Role of macro/micro structures of cranial bone in avoiding impact injury of woodpecker’s head

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Aims

It is a miracle of nature that woodpeckers (Picoides) drum tree trunks at a speed of 6–7 m/s with a deceleration of approximately 1000 g, but no head injuries [1-3]. Indeed, woodpecker drums about 10–20 bouts continuously, and every bout takes about 50 milliseconds. It drums about 12,000 times per day on average. In view of biomechanics it is not well understood why woodpeckers resist head impact injuries. Several research groups have studied the mechanism of resist impact injuries in woodpecker’s head [2–10]. Additionally, there is overwhelming evidence that bone mass and micro-architecture are sensitive to the mechanical stimuli, such that make its mechanical behavior both in microstructure and strength adapt to the environmental changes [11–15]. However, little attention has been paid to quantitative estimation of macro/micro morphology on woodpecker’s cranial bone.

Here, we investigated macro/micro morphological structure of woodpecker’s skull quantitatively. The purpose of this study was to investigate the role of macro/micro structures of cranial bone in avoiding impact injury of woodpecker’s head.

Method

Great Spotted woodpecker (Dendrocopos major) was selected for its wide distribution in the northern China. For comparison, Eurasian hoopoe (Upupa epops), a related bird with comparable size that pecks on insects inside the soil mainly, was also selected to be compared with woodpecker.

The two birds were scanned with micro-computed tomography (micro-CT, SkyScan1076, SkyScan, Belgium) respectively (Figure 1). The spatial resolution for specimen scanning was set to 18 μm. SkyScan NRecon package is used to reconstruct cross-section images from tomography projection images, mainly the cone-beam X-ray projections. Then, the quantitative analysis of micro-morphology of the cranial bone was done with the SkyScan CTAn package. The micro-structural parameters such as bone volume fraction (BV/TV), structure model index (SMI), trabecular thickness (Tb.Th), trabecular number (Tb.N), trabecular separation (Tb.Sp), bone mineral density (BMD), defined in Table 1, were calculated from micro-CT images. Three-dimensional micro-structural model of selected zone on the birds’ skull has been output to the CTVol package as shown in Figure (d,h). Data analysis was conducted by means of SPSS 16.0 software.
Figure 1: The Great Spotted woodpecker was scanned with micro-computed tomography (micro-CT, Skyscan1076, Skyscan, Belgium)

Table 1 Definitions of various micro-structural parameters analyzed in this study

<table>
<thead>
<tr>
<th>Parameters Abbrev</th>
<th>Definition (Units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone volume fraction</td>
<td>BV/TV</td>
</tr>
<tr>
<td>Structural model index</td>
<td>SMI</td>
</tr>
<tr>
<td>Trabecular thickness</td>
<td>Tb.Th</td>
</tr>
<tr>
<td>Trabecular number</td>
<td>Tb.N</td>
</tr>
<tr>
<td>Trabecular separation</td>
<td>Tb.Sp</td>
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<tr>
<td>Bone mineral density</td>
<td>BMD</td>
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Results
The micro-structural parameters were presented as means±standard deviation (SD) based on the micro-CT images in Table 2. The differences of these micro-structural parameters except Tb.Sp were found to be statistically significant (p=0.05) between Great Spotted woodpecker and Eurasian hoopoe. According to the SMI values and Figure 2 (d,h), more plate-like spongy bones were observed in woodpecker’s cranial bone, while more rod-like for Eurasian hoopoe.

Table 2 Micro-structural parameters of the occiput of Great Spotted Woodpecker and Eurasian Hoopoe

<table>
<thead>
<tr>
<th></th>
<th>Great Spotted Woodpecker (means ± SD)</th>
<th>Eurasian Hoopoe (means ± SD)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone volume fraction [ BV/TV (%)]</td>
<td>8.587±1.673</td>
<td>4.562±0.799*</td>
<td>0.023</td>
</tr>
<tr>
<td>Structural model index [SMI]</td>
<td>1.194±0.311</td>
<td>1.561±0.225*</td>
<td>0.035</td>
</tr>
<tr>
<td>Trabecular thickness [Tb.Th(µm)]</td>
<td>190±18</td>
<td>127±15*</td>
<td>0.041</td>
</tr>
<tr>
<td>Trabecular number [Tb.N(1/mm)]</td>
<td>0.506±0.123</td>
<td>0.411±0.086</td>
<td>0.067</td>
</tr>
<tr>
<td>Trabecular separation [Tb.Sp(µm)]</td>
<td>451±286</td>
<td>712±213*</td>
<td>0.017</td>
</tr>
<tr>
<td>Bone mineral density [BMD(g/cm³)]</td>
<td>0.218±0.015</td>
<td>0.101±0.011*</td>
<td>0.012</td>
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</table>

*p<0.05

As shown in Figure 2, silhouette of woodpecker skull on the coronal plane was smooth and close to ellipsoid compared to Eurasian hoopoe; The brain of woodpecker was tightly packed by relatively dense cranial bone comprising of cortical and spongy bone with less spongy bone compared to Eurasian hoopoe.
Figure 2: Micro-CT scan images of (a,b,c) Great Spotted Woodpecker and (e,f,g) Eurasian hoopoe; Micro-structure of selected zone on (d) woodpecker’s skull; (h) Hoopoe’s skull

**Conclusion**

Of the many features characterizing birds, the macro/micro structures of cranial bone is iconic especially for the woodpecker. More plate-like spongy bones were observed in woodpecker’s cranial bone, while more rod-like for Eurasian hoopoe. The micro morphology of cranial bone might play an important role for preventing woodpecker’s head injury.

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**References:**