A study of 2D landmark data accuracy in representing 3D mouse skull form.

C. Percival1, M. Chimera1, M. Kim1, J. Kenney-Hunt2, A. Conley3, C. O’Connor4, C. Roseman4, J. Cheverud5, J. Richtsmeier1. 1Department of Anthropology, Pennsylvania State University, 2Department of Biology, University of South Carolina, 3Division of Biological & Biomedical Sciences, Washington University, 4Department of Anthropology, University of Illinois, 5Department of Anatomy & Neurobiology, Washington University.

Introduction

Landmarks and linear distances between them are commonly used to quantify morphology. Even with the increasing availability of 3D landmarking technology, previously collected 2D landmarks will continue to be used and sometimes necessary when 3D technology is unavailable. Therefore, it is important to understand how accurately 2D landmarks reflect 3D objects and the precautions necessary when 2D and 3D landmark data are compared. To answer these questions, we acquired coordinates for 14 homologous landmarks (Fig. 1) on 3D mouse skulls from superior, inferior, and left lateral photographs (2D) and from surface reconstructions of micro-CT images (3D) of the skulls. Linear distances (LD) between landmark pairs were calculated from the 2D (LD2D) and 3D (LD3D) landmark coordinates. Differences between corresponding LDs (LD3D – LD2D) were calculated.

Hypotheses

1) Correlations between 2D Linear Distances (LD2D) and 3D Linear Distances (LD3D) should be high and their variances similar.
2) Generally, LD3D should be different from and greater than LD2D.
3) The difference in Linear Differences (LD3D – LD2D) should increase as the distance between landmark endpoints increases along the axis perpendicular to the 2D camera lens.

Correlation and Variance of 2D and 3D Measures

The correlations between LD3D and LD2D for most LDs were significant, but there were some for which this was not the case (Fig 2). This lack of correlation suggests that a significant portion of LD3D is not represented in the dimensions represented by LD2D or that the associated 2D and 3D landmarks are not equivalent.

Linear distance data are commonly used in analyses that compare variances (eg: modularity/integration, quantitative genetics), so it is important to know if the variance of a portion of LD3D is not represented in the dimensions represented by LD2D was significant, but there were some

Differences Between 2D and 3D Measurements

A one sample t-test was run for each LD across individuals to determine if LD3D – LD2D was significantly different from zero. LD3D – LD2D for most LDs was statistically different from zero (p<.05) (Table 1). Contrary to hypothesis 2, it was found that LD3D was often greater than LD2D. This may be the result of differences in scaling for the 2D and 3D measurements. For the CT surfaces, each voxel has known dimensions. But, in the photographs, each distance is scaled indirectly by a ruler that is also in the image. The placement of this ruler in relation to the landmarks may be influential.

Standardized Differences Between 2D and 3D Measurements

Differences between LD3D and LD2D were standardized by the 3D distance for each individual to determine if the measurement differences were significant in practice. This measure represents the proportion of the LD represented by LD3D – LD2D. A minimum, mean, and maximum of the average standardized differences were produced for short, medium, and long LDs. Shorter LDs tend to have greater standardized differences (Fig 4). The linear distances of the lateral view have particularly high standardized differences.

Bias by Relationship to Plane of Photography

We hypothesized that LDs connecting landmarks that were farther apart along the axis perpendicular to the 2D camera would tend to have greater LD3D – LD2D differences. For each view, we selected three landmarks approximately the same distance away from the camera to define a plane parallel to the camera (eg. midline points for the lateral view). The distance of each landmark to this plane was calculated from 3D data. For each LD, we calculated the “plane metric” as the absolute difference of the endpoints in this value. A linear regression of the average LD3D – LD2D difference and the plane metric was produced. A significant linear relationship exists between these variables for the lateral and superior views, but not for the inferior view (Fig 5). LD3D – LD2D will increase as the distance between landmark endpoints increases along the axis perpendicular to the 2D camera lens in the superior and lateral views. It may be that the landmarks of the inferior view are closer along this axis than landmarks in the other views.

Conclusions

For the superior and inferior views, measurements of linear distances taken from 2D photographs and 3D CT surfaces are usually correlated, with similar variance. Therefore, the differences between them are usually relatively small, especially for longer linear distances, even if raw 2D and 3D measurements are not equivalent. The lateral view, which has the greatest range of plane metrics, includes several LDs that are not significantly correlated and that have unacceptable standardized differences. The regression of differences and plane metrics indicate that LDs which occur along the plane not accounted for in 2D photographs usually have the greatest LD3D – LD2D differences. 2D views and landmarks should be selected to have little variation along this third plane, if 2D and 3D LDs are to be comparable. Also, homologous LDs in different 2D views may represent 3D measurements quite differently.

Table 1: Significant differences between 3D and 2D measured distances

<table>
<thead>
<tr>
<th>Number of LD</th>
<th>Inferior</th>
<th>Superior</th>
<th>Lateral</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Significantly Different (α=.05)</td>
<td>93</td>
<td>86</td>
<td>89</td>
</tr>
</tbody>
</table>

Figure 1: Landmark Definitions

Figure 2: Nonsignificant correlations between 2D and 3D measurements of linear distances.

Red: p-value >.05
Orange: .01 < p-value < .05
No Line: p-value < .01

Figure 3: Significant differences in variance between 2D and 3D measurements of linear distances.

Red: p-value >.05
Orange: .01 < p-value < .05
No Line: p-value < .01

Figure 4: Maximum, Mean, and Minimum of mean standardized differences between 2D and 3D.

Figure 5: Regressions of LD differences and plane metric differences by view.

Key

Superior: p-value .001
Lateral: p-value .001
Inferior: p-value .040

Funded by NSF-BCS0725227, NSF-BCS0523637, NIH-ROI-DE018500, NIH-RR015116.