inner_2	2	4	4	2	6	6	5	3	4	3	7	1
CL_AL_Inner_3	3	8	6	5	6	5	3	2	4	6	4	2
CL_AL_Inner_4	1	2	2	2	1	1	2	1	1	3	2	2
CL_AL_Inner_5	9	9	10	14	17	18	2	2	2	2	4	0
CL_AL_Inner_6	2	0	1	1	0	1	2	2	3	4	3	0

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
9	9	9	9	9	7	3	3	5	4	5	2
2	3	3	2	5	5	4	2	3	2	6	1
2	6	5	4	5	4	2	2	3	5	3	2
1	2	2	2	1	1	2	1	1	3	2	2
7	7	8	11	13	14	2	2	2	2	4	0
2	0	1	1	0	1	2	2	3	4	3	0

28 YO

Posterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	17	19	21	20	23	19	30	25	37	35	37	34
CL_AL_Outer_2	22	22	29	30	28	38	48	41	46	52	52	55
CL_AL_Outer_3	24	27	13	18	17	15	21	14	14	19	16	12
CL_AL_Outer_4	24	18	19	24	26	25	34	36	31	29	25	30
CL_AL_Outer_5	12	8	12	8	8	9	30	24	22	29	28	27
CL_AL_Outer_6	19	17	18	15	22	18	12	18	16	17	14	8

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
13	15	17	16	18	15	29	25	36	34	36	33
17	17	23	24	22	30	47	40	45	51	51	54
19	21	10	14	13	12	21	14	14	19	16	12
19	14	15	19	20	20	33	35	30	28	25	29
9	6	9	6	6	7	29	24	22	28	28	27
15	13	14	12	17	14	12	18	16	17	14	8

Posterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	24	26	28	27	31	28	21	23	18	20	13	14
CL_AL_Mid_2	23	30	30	36	38	21	4	6	11	11	7	12
CL_AL_Mid_3	17	22	19	28	32	35	24	15	17	19	17	11
CL_AL_Mid_4	18	15	19	19	23	14	23	21	28	25	24	26
CL_AL_Mid_5	14	17	16	16	11	12	21	23	20	22	23	26
CL_AL_Mid_6	9	12	10	18	13	13	21	24	23	14	13	8

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
19	20	22	21	24	22	21	23	18	20	13	14
18	24	24	28	30	17	4	6	11	11	7	12
13	17	15	22	25	28	24	15	17	19	17	11
14	12	15	15	18	11	23	21	28	25	24	26
11	13	13	13	9	9	21	23	20	22	23	26
7	9	8	14	10	10	21	24	23	14	13	8

Posterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	5	5	7	5	4	6	3	3	1	4	4	5
CL_AL_Inner_2	7	11	13	9	9	6	3	2	2	1	2	2
CL_AL_Inner_3	6	7	11	12	15	15	13	6	8	9	5	10
CL_AL_Inner_4	8	13	8	15	10	9	6	4	6	7	5	7
CL_AL_Inner_5	9	5	7	6	4	3	2	3	5	4	3	5
CL_AL_Inner_6	6	5	8	8	5	5	2	2	2	2	6	1

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
4	4	6	4	3	5	3	3	1	4	4	5
6	9	10	7	7	5	3	2	2	1	2	2
5	6	9	9	12	12	13	6	8	9	5	10
6	10	6	12	8	7	6	4	6	7	5	7
7	4	6	5	3	2	2	2	4	3	2	4
5	4	6	6	4	4	2	2	2	2	5	1

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Anterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	25	23	18	20	21	16	6	8	10	12	8	8
CL_AL_Outer_2	24	24	18	11	12	8	6	3	7	10	4	7
CL_AL_Outer_3	13	12	10	8	7	9	5	9	8	14	8	7
CL_AL_Outer_4	12	12	16	11	8	11	19	14	7	9	9	11
CL_AL_Outer_5	15	11	10	8	7	9	8	7	9	8	7	11
CL_AL_Outer_6	17	18	19	17	13	16	7	8	6	5	8	9

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
20	18	14	16	17	13	6	8	10	12	8	8
19	19	14	9	9	6	6	3	7	10	4	7
10	9	8	6	6	7	5	9	8	14	8	7
9	9	13	9	6	9	19	14	7	9	9	11
12	9	8	6	6	7	8	7	9	8	7	11
13	14	15	13	10	13	7	8	6	5	8	9

Anterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	16	18	19	18	18	12	2	5	4	5	2	2
CL_AL_Mid_2	22	21	21	21	21	19	5	4	5	2	4	2
CL_AL_Mid_3	12	13	17	17	18	15	16	10	10	14	13	4
CL_AL_Mid_4	10	9	6	8	7	6	8	5	7	3	3	4
CL_AL_Mid_5	8	6	7	6	6	9	1	2	5	3	7	5
CL_AL_Mid_6	12	12	12	18	18	13	2	4	2	2	1	5

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
13	14	15	14	14	9	2	5	4	5	2	2
17	17	17	17	17	15	5	4	5	2	4	2
9	10	13	13	14	12	16	10	10	14	13	4
8	7	5	6	6	5	8	5	7	3	3	4
6	5	6	5	5	7	1	2	5	3	7	5
9	9	9	14	14	10	2	4	2	2	1	5

Anterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	9	3	4	5	6	5	2	4	2	4	7	4
CL_AL_Inner_2	8	6	2	8	8	9	2	5	6	2	2	4
CL_AL_Inner_3	14	11	9	10	9	11	5	8	8	6	3	4
CL_AL_Inner_4	14	7	7	5	12	6	6	14	8	12	15	10
CL_AL_Inner_5	3	4	6	8	9	9	3	3	6	4	3	2
CL_AL_Inner_6	12	18	14	8	6	7	6	4	8	5	4	5

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
7	2	3	4	5	4	2	4	2	4	7	4
6	5	2	6	6	7	2	5	6	2	2	4
11	9	7	8	7	9	5	8	8	6	3	4
11	6	6	4	9	5	6	14	8	12	15	10
2	3	5	6	7	7	3	3	6	4	3	2
9	14	11	6	5	6	6	4	8	5	4	5

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Posterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	56	53	49	58	55	54	19	28	20	25	20	21
CL_AL_Outer_2	30	22	23	21	16	19	18	18	22	22	19	19
CL_AL_Outer_3	30	39	35	35	26	26	10	15	15	19	17	18
CL_AL_Outer_4	12	15	9	12	6	6	24	20	21	22	24	26
CL_AL_Outer_5	23	22	22	17	23	31	20	18	10	11	7	6
CL_AL_Outer_6	50	43	41	40	45	45	14	16	17	14	14	19

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
44	42	39	46	43	42	19	28	20	25	20	21
24	17	18	17	13	15	18	18	22	22	19	19
24	31	28	28	20	20	10	15	15	19	17	18
9	12	7	9	5	5	24	20	21	22	24	26
18	17	17	13	18	24	20	18	10	11	7	6
39	34	32	31	35	35	14	16	17	14	14	19

Posterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	36	36	45	55	45	44	41	42	41	40	49	41
CL_AL_Mid_2	35	32	35	34	32	25	13	23	15	20	19	24
CL_AL_Mid_3	34	28	24	22	26	24	14	19	10	14	10	12
CL_AL_Mid_4	21	21	16	18	21	26	15	11	9	6	5	6
CL_AL_Mid_5	29	28	31	37	39	29	12	11	11	4	4	4
CL_AL_Mid_6	22	29	29	19	27	19	9	12	12	13	3	5

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
28	28	35	43	35	35	40	41	40	39	48	40
28	25	28	27	25	20	13	23	15	20	19	24
27	22	19	17	20	19	14	19	10	14	10	12
17	17	13	14	17	20	15	11	9	6	5	6
23	22	24	29	31	23	12	11	11	4	4	4
17	23	23	15	21	15	9	12	12	13	3	5

Posterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	15	14	17	13	10	10	8	7	4	9	7	5
CL_AL_Inner_2	13	16	22	18	22	14	10	7	5	8	8	6
CL_AL_Inner_3	7	6	3	6	5	4	11	10	10	10	7	9
CL_AL_Inner_4	12	20	15	16	13	12	10	14	14	24	21	11
CL_AL_Inner_5	11	9	15	19	19	18	5	3	6	11	12	8
CL_AL_Inner_6	14	20	19	13	13	16	11	11	8	10	14	11

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
12	11	13	10	8	8	8	7	4	9	7	5
10	13	17	14	17	11	10	7	5	8	8	6
6	5	2	5	4	3	11	10	10	10	7	9
9	16	12	13	10	9	10	14	14	24	21	11
9	7	12	15	15	14	5	3	6	11	12	8
11	16	15	10	10	13	11	11	8	10	14	11

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Anterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	20	17	14	13	18	17	10	6	7	3	4	-
CL_AL_Outer_2	18	18	11	14	18	17	10	15	8	15	17	16
CL_AL_Outer_3	17	16	14	16	15	16	11	7	12	10	10	-
CL_AL_Outer_4	17	25	22	15	19	15	8	10	13	7	10	-
CL_AL_Outer_5	18	22	21	19	23	25	8	7	9	12	15	10
CL_AL_Outer_6	16	16	21	22	-	-	7	9	6	2	2	-

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
16	13	11	10	14	13	10	6	7	3	4	-
14	14	9	11	14	13	10	15	8	15	17	16
13	13	11	13	12	13	11	7	12	10	10	-
13	20	17	12	15	12	8	10	13	7	10	-
14	17	17	15	18	20	8	7	9	12	15	10
13	13	17	17	-	-	7	9	6	2	2	-

Anterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	15	13	14	12	11	11	6	5	6	0	5	2
CL_AL_Mid_2	4	5	7	7	10	9	1	3	7	6	7	6
CL_AL_Mid_3	21	15	15	17	13	15	7	10	7	7	11	9
CL_AL_Mid_4	10	7	6	9	9	6	4	3	4	6	4	1
CL_AL_Mid_5	11	10	20	12	9	10	5	14	4	11	16	10
CL_AL_Mid_6	14	16	19	10	14	10	3	3	9	4	5	4

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
12	10	11	9	9	9	6	5	6	0	5	2
3	4	6	6	8	7	1	3	7	6	7	6
17	12	12	13	10	12	7	10	7	7	11	9
8	6	5	7	7	5	4	3	4	6	4	0
9	8	16	9	7	8	5	14	4	11	16	10
11	13	15	8	11	8	3	3	9	4	5	4

Anterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	8	13	15	13	12	10	4	2	3	5	4	1
CL_AL_Inner_2	6	7	5	8	7	4	2	4	3	3	3	1
CL_AL_Inner_3	7	8	6	7	7	8	7	4	3	0	1	1
CL_AL_Inner_4	10	12	11	6	8	6	1	3	2	1	5	0
CL_AL_Inner_5	4	1	3	3	3	2	6	3	1	2	6	3
CL_AL_Inner_6	4	4	1	1	2	2	0	0	0	1	2	1

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
6	10	12	10	9	8	4	2	3	5	4	1
5	6	4	6	6	3	2	4	3	3	3	1
6	6	5	6	6	6	7	4	3	0	1	1
8	9	9	5	6	5	1	3	2	1	5	0
3	1	2	2	2	2	6	3	1	2	6	3
3	3	1	1	2	2	0	0	0	1	2	1

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Posterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	43	35	49	50	39	33	26	31	30	28	20	15
CL_AL_Outer_2	28	30	34	31	30	30	13	6	11	12	11	10
CL_AL_Outer_3	18	18	24	35	26	15	27	19	30	27	25	20
CL_AL_Outer_4	9	5	9	13	13	8	31	33	36	22	22	18
CL_AL_Outer_5	24	22	20	21	19	22	27	32	26	27	32	21
CL_AL_Outer_6	20	17	18	10	15	15	25	24	21	29	24	33

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
34	28	39	39	31	26	26	30	29	28	20	15
22	24	27	24	24	24	13	6	11	12	11	10
14	14	19	28	20	12	27	19	29	27	25	20
7	4	7	10	10	6	30	32	35	22	22	18
19	17	16	17	15	17	27	31	26	27	31	21
16	13	14	8	12	12	25	24	21	28	24	32

Posterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	24	20	26	30	21	23	7	11	12	21	14	17
CL_AL_Mid_2	16	15	13	11	10	10	14	13	10	8	10	11
CL_AL_Mid_3	32	39	31	29	33	35	8	12	13	10	11	13
CL_AL_Mid_4	13	18	14	19	13	14	18	15	18	17	17	11
CL_AL_Mid_5	5	3	4	6	5	2	36	30	21	16	24	19
CL_AL_Mid_6	26	31	25	25	25	21	23	23	25	16	14	13

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
19	16	20	24	17	18	7	11	12	21	14	17
13	12	10	9	8	8	14	13	10	8	10	11
25	31	24	23	26	28	8	12	13	10	11	13
10	14	11	15	10	11	18	15	18	17	17	11
4	2	3	5	4	2	35	29	21	16	24	19
20	24	20	20	20	17	23	23	25	16	14	13

Posterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	3	1	1	0	2	2	3	2	0	2	2	4
CL_AL_Inner_2	2	4	3	1	2	2	13	12	6	4	3	2
CL_AL_Inner_3	22	19	14	18	11	14	5	4	4	4	6	6
CL_AL_Inner_4	12	8	12	12	7	5	2	1	5	5	3	3
CL_AL_Inner_5	4	8	11	12	13	10	6	6	3	3	6	3
CL_AL_Inner_6	12	18	11	9	9	12	22	12	10	17	18	12

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
2	1	1	0	2	2	3	2	0	2	2	4
2	3	2	1	2	2	13	12	6	4	3	2
17	15	11	14	9	11	5	4	4	4	6	6
9	6	9	9	6	4	2	1	5	5	3	3
3	6	9	9	10	8	6	6	3	3	6	3
9	14	9	7	7	9	22	12	10	17	18	12

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Anterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	20	23	29	23	20	22	6	5	5	2	3	4
CL_AL_Outer_2	25	27	24	22	20	23	2	7	13	8	10	4
CL_AL_Outer_3	13	8	9	11	7	7	1	2	1	3	1	4
CL_AL_Outer_4	17	22	24	25	22	21	3	1	0	5	1	5
CL_AL_Outer_5	11	13	12	8	13	16	2	4	6	2	5	5
CL_AL_Outer_6	4	10	4	5	7	5	3	2	1	2	2	2

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
16	18	23	18	16	17	6	5	5	2	3	4
20	21	19	17	16	18	2	7	13	8	10	4
10	6	7	9	6	6	1	2	1	3	1	4
13	17	19	20	17	17	3	1	0	5	1	5
9	10	9	6	10	13	2	4	6	2	5	5
3	8	3	4	6	4	3	2	1	2	2	2

Anterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	6	8	8	10	10	9	6	5	4	6	3	5
CL_AL_Mid_2	6	9	12	6	11	11	2	5	7	7	3	3
CL_AL_Mid_3	18	19	23	16	18	16	10	7	6	6	11	4
CL_AL_Mid_4	3	2	3	5	4	3	3	1	2	2	1	0
CL_AL_Mid_5	10	13	11	10	10	6	5	1	3	6	5	6
CL_AL_Mid_6	16	14	13	15	14	16	6	3	6	5	3	-

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
5	6	6	8	8	7	6	5	4	6	3	5
5	7	9	5	9	9	2	5	7	7	3	3
14	15	18	13	14	13	10	7	6	6	11	4
2	2	2	4	3	2	3	1	2	2	1	0
8	10	9	8	8	5	5	1	3	6	5	6
13	11	10	12	11	13	6	3	6	5	3	-

Anterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	5	7	8	6	7	11	8	9	5	6	7	6
CL_AL_Inner_2	12	5	5	8	3	6	5	3	4	3	6	2
CL_AL_Inner_3	3	4	2	5	7	5	4	1	0	2	3	0
CL_AL_Inner_4	0	2	2	6	4	3	7	9	7	6	8	3
CL_AL_Inner_5	3	2	1	2	1	3	2	2	1	0	0	0
CL_AL_Inner_6	5	4	4	4	7	7	1	5	4	8	2	1

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
4	6	6	5	6	9	8	9	5	6	7	6
9	4	4	6	2	5	5	3	4	3	6	2
2	3	2	4	6	4	4	1	0	2	3	0
0	2	2	5	3	2	7	9	7	6	8	3
2	2	1	2	1	2	2	2	1	0	0	0
4	3	3	3	6	6	1	5	4	8	2	1

66 YO

Posterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	0	2	4	4	4	7	7	7	9	9	10	4
CL_AL_Outer_2	11	8	4	10	11	8	9	8	9	5	6	6
CL_AL_Outer_3	1	1	2	3	3	3	3	3	3	2	0	6
CL_AL_Outer_4	8	9	6	8	8	8	21	24	24	16	21	20
CL_AL_Outer_5	12	9	10	11	5	10	27	33	27	20	17	22
CL_AL_Outer_6	12	3	3	3	5	4	6	8	6	6	0	2

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
0	2	3	3	3	6	7	7	9	9	10	4
9	6	3	8	9	6	9	8	9	5	6	6
1	1	2	2	2	2	3	3	3	2	0	6
6	7	5	6	6	6	21	24	24	16	21	20
9	7	8	9	4	8	27	32	27	20	17	22
9	2	2	2	4	3	6	8	6	6	0	2

Posterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	3	5	5	4	3	4	23	20	17	26	18	22
CL_AL_Mid_2	4	5	6	3	5	7	2	6	4	6	5	4
CL_AL_Mid_3	14	10	7	9	11	11	22	22	13	24	23	12
CL_AL_Mid_4	14	12	13	8	15	15	11	11	15	16	10	11
CL_AL_Mid_5	2	3	1	1	2	6	10	11	14	10	11	14
CL_AL_Mid_6	12	12	13	14	19	10	3	5	7	6	3	2

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
2	4	4	3	2	3	23	20	17	26	18	22
3	4	5	2	4	6	2	6	4	6	5	4
11	8	6	7	9	9	22	22	13	24	23	12
11	9	10	6	12	12	11	11	15	16	10	11
2	2	1	1	2	5	10	11	14	10	11	14
9	9	10	11	15	8	3	5	7	6	3	2

Posterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	3	3	6	7	4	1	11	10	17	13	6	6
CL_AL_Inner_2	1	2	4	0	0	2	1	3	7	4	3	0
CL_AL_Inner_3	0	2	2	4	4	3	7	6	2	1	2	3
CL_AL_Inner_4	2	0	0	1	0	5	1	1	4	3	5	5
CL_AL_Inner_5	4	3	2	4	6	3	5	6	7	8	8	10
CL_AL_Inner_6	1	5	3	2	3	2	8	13	7	12	9	10

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
2	2	5	6	3	1	11	10	17	13	6	6
1	2	3	0	0	2	1	3	7	4	3	0
0	2	2	3	3	2	7	6	2	1	2	3
2	0	0	1	0	4	1	1	4	3	5	5
3	2	2	3	5	2	5	6	7	8	8	10
1	4	2	2	2	2	8	13	7	12	9	10

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Anterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	11	12	14	14	20	15	5	2	1	7	10	6
CL_AL_Outer_2	17	13	18	18	18	21	7	7	7	3	7	11
CL_AL_Outer_3	15	21	20	24	20	20	9	9	8	8	7	8
CL_AL_Outer_4	19	19	17	19	18	21	14	11	11	11	12	10
CL_AL_Outer_5	11	8	13	13	10	11	6	9	8	6	7	6
CL_AL_Outer_6	19	16	17	20	18	17	6	7	7	9	5	9

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
9	9	11	11	16	12	5	2	1	7	10	6
13	10	14	14	14	17	7	7	7	3	7	11
12	17	16	19	16	16	9	9	8	8	7	8
15	15	13	15	14	17	14	11	11	11	12	10
9	6	10	10	8	9	6	9	8	6	7	6
15	13	13	16	14	13	6	7	7	9	5	9

Anterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	5	6	4	5	4	3	2	3	1	1	1	0
CL_AL_Mid_2	13	15	14	13	14	17	3	6	5	3	6	0
CL_AL_Mid_3	11	12	12	11	8	7	7	6	5	3	8	3
CL_AL_Mid_4	6	9	7	4	7	10	4	4	5	3	2	7
CL_AL_Mid_5	12	4	2	4	4	6	2	1	0	0	1	3
CL_AL_Mid_6	4	4	5	5	6	4	2	3	2	3	3	0

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
4	5	3	4	3	2	2	3	1	1	1	0
10	12	11	10	11	13	3	6	5	3	6	0
9	9	9	9	6	6	7	6	5	3	8	3
5	7	6	3	6	8	4	4	5	3	2	7
9	3	2	3	3	5	2	1	0	0	1	3
3	3	4	4	5	3	2	3	2	3	3	0

Anterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	3	5	5	6	5	6	11	6	3	7	4	4
CL_AL_Inner_2	9	13	10	11	7	7	11	13	8	8	11	9
CL_AL_Inner_3	14	10	7	4	7	7	6	4	9	6	7	7
CL_AL_Inner_4	5	3	9	6	7	5	13	16	11	8	8	8
CL_AL_Inner_5	4	12	13	6	9	8	13	7	7	1	6	5
CL_AL_Inner_6	3	4	4	6	9	9	9	11	11	15	9	13

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
2	4	4	5	4	5	11	6	3	7	4	4
7	10	8	9	6	6	11	13	8	8	11	9
11	8	6	3	6	6	6	4	9	6	7	7
4	2	7	5	6	4	13	16	11	8	8	8
3	9	10	5	7	6	13	7	7	1	6	5
2	3	3	5	7	7	9	11	11	15	9	13

76 YO

Posterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	36	39	40	45	38	39	12	13	17	18	16	12
CL_AL_Outer_2	50	41	39	41	43	40	11	7	12	12	11	14
CL_AL_Outer_3	69	62	61	56	61	61	24	25	18	19	19	11
CL_AL_Outer_4	24	19	28	18	19	20	21	22	21	26	17	16
CL_AL_Outer_5	27	14	16	20	22	17	22	28	27	23	19	14
CL_AL_Outer_6	12	17	12	12	17	11	19	19	17	14	18	19

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
28	31	31	35	30	31	12	13	17	18	16	12
39	32	31	32	34	31	11	7	12	12	11	14
54	49	48	44	48	48	24	25	18	19	19	11
19	15	22	14	15	16	21	22	21	26	17	16
21	11	13	16	17	13	22	28	27	23	19	14
9	13	9	9	13	9	19	19	17	14	18	19

Posterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	11	13	18	16	18	20	14	16	21	15	12	16
CL_AL_Mid_2	16	19	20	15	15	9	15	15	11	16	15	23
CL_AL_Mid_3	21	27	33	28	25	25	5	7	7	5	6	6
CL_AL_Mid_4	44	42	40	38	40	35	21	16	17	11	13	12
CL_AL_Mid_5	15	12	12	18	16	22	13	13	9	7	2	4
CL_AL_Mid_6	25	21	21	17	17	20	7	14	11	11	13	13

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
9	10	14	13	14	16	14	16	21	15	12	16
13	15	16	12	12	7	15	15	11	16	15	23
17	21	26	22	20	20	5	7	7	5	6	6
35	33	31	30	31	28	21	16	17	11	13	12
12	9	9	14	13	17	13	13	9	7	2	4
20	17	17	13	13	16	7	14	11	11	13	13

Posterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	23	21	21	17	17	15	9	9	9	10	10	7
CL_AL_Inner_2	17	18	18	17	19	22	17	13	10	8	6	8
CL_AL_Inner_3	10	7	10	9	10	8	17	15	14	15	12	12
CL_AL_Inner_4	6	9	7	5	5	6	4	4	3	3	4	3
CL_AL_Inner_5	11	10	8	8	4	6	2	8	4	7	9	8
CL_AL_Inner_6	18	12	16	18	13	15	8	12	12	17	11	9

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
18	17	17	13	13	12	9	9	9	10	10	7
13	14	14	13	15	17	17	13	10	8	6	8
8	6	8	7	8	6	17	15	14	15	12	12
5	7	6	4	4	5	4	4	3	3	4	3
9	8	6	6	3	5	2	8	4	7	9	8
14	9	13	14	10	12	8	12	12	17	11	9

82 YO

Anterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	0	0	0	0	0	1	0	1	0	0	0	0
CL_AL_Outer_2	0	5	4	4	4	5	4	4	3	4	3	4
CL_AL_Outer_3	1	0	3	2	1	0	1	0	0	1	2	4
CL_AL_Outer_4	5	8	7	5	4	1	7	8	11	8	7	4
CL_AL_Outer_5	6	2	6	6	9	6	0	1	2	4	7	3
CL_AL_Outer_6	8	10	10	13	10	10	3	4	4	4	2	1

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
0	0	0	0	0	1	0	1	0	0	0	-
0	4	3	3	3	4	4	4	3	4	3	4
1	0	2	2	1	0	1	0	0	1	2	-
4	6	6	4	3	1	7	8	11	8	7	-
5	2	5	5	7	5	0	1	2	4	7	3
6	8	8	10	-	-	3	4	4	4	2	-

Anterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	6	7	8	7	8	9	3	0	0	4	4	2
CL_AL_Mid_2	6	4	4	7	11	8	2	1	0	2	2	3
CL_AL_Mid_3	-	-	-	-	-	-	-	-	-	-	-	-
CL_AL_Mid_4	10	12	7	11	9	7	7	4	5	3	4	6
CL_AL_Mid_5	5	4	3	4	3	0	3	1	3	0	1	2
CL_AL_Mid_6	9	6	4	4	4	2	3	1	6	1	6	8

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
5	6	6	6	6	7	3	0	0	4	4	2
5	3	3	6	9	6	2	1	0	2	2	3
-	-	-	-	-	-	-	-	-	-	-	-
8	9	6	9	7	6	7	4	5	3	4	0
4	3	2	3	2	0	3	1	3	0	1	2
7	5	3	3	3	2	3	1	6	1	6	8

Anterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	1	3	3	1	0	2	5	2	0	2	1	1
CL_AL_Inner_2	0	2	1	3	1	4	2	2	3	6	3	4
CL_AL_Inner_3	1	1	1	0	1	1	0	1	1	1	1	2
CL_AL_Inner_4	2	6	1	1	1	2	3	4	6	5	4	4
CL_AL_Inner_5	4	9	5	10	5	3	0	1	4	1	5	1
CL_AL_Inner_6	6	6	3	2	8	5	3	2	7	5	6	4

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
1	2	2	1	0	2	5	2	0	2	1	1
0	2	1	2	1	3	2	2	3	6	3	4
1	1	1	0	1	1	0	1	1	1	1	2
2	5	1	1	1	2	3	4	6	5	4	4
3	7	4	8	4	2	0	1	4	1	5	1
5	5	2	2	6	4	3	2	7	5	6	4

82 YO

Posterolateral Outer

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Outer_1	17	14	24	17	21	19	29	34	32	32	25	21
CL_AL_Outer_2	7	9	12	7	8	7	4	6	6	4	7	6
CL_AL_Outer_3	7	11	11	7	13	20	7	11	10	7	9	5
CL_AL_Outer_4	23	24	30	30	26	25	7	14	21	23	20	17
CL_AL_Outer_5	9	5	4	6	5	10	16	13	16	16	14	16
CL_AL_Outer_6	11	6	8	7	10	9	19	10	13	10	12	9

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
13	11	19	13	17	15	28	33	31	31	25	21
6	7	9	6	6	6	4	6	6	4	7	6
6	9	9	6	10	16	7	11	10	7	9	5
18	19	24	24	20	20	7	14	21	23	20	17
7	4	3	5	4	8	16	13	16	16	14	16
9	5	6	6	8	7	19	10	13	10	12	9

Posterolateral Middle

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Mid_1	6	5	5	3	4	2	1	1	0	0	1	0
CL_AL_Mid_2	1	0	1	2	2	0	0	1	3	0	0	4
CL_AL_Mid_3	2	3	3	4	5	5	1	0	0	1	2	2
CL_AL_Mid_4	3	4	3	4	5	3	1	1	1	1	2	0
CL_AL_Mid_5	3	4	6	5	4	3	3	0	1	1	1	2
CL_AL_Mid_6	10	6	2	4	6	4	4	4	4	2	4	4

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
5	4	4	2	3	2	1	1	0	0	1	0
1	0	1	2	2	0	0	1	3	0	0	4
2	2	2	3	4	4	1	0	0	1	2	2
2	3	2	3	4	2	1	1	1	1	2	0
2	3	5	4	3	2	3	0	1	1	1	2
8	5	2	3	5	3	4	4	4	2	4	4

Posterolateral Inner

Image ID	Horizontal						Vertical					
	1	2	3	4	5	6	1	2	3	4	5	6
CL_AL_Inner_1	3	3	3	4	5	4	3	2	1	1	4	2
CL_AL_Inner_2	1	1	1	2	2	2	3	2	3	6	6	5
CL_AL_Inner_3	5	4	2	2	2	0	3	3	3	2	1	2
CL_AL_Inner_4	13	8	8	10	9	3	6	6	6	9	11	6
CL_AL_Inner_5	7	9	13	11	3	2	5	7	6	3	7	8
CL_AL_Inner_6	6	6	2	3	4	5	7	7	4	2	3	2

Normalised (intercepts per 100µm)

Horizontal						Vertical					
1	2	3	4	5	6	1	2	3	4	5	6
2	2	2	3	4	3	3	2	1	1	4	2
1	1	1	2	2	2	3	2	3	6	6	5
4	3	2	2	2	0	3	3	3	2	1	2
10	6	6	8	7	2	6	6	6	9	11	6
6	7	10	9	2	2	5	7	6	3	7	8
5	5	2	2	3	4	7	7	4	2	3	2

APPENDIX 4: MECHANICAL TESTING DATA

Specimen			Initial Modulus (MPa)		Ultimate Modulus (MPa)		Extensibility (mm/mm)	
Age	**Grade**	**Location**	**Before Treatment**	**After Treatment**	**Before Treatment**	**After Treatment**	**Before Treatment**	**After Treatment**
16	1	AL	0.011	0.005	0.045	0.008	0.175	0.372
28	2	AL	0.036	0.003	0.228	0.033	0.139	0.650
		PL	0.012	0.003	0.063	0.013	0.306	1.316
40	1	AL	0.096	0.003	0.215	0.018	0.159	1.428
		PL	0.100	0.003	0.204	0.013	0.170	1.446
57	2	AL	0.090	0.008	0.201	0.038	0.160	0.463
		PL	0.038	0.005	0.111	0.011	0.125	0.774
66	3	AL	0.066	0.003	0.254	0.044	0.161	0.612
		PL	0.105	0.004	0.398	0.020	0.133	1.165
76	3	PL	0.024	0.006	0.087	0.016	0.431	1.163
80	4	AL	0.174	0.007	0.601	0.088	0.182	0.538
		PL	0.036	0.002	0.176	0.014	0.156	1.092
87	4	AL	0.124	0.004	0.262	0.039	0.061	0.593
		PL	0.074	0.006	0.244	0.055	0.211	1.155
	Median IQR		0.070 (0.033,0.102)	0.004 (0.003,0.006)	0.209 (0.105,0.256)	0.019 (0.013,0.040)	0.160 (0.137,0.190)	0.933 (0.579,1.203)

Table A4.1. Mechanical testing data – elastase treated group.

Specimen			Initial Modulus (MPa)		Ultimate Modulus (MPa)		Extensibility (mm/mm)	
Age	Grade	Location	Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment
16	1	AL	0.006	0.003	0.041	0.046	0.181	0.292
		PL	0.006	0.004	0.045	0.073	0.317	0.565
28	2	AL	0.039	0.013	0.207	0.194	0.169	0.346
40	1	AL	0.107	0.058	0.182	0.164	0.125	0.231
57	2	AL	0.115	0.059	0.264	0.240	0.112	0.218
		PL	0.040	0.002	0.101	0.071	0.133	0.248
66	3	AL	0.165	0.106	0.326	0.383	0.112	0.188
		PL	0.122	0.039	0.273	0.152	0.159	0.214
76	3	AL	0.090	0.068	0.320	0.434	0.150	0.276
		PL	0.103	0.051	0.253	0.237	0.222	0.380
80	4	AL	0.262	0.164	0.727	0.768	0.141	0.156
		PL	0.014	0.006	0.077	0.100	0.232	0.675
87	4	AL	0.062	0.040	0.162	0.156	0.202	0.256
		PL	0.080	0.047	0.325	0.228	0.184	0.305
	Median		0.085	0.043	0.230	0.179	0.164	0.266
	IQR		(0.033,0.117)	(0.005,0.061)	(0.095,0.321)	(0.093,0.276)	(0.13,0.188)	(0.217,0.354)

Table A4.2. Mechanical testing data – chondroitinase ABC treated group.

Treatment Group	Before Treatment (MPa)	After Treatment (MPa)	Median Change		p
			MPa	%	
Elastase	0.070 (0.033,0.102)	0.004 (0.003,0.006)	-0.065 (-0.097,-0.042)	-93	<0.001
Chondroitinase ABC	0.085 (0.033,0.117)	0.043 (0.005,0.061)	-0.041 (-0.055,-0.025)	-49	<0.001

Table A4.3. Change in initial modulus following enzyme treatment. Each n = 14, median (IQR), Wilcoxon signed ranks tests.

Treatment Group	Before Treatment (MPa)	After Treatment (MPa)	Median Change		p
			MPa	%	
Elastase	0.209 (0.105,0.256)	0.019 (0.013,0.040)	-0.190 (-0.207,-0.116)	-91	<0.001
Chondroitinase ABC	0.230 (0.095,0.321)	0.179 (0.093,0.276)	-0.010 (-0.023,-0.26)	-4	0.86

Table A4.4. Change in ultimate modulus following enzyme treatment. Each n = 14, median (IQR), Wilcoxon signed ranks tests.

Treatment Group	Before Treatment (mm/mm)	After Treatment (mm/mm)	Median Change		p
			mm/mm	%	
Elastase	0.160 (0.137,0.190)	0.933 (0.579,1.203)	+0.691 (0.466,0.994)	+431	<0.001
Chondroitinase ABC	0.164 (0.13,0.188)	0.266 (0.217,0.354)	+0.113 (0.084,0.150)	+69	<0.001

Table A4.5. Change in extensibility following enzyme treatment. Each n = 14, median (IQR), Wilcoxon signed ranks tests.

Property	Anterolateral Quadrant	Posterolateral Quadrant	p
Initial Modulus (MPa)	0.096 ± 0.062	0.055 ± 0.040	0.11
Ultimate Modulus (MPa)	0.272 ± 0.178	0.167 ± 0.103	0.17
Extensibility (mm/mm)	0.149 ± 0.016	0.223 ± 0.081	0.02

Table A4.6. Regional variations in pre-treatment mechanical properties. Each n = 8, mean ± SD, paired t-tests.

Property	Anterolateral Quadrant	Posterolateral Quadrant	p
Initial Modulus (MPa)*	0.005 ± 0.002	0.004 ± 0.002	0.55
Ultimate Modulus (MPa)**	0.038 (0.018,0.044)	0.014 (0.013,0.020)	0.16
Extensibility (mm/mm)**	0.593 (0.463,0.650)	1.163 (1.092,1.316)	0.02

Table A4.7. Regional variations in mechanical properties following elastase treatment. Each n = 7; *mean ± SD, unpaired t-test; **median (IQR), Mann-Whitney U test.

Property	Anterolateral Quadrant*	Posterolateral Quadrant**	p
Initial Modulus (MPa)	0.058 (0.020,0.096)	0.022 (0.004,0.048)	0.08
Extensibility (mm/mm)	0.243 (0.196,0.288)	0.342 (0.240,0.592)	0.11

Table A4.8. Regional variations in mechanical properties following chondroitinase ABC treatment. Median (IQR), Mann-Whitney U tests; *n = 8, **n = 6.

Property	Anterolateral Quadrant	Posterolateral Quadrant	p
Initial Modulus (% decrease)*	95 (90,97)	91 (78,96)	0.56
Ultimate Modulus (% decrease)**	85 ± 3	87 ± 7	0.46
Extensibility (% increase)**	401 ± 305	513 ± 218	0.45

Table A4.9. Regional variations in the magnitude of the changes in mechanical properties after elastase treatment. Each n = 7; *median (IQR), Mann-Whitney U test; **mean ± SD, unpaired t-test.

Property	Anterolateral Quadrant*	Posterolateral Quadrant**	p
Initial Modulus (% decrease)	42 (23,49)	56 (38,75)	0.18
Extensibility (% increase)	76 (36,93)	75 (58,112)	0.75

Table A4.10. Regional variations in the magnitude of the changes in mechanical properties after chondroitinase ABC treatment. Median (IQR), Mann-Whitney U test; *n = 8, **n = 6.

Property	Non-Degenerate*	Degenerate**	p
Initial Modulus (MPa)	0.039 (0.012,0.098)	0.090 (0.062,0.124)	0.048
Ultimate Modulus (MPa)	0.182 (0.054,0.211)	0.262 (0.176,0.326)	0.005
Extensibility (mm/mm)	0.160 (0.129,0.178)	0.161 (0.141,0.211)	0.549

Table A4.11. Variations in pre-treatment mechanical properties with degenerative condition. Pooled anterolateral and posterolateral, median (IQR), Mann-Whitney U test; *n = 13, **n = 15.

Property	Non-Degenerate	Degenerate	p
Initial Modulus (MPa)*	0.004 ± 0.002	0.005 ± 0.002	0.679
Ultimate Modulus (MPa)*	0.019 ± 0.012	0.039 ± 0.027	0.090
Extensibility (mm/mm)**	0.774 (0.463,1.428)	1.092 (0.593,1.163)	0.805

Table A4.12. Variations in mechanical properties with degenerative condition following treatment with elastase. Pooled anterolateral and posterolateral, each n = 7; *mean ± SD, unpaired t-test; **median (IQR), Mann-Whitney U test.

Property	Non-Degenerate*	Degenerate**	p
Initial Modulus (MPa)	0.009 (0.003,0.058)	0.049 (0.039,0.096)	0.108
Extensibility (mm/mm)	0.270 (0.228,0.400)	0.266 (0.195,0.361)	0.755

Table A4.13. Variations in mechanical properties with degenerative condition following treatment with chondroitinase ABC. Pooled anterolateral and posterolateral, median (IQR), Mann-Whitney U test; *n = 6, **n = 8.

Property	Non-Degenerate	Degenerate	p
Initial Modulus (% decrease)*	90 (78,97)	95 (91,96)	0.404
Ultimate Modulus (% decrease)**	86 ± 5	86 ± 6	0.785
Extensibility (% increase)**	439 ± 265	476 ± 279	0.805

Table A4.14. Variations in the magnitude of the change in mechanical properties with degenerative condition following treatment with elastase. Pooled anterolateral and posterolateral, each n = 7; *median (IQR), Mann-Whitney U test; **mean ± SD, unpaired t-test.

Property	Non-Degenerate	Degenerate	p
Initial Modulus (% decrease)	49 (42,74)	40 (35,58)	0.401
Extensibility (% increase)	86 (74,97)	67 (29,81)	0.108

Table A4.15. Variations in the magnitude of the change in mechanical properties with degenerative condition following treatment with chondroitinase ABC. Pooled anterolateral and posterolateral, median (IQR), Mann-Whitney U test; *n = 6, **n = 8.

APPENDIX 5: REAGENT SOURCES

Reagent		Source
Acetic acid	-	Merck, Whitehouse Station, NJ, USA
Acetonitrile	-	Ajax Finechem, Taren Point, NSW, Australia
Acetylacetone	-	Sigma-Aldrich, St Louis, MO, USA
Albumin conjugated desmosine	-	Elastin Products Company, Owensville, MO, USA
Alcian blue 8GX	-	Sigma-Aldrich, St Louis, MO, USA
Ammonium formate	-	Ajax Finechem, Taren Point, NSW, Australia
Antidesmosine-KLH	-	Elastin Products Company, Owensville, MO, USA
Benzamidine hydrochloride	-	Sigma-Aldrich, St Louis, MO, USA
Bovine serum albumin	-	Sigma-Aldrich, St Louis, MO, USA
Butanol	-	Ajax Finechem, Taren Point, NSW, Australia
Chloramine-T	-	Sigma-Aldrich , St Louis, MO, USA
Chondroitinase ABC	-	Sigma-Aldrich , St Louis, MO, USA
Citric acid	-	Ajax Finechem, Taren Point, NSW, Australia
Crystal violet	-	Sigma-Aldrich, St Louis, MO, USA
DePeX mounting medium	-	VWR, Belfast, Ireland
Desmosine standard	-	Elastin Products Company, Owensville, MO, USA
Dextrin	-	Sigma-Aldrich, St Louis, MO, USA
D-glucuronic acid lactone	-	Sigma-Aldrich, St Louis, MO, USA
Elastase, porcine pancreatic	-	Sigma-Aldrich, St Louis, MO, USA
Ethanol (for histology)	-	Ace Chemical Company, Camden Park, SA, Australia
Ethanol (for biochemistry)	-	Ajax Finechem, Taren Point, NSW, Australia
Ferric chloride	-	Sigma-Aldrich, St Louis, MO, USA
Formaldehyde	-	Ace Chemical Company, Camden Park, SA, Australia

Formic acid	-	Ajax Finechem, Taren Point, NSW, Australia
Gelatin	-	Ward Mckenzie, Alton, VIC, Australia
Heptofluorbutyric acid	-	Sigma-Aldrich, St Louis, MO, USA
Hydrochloric acid	-	Ajax Finechem, Taren Point, NSW, Australia
Hydrogen peroxide	-	Sigma-Aldrich, St Louis, MO, USA
Meta-hydroxydiphenyl	-	Sigma-Aldrich , St Louis, MO, USA
Methanol	-	Ajax Finechem, Taren Point, NSW, Australia
Microgranular cellulose	-	Sigma-Aldrich, St Louis, MO, USA
N-Ethylmaleimide	-	Sigma-Aldrich, St Louis, MO, USA
New fuchsin	-	Sigma-Aldrich, St Louis, MO, USA
O-phenylenediamine	-	DAKO, Glostrup, Denmark
Oxalic Acid	-	Ajax Finechem, Taren Point, NSW, Australia
P-dimethylaminobenzaldehyde	-	Sigma-Aldrich, St Louis, MO, USA
Phosphate buffered saline	-	Sigma-Aldrich, St Louis, MO, USA
Picric acid	-	Sigma-Aldrich, St Louis, MO, USA
Phenylmethanesulfonyl fluoride	-	Sigma-Aldrich, St Louis, MO, USA
Ponceau s	-	Sigma-Aldrich, St Louis, MO, USA
Potassium permanganate	-	Sigma-Aldrich, St Louis, MO, USA
Propan-2-ol	-	Ajax Finechem, Taren Point, NSW, Australia
Proteinase k	-	Roche, Basel, Switzerland.
Pyridinoline/deoxypyridinoline standard	-	IMVS Division of Clinical Biochemistry, Adelaide, SA, Australia
Resorcin	-	Sigma-Aldrich, St Louis, MO, USA
Sodium azide	-	Sigma-Aldrich, St Louis, MO, USA
Sodium acetate (anhydrous)	-	Ajax Finechem, Taren Point, NSW, Australia
Sodium chloride	-	Ajax Finechem, Taren Point, NSW, Australia

Sodium hydroxide	-	Ajax Finechem, Taren Point, NSW, Australia
Sodium tetraborate	-	Ajax Finechem, Taren Point, NSW, Australia
Sulphuric acid	-	Ajax Finechem, Taren Point, NSW, Australia
Tetrahydrofuran	-	Ajax Finechem, Taren Point, NSW, Australia
TRIS hydrochloride	-	Sigma-Aldrich, St Louis, MO, USA
Tri-sodium citrate hydrate	-	Sigma-Aldrich, St Louis, MO, USA
TWEEN 20	-	Bio-rad, Hercules, CA, USA
Trypsin inhibitor from soybean	-	Sigma-Aldrich, St Louis, MO, USA
Victoria blue 4R	-	Sigma-Aldrich, St Louis, MO, USA
Xylenes	-	Ajax Finechem, Taren Point, NSW, Australia

APPENDIX 6: PUBLICATIONS

Smith, L. & Fazzalari, N. (2006) Regional variations in the density and arrangement of elastic fibres in the anulus fibrosus of the human lumbar disc.
Journal of Anatomy, v.209 (3) pp. 359-367

NOTE: This publication is included on pages 257-265 in the print copy of the thesis held in the University of Adelaide Library.

It is also available online to authorised users at:

http://dx.doi.org/10.1111/j.1469-7580.2006.00610.x

Smith, L., Byers, S., Costi, J. & Fazzalari, N. (2007) Elastic fibers enhance the mechanical integrity of the human lumbar anulus fibrosus in the radial direction. *Annals of Biomedical Engineering, v.36 (2) pp. 214-223*

NOTE: This publication is included on pages 266-275 in the print copy of the thesis held in the University of Adelaide Library.

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http://dx.doi.org/10.1007/s10439-007-9421-8

BIBLIOGRAPHY

Acaroglu, E. R., Iatridis, J. C., Setton, L. A., Foster, R. J., Mow, V. C. and Weidenbaum, M. (1995). *Degeneration and aging affect the tensile behavior of human lumbar anulus fibrosus*. Spine. 20(15): 2690-2701.

Adams, M. A., Freeman, B. J., Morrison, H. P., Nelson, I. W. and Dolan, P. (2000). *Mechanical initiation of intervertebral disc degeneration*. Spine. 25(13): 1625-1636.

Adams, M. A., McNally, D. S. and Dolan, P. (1996). *'Stress' distributions inside intervertebral discs. The effects of age and degeneration*. Journal of Bone and Joint Surgery - British Volume. 78(6): 965-972.

Adams, P. and Muir, H. (1976). *Qualitative changes with age of proteoglycans of human lumbar discs*. Annals of the Rheumatic Diseases. 35(4): 289-296.

Akhtar, S. P., Davies, J. R. P. and Caterson, B. P. (2005a). *Ultrastructural localization and distribution of proteoglycan in normal and scoliotic lumbar disc.* Spine. 30(11): 1303-1309.

Akhtar, S. P., Davies, J. R. P. and Caterson, B. P. (2005b). *Ultrastructural immunolocalization of alpha-elastin and keratan sulfate proteoglycan in normal and scoliotic lumbar disc.* Spine. 30(15): 1762-1769.

Andersson, G. B. (1999). *Epidemiological features of chronic low-back pain*. Lancet. 354(9178): 581-585.

Armeniades, C. D., Lake, L. W. and Missirlis, Y. F. (1973). *Histologic origin of aortic tissue mechanics: the role of collagenous and elastic structures*. Applied Polymer Symposia. 22: 319-339.

Askeland, D. R. (1996). The Science and Engineering of Materials. 3rd ed. London: Chapman and Hall, 854 p.

Bader, D. L., Kempson, G. E., Barrett, A. J. and Webb, W. (1981). *The effects of leucocyte elastase on the mechanical properties of adult human articular cartilage in tension*. Biochimica et Biophysica Acta. 677(1): 103-108.

Bancroft, J. D., Cook, H. C. and Turner, D. R. (1994). Manual of histological techniques and their diagnostic application. 2nd ed. London: Churchill Livingstone, 457 p.

Basalo, I. M., Raj, D., Krishnan, R., Chen, F. H., Hung, C. T. and Ateshian, G. A. (2005). *Effects of enzymatic degradation on the frictional response of articular cartilage in stress relaxation*. Journal of Biomechanics. 38(6): 1343-1349.

Bass, E. C., Duncan, N. A., Hariharan, J. S., Dusick, J., Bueff, H. U. and Lotz, J. C. (1997). *Frozen storage affects the compressive creep behavior of the porcine intervertebral disc*. Spine. 22(24): 2867-2876.

Battie, M. C. and Videman, T. (2006). *Lumbar Disc Degeneration: Epidemiology and Genetics*. Journal of Bone and Joint Surgery - American Volume. 88(Suppl 2): 3-9.

Berlemann, U., Gries, N. C. and Moore, R. J. (1998). *The relationship between height, shape and histological changes in early degeneration of the lower lumbar discs*. European Spine Journal. 7(3): 212-217.

Best, B. A., Guilak, F., Setton, L. A., Zhu, W., Saed-Nejad, F., Ratcliffe, A., Weidenbaum, M. and Mow, V. C. (1994). *Compressive mechanical properties of the human anulus fibrosus and their relationship to biochemical composition*. Spine. 212-221.

Bialkower, B. (1974). Connective tissue biomechanics: correlations with biochemistry and morphology. Ph.D. Thesis, Monash University, 60 p.

Black, L. D., Brewer, K. K., Morris, S. M., Schreiber, B. M., Toselli, P., Nugent, M. A., Suki, B. and Stone, P. J. (2005). *Effects of elastase on the mechanical and failure properties of engineered elastin-rich matrices*. Journal of Applied Physiology. 98(4): 1434-1441.

Blumenkrantz, N. and Asboe-Hansen, G. (1973). *New method for quantitative determination of uronic acids*. Analytical Biochemistry. 54(2): 484-489.

Brown, R. E., Butler, J. P., Rogers, R. A. and Leith, D. E. (1994). *Mechanical connections between elastin and collagen*. Connective Tissue Research. 30(4): 295-308.

Bruehlmann, S. B., Hulme, P. A. and Duncan, N. A. (2004a). *In situ intercellular mechanics of the bovine outer annulus fibrosus subjected to biaxial strains*. Journal of Biomechanics. 37(2): 223-231.

Bruehlmann, S. B., Matyas, J. R. and Duncan, N. A. (2004b). *ISSLS prize winner: Collagen fibril sliding governs cell mechanics in the anulus fibrosus: an in situ confocal microscopy study of bovine discs*. Spine. 29(23): 2612-20.

Bruehlmann, S. B., Rattner, J. B., Matyas, J. R. and Duncan, N. A. (2002). *Regional variations in the cellular matrix of the annulus fibrosus of the intervertebral disc*. Journal of Anatomy. 201(2): 159-171.

Buckwalter, J. A. (1995). *Aging and degeneration of the human intervertebral disc*. Spine. 20(11): 1307-1314.

Buckwalter, J. A., Cooper, R. R. and Maynard, J. A. (1976). *Elastic fibers in human intervertebral discs*. Journal of Bone and Joint Surgery - American Volume. 58(1): 73-76.

Caldini, E. G., Caldini, N., De-Pasquale, V., Strocchi, R., Guizzardi, S., Ruggeri, A. and Montes, G. S. (1990). *Distribution of elastic system fibres in the rat tail tendon and its associated sheaths*. Acta Anatomica. 139(4): 341-348.

Carson, F. L. (1990). Histotechnology. A Self-Instructional Text. 1st ed. Chicago: ASCP Press, 294 p.

Cassidy, J. J., Hiltner, A. and Baer, E. (1989). *Hierarchical structure of the intervertebral disc*. Connective Tissue Research. 23(1): 75-88.

Chan, R. W., Gray, S. D. and Titze, I. R. (2001). *The importance of hyaluronic acid in vocal fold biomechanics*. Otolaryngology Head and Neck Surgery. 124(6): 607-614.

Chrzanowski, P., Keller, S., Cerreta, J., Mandl, I. and Turino, G. M. (1980). *Elastin content of normal and emphysematous lung parenchyma*. American Journal of Medicine. 69(3): 351-359.

Clavert, P., Kempf, J.-F., Bonnomet, F., Boutemy, P., Marcelin, L. and Kahn, J.-L. (2001). *Effects of freezing/thawing on the biomechanical properties of human tendons*. Surgical and Radiologic Anatomy. 23(4): 259-262.

Clement, C., Bravetti, P., Plenat, F., Foliguet, B., Haddioui, A. E., Gaudy, J. F. and Weissenbach, M. (2006). *Quantitative analysis of the elastic fibres in the human temporomandibular articular disc and its attachments*. International Journal of Oral and Maxillofacial Surgery. 35(12): 1120-1126.

Cloyd, J. M. and Elliott, D. M. (2007). *Elastin content correlates with human disc degeneration in the anulus fibrosus and nucleus pulposus*. Spine. 32(17): 1826-1831.

Costi, J. J., Hearn, T. C. and Fazzalari, N. L. (2002). *The effect of hydration on the stiffness of intervertebral discs in an ovine model*. Clinical Biomechanics. 17(6): 446-455.

Costi, J. J., Stokes, I. A., Gardner-Morse, M., Laible, J. P., Scoffone, H. M. and Iatridis, J. C. (2007). *Direct measurement of intervertebral disc maximum shear strain in six degrees of freedom: motions that place disc tissue at risk of injury*. Journal of Biomechanics. 40(11): 2457-2466.

Covault, H., Lubrano, T., Dietz, A. and Rubinstein, H. (1982). *Liquid-chromatographic measurement of elastin*. Clinical Chemistry. 28(7): 1465-1468.

Curtis, F. (1905). *Methode de coloration elective du tissue conjonctif*. Comptes Rendus des Seances de la Societe de Biologie et de ses Filiales. 58: 1038-1040.

de Carvalho, H. F. and Taboga, S. R. (1996). *Fluorescence and confocal laser scanning microscopy imaging of elastic fibers in hematoxylin-eosin stained sections*. Histochemistry and Cell Biology. 106(6): 587-592.

de Lurdes Pinto, M., Goncalves, C., Rodrigues, P. and Bairos, V. A. (2006). *Quantification by image analysis of the gallus gallus lung elastic fibres from embryonic to adult birds*. Anatomia, Histologia, Embryologia: Journal of Veterinary Medicine Series C. 35(5): 293-298.

Debelle, L. and Tamburro, A. M. (1999). *Elastin: molecular description and function*. The International Journal of Biochemistry and Cell Biology. 31(2): 261-272.

Dhillon, N., Bass, E. C. and Lotz, J. C. (2001). *Effect of frozen storage on the creep behavior of human intervertebral discs*. Spine. 26(8): 883-888.

Duance, V. C., Crean, J. K., Sims, T. J., Avery, N., Smith, S., Menage, J., Eisenstein, S. M. and Roberts, S. (1998). *Changes in collagen cross-linking in degenerative disc disease and scoliosis*. Spine. 1998 Dec 1;23(23):2545-51. 23(23): 2545-2551.

Ebara, S., Iatridis, J. C., Setton, L. A., Foster, R. J., Mow, V. C. and Weidenbaum, M. (1996). *Tensile properties of nondegenerate human lumbar anulus fibrosus*. Spine. 21(4): 452-461.

Edwards, W. T., Ordway, N. R., Zheng, Y., McCullen, G., Han, Z. and Yuan, H. A. (2001). *Peak stresses observed in the posterior lateral anulus*. Spine. 26(16): 1753-1759.

Elliott, D. M. and Setton, L. A. (2001). *Anisotropic and inhomogeneous tensile behavior of the human anulus fibrosus: experimental measurement and material model predictions*. Journal of Biomechanical Engineering. 123(3): 256-263.

Eyre, D. R. (1979). *Biochemistry of the intervertebral disc*. International Review of Connective Tissue Research. 8: 227-291.

Eyre, D. R., Dickson, I. R. and Van Ness, K. P. (1988). *Collagen cross-linking in human bone and articular cartilage. Age-related changes in the content of mature hydroxypyridinium residues.* Biochemical Journal. 252(2): 495-500.

Eyre, D. R., Koob, T. J. and Van Ness, K. P. (1984). *Quantitation of hydroxypyridinium crosslinks in collagen by high-performance liquid chromatography*. Analytical Biochemistry. 137(2): 380-388.

Eyre, D. R. and Muir, H. (1976). *Types I and II collagens in intervertebral disc. Interchanging radial distributions in annulus fibrosus.* Biochemical Journal. 157(1): 267-270.

Fagan, A., Moore, R., Vernon Roberts, B., Blumbergs, P. and Fraser, R. (2003). *ISSLS prize winner: The innervation of the intervertebral disc: a quantitative analysis*. Spine. 28(23): 2570-2576.

Feng, H., Danfelter, M., Stromqvist, B. and Heinegard, D. (2006). *Extracellular matrix in disc degeneration*. Journal of Bone and Joint Surgery - American Volume. 88(Suppl 2): 25-29.

Flynn, J., Rudert, M. J., Olson, E., Baratz, M. and Hanley, E. (1990). *The effects of freezing or freeze-drying on the biomechanical properties of the canine intervertebral disc*. Spine. 15(6): 567-570.

Franchi, M., Fini, M., Quaranta, M., De Pasquale, V., Raspanti, M., Giavaresi, G., Ottani, V. and Ruggeri, A. (2007). *Crimp morphology in relaxed and stretched rat Achilles tendon*. Journal of Anatomy. 210(1): 1-7.

Fujita, Y., Duncan, N. A. and Lotz, J. C. (1997). *Radial tensile properties of the lumbar annulus fibrosus are site and degeneration dependent*. Journal of Orthopaedic Research. 15(6): 814-819.

Fujita, Y., Wagner, D. R., Biviji, A. A., Duncan, N. A. and Lotz, J. C. (2000). *Anisotropic shear behavior of the annulus fibrosus: effect of harvest site and tissue prestrain*. Medical Engineering and Physics. 22(5): 349-357.

Fung, Y. C. (1981). Biomechanics: Mechanical Properties of Living Tissues. ed. New York: Springer-Verlag, 433 p.

Galante, J. O. (1967). *Tensile properties of the human lumbar annulus fibrosus*. Acta Orthopaedica Scandinavica. Supplementum. 100: 1-91.

Garfin, S. R., Gertzbein, S. and Eismont, F. (1996a). "Fractures of the lumbar spine: evaluation, classification and treatment." In: The Lumbar Spine, edited by S. W. Wiesel, J. N. Weinstein, H. N. Herkowitz, J. Dvorak and G. Bell. Philadelphia: Saunders, pp 822-873.

Garfin, S. R. and Herkowitz, H. N. (1996b). "Lumbar Disc Degeneration: Normal Aging or Disease Process." In: The Lumbar Spine, edited by S. W. Wiesel, J. N. Weinstein, H. N. Herkowitz, J. Dvorak and G. Bell. Philadelphia: Saunders, pp 458-473.

Gleizes, V., Viguier, E., FÃ©ron, J. M., Canivet, S. and Lavaste, F. (1998). *Effects of freezing on the biomechanics of the intervertebral disc*. Surgical and Radiologic Anatomy. 20(6): 403-407.

Goh, S., Tan, C., Price, R. I., Edmondston, S. J., Song, S., Davis, S. and Singer, K. P. (2000). *Influence of age and gender on thoracic vertebral body shape and disc degeneration: an MR investigation of 169 cases*. Journal of Anatomy. 197(4): 647-657.

Gosline, J. M. (1976). *The physical properties of elastic tissue*. International Review of Connective Tissue Research. 7: 211-249.

Green, T. P., Adams, M. A. and Dolan, P. (1993). *Tensile properties of the annulus fibrosus. II. Ultimate tensile strength and fatigue life*. European Spine Journal. 2(4): 209-214.

Gruber, H. E. and Hanley, E. N., Jr. (2002). *Ultrastructure of the human intervertebral disc during aging and degeneration: comparison of surgical and control specimens*. Spine. 27(8): 798-805.

Gu, W. Y., Mao, X. G., Foster, R. J., Weidenbaum, M., Mow, V. C. and Rawlins, B. A. (1999). *The anisotropic hydraulic permeability of human lumbar anulus fibrosus. Influence of age, degeneration, direction, and water content*. Spine. 24(23): 2449-2455.

Guerin, H. A. L. and Elliott, D. M. (2006). *Degeneration affects the fiber reorientation of human annulus fibrosus under tensile load*. Journal of Biomechanics. 39(8): 1410-1418.

Guerin, H. L. and Elliott, D. M. (2007). *Quantifying the contributions of structure to annulus fibrosus mechanical function using a nonlinear, anisotropic, hyperelastic model*. Journal of Orthopaedic Research. 25(4): 508-516.

Haefeli, M., Kalberer, F., Saegesser, D., Nerlich, A., Boos, N. and Paesold, G. (2006). *The course of macroscopic degeneration in the human lumbar intervertebral disc*. Spine. 31(14): 1522-1531.

Hansson, T. and Keller, T. S. (1996). "Osteoporosis of the Spine." In: The Lumbar Spine, edited by S. W. Wiesel, J. N. Weinstein, H. N. Herkowitz, J. Dvorak and G. Bell. Philadelphia: Saunders, pp 969-988.

Hickey, D. S. and Hukins, D. W. (1979). *Effect of methods of preservation on the arrangement of collagen fibrils in connective tissue matrices: an x-ray diffraction study of annulus fibrosus.* Connective Tissue Research. 6(4): 223-228.

Hickey, D. S. and Hukins, D. W. (1981). *Collagen fibril diameters and elastic fibres in the annulus fibrosus of human fetal intervertebral disc*. Journal of Anatomy. 133(3): 351-357.

Holm, S. (1996). "Nutrition and Pathophysiologic Aspects of the Lumbar Intervertebral Disc." In: The Lumbar Spine, edited by S. W. Wiesel, J. N. Weinstein, H. N. Herkowitz, J. Dvorak and G. Bell. Philadelphia: Saunders, pp 285-309.

Holzapfel, G. A., Schulze-Bauer, C. A. J., Feigl, G. and Regitnig, P. (2004). *Single lamellar mechanics of the human lumbar anulus fibrosus*. Biomechanics and Modeling in Mechanobiology. 3(3): 125-140.

Humphrey, J. D. (2003). *Continuum biomechanics of soft biological tissues*. Proceedings of the Royal Society of London A. 459(2029): 3-46.

Humphrey, J. D. and Canham, P. B. (2000). *Structure, mechanical properties, and mechanics of intracranial saccular aneurysms*. Journal of Elasticity. 61(1): 49-81.

Humzah, M. D. and Soames, R. W. (1988). *Human intervertebral disc: structure and function*. Anatomical Record. 220(4): 337-356.

Iatridis, J. C. and ap Gwynn, I. (2004). *Mechanisms for mechanical damage in the intervertebral disc annulus fibrosus*. Journal of Biomechanics. 37(8): 1165-1175.

Iatridis, J. C., Kumar, S., Foster, R. J., Weidenbaum, M. and Mow, V. C. (1999). *Shear mechanical properties of human lumbar annulus fibrosus*. Journal of Orthopaedic Research. 17(5): 732-737.

Iatridis, J. C., MacLean, J. J. and Ryan, D. A. (2005). *Mechanical damage to the intervertebral disc annulus fibrosus subjected to tensile loading*. Journal of Biomechanics. 38(3): 557-565.

Iatridis, J. C., Setton, L. A., Foster, R. J., Rawlins, B. A., Weidenbaum, M. and Mow, V. C. (1998). *Degeneration affects the anisotropic and nonlinear behaviors of human anulus fibrosus in compression*. Journal of Biomechanics. 31(6): 535-544.

Ishii, T. and Asuwa, N. (2000). *Collagen and elastin degradation by matrix metalloproteinases and tissue inhibitors of matrix metalloproteinase in aortic dissection*. Human Pathology. 31(6): 640-646.

Johnson, E. F., Berryman, H., Mitchell, R. and Wood, W. B. (1985). *Elastic fibres in the anulus fibrosus of the adult human lumbar intervertebral disc. A preliminary report*. Journal of Anatomy. 143: 57-63.

Johnson, E. F., Caldwell, R. W., Berryman, H. E., Miller, A. and Chetty, K. (1984). *Elastic fibers in the anulus fibrosus of the dog intervertebral disc*. Acta Anatomica. 118(4): 238-242.

Johnson, E. F., Chetty, K., Moore, I. M., Stewart, A. and Jones, W. (1982). *The distribution and arrangement of elastic fibres in the intervertebral disc of the adult human*. Journal of Anatomy. 135((2)): 301-309.

Kakivaya, S. R. and Hoeve, C. A. (1975). *The glass point of elastin*. Proceedings of the National Academy of Sciences of the United States of America. 72(9): 3505-3507.

Karlinsky, J. B., Snider, G. L., Franzblau, C., Stone, P. J. and Hoppin, F. G. (1976). *In vitro effects of elastase and collagenase on mechanical properties of hamster lungs*. American Review of Respiratory Disease. 113(6): 769-777.

Kasra, M., Parnianpour, M., Shirazi-Adl, A., Wang, J. L. and Grynpas, M. D. (2004). *Effect of strain rate on tensile properties of sheep disc anulus fibrosus*. Technology and Health Care. 12(4): 333-342.

Kempson, G. E., Muir, H., Pollard, C. and Tuke, M. (1973). *The tensile properties of the cartilage of human femoral condyles related to the content of collagen and glycosaminoglycans*. Biochimica et Biophysica Acta. 297(2): 456-472.

Kettler, A. and Wilke, H.-J. (2006). *Review of existing grading systems for cervical or lumbar disc and facet joint degeneration*. European Spine Journal. 15(6): 705-718.

Kielty, C. M. (2006). *Elastic fibres in health and disease*. Expert Reviews in Moelcular Medicine. 8(19): 1-23.

Kielty, C. M., Sherratt, M. J. and Shuttleworth, C. A. (2002). *Elastic fibres*. Journal of Cell Science. 115(14): 2817-2828.

Kielty, C. M., Wess, T. J., Haston, L., Ashworth, J. L., Sherratt, M. J. and Shuttleworth, C. A. (2002). *Fibrillin-rich microfibrils: elastic biopolymers of the extracellular matrix*. Journal of Muscle Research and Cell Motility. 23(5-6): 581-596.

Kielty, C. M., Woolley, D. E., Whittaker, S. P. and Shuttleworth, C. A. (1994). *Catabolism of intact fibrillin microfibrils by neutrophil elastase, chymotrypsin and trypsin*. FEBS Letters. 351(1): 85-89.

Kiernan, J. A. (1990). Histological and Histochemical Methods. Theory and Practice. 2nd Edition ed. Oxford: Pergamon Press, 433 p.

Klein, J. A. and Hukins, D. W. (1982a). *X-ray diffraction demonstrates reorientation of collagen fibres in the annulus fibrosus during compression of the intervertebral disc*. Biochimica et Biophysica Acta. 717(1): 61-64.

Klein, J. A. and Hukins, D. W. (1982b). *Collagen fibre orientation in the annulus fibrosus of intervertebral disc during bending and torsion measured by x-ray diffraction*. Biochimica et Biophysica Acta. 719(1): 98-101.

Konig, K., Schenke-Layland, K., Riemann, I. and Stock, U. A. (2005). *Multiphoton autofluorescence imaging of intratissue elastic fibers*. Biomaterials. 26(5): 495-500.

Kozaci, L. D., Guner, A., Oktay, G. and Guner, G. (2006). *Alterations in biochemical components of extracellular matrix in intervertebral disc herniation: role of MMP-2 and TIMP-2 in type II collagen loss.* Cell Biochemistry and Function. 24(5): 431-436.

Kurutz, M. (2006). *Age-sensitivity of time-related in vivo deformability of human lumbar motion segments and discs in pure centric tension*. Journal of Biomechanics. 39(1): 147-157.

Langrana, N. A., Edwards, W. T. and Sharma, M. (1996). "Biomechanical analysis of loads of the lumbar spine." In: The Lumbar Spine, edited by S. W. Wiesel, J. N. Weinstein, H. N. Herkowitz, J. Dvorak and G. Bell. Philadelphia: Saunders, pp 163-181.

Le Maitre, C. L., Freemont, A. J. and Hoyland, J. A. (2006). *Human disc degeneration is associated with increased MMP 7 expression*. Biotechnic and Histochemistry. 81(4-6): 125-131.

Lee, T. C., Midura, R. J., Hascall, V. C. and Vesely, I. (2001). *The effect of elastin damage on the mechanics of the aortic valve*. Journal of Biomechanics. 34(2): 203-210.

Lewin, T. (1964). *Osteoarthritis in lumbar synovial joints*. Acta Orthopaedica Scandinavica. Supplementum.(73): 1-112.

Lipson, S. J. (1996). "Biochemistry and Cell Biology of the Intervertebral Disc: Aging versus Degeneration." In: The Lumbar Spine, edited by S. W. Wiesel, J. N. Weinstein, H. N. Herkowitz, J. Dvorak and G. Bell. Philadelphia: Saunders, pp 310-316.

Marchand, F. and Ahmed, A. M. (1989). *Mechanical properties and failure mechanisms of the lumbar disc annulus*. 35th Annual Meeting, Orthopaedic Research Society. 14: 355.

Marchand, F. and Ahmed, A. M. (1990). *Investigation of the laminate structure of lumbar disc anulus fibrosus*. Spine. 15(5): 402-410.

Maroudas, A., Stockwell, R. A., Nachemson, A. and Urban, J. (1975). *Factors involved in the nutrition of the human lumbar intervertebral disc: cellularity and diffusion of glucose in vitro*. Journal of Anatomy. 120(1): 113-130.

McNally, D. S. and Adams, M. A. (1992). *Internal intervertebral disc mechanics as revealed by stress profilometry*. Spine. 17(1): 66-73.

Mecham, R. P., Broekelmann, T. J., Fliszar, C. J., Shapiro, S. D., Welgus, H. G. and Senior, R. M. (1997). *Elastin degradation by matrix metalloproteinases. Cleavage site specificity and mechanisms of elastolysis*. Journal of Biological Chemistry. 272(29): 18071-18076.

Mikawa, Y., Hamagami, H., Shikata, J. and Yamamuro, T. (1986). *Elastin in the human intervertebral disk. A histological and biochemical study comparing it with elastin in the human yellow ligament*. Archives of Orthopaedic and Traumatic Surgery. 105(6): 343-349.

Miller, P. J. (1971). *An elastin stain*. Medical Laboratory Technology. 28(2): 148-149.

Missirlis, Y. F. (1977). *Use of enzymolysis techniques in studying the mechanical properties of connective tissue components*. Journal of Bioengineering. 1(3): 215-222.

Mizuno, H., Roy, A. K., Zaporojan, V., Vacanti, C. A., Ueda, M. and Bonassar, L. J. (2006). *Biomechanical and biochemical characterization of composite tissue-engineered intervertebral discs*. Biomaterials. 27(3): 362-370.

Montes, G. S. (1996). *Structural biology of the fibres of the collagenous and elastic systems*. Cell Biology International. 20(1): 15-27.

Nelson, D. L. and Cox, M. M. (2005). Lehninger: Principles of Biochemistry. Fourth Edition ed. New York: Freeman, p.

Nerurkar, N. L., Elliott, D. M. and Mauck, R. L. (2007). *Mechanics of oriented electrospun nanofibrous scaffolds for annulus fibrosus tissue engineering*. Journal of Orthopaedic Research. 25(8): 1018-1028.

Oakes, B. W. and Bialkower, B. (1977). *Biomechanical and ultrastructural studies on the elastic wing tendon from the domestic fowl*. Journal of Anatomy. 123(2): 369-387.

Oegema, T. R. (1993). *Biochemistry of the intervertebral disc*. Clinics in Sports Medicine. 12(3): 419-439.

O'Halloran, D. M. and Pandit, A. S. (2007). *Tissue-engineering approach to regenerating the intervertebral disc*. Tissue Engineering. 13(8): 1927-1954.

Olczyk, K. (1994). *Age-related changes of elastin content in human intervertebral discs*. Folia Histochemica et Cytobiologica. 32(1): 41-44.

Osakabe, T., Seyama, Y. and Yamashita, S. (1995). *Comparison of ELISA and HPLC for the determination of desmosine or isodesmosine in aortic tissue elastin*. Journal of Clinical Laboratory Analysis. 9(5): 293-296.

Oxlund, H. and Andreassen, T. T. (1980). *The roles of hyaluronic acid, collagen and elastin in the mechanical properties of connective tissues*. Journal of Anatomy. 131(4): 611-620.

Oxlund, H., Manschot, J. and Viidik, A. (1988). *The role of elastin in the mechanical properties of skin*. Journal of Biomechanics. 21(3): 213-218.

Pearcy, M. J. and Tibrewal, S. B. (1984). *Lumbar intervertebral disc and ligament deformations measured in vivo*. Clinical Orthopaedics and Related Research. 191: 281-286.

Perie, D., Iatridis, J. C., Demers, C. N., Goswami, T., Beaudoin, G., Mwale, F. and Antoniou, J. (2006a). *Assessment of compressive modulus, hydraulic permeability and matrix content of trypsin-treated nucleus pulposus using quantitative MRI*. Journal of Biomechanics. 39(8): 1392-1400.

Perie, D. S., Maclean, J. J., Owen, J. P. and Iatridis, J. C. (2006b). *Correlating material properties with tissue composition in enzymatically digested bovine annulus fibrosus and nucleus pulposus tissue*. Annals of Biomedical Engineering. 34(5): 769-777.

Pezowicz, C. A., Robertson, P. A. and Broom, N. D. (2005). *Intralamellar relationships within the collagenous architecture of the annulus fibrosus imaged in its fully hydrated state*. Journal of Anatomy. 207(4): 299-312.

Pezowicz, C. A., Robertson, P. A. and Broom, N. D. (2006a). *The structural basis of interlamellar cohesion in the intervertebral disc wall*. Journal of Anatomy. 208(3): 317-330.

Pezowicz, C. A. P., Schechtman, H. P., Robertson, P. A. M. D. and Broom, N. D. P. (2006b). *Mechanisms of Anular Failure Resulting From Excessive Intradiscal Pressure: A Microstructural-Micromechanical Investigation*. Spine. 31(25): 2891-2903.

Pfirrmann, C. W., Metzdorf, A., Zanetti, M., Hodler, J. and Boos, N. (2001). *Magnetic resonance classification of lumbar intervertebral disc degeneration*. Spine. 26(17): 1873-1878.

Pokharna, H. K. and Phillips, F. M. (1998). *Collagen Crosslinks in Human Lumbar Intervertebral Disc Aging*. Spine. 23(15): 1645-1648.

Porter, K., Dooner, J. J. and Lopez, A. (1977). *Further study of elastic fibers in human attached gingiva*. Journal of Periodontology. 48(11): 711-713.

Postacchini, F., Bellocci, M. and Massobrio, M. (1984). *Morphologic changes in annulus fibrosus during aging. An ultrastructural study in rats*. Spine. 9(6): 596-603.

Raspanti, M., Manelli, A., Franchi, M. and Ruggeri, A. (2005). *The 3D structure of crimps in the rat Achilles tendon*. Matrix Biology. 24(7): 503-507.

Rieppo, J., Toyras, J., Nieminen, M. T., Kovanen, V., Hyttinen, M. M., Korhonen, R. K., Jurvelin, J. S. and Helminen, H. J. (2003). *Structure-function relationships in enzymatically modified articular cartilage*. Cells Tissues Organs. 175(3): 121-132.

Ritty, T. M., Ditsios, K. and Starcher, B. C. (2002). *Distribution of the elastic fiber and associated proteins in flexor tendon reflects function*. Anatomical Record. 268(4): 430-440.

Roberts, S., Menage, J. and Urban, J. P. (1989). *Biochemical and Structural Properties of the Cartilage End-Plate and its Relation to the Intervertebral Disc*. Spine. 14(2): 166-174.

Roberts, S. P., Caterson, B. P., Menage, J. H. N. D., Evans, E. H. B., Jaffray, D. C. F. and Eisenstein, S. M. F. (2000). *Matrix metalloproteinases and aggrecanase: their role in disorders of the human Intervertebral disc*. Spine. 25(23): 3005-3013.

Scarselli, V. (1961). *Increase in elastin content of the human aorta during growth*. Nature. 191(4789): 710-711.

Schiebler, M. L., Grenier, N., Fallon, M., Camerino, V., Zlatkin, M. and Kressel, H. Y. (1991). *Normal and degenerated intervertebral disk: in vivo and in vitro MR*

imaging with histopathologic correlation. American Journal of Roentgenology. 157(1): 93-97.

Schmidt, H., Kettler, A., Heuer, F., Simon, U., Claes, L. and Wilke, H. J. (2007). *Intradiscal pressure, shear strain, and fiber strain in the intervertebral disc under combined loading*. Spine. 32(7): 748-755.

Schmidt, M. B., Mow, V. C., Chun, L. E. and Eyre, D. R. (1990). *Effects of proteoglycan extraction on the tensile behavior of articular cartilage*. Journal of Orthopaedic Research. 8(3): 353-363.

Schmorl, G. and Junghanns, H. (1971). The Human Spine in Health and Disease. 2nd ed. New York: Grune and Stratton, 504 p.

Sedowofia, K. A. P., Tomlinson, I. W. M. M., Weiss, J. B. M. D., Hilton, R. C. M. M. and Jayson, M. I. V. M. F. (1982). *Collagenolytic enzyme systems in human intervertebral disc: their control, mechanism, and their possible role in the initiation of biomechanical failure*. Spine. 7(3): 213-222.

Shah, J. S., Hampson, W. G. and Jayson, M. I. (1978). *The distribution of surface strain in the cadaveric lumbar spine*. Journal of Bone and Joint Surgery - British Volume. 60(2): 246-251.

Sheehan, D. C. and Hrapchak, B. B. (1973). Theory and Practice of Histotechnology. ed. St Louis: The C.V. Mosby Company, 218 p.

Sherratt, M. J., Baldock, C., Haston, J. L., Holmes, D. F., Jones, C. J., Shuttleworth, C. A., Wess, T. J. and Kielty, C. M. (2003). *Fibrillin microfibrils are stiff reinforcing fibres in compliant tissues*. Journal of Molecular Biology. 332(1): 183-193.

Skaggs, D. L., Weidenbaum, M., Iatridis, J. C., Ratcliffe, A. and Mow, V. C. (1994). *Regional variation in tensile properties and biochemical composition of the human lumbar anulus fibrosus*. Spine. 19(12): 1310-1319.

Snedecor, G. W. and Cochran, W. G. (1967). Statistical Methods. 6th ed. Ames: Iowa State University Press, 593 p.

Starcher, B. (2001). *A Ninhydrin-Based Assay to Quantitate the Total Protein Content of Tissue Samples*. Analytical Biochemistry. 292(1): 125-129.

Stegemann, H. (1958). *Microdetermination of hydroxyproline with chloramine-T and p-dimethylaminobenzaldehyde*. Hoppe-Seyler's Zeitschrift für physiologische Chemie. 311: 41-45.

Stokes, I. A. (1987). *Surface strain on human intervertebral discs*. Journal of Orthopaedic Research. 5(3): 348-55.

Szirmai, J. A. (1970). "Structure of the intervertebral disc." In: Chemistry and Molecular Biology of the Intercellular Matrix, edited by E. A. Balazs. London: Academic Press, pp 1279–1308.

Thompson, J. P., Pearce, R. H., Schechter, M. T., Adams, M. E., Tsang, I. K. and Bishop, P. B. (1990). *Preliminary evaluation of a scheme for grading the gross morphology of the human intervertebral disc*. Spine. 15(5): 411-415.

Thompson, R. E., Pearcy, M. J., Downing, K. J., Manthey, B. A., Parkinson, I. H. and Fazzalari, N. L. (2000). *Disc lesions and the mechanics of the intervertebral joint complex*. Spine. 25(23): 3026-3035.

Torzilli, P. A., Arduino, J. M., Gregory, J. D. and Bansal, M. (1997). *Effect of proteoglycan removal on solute mobility in articular cartilage*. Journal of Biomechanics. 30(9): 895-902.

Toshima, M., Ohtani, Y. and Ohtani, O. (2004). *Three-dimensional architecture of elastin and collagen fiber networks in the human and rat lung*. Archives of Histology and Cytology. 67(1): 31-40.

Tsantrizos, A., Ito, K., Aebi, M. and Steffen, T. (2005). *Internal strains in healthy and degenerated lumbar intervertebral discs*. Spine. 30(19): 2129-2137.

Tsuji, H., Hirano, N., Ohshima, H., Ishihara, H., Terahata, N. and Motoe, T. (1993). *Structural variation of the anterior and posterior anulus fibrosus in the development of human lumbar intervertebral disc: A risk factor for intervertebral disc rupture*. Spine. 18(2): 204-210.

Urban, J. (1996). "Disc Biochemistry in Relation to Function." In: The Lumbar Spine, edited by S. W. Wiesel, J. N. Weinstein, H. N. Herkowitz, J. Dvorak and G. Bell. Philadelphia: Saunders, pp 271-280.

Vernon-Roberts, B. (1988). "Disc Pathology and Disease States." In: The Biology of the Intervertebral Disc, edited by P. Ghosh. CRC Press, pp 73-119.

Vernon-Roberts, B., Fazzalari, N. L. and Manthey, B. A. (1997). *Pathogenesis of tears of the anulus investigated by multiple-level transaxial analysis of the T12-L1 disc*. Spine. 22(22): 2641-2646.

Verplanke, A. J., Watanabe, T., Ishimori, K., Matsuki, H. and Kasuga, H. (1988). *Experience with an enzyme-linked immuno sorbent assay for the quantitation of urinary desmosine*. Tokai Journal of Experimental and Clinical Medicine. 13(3): 159-163.

Vesely, I. (1998). *The role of elastin in aortic valve mechanics*. Journal of Biomechanics. 31(2): 115-123.

Viidik, A., Danielson, C. C. and Oxlund, H. (1982). *On fundamental and phenomenological models, structure and mechanical properties of collagen, elastin and glycosaminoglycan complexes*. Biorheology. 19(3): 437-51.

Wagner, D. R. and Lotz, J. C. (2004). *Theoretical model and experimental results for the nonlinear elastic behavior of human annulus fibrosus*. Journal of Orthopaedic Research. 22(4): 901-909.

Wagner, D. R., Reiser, K. M. and Lotz, J. C. (2006). *Glycation increases human annulus fibrosus stiffness in both experimental measurements and theoretical predictions*. Journal of Biomechanics. 39(6): 1021-1029.

Wagner, M., Sether, L. A., Yu, S., Ho, P. S. P. and Haughton, V. M. (1988). *Age changes in the lumbar intervertebral disc studied with magnetic resonance and cryomicrotomy*. Clinical Anatomy. 1(2): 93-103.

Watanabe, T., Ishimori, K., Verplanke, A. J., Matsuki, H. and Kasuga, H. (1989). *An enzyme-linked immunosorbent assay (ELISA) for the quantitation of urinary desmosine*. Tokai Journal of Experimental and Clinical Medicine. 14(4): 347-356.

Watson, R. E. B., Griffiths, C. E. M., Craven, N. M., Shuttleworth, C. A. and Kielty, C. M. (1999). *Fibrillin-rich microfibrils are reduced in photoaged skin. Distribution at the dermal-epidermal junction*. Journal of Investigative Dermatology. 112(5): 782-787.

Wayne, J. S., Kraft, K. A., Shields, K. J., Yin, C., Owen, J. R. and Disler, D. G. (2003). *MR imaging of normal and matrix-depleted cartilage: correlation with biomechanical function and biochemical composition*. Radiology. 228(2): 493-499.

Weiler, Weiler, C., Nerlich, Nerlich, A., Zipperer, Zipperer, J., Bachmeier, Bachmeier, B., Boos and Boos, N. (2002). *Expression of major matrix metalloproteinases is associated with intervertebral disc degradation and resorption*. European Spine Journal. 11(4): 308-320.

Weinstein, J. (1996). "Spinal Tumors." In: The Lumbar Spine, edited by S. W. Wiesel, J. N. Weinstein, H. N. Herkowitz, J. Dvorak and G. Bell. Philadelphia: Saunders, pp 917-944.

Wilda, H. and Gough, J. E. (2006). *In vitro studies of annulus fibrosus disc cell attachment, differentiation and matrix production on PDLLA/45S5 Bioglass composite films*. Biomaterials. 27(30): 5220-5229.

Wiltse, L. L. and Rothman, S. L. G. (1996). "Lumbar and Lumbosacral Spondylolisthesis: Classification, Diagnosis and Natural History." In: The Lumbar Spine, edited by S. W. Wiesel, J. N. Weinstein, H. N. Herkowitz, J. Dvorak and G. Bell. Philadelphia: Saunders, pp 621-654.

Woo, S. L.-Y., Orlando, C. A., Camp, J. F. and Akeson, W. H. (1986). *Effects of postmortem storage by freezing on ligament tensile behavior*. Journal of Biomechanics. 19(5): 399-404.

Wu, H.-C. and Yao, R.-F. (1976). *Mechanical behavior of the human annulus fibrosus*. Journal of Biomechanics. 9(1): 1-2.

Yamagata, T., Saito, H., Habuchi, O. and Suzuki, S. (1968). *Purification and properties of bacterial chondroitinases and chondrosulfatases*. Journal of Biological Chemistry. 243(7): 1523-1535.

Yerramalli, C., Chou, A., Miller, G., Nicoll, S., Chin, K. and Elliott, D. (2007). *The effect of nucleus pulposus crosslinking and glycosaminoglycan degradation on disc mechanical function*. Biomechanics and Modeling in Mechanobiology. 6(1): 13-20.

Yoon, J. H. and Halper, J. (2005). *Tendon proteoglycans: biochemistry and function*. Journal of Musculoskeletal and Neuronal Interactions. 5(1): 22-34.

Yu, J. (2002). *Elastic tissues of the intervertebral disc*. Biochemical Society Transactions. 30(6): 848-852.

Yu, J., Fairbank, J. C., Roberts, S. and Urban, J. P. (2005). *The elastic fiber network of the anulus fibrosus of the normal and scoliotic human intervertebral disc*. Spine. 30(16): 1815-1820.

Yu, J., Tirlapur, U., Fairbank, J., Handford, P., Roberts, S., Winlove, C. P., Cui, Z. and Urban, J. P. (2007). *Microfibrils, elastin fibres and collagen fibres in the human intervertebral disc and bovine tail disc*. Journal of Anatomy. 210(4): 460-471.

Yu, J., Winlove, P. C., Roberts, S. and Urban, J. P. (2002). *Elastic fibre organization in the intervertebral discs of the bovine tail*. Journal of Anatomy. 201(6): 465-475.

Yuan, H., Kononov, S., Cavalcante, F. S., Lutchen, K. R., Ingenito, E. P. and Suki, B. (2000). *Effects of collagenase and elastase on the mechanical properties of lung tissue strips*. Journal of Applied Physiology. 89(1): 3-14.