**SUPPORTING INFORMATION (SI)**

**“Comparative biomechanical modeling of metatherian and placental saber-tooths: A different kind of bite for an extreme pouched predator”**

**Text S1**

**Body mass**

The postcranial skeleton of *Smilodon fatalis* is extremely robust and far more massive than that of any extant cat [[1](#_ENREF_1)]. Recent body mass estimates based on postcranial data suggest that it was up to around 280 kg, comparable to the very largest living felid subspecies, the Siberian tiger [[2](#_ENREF_2)]. Thus, estimates based on cranial dimensions, deduced on the basis of regression data from living felids, almost certainly underestimate its body weight. The body mass estimate for the specimen of *S. fatalis* included in this study was generated using a previously applied approach [[3](#_ENREF_3)], i.e., geometric similitude was assumed between the specimen used in our study (FMNH P 12418) and the only specimen of *S. fatalis* for which a near complete skeleton is known (LACM PMS 1-1). That is, body mass for this near-complete specimen was calculated on the basis of proximal limb bone minimum circumference data and a 2/3rd power relationship was then assumed between the basal skull length and the body mass. The body mass estimate for FMNH P 12418 using this approach was ~ 259 kg. The body mass estimate of ~ 82 for *T. atrox* was obtained directly from the literature [[4](#_ENREF_4)]. This figure was a mean derived on the basis of three different quantitative approaches for this specimen [[5](#_ENREF_5)]. For *P. pardus* the body mass estimate of ~68 kg was obtained on the basis of skull-length/body-mass regression data from extant felids [[6](#_ENREF_6)].

**Figure S1.** Variations in canine bite reaction force (BF) and jaw muscle recruitment (MR) with changing gape angle in *Smilodon fatalis*, *Thylacosmilus atrox* and *Panthera pardus*. N = Newtons.

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| --- | --- | --- | --- | --- | --- |
| **Table S1**  Inputs for Finite Element Model (FEM) of *Smilodon fatalis* (FMNH P12418) | | | | | |
|  |  |  |  |  |  |
| Force /Muscle area (KPa) [[7](#_ENREF_7)] | 300 | Basal-condylar length (mm) | | 310.74 |  |
| Unilateral X-sectional area - Temporalis (mm^2) | 4481.28 | Cranial width at zygomatic arch (mm) | | 196.91 |  |
| Unilateral X-sectional area - Masseter (mm^2) | 3796.17 | Mandible length (mm) | | 203.98 |  |
|  |  | Mandible width at condyles (mm) | | 163.28 |  |
| Unilateral Temporalis muscle force (N) | 1344.38 | Total skull bone volume (mm^3) | | 1.55E+06 |  |
| Unilateral Masseteric muscle force(N) | 1138.85 | Surface area (mm^2) | | 3.26E+05 |  |
| Total muscle force (N) | 2483.24 | Number of tet4 brick elements in FE model | | 1643322 |  |
|  |  |  |  |  |  |
| Jaw muscle X-sectional areas (mm^2) | | % area occupied | Truss elements on each side of the skull | Force/beam (N) | Truss diameter (mm) |
| Temporalis superficialis | 8175.48 | 16.78 | 17 | 19.77 | 9.16 |
| Temporalis profundus | 18119.12 | 37.18 | 37 | 19.77 | 9.16 |
| Temporalis zygomaticus | 6950.105 | 14.26 | 14 | 19.77 | 9.16 |
| Masseter superficialis | 4988.14 | 10.24 | 10 | 39.27 | 6.46 |
| Masseter profundus | 5030.212 | 10.32 | 11 | 39.27 | 6.46 |
| Zygomatico-mandibularis | 3890.397 | 7.98 | 8 | 39.27 | 6.46 |
| Pterygoideus internus | 1061.358 | 2.18 | 2 | balancing beam | 7.00 |
| Pterygoideus externus | 515.6937 | 1.06 | 1 | balancing beam | 7.00 |
| Head-depressing muscle X-sectional areas (mm^2) | | Truss elements on either side of the skull | Force/beam (N) | Truss diameter (mm) |  |
| Sternomastoideus | 1926.791 | 40 | 25 | 5 |  |
| Obliquus capitis | 6688.694 | 30 | 25 | 5 |  |
| ‘Brick’ material properties [[8](#_ENREF_8),[9](#_ENREF_9)] | Young's modulus (GPa) | Density (T/mm^3) |  |  |  |
| Cranium and Mandible | 21.734 | 1.86E-09 |  |  |  |
| Dentine | 32.704 | 2.526E-09 |  |  |  |
| Enamel | 38.575 | 2.861E-09 |  |  |  |
|  |  |  |  |  |  |
| Beam material properties | Young's modulus (MPa) | Density (T/mm^3) | Diameter (mm) |  |  |
| Muscle trusses | 1.00E-01 | 1.01E-09 | table above |  |  |
| Occipital beams | Structural steel (Strand7 material library SS4100-1998) | | 5.00 |  |  |
| Cotyle beams | 0.50 |  |  |
| Condyle beams | 0.50 |  |  |
| Hinge beam | 5.00 |  |  |
| Origin and Insertion beams | 0.50 |  |  |
|  | | | |  |  |

**Table S2**

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| Inputs for Finite Element Model (FEM) of *Thylacosmilus atrox* (FMNH P14531 and FMNH P14344) | | | | | |
|  |  |  |  |  |  |
| Force /Muscle area (KPa) [[7](#_ENREF_7)] | 300 | Basal-condylar length (mm) | | 219.141 |  |
| Unilateral X-sectional area - Temporalis (mm^2) | 1717.47 | Cranial width at Zygomatic arch, mm | | 139.305 |  |
| Unilateral X-sectional area - Masseter (mm^2) | 1748.08 | Mandible length (anterior dentary to condyle), mm | | 192.851 |  |
|  |  | Mandible width at condyles, mm | | 132.842 |  |
| Unilateral Temporalis muscle force (N) | 515.24 | Total skull bone volume (mm^3) | | 1.14E+06 |  |
| Unilateral Masseteric muscle force(N) | 524.42 | Surface area (mm^2) | | 2.66E+05 |  |
| Total muscle force (N) | 1039.67 | Number of tet4 elements in FE model | | 1643322 |  |
|  |  |  |  |  |  |
| Jaw muscle cross-sectional areas (mm^2) | | % area occupied | Truss elements on either side of the skull | Force/beam (N) | Truss diameter (mm) |
| Temporalis superficialis | 4013.01 | 12.96 | 13 | 9.37 | 6.31 |
| Temporalis profundus | 9091.46 | 29.36 | 29 | 9.37 | 6.31 |
| Temporalis zygomaticus | 4055.56 | 13.10 | 13 | 9.37 | 6.31 |
| Masseter superficialis | 5424.58 | 17.52 | 17 | 12.79 | 7.37 |
| Masseter profundus | 4527.18 | 14.62 | 15 | 12.79 | 7.37 |
| Zygomatico-mandibularis | 2722.71 | 8.79 | 9 | 12.79 | 7.37 |
| Pterygoideus internus | 784.875 | 2.53 | 3 | balancing beam | 7.00 |
| Pterygoideus externus | 343.757 | 1.11 | 1 | balancing beam | 7.00 |
| Head-depressing cross-sectional areas (mm^2) | | Truss elements on either side of the skull | Force/beam (N) | Truss diameter (mm) |  |
| Sternomastoideus | 786.45 | 40 | 25 | 5 |  |
| Obliquus capitis | 2897.2 | 30 | 25 | 5 |  |
| Brick material properties [[8](#_ENREF_8),[9](#_ENREF_9)] | Young's modulus (GPa) | Density (T/mm^3) |  |  |  |
| Cranium and mandible | 21.734 | 1.86E-09 |  |  |  |
| Dentine | 32.704 | 2.526E-09 |  |  |  |
| Enamel | 38.575 | 2.861E-09 |  |  |  |
|  |  |  |  |  |  |
| Beam material properties | Young's modulus (MPa) | Density (T/mm^3) | Diameter (mm) |  |  |
| Muscle trusses | 1.00E-01 | 1.01E-09 | table above |  |  |
| Occipital beams | Structural steel (Strand7 material library SS4100-1998) | | 5.00 |  |  |
| Cotyle beams | 0.50 |  |  |
| Condyle beams | 0.50 |  |  |
| Hinge beam | 5.00 |  |  |
| Origin and Insertion beams | 0.50 |  |  |
|  | | | | | |

**Table S3**

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| --- | --- | --- | --- | --- | --- |
| Inputs for Finite Element Model (FEM) of *Panthera pardus* (MM149) | | | | | |
|
| Force /Muscle area (KPa) [[7](#_ENREF_7)] | 300 | Basal-condylar length (mm) | | 216.974 |  |
| Unilateral X-sectional area - Temporalis (mm^2) | 3002.29 | Cranial width at Zygomatic arch, mm | | 155.839 |  |
| Unilateral X-sectional area - Masseter (mm^2) | 1580.24 | Mandible length (anterior dentary to condyle), mm | | 159.145 |  |
|  |  | Mandible width at condyles, mm | | 137.753 |  |
| Unilateral Temporalis muscle force (N) | 900.69 | Total skull bone volume (mm^3) | | 5.43E+05 |  |
| Unilateral Masseteric muscle force (N) | 474.07 | Surface area (mm^2) | | 1.65E+05 |  |
| Total muscle force (N) | 1374.76 | Number of tet4 elements in FE model | | 1631130 |  |
| Jaw muscle cross-sectional areas (mm^2) | | % area occupied | Truss elements on either side of the skull | Force/beam (N) | Truss diameter (mm) |
| Temporalis superficialis | 12296.8 | 32.60702308 | 33 | 14.39 | 7.82 |
| Temporalis profundus | 6117.92 | 16.22268872 | 16 | 14.39 | 7.82 |
| Temporalis zygomaticus | 4920.82 | 13.04837774 | 13 | 14.39 | 7.82 |
| Masseter superficialis | 5589.89 | 14.82252881 | 15 | 23.53 | 9.99 |
| Masseter profundus | 4172.99 | 11.06538134 | 11 | 23.53 | 9.99 |
| Zygomatico-mandibularis | 3065.64 | 8.129057499 | 8 | 23.53 | 9.99 |
| Pterygoideus internus | 1087.61 | 2.883979928 | 3 | balancing beam | 7.00 |
| Pterygoideus externus | 460.451 | 1.220962884 | 1 | balancing beam | 7.00 |
| Head-depressing muscle cross-sectional areas (mm^2) | | Truss elements on either side of the skull | Force/beam (N) | Truss diameter (mm) |  |
| Sternomastoideus | 1273.25 | 40 | 25 | 5 |  |
| Obliquus capitis | 2672.62 | 30 | 25 | 5 |  |
| Brick material properties[[8](#_ENREF_8),[9](#_ENREF_9)] | Young's modulus (GPa) | Density (T/mm^3) |  |  |  |
| Cranium and mandible | 21.734 | 1.86E-09 |  |  |  |
| Dentine | 32.704 | 2.526E-09 |  |  |  |
| Enamel | 38.575 | 2.861E-09 |  |  |  |

|  |  |  |
| --- | --- | --- |
|  |  |  |
| Beam material properties | Young's modulus (MPa) | Density (T/mm^3) |
| Muscle trusses | 1.00E-01 | 1.01E-09 |
| Occipital beams | Structural steel (Strand7 material library SS4100-1998) | |
| Cotyle beams |
| Condyle beams |
| Hinge beam |
| Origin and Insertion beams |

**Table S4**

Mean landmark point Von Mises (VM) stresses for jaw-muscle-driven bite scaled to body mass. 345 homologous landmarks were placed on the surfaces of the three models using Landmark.exe following recently published methods [[10](#_ENREF_10)] and see Figure 1 of article. Mean landmark point Von Mises stresses were calculated by taking the mean VM stress of the three closest ‘brick’ elements to each of these landmarks [[10](#_ENREF_10)]. This allows direct comparison of results of FEAs of the three FEMs under different biting regimes. Ant Edge C = anterior edge of canine, Distal C = distal edge of canine, Lat Zygo Arch = lateral zygomatic arch, Lat Mand = lateral mandible. **M** = mean, **SD** = standard deviation, **Mx** = maximum.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **Species** | **Ant Edge C** | **Sagittal Line** | **Distal C** | **Lat Zygo Arch** | **Nuchal Crest** | **Lat Mand** | | *P. pardus* ***M*** | 1.063 | 0.157 | 0.186 | 1.803 | 0.254 | 4.527 | | *P. pardus* ***SD*** | 0.896 | 0.126 | 0.067 | 0.986 | 0.207 | 5.933 | | *P.pardus* ***Mx*** | 2.375 | 0.472 | 0.288 | 3.413 | 0.626 | 16.808 | | *S. fatalis* ***M*** | 1.535 | 0.347 | 0.475 | 4.307 | 0.286 | 12.356 | | *S. fatalis* ***SD*** | 1.141 | 0.157 | 0.187 | 1.822 | 0.373 | 7.727 | | *S. fatalis* ***Mx*** | 4.212 | 0.584 | 0.736 | 7.744 | 1.125 | 31.884 | | *T. atrox* ***M*** | 2.114 | 0.239 | 1.167 | 7.908 | 4.182 | 7.473 | | *T. atrox* ***SD*** | 2.042 | 0.124 | 1.217 | 3.818 | 2.705 | 8.147 | | *T. atrox* ***Mx*** | 7.502 | 0.410 | 4.133 | 13.634 | 9.020 | 21.125 | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| **Table S5**  Mean landmark point Von Mises stresses for neck-muscle-driven bite scaled to body mass. Ant Edge C = anterior edge of canine, Distal C = distal edge of canine, Lat Zygo Arch = lateral zygomatic arch, Lat Mand = lateral mandible. **M** = mean, **SD** = standard deviation, **Mx** = maximum.   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **Species** | **Ant Edge C** | **Sagittal Line** | **Distal C** | **Lat Zygo Arch** | **Nuchal Crest** | **Lat Mand** | | *P. pardus M* | 1.523 | 0.998 | 0.516 | 0.251 | 2.685 | 0.204 | | *P. pardus SD* | 1.218 | 1.609 | 0.292 | 0.146 | 2.475 | 0.234 | | *P. pardus Mx* | 3.325 | 5.365 | 1.156 | 0.488 | 8.392 | 0.731 | | *S. fatalis M* | 1.803 | 0.530 | 0.628 | 0.455 | 0.566 | 0.412 | | *S. fatalis SD* | 3.673 | 0.580 | 0.415 | 0.228 | 0.456 | 0.804 | | *S. fatalis Mx* | 12.208 | 1.701 | 1.414 | 1.024 | 1.387 | 2.600 | | *T. atrox M* | 0.325 | 0.110 | 0.197 | 0.265 | 0.432 | 0.189 | | *T. atrox SD* | 0.321 | 0.128 | 0.265 | 0.186 | 0.244 | 0.087 | | *T. atrox Mx* | 0.743 | 0.451 | 0.921 | 0.590 | 0.827 | 0.289 | |  |  |  |  |  |  |

1. Wroe S, Lowry MB, Anton M (2008) How to build a mammalian super-predator. Zoology 111: 196-203.

2. Christiansen P, Harris JM (2005) Body size of *Smilodon* (Mammalia: Felidae). Journal of Morphology 266: 369-384.

3. McHenry CR, Wroe S, Clausen PD, Moreno K, Cunningham E (2007) Supermodeled sabercat, predatory behavior in *Smilodon fatalis* revealed by high-resolution 3D computer simulation. Proceedings of the National Academy of Sciences (USA) 104: 16010-16015.

4. Argot C (2004) Functional-adaptive features and palaeobiologic implications of the postcranial skeleton of the late Miocene sabretooth borhyaenoid *Thylacosmilus atrox* (Metatheria). Alcheringa 28: 229-266.

5. Anyonge, W. (1993) Body mass in large extant and extinct carnivores. Journal of Zoology (London) 231: 339-350.

6. Van Valkenburgh B (1990) Skeletal and dental predictors of body mass in carnivores. In: Damuth J, MacFadden BJ, editors. Body size in mammalian paleobiology: Estimation and biological applications. Cambridge: Cambridge University Press. pp. 181-205.

7. Weijs WA, Hillen B (1985) Cross-sectional area and estimated intrinsic strength of the human jaw muscles. Acta Morphol Neerl Scand 23: 267-274.

8. Rho JY, Hobatho MC, Ashman RB (1995) Relations of mechanical properties to density and CT numbers in human bone. Medical Engineering and Physiology 17: 347-355.

9. Alexander RM (1980) Forces in animal joints. Engineering Medical 9: 93-97.

10. Parr W, Wroe S, Chamoli U, Richards HS, McCurry M, et al. (2012) Toward integration of geometric morphometrics and computational biomechanics: New methods for 3D virtual reconstruction and quantitative analysis of Finite Element Models. Journal of Theoretical Biology 301: 1-14.