# Supplementary Information

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Table S1: Peak stress results for scaled and unscaled models according to load case in all four species analysed. Safety factor calculations based on scaled model results.

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| --- | --- | --- | --- | --- | --- |
| **Species** | **Load case** | | **Scaled peak stress (MPa)** | **Unscaled peak stress (MPa)** | **Safety Factor** |
| *Megaloceros giganteus* | Pushing | Average | 1480 | 195 | 0.1 |
| Maximum | 2169 | 295 | 0.1 |
| Average (alternative) | 351 | 89 | 0.5 |
| Maximum (alternative) | 512 | 134 | 0.4 |
| Twisting | Average | 1723 | 146 | 0.1 |
| Maximum | 2541 | 242 | 0.1 |
| Average (alternative) | 147 | 114 | 1.2 |
| Maximum (alternative) | 216 | 180 | 0.8 |
| *Cervus elaphus* | Pushing | Average | 37 | 37 | 4.9 |
| Maximum | 55 | 55 | 3.3 |
| Average (alternative) | 146 | 146 | 1.2 |
| Maximum (alternative) | 215 | 215 | 0.8 |
| Twisting | Average | 41 | 41 | 4.4 |
| Maximum | 63 | 63 | 2.9 |
| Average (alternative) | 111 | 111 | 1.6 |
| Maximum (alternative) | 165 | 165 | 1.1 |
| *Dama dama* | Pushing | Average | 190 | 179 | 0.9 |
| Maximum | 281 | 232 | 0.6 |
| Twisting | Average | 118 | 92 | 1.5 |
| Maximum | 174 | 124 | 1.0 |
| *Alces alces* | Pushing | Average | 154 | 118 | 1.2 |
| Maximum | 224 | 185 | 0.8 |
| Twisting | Average | 64 | 86 | 2.8 |
| Maximum | 96 | 132 | 1.9 |



Figure S1: Left hand side images: cross sectional outlines of internal geometry from the *Megaloceros giganteus* model constructed in the present study. Lettering above outlines indicates equivalent position to Kitchener’s (1987) sections (right hand side of the image). Antler orientated in the same fashion as in Kitchener (1987): dorsal – top; ventral – bottom; anterior – left; posterior right. Right hand antler shown. Note that sections are only roughly equivalent in position to Kitchener as a different antler was scanned to that (destructively) sectioned by Kitchener. The tet4 Finite Elements are shown in the cross sections of the 3D model, coloured yellow (external elements representing cortical bone) and red (internal elements representing cancellous bone). Cross section i-k has a close up of the external (yellow) and internal (red) tet4 elements. Internal geometry was removed for analysis.



Figure S2: Right and left *Megaloceros giganteus* antler reconstructions showing internal (opaque red) and external (translucent brown) geometry. A) anterior view point, b) superior viewpoint, c) lateral (left) view point.



Figure S3: Forces were applied at locations where the antlers were likely to have contacted during combat. Pushing and twisting loads were analysed. An alternative force location was also tested for *Megaloceros* and *Cervus elaphus*.



Figure S4: Unscaled finite element results of a pushing load. a) *Megaloceros giganteus* average load case, b) *Megaloceros giganteus* maximum load case, c) *Cervus elaphus* average load case, d) *Cervus elaphus* maximum load case, e) *Dama dama* average load case, f) *Dama dama* maximum load case, g) *Alces alces* average load case, h) *Alces alces* maximum load case.



Figure S5: Unscaled finite element results of a twisting load. a) *Megaloceros giganteus* average load case, b) *Megaloceros giganteus* maximum load case, c) *Cervus elaphus* average load case, d) *Cervus elaphus* maximum load case, e) *Dama dama* average load case, f) *Dama dama* maximum load case, g) *Alces alces* average load case, h) *Alces alces* maximum load case.



Figure S6: Unscaled finite element analysis results for alternative force placement on *Megaloceros* and *Cervus* under both pushing and twisting loads. Forces in *Megaloceros* were placed more narrowly than in the original analysis, while in *Cervus*, forces were placed more distally on the antlers. Pushing loads: a) *Megaloceros giganteus* average load case, b) *Megaloceros giganteus* maximum load case, c) *Cervus elaphus* average load case, d) *Cervus elaphus* maximum load case. Twisting loads: e) *Megaloceros giganteus* average load case, f) *Megaloceros giganteus* maximum load case, g) *Cervus elaphus* average load case, h) *Cervus elaphus* maximum load case.