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Skeletal trauma reflects hunting behaviour in extinct sabre-tooth cats and dire wolves

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Supplementary Materials and Methods

Minimum Number of Individuals (MNI) (Supplementary Table 1)

Skeletal part representation was determined by generating MNI counts for each species. The count of a particular skeletal element or portion of an element was tallied per side and the most numerous count was used. This produced a conservative estimate of individual numbers (White 1953).

Analysis of Injury Frequency by Element

To compare overall rates of trauma across the entire skeleton between the two species, it was essential to take into account possible taphonomic bias in the frequency of preserved individual elements. To deal with this potential bias, we calculated an expected estimate of the number of elements with trauma based on their relative frequency within the pit. For the expected values, we calculated the frequency at which all elements would be injured if injuries were evenly distributed, then multiplied the total number of each element in the sample by that frequency to get an expected count. We compared the observed versus the expected number to determine if the bone was injured at a higher rate than expected (Supplementary Table 2). We also analyzed trauma frequency on a per bone basis by calculating the proportion of all bones with trauma for each element (e.g. humerus, scapula). These data were used to compare trauma frequencies for each bone between the two species (Supplementary Table 3). Statistical significance of all differences in frequency was tested by a G test of independence using the analysis software R (www.R-project.org) and the package DescTools. The G test of independence is a proportions test similar to chi-squared test; a description of the test can be found in the Handbook of Biological Statistics (3rd ed.). Sparky House Publishing, Baltimore, Maryland. Pp 68-76.

GIS Analysis of Pathology Distribution

Polygonal and Point Representations of Trauma. Individual pathologies diagnosed as trauma were translated into vector polygons using hand-drawn representations of the skeletal pathologies (75%) or photographs (25%). All pathologies were mapped to the left side in lateral view for clarity, compressing all pathologies into a two-dimensional plane (Supplementary Figure 1). Original orientation (e.g. medial, cranial) was stored as an attribute of the polygon allowing orientations to be filtered if desired. Polygons were not used for spatial analysis but were converted into centroids. Thus each pathology was represented by a single centroid or point on the skeletal maps.

Polygonal Visualization of Pathologies Filtered by Type. All ArcMap data can be selected by attributes input by the user, in this case orientation, specimen number, and pathology type. We initially sorted pathologies into the broad categories of chronic, fracture/impact, wound, osteoarthritis, dental, developmental pathology, unknown etiology, and pathologies unique to the spinal column and not covered by the previous categories. The majority of injuries common to *Canis dirus* and *Smilodon fatalis* were chronic injuries (56.4-85.1%), followed by fractures (10-14%) and wounds (<5%).

For our analyses, we merged putative chronic, fracture, and osteoarthritic injuries into a single category, trauma. Chronic injuries consistent with hunting mode dominate the pathology collection in both species, and thus the density maps likely capture pathologies predominately resulting from prey capture. Wound distribution is broadly similar to that of traumatic injury (Supplementary Figure 2); thus, the injuries classified as traumatic may include some injuries caused by conflict with other carnivorans. However, we deduce that the preponderance of the traumatic pathologies was incurred by hunting because of their anatomical position and the hunting mode of each predator.

Average Nearest Neighbor Distance (ANND). ANND was used to test for significant clustering of traumatic+chronic centroids within a defined region. We defined 11 regions: cranium, each vertebral region, forelimb, manus, ribcage, pelvis+sacrum, hindlimb, pes. Pathology distribution is considered clustered if the average distance between centroids is less than expected for a hypothetical random distribution over the area being analyzed. *Smilodon* cranial and all caudal injuries were not analyzed due to insufficient pathology counts in those regions.

Supplementary Table 1. Element counts for CD (*Canis dirus*) and SF (*Smilodon fatalis*) used to determine MNI

ELEMENT	REGION	PATHOLOGICAL CD	NON-PATH CD	TOTAL CD	PATHOLOGICAL SF	NON-PATH SF	TOTAL SF	MNI
Skull	cranium	15	254	269	2	312	314	
dentary (rami)	cranium	70	547	617	5	225	230	
CV1	cervical	20	351	371	11	290	301	MNI CDI
CV2	cervical	13	310	323	7	300	307	
CV3	cervical	17	229	246	19	305	324	
CV4	cervical	6	247	253	10	287	297	
CV5	cervical	2	229	231	15	304	319	
CV6	cervical	8	234	242	14	275	289	
CV7	cervical	7	163	170	11	262	273	
TV1	thoracic	5	185	190	23	285	308	
TV2	thoracic	2	134	136	23	280	303	
TV3	thoracic	3	121	124	54	84	138	
TV4	thoracic	2	63	65	33	309	342	MNI SFA
TV5	thoracic	0	127	127	26	262	288	
TV6	thoracic	2	75	77	24	231	255	
TV7	thoracic	4	274	278	38	77	115	
TV8	thoracic	6	267	273	17	166	183	
TV9	thoracic	4	224	228	45	210	255	
TV10	thoracic	2	85	87	47	206	253	
TV11	thoracic	3	112	115	33	196	229	
TV12	thoracic	1	75	76	41	197	238	
TV13	thoracic	4	96	100	96	246	342	
L1	lumbar	9	162	171	87	41	128	
L2	lumbar	1	198	199	24	29	53	
L3	lumbar	3	241	244	29	50	79	
L4	lumbar	7	151	158	23	11	34	
L5	lumbar	5	281	286	30	28	58	
L6	lumbar	3	195	198	39	46	85	
L7	lumbar	16	198	214	31	43	74	
Sacra(all)	pelvosacral	12	122	134	35	709	744	
Innominate	pelvosacral	19	226	245	32	540	572	
AntCauV	caudal	6	117	123	15	234	249	
PosteriorCauV	caudal	2	NA	2	0	190	190	
Rib 1	ribcage	10	322	332	11	NA	11	
Rib 2	ribcage	2	264	266	8	NA	8	
Rib 3	ribcage	0	197	197	2	NA	2	
Rib 4	ribcage	2	340	342	6	NA	7	
Rib 5	ribcage	0	214	214	2	NA	2	
Rib 6	ribcage	2	170	172	8	NA	4	
Rib 7	ribcage	3	164	167	0	NA	0	
Rib 8	ribcage	3	167	170	10	NA	10	
Rib 9	ribcage	11	224	235	13	NA	14	
Rib 10	ribcage	5	247	252	25	NA	19	
Rib 11	ribcage	11	207	218	14	NA	12	

Rib 12	ribcage	4	300	304	24	NA	23	
Rib 13	ribcage	9	252	261	17	NA	15	
Rib, unidentified	ribcage	7	NA	7	4	NA	4	
Sternebra	ribcage	1	NA	1	NA	NA	6	
Manubrium	ribcage	2	NA	2	101	NA	7	
Lumbar rib	developmental pathology	0	NA	0	4	NA	NA	
Phalanges, unidentified	front and hind limb	32	1307	1339	18	14	32	
scapula	front limb	4	120	124	37	394	431	
Humerus	front limb	14	295	309	3	392	395	
Radius	front limb	30	402	432	10	505	515	
ulna	front limb	20	311	331	4	381	385	
scapholunar	front limb	2	187	189	0	357	357	
Pisiform	front limb	0	68	68	2	153	155	
Trapezium	front limb	0	32	32	0	43	43	
Trapezoid	front limb	0	0	0	0	30	30	
Magnum	front limb	0	0	0	0	94	94	
Unciform	front limb	0	27	27	0	157	157	
MC1	front limb	0	34	34	1	122	123	
MC2	front limb	3	511	514	7	397	404	
MC3	front limb	9	516	525	6	385	391	
MC4	front limb	13	550	563	3	370	373	
MC5	front limb	12	478	490	1	379	380	
1st carpal phalanx, digit I	front limb	NA	NA	NA	NA	134	134	
1st carpal phalanx, digit II	front limb	NA	NA	NA	NA	255	255	
1st carpal phalanx, digit III	front limb	NA	NA	NA	NA	259	259	
1st carpal phalanx, digit IV	front limb	NA	NA	NA	NA	199	199	
1st carpal phalanx, digit V	front limb	NA	NA	NA	NA	205	205	
2nd carpal phalanx, digit II	front limb	NA	NA	NA	NA	108	108	
2nd carpal phalanx, digit III	front limb	NA	NA	NA	NA	111	111	
2nd carpal phalanx, digit V	front limb	NA	NA	NA	NA	65	65	
femur	hind limb	43	209	252	14	667	681	
patella	hind limb	0	NA	NA	5	NA		
tibia	hind limb	13	441	454	10	142	152	
fibula	hind limb	4	121	125	11	450	461	
calcaneus	hind limb	22	552	574	11	442	453	
astragalus	hind limb	1	345	346	0	483	483	
cuboid	hind limb	2	91	93	2	183	185	
navicular	hind limb	1	62	63	6	NA	6	
ectocuneiform	hind limb	1	12	13	2	86	88	
cuneiform	hind limb	1	NA	1	0	1	1	
MT1	hind limb	0	NA	0	3	4	7	
MT2	hind limb	7	428	435	15	363	378	
MT3	hind limb	17	562	579	8	438	446	

MT4	hind limb	12	563	575	10	459	469	
MT5	hind limb	36	504	540	2	413	415	
1st tarsal phalanx	hind limb	NA	1119	1119	5	259	264	
1st tarsal phalanx, digit III	hind limb	NA	NA	NA	NA	59	59	
1st tarsal phalanx, digit IV	hind limb	NA	NA	NA	NA	87	87	
1st tarsal phalanx, digit V	hind limb	NA	NA	NA	NA	139	139	
2nd tarsal phalanx	hind limb	NA	221	221	NA	171	171	
2nd tarsal phalanx, digit III	hind limb	NA	NA	NA	NA	89	89	
2nd tarsal phalanx, digit IV	hind limb	NA	NA	NA	NA	190	190	
3rd tarsal phalanx	hind limb	NA	54	54	NA	NA	NA	
sesamoid	miscellaneous	0	5	5	0	242	242	
baculum	miscellaneous	1	77	78	0	NA	0	
TOTALS		651	19565		1384	18106		

Supplementary Table 2. Per Element Observed vs Expected Values. The expected number of elements with trauma was calculated using the null distribution (equal frequency of injury to all elements) and a G test of independence. A significant difference (p<.05) from the null distribution within each species is indicated with asterisks and bold type. CDI, *Canis dirus*. SFA, *Smilodon fatalis*.

Element	Observed CDI	Expected CDI	Total Non-path	Significance Within Species	Observed SFA	Expected SFA	Total Non-path	Significance Within Species
CV1	**17**	**14**	**351**	*	**2**	**17**	**290**	*
CV2	13	12	310		4	18	300	
CV3	**17**	**9**	**229**	*	8	18	305	
CV4	4	10	247		6	17	287	
CV5	2	9	229		5	18	304	
CV6	8	9	234		4	16	275	
CV7	6	6	163		5	16	262	
TV1	2	7	185		13	17	285	
TV2	1	5	134		11	17	280	
TV3	3	5	121		**9**	**5**	**84**	*
TV4	2	3	75		7	19	309	
TV5	0	5	127		8	16	262	
TV6	**1**	**3**	**75**	*	13	14	231	
TV7	**1**	**12**	**308**	*	**10**	**5**	**77**	*
TV8	3	10	267		4	10	166	
TV9	3	9	224		**15**	**13**	**210**	*
TV10	1	3	85		**23**	**13**	**206**	*
TV11	1	4	112		**23**	**13**	**196**	*
TV12	1	6	164		**31**	**13**	**197**	*
TV13	2	8	209		**71**	**19**	**246**	*
L1	6	6	162		**30**	**5**	**59**	*
L2	1	8	198		**16**	**3**	**42**	*
L3	**0**	**9**	**241**	*	**19**	**2**	**72**	*
L4	2	6	151		**13**	**2**	**16**	*
L5	3	11	281		**28**	**4**	**40**	*
L6	2	7	195		**26**	**5**	**66**	*
L7	8	8	198		**11**	**4**	**62**	*
sacrum	24	15	366		19	44	728	
Innominate	**16**	**11**	**266**	*	27	33	540	
Femur	**37**	**9**	**209**	*	11	25	414	
Tibia	**39**	**17**	**420**	*	**9**	**9**	**142**	*
Fibula	**29**	**16**	**394**	*	13	15	248	
Scapula	2	5	120		**27**	**16**	**247**	*
Humerus	**13**	**12**	**295**	*	**2**	**31**	**521**	*

Radius	**29**	**16**	**402**	*	10	15	240	
Ulna	**20**	**13**	**311**	*	3	5	89	
Skull	9	10	254		**1**	**18**	**312**	*

Supplementary Table 3. Sample size for each element and the percent that exhibited trauma for *Smilodon* (SFA) and *C. dirus* (CDI). Within species, the frequency of injury across skeletal elements departs significantly from uniform (SFA G= 941.75, p<2.2e-16; CD G=307.17, p<2.2 e-16). A proportions test was used to test for significant difference between the two species. Significance is indicated with asterisks and bold type.

Element	SFA % Trauma	CDI % Trauma	Significance Between Species
CV1	**0.7%**	**4.8%**	*
CV2	**1.3%**	**4.2%**	*
CV3	2.6%	7.4%	
CV4	**2.1%**	**1.6%**	*
CV5	1.6%	0.9%	
CV6	1.5%	3.4%	
CV7	1.9%	3.7%	
TV1	4.6%	1.1%	
TV2	3.9%	0.7%	
TV3	**10.7%**	**2.5%**	*
TV4	2.3%	2.7%	
TV5	3.1%	0.0%	
TV6	5.6%	1.3%	
TV7	**13.0%**	**0.3%**	*
TV8	2.4%	1.1%	
TV9	**7.1%**	**1.3%**	*
TV10	**11.2%**	**1.2%**	*
TV11	**11.7%**	**0.9%**	*
TV12	**15.7%**	**0.6%**	*
TV13	**28.9%**	**1.0%**	*
L1	**50.8%**	**3.7%**	*
L2	**38.1%**	**0.5%**	*
L3	**26.4%**	**0.0%**	*
L4	**81.3%**	**1.3%**	*
L5	**70.0%**	**1.1%**	*
L6	**39.4%**	**1.0%**	*
L7	**17.7%**	**4.0%**	*
Sacrum	2.6%	6.6%	
Innominate	5.0%	6.0%	
Femur	**2.7%**	**17.7%**	*
Tibia	**6.3%**	**9.3%**	*
Fibula	5.2%	7.4%	
Scapula	**10.9%**	**1.7%**	*
Humerus	**0.4%**	**4.4%**	*

Radius	4.2%	7.2%	
Ulna	3.4%	6.4%	
Skull	0.3%	3.5%	

82 **Supplementary Table 4. Percentage of traumatic pathology by region.**

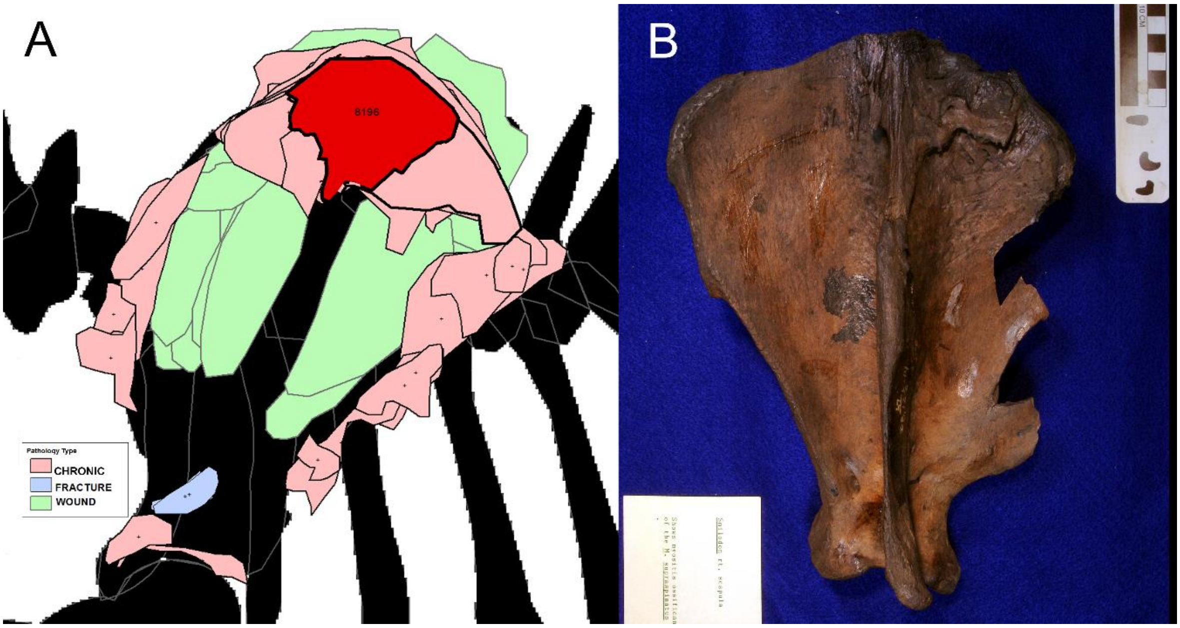
Skeletal Region	*S. fatalis*		*C. dirus*	
	Total # pathological elements	% of total	Total # pathological elements	% of total
Skull and dentary	**2**	**<1**	**10**	**1.8**
Vertebral Column				
Cervical	34	4.4	67	12.1
Thoracic	231	29.8	21	3.8
Lumbar	143	18.4	22	4.0
Sacral	8	<1	5	1
Caudal	15	2	4	<1
Total Vertebrae	**431**	**56**	**119**	**21.6**
Forelimb				
Scapula	27	3.5	2	<1
Humerus, radius, Ulna	15	2	62	11.2
Manus	37	4.8	61	11
Total Forelimb	**79**	**10.2**	**125**	**22.6**

Hindlimb				
Innominate	21	2.7	12	2.2
Femur, Patella, Tibia, Fibula	37	4.8	105	19.0
Pes	62	7.7	118	21.3
Total Hindlimb	**120**	**12.5**	**235**	**42.4**
Ribcage	131	16.9	63	11.4
Sternum	13	1.7	2	<1
	144	**19**	**65**	**11.7**
Total Skeleton	776	99.7	554	100

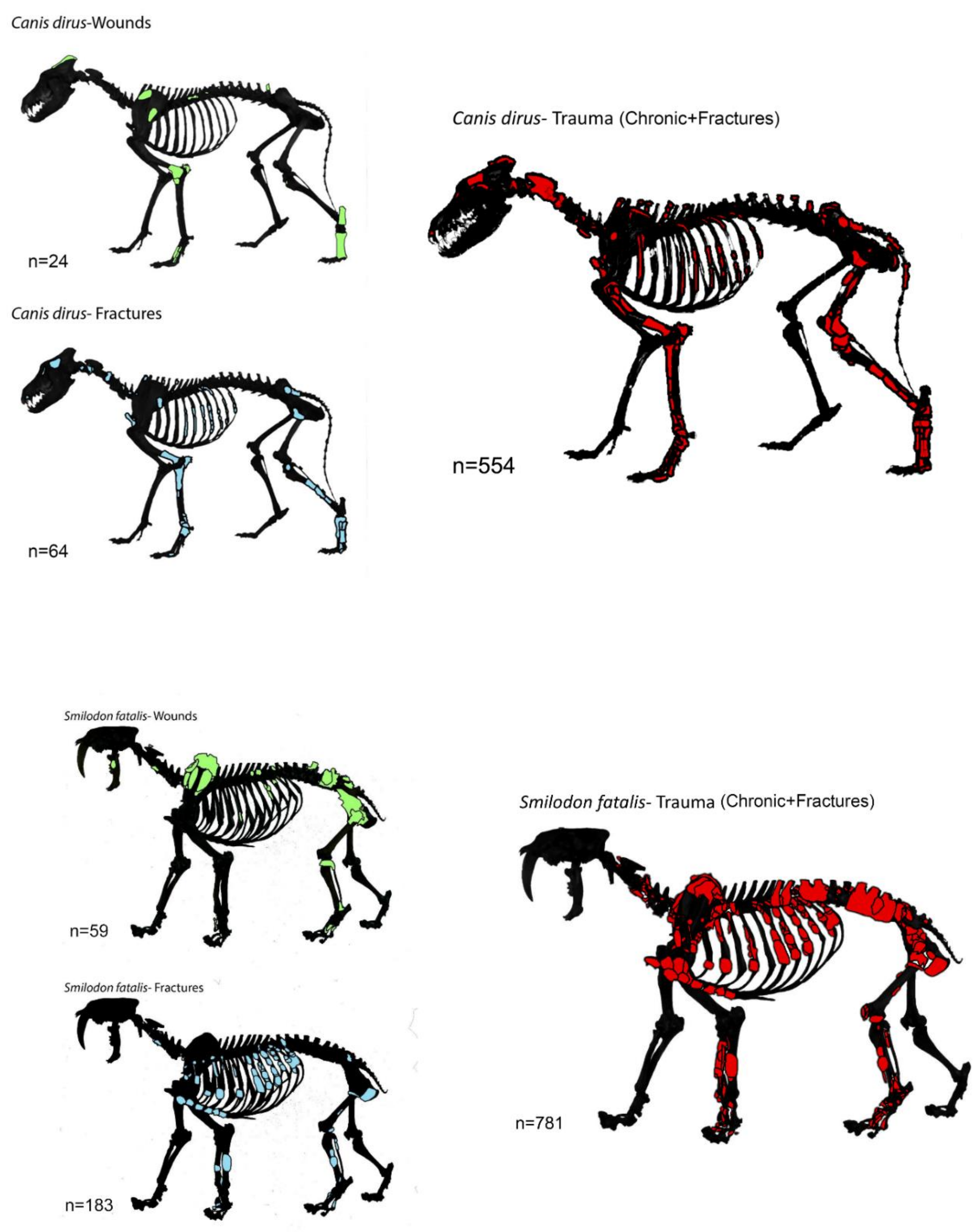
Supplementary Table 5. Average Nearest Neighbor Distance ratio and statistics. A distance ratio of 1 indicates a perfectly even distribution over the defined region, while values <1 indicate clustered points.

S. fatalis	Distance Ratio	Z	p	Count	Cluster
Hindlimb	0.37881	-4.12994	0.85967	37	most
Thoracic	0.531956	-14.1858	0	231	
Pes	0.612903	-5.7834	0	62	
Pelvic/Sacral	0.636175	-6.72249	0.85967	29	
Manus	0.663279	0.000173	0	34	
Forelimb	0.678185	-4.12994	0.000036	42	
Rib	0.866324	-3.07942	0.002074	144	least
Cervical	1.003	0.041049	0.967257	34	random
Lumbar	1.017	0.373243	0.708968	143	
Cranium	NA			2	

C. dirus	Distance Ratio	Z	p	Count	Cluster
Pes	0.34106	-13.577	0.000001	118	most
Manus	0.38934	-9.9126	0.000001	61	
Cervical	0.481942	-8.29199	0	67	
Cranium	0.599227	-3.25286	0.001	10	
Rib	0.6698	-5.1305	0.000001	65	
Forelimb	0.69931	-4.778	0.000002	64	
Thoracic	0.769105	-2.0718	0.0382	21	
Hindlimb	0.87817	-2.889	0.003859	105	
Pelvic/Sacral	0.9842	-0.131	0.8955	17	least
Lumbar	1.02	10.01	0	22	random



Supplementary Figure 1. Digitzation of skeletal pathologies. (A) All Pit 61/67 *Smilodon* scapular injuries colored by injury type. The centroids of traumatic injury are represented dots above the polygon layer. The dark red polygon, an example of calcified hematoma (myositis ossificans) labelled 8196, was digitized from photograph (B). All injuries were mapped onto the left side of the skeleton, thus the injured portion of 8196, a right scapula, appears mirrored. Missing portions of specimen 8196 were caused by post-mortem damage.



Supplementary Figure 2. Polygonal representations of pathologies filtered to show only healed fractures, infected wounds and traumatic injuries. Wound distribution is not included in traumatic pathology analysis. Wounds are not considered putative hunting injuries because they are likely to be caused by a variety of other behaviors, such as lacerations from environmental hazards and conflict with other carnivorans. SF base map adapted from Harris, John M., and George T. Jefferson, eds. *Rancho La Brea: treasures of the tar pits*. No. 31. Natural History Museum of Los Angeles County, 1985. CD base map adapted from Stock, Chester, and John Michael Harris. *Rancho La Brea: a record of Pleistocene life in California*. No. 37. Natural History Museum of Los, 1992.

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