Supplemental information for "Human L3L4 intervertebral disc mean 3D shape, modes of variation, and their relationship to degeneration"

John M. Peloquin, M.Eng.[1], Jonathon H. Yoder, M.S.[1], Nathan T. Jacobs, B.S.[1], Sung M. Moon, Ph.D.[1], Alexander C. Wright, Ph.D.[1], Edward J. Vresilovic, M.D.[2], and Dawn M. Elliott, Ph.D.[1,3]

[1] University of Pennsylvania, Philadelphia, PA, 19104, USA
[2] Penn State College of Medicine, Hershey, PA, 17033, USA
[3] University of Delaware, Newark, DE, 19716, USA

Algorithm for alignment of discs

Before the statistical shape model was constructed, every image was aligned to a common coordinate system (see section "Image segmentation" in Methods)—in this case, the anatomical coordinate system. This was done automatically, using the fact that the distribution of disc volume (i.e. the mass moment) is greatest in the left-right direction. Considering only the remaining degrees of freedom, the next greatest mass moment is along the posterior-anterior direction, and the remaining degree of freedom is the inferior-superior direction. Mathematically, this procedure is equivalent to principal component analysis of voxel coordinates, provided only voxels belonging to the disc are used. A minimal example is provided below to illustrate the algorithm. The language is Matlab.

```
% Align a disc segmentation to its major axes
%
% X := x coordinates for each voxel in the disc
% Y := y coordinates ...
% Z := z coordinates ...
% disc := the disc segmentation image,  {0, 1}
%
[U, E, V] = svd([X Y Z] * [X Y Z]');
U = U .* repmat(sign(diag(U))', 3, 1); % make unit vectors positive
XI = zeros(size(X));
YI = XI;
```

```
ZI = XI;
for ii = 1:size(X, 1)
    for jj = 1:size(X, 2)
        for kk = 1:size(X, 3)
            xyz = U * [X(ii, jj, kk); ...
                       Y(ii, jj, kk); ...
                       Z(ii, jj, kk)];
            XI(ii, jj, kk) = xyz(1);
            YI(ii, jj, kk) = xyz(2);
            ZI(ii, jj, kk) = xyz(3);
        end
    end
end
aligned = interp3(X, Y, Z, disc, XI, YI, ZI);
```

Shape model raw data

So that readers may construct their own synthetic disc shapes, we have provided the raw shape model data in `L3L4_shape_model.h5` as supplemental digital content. The file is in `HDF5` format (`http://www.hdfgroup.org/HDF5/`), an open format which works with all common scientific programming languages.

The file contains four datasets:

components
: The matrix of principal components. The ith row indexes voxel i, and the jth column indexes principal component j. In the methods section, this matrix is referred to as Φ. Here, each principal component has been normalized so that it is a unit vector.

image_dimensions
: The number of voxels in the x, y, and z dimensions. This information is required to reshape the principal component vectors into a 3D image matrix. The vectors should be reshaped using a Fortran-like order; the element index iterates over x fastest and z slowest.

meanshape
: The mean shape, in vector form (Φ_0 in the methods section).

standard_deviation
: A vector, the ith element of which is the observed standard deviation for principal component unit vector i.