Discovery of an Avialae bird from China, *Shenzhouraptor sinensis* gen. et sp. nov.

by

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Abstract*

The text describes a new specimen of the Avialae from the Early Cretaceous Jiufotang Fm. of Liaoning Province, China. The specimen is edentulous, its forelimb is distinctly longer than its hind limb, the tail is composed of over 20 caudals, the furcula is U-shaped, and flight feathers exceed torso length. These characters express a genuine ability for flight, such that the new specimen represents a transitional phase between the Dinosauria and Aves and is formally erected as *Shenzhouraptor sinensis* gen. et sp. nov.

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Introduction

Within recent years, the Mesozoic Jehol Fauna of western Liaoning Province has produced numerous species of small theropod dinosaurs with feathers (Ji and Ji, 1996; Ji and Ji, 1997; Ji et al., 1998; Xu et al. A, 1999; Xu et al. B, 1999, Xu et al., 2000; Zhou and Wang, 2000; Zhou et al., 2000; Ji et al., 2001, Norell et al., 2002) attracting broad international attention from the scientific community and further propelling international research into avian origins. However, all previous discoveries of dinosaurs with feathers indicate an inability for flight, as they were instead all cursorially adapted. Thus, there continued the search for a feathered dinosaur with a genuine ability for flight. In the spring of 2002, a completely preserved small, feathered theropod dinosaur was excavated from the Early Cretaceous Jiufotang Fm., in the Toutai village region of Yixian Co., Liaoning Province. Its co-existing fauna includes the swimming diapsid *Hyphalosaurus,* the ornithopod *Jinzhousaurus*, the amiiform fish *Sinamia,* and the teleost fishes *Longdiechthys* and *Jinanichthys*. The new theropod specimen is housed in the Liaoning Provincial Museum of Paleontology. It is believed this specimen had a genuine ability for flight based upon its pectoral and pelvic girdles, limb morphology, and feather development, allowing its assignment to the Avialae. It is erected as *Shenzhouraptor sinensis* gen. et sp. nov. This first discovery of a dinosaur with genuine ability for flight advances the diagnosis for avian taxonomy and provides significant data for the study of avian flight origins.

Description

Dinosauria Owen, 1842
Theropoda Marsh, 1881
Coelurosauria Huene, 1914
Maniraptora Gauthier, 1986
Avialae Gautheir, 1986
Unnamed Clade
***Shenzhouraptor sinensis* gen. et sp. nov.**

(Plate I; Plate II, Figures A-C, Text figure 1)

Etymology: Shenzhou - Pinyin Chinese for an ancient appellation referring to China. Raptor - Latin for violent plunder. Sinensis - Latin referring to China.

Type: A well-preserved skeleton with feathers partially covering the forelimbs and caudal region (Plate I). Liaoning Provincial Museum of Paleontology #LPM 0193.

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* Translator's note: The Chinese title for this paper reads The first discovery of a genuine flying "dinosaur" - *Shenzhouraptor sinensis* (gen. et sp. nov.).

Diagnosis: A relatively small member of the Avialae with a tail possessing slightly more than 23 vertebrae and centra lengths three to four times their height. Forelimb is extremely robust and well developed, being 1.27 times the length of the hind limb. Deltopectoral crest on the humerus is long, phalanx I of digit II is extremely broad, and forelimb feathers are long, distinctly exceeding the combined length of the ulna and metacarpals.

Description: The specimen length slightly exceeds 50 cm.

The skull has been laterally compressed, and anteroposteriorly there is slight folding and damage, thus the preservation of the skull and mandible is rather poor. In outline it is triangular and there is no dentition visible. Suture lines determining the premaxilla, maxilla, and nasal are vague and the configuration, size, and morphology of the antorbital fenestra and orbit are also unclear. The dentary is relatively straight and robust.

Five to six cervical vertebrae are preserved, with their anterior and posterior breadth slightly larger than the centra in the midseries. There are ten relatively well preserved dorsal vertebrae in addition to two more vertebrae which also appear to be dorsals. In the series of 10, the anterior two are preserved in anterior view, illustrating the neural arch breadth to be distinctly greater than the anterior centrum breadth. The arch is large and circular, the neural spine is moderate in height, and the prezygapophyses are relatively well developed. The middle and posterior seven dorsals are articulated and exposed on their left side, illustrating their termini to be larger than their midsection and the ventral margin of the centra are distinctly medially depressed on the midline. Approaching the dorsal region there are well-developed pleurocoels.

Only three fused sacral vertebrae can be documented, but the precise total count is indeterminate. The three fused sacrals are rather broad, there is a distinct low crest along the apical midline, and the diapophyses are relatively long.

The caudal series is relatively complete, with a preserved length of 32 cm. A count of 23-25 vertebrae is generally recognized, although it is possible there were more. Morphological variation in the anterior and posterior caudals is minor, all being thin and baton-shaped. Centrum length is three to four times the anterior centrum height. Nearly all caudal neural arches are poorly preserved, and chevrons are barely divisible on the posterior few vertebrae, being low and long, or nearly equivalent in length to the centra.

The pectoral girdle is not very well preserved (Fig. 1A). The anterior end of the right scapula is poorly preserved. The preserved length of the left scapula is 4.8 cm, although its terminus is broken, but the anterior and middle sections are well preserved, the anterior end being relatively broad with a well-developed acromion. The glenoid posterior to it is semispherical, and the majority of the glenoid fossa is laterally oriented. In lateral view, the distal end of the left scapula is distinctly ventrally curved, and the blade thins distinctly posteriorly. The dorsal margin of the blade is relatively thin, and ventral margin relatively thick. A portion of the left coracoid is preserved although precise morphological characters are vague. There is a symmetrically curved element on both sides of the anterior left scapula that should represent the furcula, but both ends are broken. The nature of its angle indicates it to be U-shaped, but whether or not a manubrium is present is indeterminate.

A relatively broad, thin, and flat element is preserved at the left proximomedial humerus and anterolateral midsection of the scapula, but its posterior and medial portions are obscured by other skeletal elements. This may represent a portion of the sternal plate.

On the left side there are relatively well preserved thick, long, and curved dorsal ribs. At the posterior margin of the midsection of ribs 2 and 3 there are short, incomplete, baton-shaped

elements that intersect the shaft with a distinct angle. As their thicknesses are equivalent to the rib shafts, these may represent uncinate processes.

There is a complete forelimb represented on the left side (Fig. 1B). The proximal right humerus is obscured by other skeletal elements as are the right radius, right distal ulna, and metacarpals. Forelimb length is approximately 25 cm, being distinctly longer than the hind limb or approximately 1.27 times its length. The humerus is robust with an extremely well-developed deltopectoral crest that exceeds two-fifths the length of the humerus. The breadth of the deltopectoral crest at its midsection is nearly one-half its length. Its lateral margin is distinctly thinner than its midsection or medial side. The distal humerus is just slightly broader than the shaft, and the radial and ulnar condyles are strongly affected by poor preservation, although they are still both distinguishable.

The radius and ulna have been slightly compressionally distorted. The radius is straight and its proximal end is overlain by the distal humerus. Because the ulna has only very slight lateral curvature an interosseous vacuity is not large. The ulna is only slightly longer than the humerus and its midshaft breadth is 1.5 times that of the radius.

Table I. Left fore limb measurements (mm).

Humerus	Length	79.8
	Midshaft breadth	7.0
	Deltopectoral crest length	32.8
	Deltopectoral crest median breadth	15.6
Radius	Exposed length	79.6
	Midshaft breadth	4.1
Ulna	Length	83.4
	Midshaft breadth	6.3
Intermedium	Anteroposterior length	4.7
	Transverse breadth	8.3
MtI and Digit I	Combined length	30.0
MtII	Length	36.7
MtIII	Length	36.6
Digit II phalanx I	Length	17.8
	Breadth	5.4
Digit II phalanx II	Length	19.2
	Midshaft breadth	1.6
Digit II phalanx III	Lateral claw length	13.9
Digit III phalanx III	Midshaft breadth	1.0

Three carpals are distinctly exposed: a semilunate is typically crescentic in morphology, its relatively flat margin overlying the entire proximal MtII and MtIII and a small portion of proximal MtI. An ulnare is pisiform in morphology and slightly smaller than the intermedium. A radiale is small and preserved between the intermedium and the distal ulna and radius.

The distal end of metacarpal I cannot be distinguished from its opposing digit but it may still be determined that this metacarpal is extremely short. MtII is straight and broad and MtIII is nearly equivalent in length to the former. It may have suffered compressional distortion, its proximal end is relatively narrow, and its midshaft is distinctly laterally curved, creating a rather large interosseous vacuity between the two.

Manus digit formula is 2-3-4-x-x. Digit I is not as long as MtI, and its ungual is slightly larger than the digit II ungual. Digit II, phalanx I is nearly half the length of MtII and slightly shorter than phalanx II, however this digit is extremely broad, its breadth being 3.3 times that of the midshaft of phalanx II. The proximal end of phalanx II is broad, whereas its midshaft and distal end are distinctly narrowed and columnar. Phalanx III of this digit is clawed with the cutaneous sheath still preserved. The first two phalanges of digit III are short and broad and they are preserved with a distinct angle between them. Thus, although a portion is poorly preserved and the contact is vague, they may be basically be identified as two phalanges. Phalanx III of digit III is slightly shorter than the combined length of the previous two, but this element is extremely gracile, columnar, and recurved. Phalanx IV is clawed, nearly half the size of the claw on the first digit, and their degree of curvature is consistent.

The pelvic girdle is not completely exposed but is unfused. The ilium is basically complete and exposed in lateral view with a length of 40.8 mm (Fig. 1C). Its dorsal margin is arced dorsally and the distinctly semicircular acetabulum is posteromedially located. The pubic peduncle is distinctly larger than the ischial peduncle, with its anterior portion long, high, and bluntly rounded. The posterior portion of the ischial peduncle is narrow and small, and its posterior end is distinctly acute. The length index for the two peduncles is 1.65.

Table 2. Left hind limb measurements (mm).

Femur length	55.4
Femur midshaft breadth	6.0
Tibia length	68.3
Tibia midshaft breadth	5.9
Metatarsal I length	7.8
Metatarsal II length	29.8
Metatarsal III length	34.6
Metatarsal IV length	31.8
Digit I phalanx I length	9.0
Digit I claw length (lateral margin)	12.1
Digit II phalanx I length	9.0
Digit II phalanx II length	10.5
Digit III length	46.1
Digit III phalanx I length	10.9
Digit III phalanx II length	10.6
Digit III phalanx III length	7.3
Digit IV phalanx I length	8.2
Digit IV phalanx II length	6.7
Digit IV phalanx III	6.2

Much of the pubis is exposed on the left side, with only the proximal end obscured by other elements. The exposed length of the straight pubic shaft is 56.4 mm. The distal pubes are in contact along a 14.0 mm fusion. This portion is preserved in posterodorsal view. The termini are slightly inflated but it cannot be determined whether there was a distinct pubic boot. Exposed on the right anterior distal pubis is a skeletal element that may represent a posterior or midsection of the ischium. If this identification is accurate, then the length of the ischium is approximately one-half that of the pubis, its terminus is relatively narrow and acute, and it has a relatively distinct posterodorsal process.

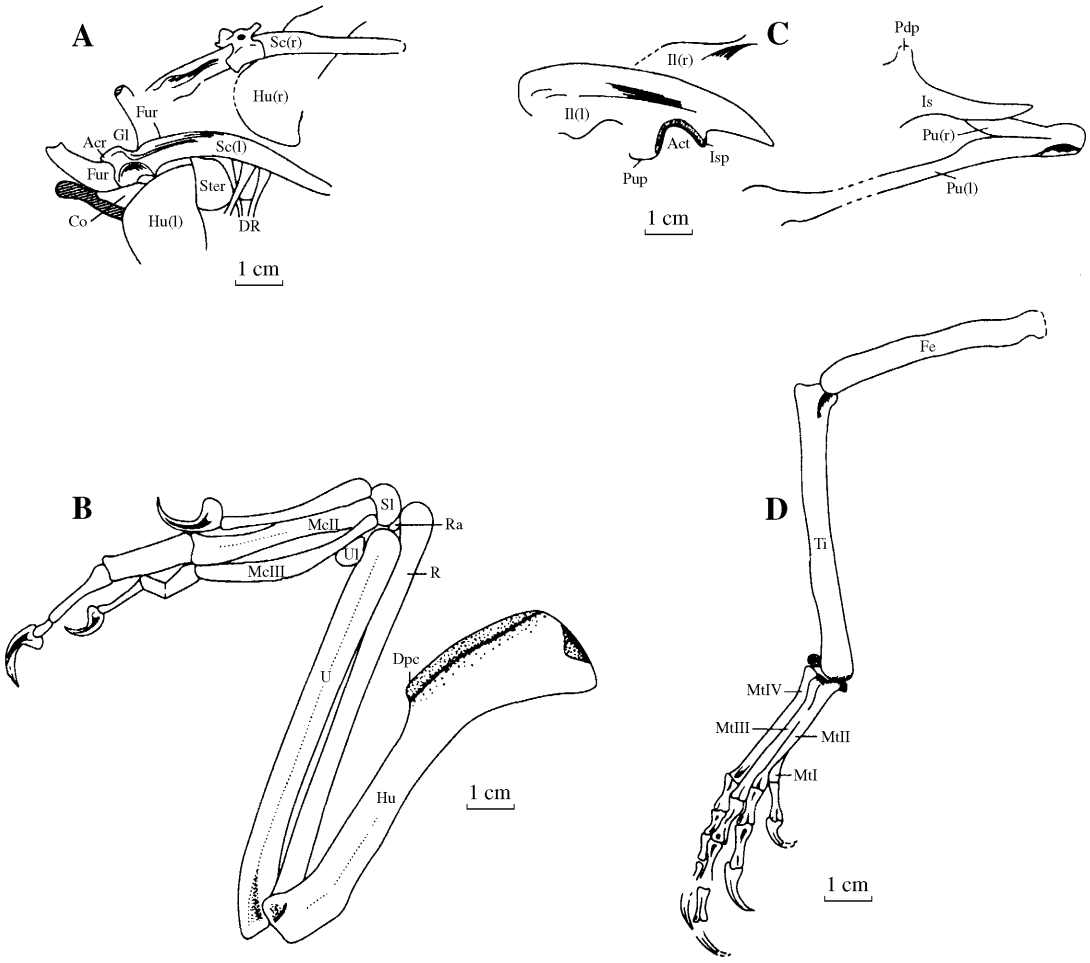

Figure 1. Skeletal regions of *Shenzhouraptor sinensis* gen. et sp. nov.
A. Pectoral girdle; B. Left forelimb; C. Pelvic girdle; D. Left hindlimb.
Acr. Acromion; Act. Acetabulum; Co. Coracoid; Dpc. Deltopectoral crest; Dr. Dorsal ribs; Fe. Femur; Fu. Furcula; Gl. Glenoid; Hu. Humerus; Il. Ilium; Is. Ischium; Isp. Ischiac peduncle; McII-III. Metacarpals II-III; MtI-IV. Metatarsals I-IV; Pdp. Posterodorsal process of the ischium; Pu. Pubis; Pup. Pubic Peduncle; R. Radius; Ra. Radiale; Sc. Scapula; Sl. Semilunate; Ster. Sternum; Ti. Tibia; U. Ulna; Ul. Ulnare; (l). left; (r). right

The hind limb is typical in morphology, the left of which is also completely preserved (Fig. 1D). The right femur, tibia, and digits are all compressionally distorted along with the tail, rendering numerous characters indistinguishable. The left hind limb is 20 cm in length, being distinctly shorter than the forelimb. The distal femur is slightly posteriorly curved, but the tibia is straight, with its shaft being nearly as robust as that on the femur. Metatarsals are poorly preserved.

Metatarsal I is located dorsodistolateral to MtII and is slightly shorter than the first phalanx of digit I. The ends of MtII-IV are fused, MtII is the shortest, and MtIII is the longest in the sequence, attaining half the length of the tibia. An MtV is not documented. The phalangeal formula is thus 2-3-4-5-0(x). Digit III is the longest in the series and digit IV is second in length, followed by digits II and I. Claw curvature on digit I is rather large but it is not retroflexed, or in opposition to the other unguals for perching. The second digit is robust, its first phalanx is slightly shorter than its median phalanx, and its claw is the largest in the series, with its lateral marginal

length being 1.5 times the length of the first phalanx of this digit. This resembles the condition in several dromaeosaurs. Digits III and IV are typical in morphology, with rather thick, long phalanges on digit III and rather gracile, short phalanges on digit IV.

The flight feathers on the forelimbs are narrow and elongated but are present in different degrees of preservation. On the left side, the primary flight feathers are preserved longest, attaining 21 cm, which surpasses the combined length of the ulna and metacarpals, or is approximately 1.2 times that of the latter. Every feather is asymmetrical, narrow, and elongate. The precise count of primary flight feathers is indistinct. Although the detailed architecture is not well preserved, impressions in the matrix indicate them to be relatively systematic, and thus they should possess a distinct vane and rachis and it is hypothesized that the barbs possess barbules and hooklets. It is believed here that this taxon had a distinct ability for flight based upon the forelimb being distinctly longer than the hind limb, the extreme length of the flight feathers, and other characters. Several relatively short feather impressions also lie at the end of the tail.

Comparison and discussion: Characters are quite distinct between the specimen described above, *Sinosauropteryx* (Ji and Ji, 1996), and *Beipiaosaurus* (Xu et al., 1999), as the former has feathers with a well-developed rachis and vane, which is quite distinct from the latter two taxa. Although feathered dromaeosaurs have been documented in western Liaoning Province (Norell et al., 2002), the current specimen under study is distinct in its undeveloped tail with baton-shaped prezygapophyses and haemal arches (tendinous construction) (Xu et al., 1999A; Xu et al., 2000; Ji et al., 2002; and Norell et al., 2002).

A great deal of attention has been provided to *Caudipteryx* due to the presence of feathers on its forelimb (Ji et al., 1998; Zhou and Wang, 2000; and Zhou et al., 2000). However, it is completely distinct from the current specimen in its extremely short forelimb (being only 40% the length of the hindlimb), and also its very short, symmetrical feathers. The specimen at hand has a forelimb that is 127% the length of the hindlimb with extremely well-developed feathers. Also, *Caudipteryx* is much smaller with a carpal region, forelimb digits, and pelvic girdle distinct from the current specimen..

Within non-avian theropods, forelimb length is always shorter than hindlimb length. Within the Avialae, these two lengths are nearly equivalent, as in *Archaeopteryx* (Padian and Chiappe, 1998). The caudal count in the current specimen is generally equivalent to that of *Archaeopteryx*, its furcula is U-shaped, and its forelimb is distinctly longer than its hindlimb, with an index more comparable to *Confuciusornis* (Ji et al., 1998; Chiappe et al., 1999), indicating that this species had the functional ability for flight.

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Explanation of plates

Plate I. Complete morphology of *Shenzhouraptor sinensis* gen. et sp. nov.

Plate II. A. Left forelimb and flight feathers. B. Left hindlimb, pubis and partial caudals. C. U-shaped furcula.