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ON THE QUADRATE OF *SINRAPTOR DONGI* (THEROPODA: ALLOSAUROIDEA) FROM THE LATE JURASSIC OF CHINA

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Abstract: When *Sinraptor dongi* was described in 1993, the quadrate was illustrated but not described. The omission of the description of this bone was unfortunate in that there is a lot of information about the quadrate that would be useful in the phylogenetic analysis of this important animal.

Keywords: *Sinraptor dongi*, Theropoda, Allosauroidea, quadrate

Rezumat: In descrierea inițială a speciei *Sinraptor dongi*, în 1993, osul cvadrat a fost figurat, dar nu şi descris. Această omisiune este cu atât mai nefericită, cu cât numeroase caractere ale elementului scheletic respectiv sunt utile în analiza filogenetică a acestui important taxon.

Cuvinte cheie: *Sinraptor dongi*, Theropoda, Allosauroidea, osul cvadrat

INTRODUCTION

One of the most important specimens collected by the Canada-China Dinosaur Project (Currie 1991, Dong 1993) was most of the skull and skeleton of a new allosauroid theropod that was given the name *Sinraptor dongi* by Currie & Zhao (1993). The thorough and well-illustrated description of this animal has made it one of the standard theropods for comparison with other animals (a search on the internet using “Google Scholar” listed more than 70 papers that referred to *Sinraptor*).

SYSTEMATIC PALAEONTOLOGY

Dinosauria Owen, 1842
Theropoda Marsh, 1881
Carnosauria von Huene, 1920
Sinraptoridae Currie and Zhao, 1993
Sinraptor dongi Currie and Zhao, 1993

Material: IVPP 10600, a nearly complete skull and partial skeleton described by Currie & Zhao (1993), includes the right quadrate that is described here for the first time.
Locality and age: Jiangjunmiao, Xinjiang, China. Upper Jurassic Shishugou Formation.
Institutional Abbreviations: BYU, Brigham Young University, Provo; FMNH, Field Museum of Natural History, Chicago, USA; IVPP, Institute of Vertebrate Paleontology and Paleoanthropology, Beijing, China; LDM, Lufeng Dinosaur Museum, Lufeng, China; MACN-CH, Museo Argentino de Ciencias Naturales "Bernardino Rivadavia", Buenos Aires, Argentina; MCF, Museo Carmen Funes, Plaza Huincul, Argentina; MOR, Museum of the Rockies, Bozeman, USA; NCSM, North Carolina State Museum of Natural Sciences, Raleigh, USA; UCMP, University of California Museum of Paleontology, Berkeley, USA; USNM, United States Museum of Natural History, Smithsonian Institute, Washington, USA.

DESCRIPTION

The right quadrate of IVPP 10600 is complete and undistorted (Fig. 1), except that the lateral wall of the quadratic foramen has been crushed somewhat into the foramen. The quadrate is a relatively tall (246 mm) bone in comparison with skull length (Fig. 2). The mandibular condyles are only 7 cm across, however, and this slenderness makes it look longer than it really is (Fig. 1B). The quadratic foramen that is relatively small (2.5 cm in height). The quadratojugal suture on the quadrate extends to the posterior margin of the quadratic foramen. The quadratic foramen has a posteromedial-anterolateral orientation through the bone, and was not visible in posterior view (Fig. 1D). There is an anteroventral flange of the quadrate that contacts the medial surface of the quadratojugal. There is no fusion between quadrate and quadratojugal, although the ridged sutural contact between the two bones must have been firm and immovable. The

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pterygoid flange is taller (17 cm) than it is anteroposteriorly long (8 cm). The ventral margin of the flange curls medially as the shelf beneath the posteroventral margin of the quadrate process of the pterygoid. The overlapping squamose suture for the pterygoid extends conspicuously more than halfway up the anteromedial surface of the pterygoid flange (Figs. 1C, 1D). The quadrate cotyle is a rounded triangle in dorsal aspect. The quadrate of *Sinraptor* is not pneumatic, although there is a deep depression, presumably pneumatic in origin, on the posterior surface of the quadrate posteromedial to the quadratic foramen. The lateral and medial mandibular condyles are separated by a shallow, oblique anteromedial-posterolateral groove. The lateral condyle is almost double the size of the medial condyle.

DISCUSSION

The quadrate of *Sinraptor dongi* is relatively primitive in that it is relatively tall as in *Ceratosaurus*, abelisaurids, *Allosaurus* and carcharodontosaurids (Fig. 2). Compared with other large theropods, it is relatively tall (24.6 mm; Fig. 2; Table 1) with a relatively narrow mandibular articulation as in abelisaurids (Bonaparte 1990) and carcharodontosaurids (Coria & Currie 2006). The quadrates of *Allosaurus* (Madsen 1976) and *Ceratosaurus* (Madsen & Welles 2000) look relatively shorter and stouter, but that is an illusion created by their relatively wider mandibular condyles. In *Allosaurus* Madsen (1976) reported that the width of the condyles is approximately half of the height of the quadrate in mature specimens of *Allosaurus*, whereas in *Sinraptor* it is less than a third the height. Tyrannosaurids (and other coelurosaurs) have relatively shorter quadrates in comparison with skull height (Fig. 2), and their relative breadth accentuates the impression of shortness.

The quadrate is essentially a curved vertical column with a quadrate cotyle on top for articulation with the squamosal, and the mandibular condyles ventrally for the jaw articulation. The broad, wing-like pterygoid ala extends anteromedially from the column. In some theropods – such as *Dilophosaurus* (Welles 1984) and *Sinosaurus* (Currie *et al.* in preparation) – there is a second wing-like process (the "dorsal wing" of Welles 1984) that extends anterolaterally from the columnar main body of the quadrate.

Whereas *Coelophysis* (Colbert 1989), *Ceratosaurus* (Madsen & Welles 2000, Rauhut 2003, but see Gilmore 1920 for an alternative interpretation), abelisaurids (Bonaparte 1990, Bonaparte *et al*. 1990, Rauhut 2003) and

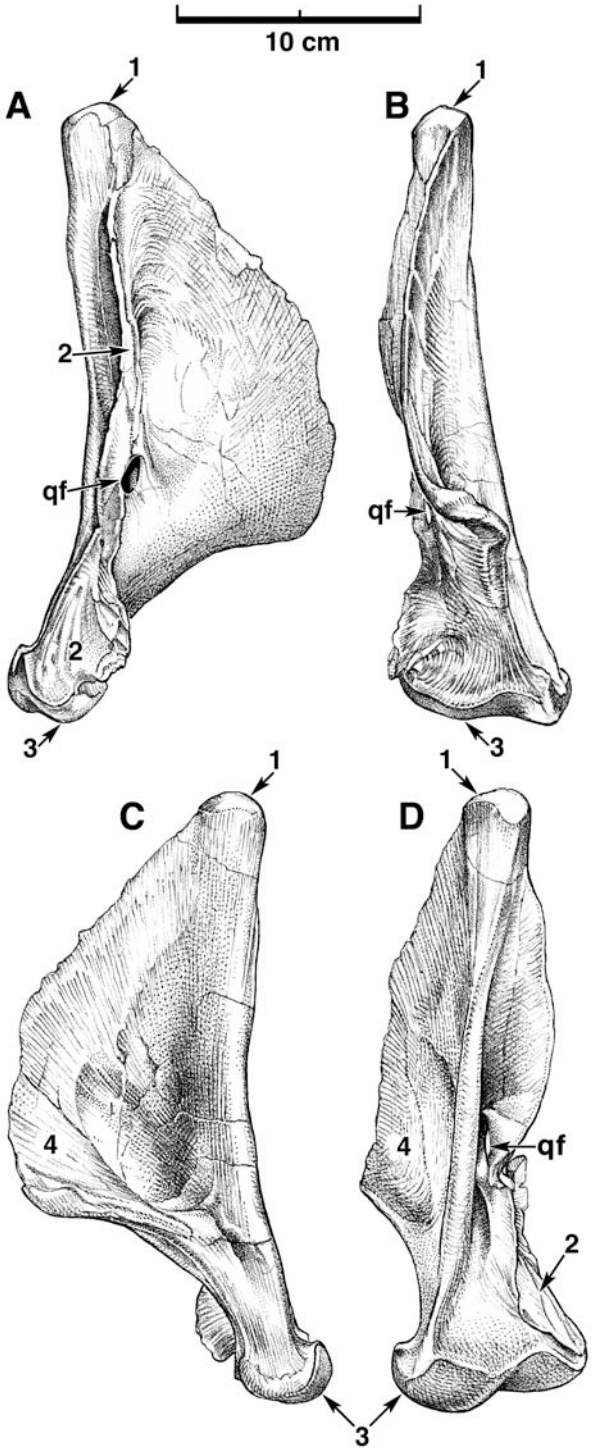

Figure 1. *Sinraptor dongi*, IVPP 10600. Drawing of the right quadrate in lateral (A), anterior (B), medial (C) and posterior (D) views. Abbreviations: qf, quadratic foramen; 1, quadrate cotyle; 2, quadratojugal suture; 3, mandibular condyles; 4, pterygoid contact. Scale bar = 10 cm.

apparently *Torvosaurus* (Britt 1991) lack quadratic foramina, there is a relatively small foramen in *Sinraptor* that is completely surrounded by the quadrate, although the quadratojugal does reach the posterolateral

margin where it overlaps the quadrate. As in *Dilophosaurus* (Welles 1984), *Acrocanthosaurus* (Currie & Carpenter 2000), *Allosaurus* (Madsen 1976), *Monolophosaurus* (Zhao & Currie 1993), and *Mapusaurus* (Coria & Currie 2006) the margins of the quadratic foramen are formed mostly by the quadrate, although at least part of the lateral boundary is formed by the quadratojugal. Spinosauroid (Charig and Milner 1997) and coelurosaur quadrates (including those of dromaeosaurids and tyrannosaurids) have enlarged the quadratic foramina enough to be referred to as quadratic fenestrae, and the lateral margins are formed entirely by the quadratojugal.

Unlike *Ceratosaurus* (Madsen & Welles 2000), abelisaurids (Bonaparte 1990) and tyrannosaurids, there is no fusion between quadrate and quadratojugal. This is similar to *Giganotosaurus*, *Mapusaurus*, *Torvosaurus* (Britt 1991) and the majority of other theropods.

Unlike tyrannosaurids and some carcharodontosaurids (Coria & Currie 2006), the quadrate of *Sinraptor* is not pneumatic.

The lateral and medial mandibular condyles are separated by a shallow groove as in *Ceratosaurus* (Madsen & Welles 2000), *Torvosaurus* (Britt 1991) and most other theropods. Whereas the lateral mandibular condyle is larger than the medial condyle in *Sinraptor*, *Ceratosaurus*, and most other theropods, the opposite is true in *Torvosaurus* (Britt 1991) and *Baryonyx* (Charig & Milner 1997).

CONCLUSIONS

The quadrate of *Sinraptor* is similar in most respects to those of allosauroids like *Acrocanthosaurus*, *Allosaurus*, *Giganotosaurus* and *Mapusaurus*. Quadrates of all of these animals have relatively small quadratic foramina. In *Acrocanthosaurus*, *Allosaurus* and *Sinraptor* the quadratic foramina are almost completely surrounded by the quadrates. Quadratic foramina are found in most theropods, including primitive forms like *Eoraptor* (Sereno et al. 1993), *Herrerasaurus* (Sereno & Novas 1993) and *Syntarsus* (Raath 1977), although they are apparently absent in abelisaurids, *Coelophysis*, *Ceratosaurus* and *Torvosaurus*. Pneumaticity appears to have developed independently in tyrannosaurids and carcharodontosaurids, and is probably related to the large sizes of these animals with a corresponding need to reduce cranial weight as much as possible. There is a tendency for the quadrates and quadratojugals to coossify in mature individuals of most of the more primitive theropods. This character was subsequently lost in tetanurans, although it developed again in mature tyrannosaurids. The “dorsal wing” of *Dilophosaurus* (Welles 1984) is present in *Sinosaurus* and *Zupaysaurus*, but its possible

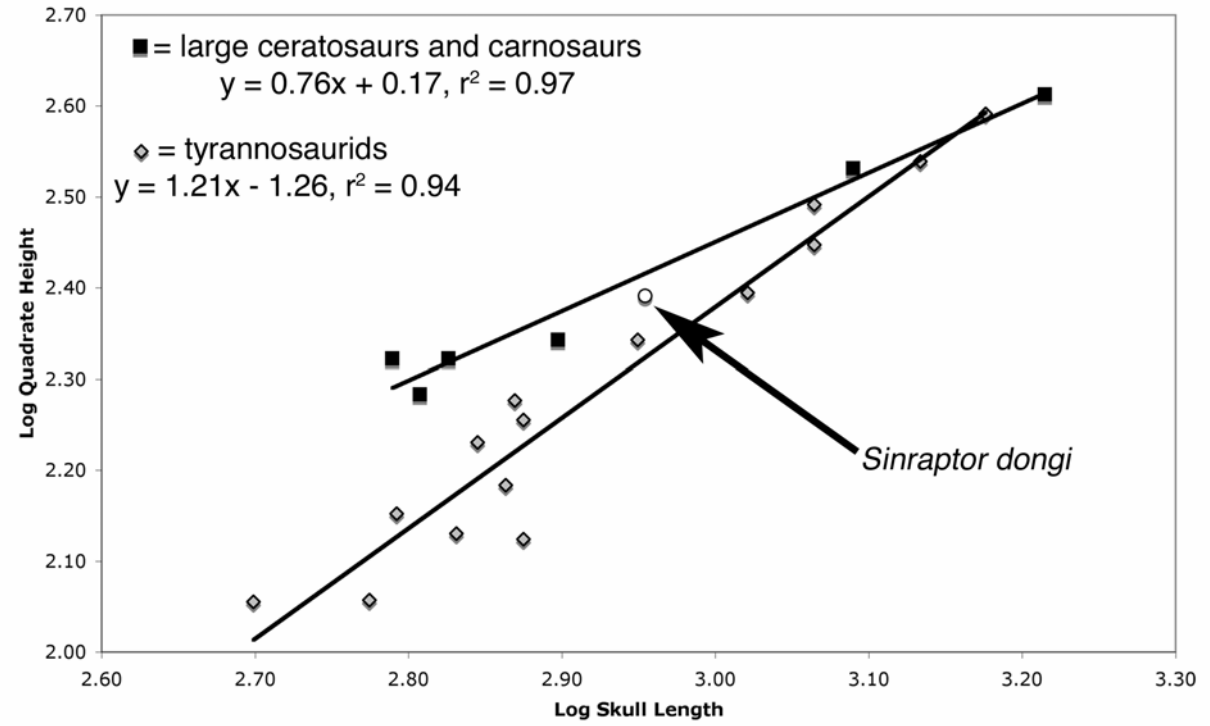

Figure 2. Comparison of quadrate height (Y-axis) to skull length (X-axis) in large theropods. Generally ceratosaurs and carnosaurs tend to have relatively taller quadrates than tyrannosaurids (and other coelurosaurs), although the difference seems to disappear in the largest theropods. The quadrate height of *Sinraptor* is more closely comparable with carnosaurs than with tyrannosaurids.

presence if obscured by fusion in abelisaurids, *Ceratosaurus* and *Cryolophosaurus*. The separation of squamosal from quadratojugal in *Coelophysis* and *Syntarsus* suggests that the "dorsal wing" is present in these animals, although it is fairly inconspicuous because of the small sizes of these animals. The designation of quadrates as either tall or short is, as it turns out, a somewhat subjective process that is not particularly useful for phylogenetic analysis. Tyrannosaurids and other coelurosaurs are the only animals that appear to have truly short (low) quadrates (Fig. 2), but the distinction of quadrate length is less obvious in the largest theropods.

In conclusion, there are numerous characters in the quadrate that can be used for phylogenetic analysis (Table 2). An attempt to determine relationships between theropods using only quadrate characters produced a poorly supported tree that nevertheless did broadly support our current understanding of theropod relationships. Clearly the addition of these characters into larger matrices will help to improve our understanding of theropod classification and relationships.

Table 1. *Quadrate measurements*. Height is the greatest distance between the quadrate cotyle and the medial condyle of the joint for the mandible. Width is the greatest anterolateral-posteromedial measurement across the ventral condyles. Abbreviations: *Acrocantho*, *Acrocanthosaurus*; *Cryolopho*, *Cryolophosaurus*; *Monolopho*, *Monolophosaurus*; *T. rex*, *Tyrannosaurus rex*.

Genus	Specimen #	Height	Width	QF	Source
Acrocantho	NCSM 14345	340	-	11	Specimen
Allosaurus	USNM 4734	192	89	13	Gilmore 1920
Carnotaurus	MACN-CH 894	221	-	0	Bonaparte *et al*. 1990
Ceratosaurus	USNM 4735	212	-	0	Gilmore 1920
Cryolopho	FMNH P1821	177	-	0	Specimen
Dilophosaurus	UCMP 37302	130	51	5	Welles 1984
Mapusaurus	MCF 108.6	350	133	14	Specimen
Monolopho	IVPP 84019	156	70	23	Specimen
Sinosaurus	LDM L10	128	-	5	Specimen
Sinraptor	IVPP 10600	246	70	25	Specimen
Torvosaurus	BYU 5110	273	119	0	Britt 1991
T. rex	MOR 555	390	-	86	Specimen
Zupaysaurus	PULR-076	90	-	20	Specimen

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Table 2. ***Character matrix for theropod quadrates***. Abbreviations: DW, Dorsal Wing; F, fused; N, not present; Ps, present and small; PL, present and large; QF, quadratic foramen; Qm, quadratic foramen bordered mostly by quadrate; Q-QJ, quadratic foramen bordered by both quadrate and quadratojugal; U, unfused.

Genus	Specimen #	Fusion	QF	Border	Pneum	DW
Acrocantho	NCSM 14345	U	Ps	Qm	NPn	N
Allosaurus	USNM 4734	U	Ps	Qm	NPn	N
Baryonyx	BMNH R9951	U	PL	Q-QJ	NPn	N
Carnotaurus	MACN-CH 894	F	N	N	NPn	N
Ceratosaurus	USNM 4735	F	N	N	NPn	N
Cryolopho	FMNH P1821	F	N	N	NPn	?
Dilophosaurus	UCMP 37302	U	Ps	Q-QJ	NPn	P
Mapusaurus	MCF 108.6	U	Ps	Q-QJ	Pn	N
Monolopho	IVPP 84019	U	Ps	Q-QJ	NPn	N
Sinosaurus	LDM L10	U	Ps	Q-QJ	NPn	P
Sinraptor	IVPP 10600	U	Ps	Qm	NPn	N
Syntarsus	Raath 1977	F	Ps	Q-QJ	NPn	P
Torvosaurus	BYU 5110	U	N	N	NPn	?
T. rex	MOR 555	F	PL	Q-QJ	Pn	N
Zupaysaurus	PULR-076	F	Ps	Q-QJ	NPn	P