A scapular facture in *Yangchuanosaurus hepingensis*(Dinosauria: Theropoda)
一例和平永川龙(恐龙:兽脚类)肩胛骨骨折

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Abstract: A scapula with healed wound of *Yangchuanosaurus* (*Sinraptor*) *hepingensis* ZDM 0024 from Zigong Dinosaur Museum of China is described. This is the first detailed description on pathology of theropoda in China. The discontinuous cortical bones, angular deformity and bony callus suggest an external force-caused wound healing in this bone, rather than a pathological fracture. *Mamenchisaurus hochuanensis* with tail club among the contemporary fauna is probably the candidate for the assault. This presents an attractive explanation to the bone fracture of *Yangchuanosaurus hepingensis*.
Key words: paleopathology; scapular fracture; *Yangchuanosaurus; Mamenchisaurus*; Upper Jurassic Shangshaximiao Formation

摘要:记述了自贡地区的和平永川龙(和平中华盗龙)(*Yangchuanosaurus*(*Sinraptor*)*hepingensis*)ZDM 0024 存在一断裂后愈合的肩胛骨,这是中国兽脚类病理学的首次详细记录。该肩胛骨有骨皮质不连续、成角畸形、骨痂形成,符合骨折后愈合的表现,而且从其病理特征看,病理性骨折的可能性很小,直接暴力所致骨折的可能性极大。还分析了同时期动物群中可能存在暴力施加者,拥有尾锤的合川马门溪龙(*Mamenchisaurus hochuanensis*)可能性最大,这为和平永川龙的骨折提供了一种有趣的解释。
关键词:古病理学;肩胛骨骨折;永川龙;马门溪龙;上侏罗统上沙溪庙组
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1 Introduction

Prior to the establishment of the term 'Dinosauria' in 1838[1], their paleopathology had existed, namely vertebral fusions in the theropod *Poikilopleuron*[1-2]. Hitherto, the descriptions of theropod pale-

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opathology included at least injury-related pathologies (fractures, bite marks, infections, stress fractures and abnormal teeth), congenital pathology (abnormal teeth and thoracic vertebral fusion) and arthritis (gout, but not osteoarthritis)[3]. Moreover, indirect evidence also indicates the morbidity of theropods, and limping theropod footprints and trackways suggest injuries or arthritis[4-7].

The paleopathological study of Chinese dinosaurs began relatively late. The only formal report is that the fibula abnormality of one *Psittacosaurus* (Ceratopsia) specimen may have been caused by the tubercle bacillus[8]. In addition, the small lumps and protuberance on cervical, dorsal and caudal vertebrae of *Mamenchisaurus hochuanensis* (Eusauropoda) CCG V 20401 are observed (Personal observation). Bone cancer may have occurred in the head of the femur of *Fusuisaurus zhaoi* (Titanosauriform) NHMG 6729 (Mo, Personal communication, Dec. 2009). Besides bone evidence, some strange footprints and trackways also suggest the morbidity of theropods, for instance, limping theropods suggest morbidity[9], and foot of track maker may constitute osteogenic tissue and bone marrow that were replaced by a hyperplasic mass of fibrous tissue[10]. However, all these morbid footprints are difficult to verify.

Currently fractured theropods have been reported at least in *Acrocanthosaurus*, *Albertosaurus*, *Allosaurus*, *Daspletosaurus*, *Deinonychus*, *Gorgosaurus*, *Megalosaurus*, *Monolophosaurus*, *Neovenator*, Ornithomimidae, Oviraptoridae, *Poekilopleuron*, *Sinraptor*, *Spinosaurus*, *Syntarsus* and *Tyrannosaurus*[3]. The morbidity was caused by external force fracture, pathological fracture and stress fracture.

The fracture described here was discovered in *Yangchuanosaurus*(*Sinraptor*) *hepingensis*[11] ZDM 0024. ZDM 0024 was discovered in the Upper Jurassic Shangshaximiao Formation of Heping Village, Zigong, Sichuan Province in 1985. In 1993, when Currie and Zhao were describing *Sinraptor*, *Y. Hepingenses* was attributed to *S. Hepingenses*[12], which is recognized widely[13-14]. In 2005, when Peng et al. were summarizing the Theropoda in Zigong, *Y. hepingensis* was judged to be valid, and *S. dongi* was attributed to *Y. dongi*[15]. Here, the conclusion of Peng et al. is adopted.

2 Institutional abbreviations

CCG=Chengdu College of Geology, Sichuan, China, NHMG=Natural History Museum of Guangxi, Nanning, China, UMNH=Utah Museum of Natural History, University of Utah, Utah, USA. USNM=United States National Museum, Washington, USA. ZDM=Zigong Dinosaur Museum, Sichuan, China.

3 Fossil Materials

A nearly complete skeleton is preserved in ZDM 0024, including the complete skull, 9 correlated cervical vertebrae, 14 dorsal vertebrae, 5 sacra and 35 caudal vertebrae, left and right scapulae, coracoids, ilia, pubes, ischia and left femur. Gao[11] observed that there were abnormalities caused by hyperosteogeny in the left scapula of ZDM 0024 but did not offer further analysis.

According to the new observation from the authors, the left scapula is slightly longer than the right scapula. A massive tuberosity region was observed on the mid-posterior end of the left scapular diaphysis, which contributes to the extra depth of the middle and distal end of the scapular diaphysis (see Fig. 1 and Table 1). The region protrudes laterally, and is 188mm in length and eminence shape. The region is raised from the scapular diaphysis by 26.08mm with a rough surface, and the medial region is 29.5mm in length, and flat and smooth in general, which extends to the distal end of the diaphysis.

4 Pathological analysis of fracture

Of the 50 theropod fractures that have been measured, thoracic rib accounts for 28%, fibula accounts for 10%; and scapula fracture accounts for 6%[16]. It appears that scapula fracture is rare. This is also true in human osteology. Fractures of the scapula are relatively rare injuries; they represent 3% to 5% of all fractures involving the shoulder girdle and 1% of frac-

tures overall[17-19].

In ZDM 0024, the left scapula is slightly longer than the right scapula. A distinct angular deformity occurs between the proximal end and the distal end of the eminence. The cortical bones are not consecutive, which indicates typical fractures. The surface of the eminence is rough. The arrangement of the trabeculae is disordered, which is very similar to the bony callus formed during fracture healing in human bones (see Fig. 2). Fracture healing is a continuous process, which can be artificially divided into three phases: inflammatory phase, bone reparative phase, and remodeling phase. The arrangement of primary bone callus is disordered. Induced by the stress, the bony callus over the stress axis is strengthened gradually, while the bony callus outside the axis is eliminated gradually. The arrangement of the trabeculae tends to be regular. In the long bones of lower limbs of humans, the complete resorption of primary bone callus is frequently detected, and eventually there is no observable difference from a healthy bone in X-rays. This fracture case discussed here happened in a weight bearing bone, where abundant muscles were attached, and the load directions were complicated. The absence of stable, consecutive and strong stress inducement interfered with the remodeling process after the formation of the primary bone callus, and eventually the massive, distinctly convex shaped bone callus was formed.

Table 1 Measurements of scapulae of ZDM 0024

Scapular	Ls	Lsd	Wco	Wds	Dpsd		Dmsd		Ddsd	
					Vl	Dl	Vl	Dl	Vl	Dl
					42.14	9.12	74.41	26.57	17.76	15.54
Right/mm	740	51	219	200	44.19	10.46	30.07	14.46	19.02	11.60

notes: Ls-length of scapular; Lsd-length of scapular diaphysis; Wco-width of coracoid; Wds-width of distal scapular; Dpsd-depth of proximal scapular diaphysis; Dmsd-depth of middle scapular diaphysis; Ddsd-depth of distal scapular diaphysis; Vl-ventral; Dl-dorsal.

Depending on various factors, bone fractures can be divided into external force fracture, pathological fracture and stress fracture. Systemic metabolic disturbance of calcium and phosphorus, infectious disease and osteoneoplasia are common in pathological fractures. The other bones of ZDM 0024 are well-preserved; no evident lesions (bone fracture in particular) are detected. Therefore it is unlikely that the fracture was caused by systemic metabolic factors or infection. Osteoneoplasia on scapula is very rare in human beings. To observe the specimen better, the diaphysis was broken up at the lateral bone callus close to the margin. In the cross-section, the margin of the bone callus is well-circumscribed with the lower cortical bones. No invasive growth or damage in bone substance was detected (see Fig. 3). Osteoneoplasia can basically be eliminated as the cause. Moreover, wound healing is impossible to occur in pathological fractures caused by tumors. In other words, this huge bone callus points away from pathological fracture was caused by tumor. In addition, this structure has no similarity with morbid scapula of *Allosaurus fragilis* USNM 4734. The latter scapula has a more triangular shape related to a large exostosis[20-21]. Therefore the fracture on this specimen was most likely cause by an external force.

5 Analysis of Behavior

For paleoanthropological paleopathology, bone fracture is not so significant. The significance lies in different fracture rates and types, which reveal important information about the lifestyle of prehistoric humans[22]. Some fractures are highly suggestive of highly violent conflicts between people[23]. This should also hold true for theropods.

Multi-layer muscles are attached on the scapula of vertebrate, working as a buffer against the violent forces that may cause trauma. These muscles can also protect the scapula against low-energy injuries. Only a direct high-energy impact can cause scapular fracture. In human osteology, the scapula is also fractured as the result of significant blunt trauma, as occurs in vehicle collisions[24]. ZDM 0024 had probably been in-

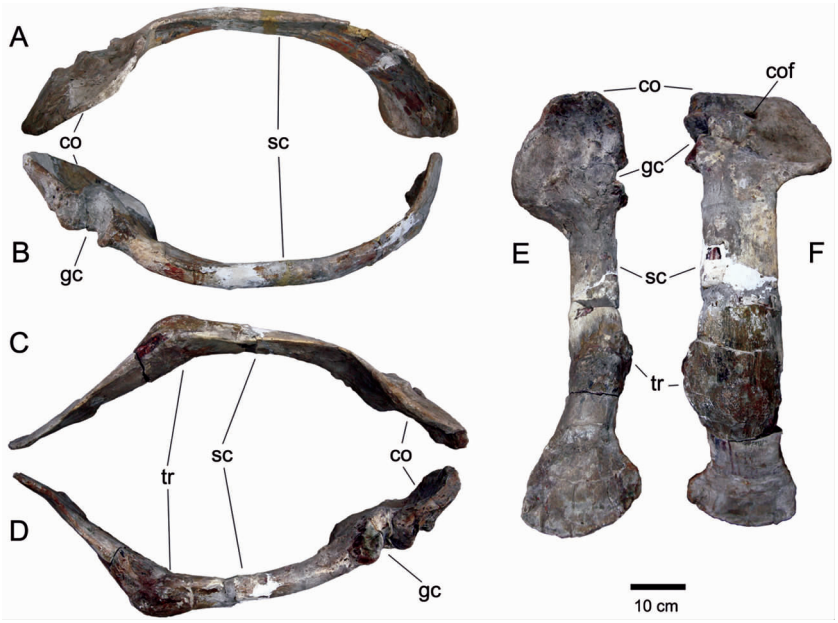

Fig. 1　Scapular of ZDM 0024

Right scapular A-dorsal, B-ventral views; Left scapular C-dorsal, D-ventral, E-medial, F-lateral views. Anatomical abbreviations: co-coracoid, cof-coracoid foramen, gc-glenoid cavity, sc-scapular, tr-tuberosity region

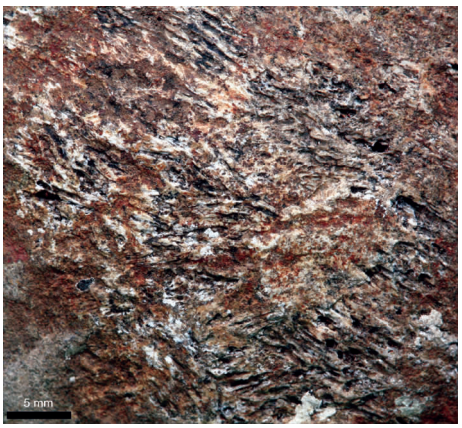

Fig. 2　Disordered trabeculae on bone callus

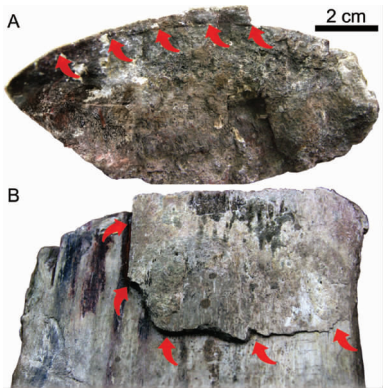

Fig. 3　Observation of the bone callus and cortical bones

Red arrows pointing to the border of fracture. A-transverse view showing bone callus; B-dorsal view showing cortical bones

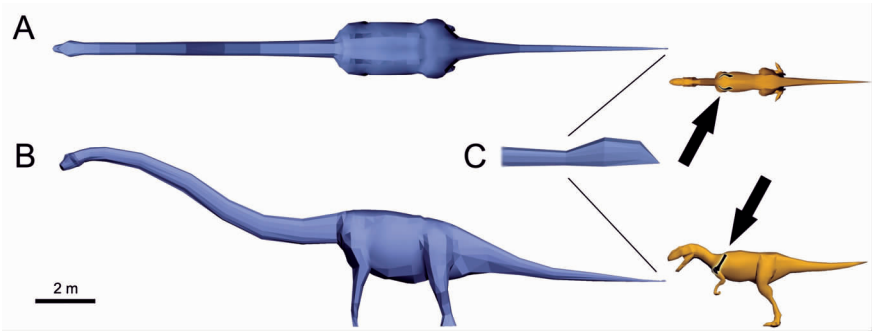

Fig. 4　3D reconstruction of *Yangchuanosaurus hepingensis* and *Mamenchisaurus hochuanensis*

The anterior body of *Y. hepingensis* is within the attacking area of the tailclub of *M. hochuanensis*. A-dorsal view, B-left lateral view, C-enlarged tail club(lateral view). Black arrow is the scapular of *Y. hepingenses*

jured in a severe violence collision. On the other hand, if the scapula had suffered from significant blunt trauma, severe chest trauma might be present[25], that would directly put the animal's life in danger. However, scapular fusion of ZDM 0024 indicates that the trauma is not so serious.

There have been 3 species of *Yangchuanosaurus* discovered: *Y. shangyouensis*[26], *Y. magus*[27] and *Y. hepingenses*[11], and they all came from the Shangshaximiao Formation. *Y. shangyouensis* is approximate 7m in length; *Y. magus* is roughly 9m in length; *Y. hepingenses* is about 8m in length. *S. dongi*[12] of *Sinraptor* with the length of about 7m was discovered in the Shishugou Formation in Xinjiang. The 3D reconstruction of *Y. hepingenses* was created by using ZDM 0024 as the basis, combined with elements from *Yangchuanosaurus* and *Sinraptor*, and consulting the reconstruction of Carnosauria[28].

The contemporary sauropods with *Y. hepingensis* from the Shangshaximiao Formation include *Mamenchisaurus hochuanensis*[29], *Mamenchisaurus youngi*[30], *Daanosaurus zhangi*[31], *Omeisaurus fuxiensis*[27] and *Zigongosaurus fuxiensis*[32]. Of which *D. zhangi* is the juvenile individual. The validity of *O. fuxiensis* and *Z. Fuxiensis* are still in doubt[15]. Only *Mamenchisaurus* is available as a comparison for *Y. hepingensis*.

There are many species of *Mamenchisaurus*. *M. constructus* is approximate 13m in length, which is the shortest *Mamenchisaurus*. *M. sinocanadorum* is approximate 26m in length, which is the longest *Mamenchisaurus*. Taking other species into consideration, the average length of *Mamenchisaurus* is 19m[29-30]. The 3D reconstruction methods were established by taking Paul and Schwarz et al. as the reference for integrated morphology[28, 33].

FEA (Finite Element Analysis) was adopted by Xing et al. to conduct the analysis towards the tail club of *M. hochuanensis*[34-35]. They believe that left-right swing of the tail club is more efficient than up-down swing. The best impact area of the tail club is the middle neural spine area, where the maximum loading impact is approximate 450N. Another piece of evidence is a pathological caudal vertebra on an *Allosaurus fragilis* (UMNH 10781) with a partially healed wound which is consistent with a puncture by a *Stegosaurus* tail-spike. Under the given conditions, the impact that the *Stegosaurus* spike exerted on the target is 360-510N. The minimum calculated impact force of 360N is more than adequate to damage the bone and tissue struck by the *Stegosaurus* spike[36]. In comparison, it is obvious that the tail club of *M. hochuanensis* with the total swinging force of the entire tail would exert a considerable impact power (the performance of the tail club will describe in another paper).

It is obvious from Fig. 4 that, the anterior body of *Yangochuanosaurus hepingenses* is included within the impact area of the tail club of *Mamenchisaurus hochuanensis*. The particular bony callus of scapula in ZDM 0024 should be caused by a severe impact perpendicular to the cortical bone. This is consistent with the impact position of the tail club of *M. hochuanensis*. Even though this does not prove that the fracture of ZDM 0024 was caused by the tail club of *M. hochuanensis*, it offers an interesting and possible explanation.

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