Evidence points out that "*Nanotyrannus*" is a juvenile *Tyrannosaurus rex*

In this paper, I comment on Larson's 2013 paper "The case for *Nanotyrannus*". All the osteological differences proposed by Larson (2013) seem to be due to ontogeny and individual variation. Therefore, Larson's claim that "*Nanotyrannus lancensis*" is not a juvenile *Tyrannosaurus rex* is incorrect. And based on their striking anatomical similarities, it is more parsimonious to assume that "*Nanotyrannus lancensis*" is the junior synonym of *Tyrannosaurus rex* and represents a juvenile stage of the taxon.

Evidence points out that "*Nanotyrannus*" is juvenile *Tyrannosaurus rex*

(Response to Larson, 2013)

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Larson (2013) compared the supposed "*Nanotyrannus*" specimens(CMNH 7541, BMR P2002.4.1.) with adult *Tyrannosaurus rex* specimens and concluded they are distinct taxa. However, all of the differences they claimed actually occur to ontogeny and variation of other tyrannosaurids or dinosaurs.

Firstly, fusion of the pelvis in BMR P2002.4.1. cannot be used as its "adult" status since the feature is a individual variation rather than ontogenetic feature in dinosaurs. For example, even young *Ceratosaurus* specimens(Carrano et al., 2008) show completely fused pelvises(Marsh 1884) and extremely young tyrannosaurid specimen LH PV18("*Raptorex kreigsteini*") shows the similar pelvis fusion status(Fowler et al., 2011) with adult *Tyrannosaurus rex*(Larson 2013). Therefore, fused pelvis of BMR P2002.4.1. is not an adult feature.

Larson also stated "BMR P2002.4.1. has visible neurocentral sutures on only the first 11 caudal vertebrae. Number 12 caudal and greater, and one of the three preserved dorsal vertebrae, shows no sutures." and used this as evidence of BMR P2002.4.1.'s more advanced ontogenetical stage than

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adult *Tyrannosaurus* specimens. However, even the two-year old specimen of *Tarbosaurus* IVPP V4878("*Shanshanosaurus huoyanshanensis*") shows the similar vertebrae fusion with adult *Tyrannosaurus rex*(Fowler et al., 2011). This strongly suggests that vertebrae fusions are not related to growth in tyrannosaurids.

BMR P2002.4.1.'s "completely fused" scapula-coracoid suture is also not appropriate for its ontogenetic status since the oviraptorosaur embryo preserved in the egg has fused scapulocoracoid(Norell et al., 2001) and even Larson stated *Tyrannosaurus* specimens had different fusions between both scapulocoracoids(Larson 2013). Therefore, this is not an ontogenetic feature, but rather an individual variation.

Larson's supposed osteological differences between "*Nanotyrannus*" and *Tyrannosaurus rex* are also problematic. BMR P2002.4.1.'s "caudoventral to lateral" scapulocoracoid glenoid different from adult *Tyrannosaurus*'s "caudoventral" glenoid actually occurs in other young theropods, including tyrannosaurids(Parrish, Henderson and Stevens, 2005). Therefore this is an ontogenetic change, not an osteological difference.

BMR P2002.4.1.'s anterior iliac hook absent from adult *Tyrannosaurus* is also not an osteological difference since the juvenile tyrannosaurid specimen closely related to *Tarbosaurus*(Fowler et al., 2011) also had similar hook(written as pendant process in Sereno et al., 2009). Considering adult *Tarbosaurus* specimens don't have anterior iliac hooks(Larson 2013), this is ontogenetically variable.

CMNH 7541 and BMR P2002.4.1.'s shallow antorbital fossa typically occurs in juvenile tyrannosaurids(Brusatte et al., 2009; Tsuihiji et al., 2011), so using this as one of the differences between *Tyrannosaurus rex*

is very weak.

Small maxillary fenestra of "*Nanotyrannus*" specimens is a common feature in young tyrannosaurids, including *Tarbosaurus* and *Daspletosaurus*(Currie 2003).

Larson also used narrower, *Gorgosaurus*-like vomer of "*Nanotyrannus*" as differences between *Tyrannosaurus rex* since the latter taxon has broad, diamond-shaped vomer. However, young *Tarbosaurus* specimen had narrow vomer as well(Tsuihiji et al., 2011).

Larson's supposed differences in quadratojugal's dorsal edge, like ascending process's notches, are problematic since young *Tarbosaurus* specimen had different quadratojugal dorsal edge with adults(Tsuihiji et al., 2011). Therefore, this is probably an ontogenetic change.

Supposed T-shaped "*Nanotyrannus*" lacrimal distinct from 7-shaped lacrimals of *Tyrannosaurus rex* is also could be explained by ontogeny since young *Tarbosaurus* had T-shaped lacrimal as well(Tsuihiji et al., 2011). BMR P2002.4.1.'s lacrimal horns are also cannot be used as osteological difference since young *Tarbosaurus* specimen GIN 100/66 also had lacrimal horns, which are absent in adults(Currie 2003).

Differences in dorsal articular surface of quadrate could also be explained by ontogeny, since the ontogenetic changes posterior portion of quadrate observed in sauropod dinosaurs(Whitlock et al., 2010).

As Larson pointed out, there are differences between subnarial foramen positions of tyrannosaurids illustrated in scientific works. This strongly suggests that position of this foramen is individually variable, therefore cannot be used as osteological differences between "*Nanotyrannus*" and *Tyrannosaurus*.

Narrow teeth of "*Nanotyrannus*" distinct from much more conical, wide teeth of *Tyrannosaurus* are typical differences between young tyrannosaurs and adults(Carr 1999; Currrie 2003). Larson also used more teeth of "*Nanotyrannus*" as evidence of it being a valid genus, but Carr (1999) showed decreases of tooth count occurred in tyrannosaurid ontogeny. Though Larson did doubt this, there is gradual decreases in tooth counts among bigger *Tyrannosaurus* specimens(Thomas Holtz, pers. comm., January 2014) so this may suggest that he is incorrect. And also, this could be an individual variation(Tsuihiji et al., 2011; Brown et al., 2015).

Larson incorrectly stated BMR P2002.4.1.'s maxillary tooth counts as 15 in the right and 16 in the left, but this is incorrect since it clearly has 14 teeth in both maxillae(Thomas Holtz, pers. comm., January 2014).

Larson's supposed respiratory differences are also problematic, since he assumed that pneumatic features do not change during the ontogeny. However, pneumatic changes do occur in ontogeny of dinosaurs, including tyrannosaurids(Witmer 1997; Brusatte et al., 2012). Considering that the young specimens of *Alioramus* had unusual cranial pneumatization, and this might be due to its ontogenetic status(Gold et al., 2013), it is probable that respiratory differences between "*Nanotyrannus*" and *Tyrannosaurus* are due to different ontogenetic stages.

One feature, pneumatopore on "*Nanotyrannus*" quadratojugal is stated by Larson as unusual among tyrannosaurids. However, as *Gorgosaurus* varies in similar feature(Currie 2003, Larson 2013), this could be an individual variation as well.

In conclusion, all of the differences between "*Nanotyrannus*" and

Tyrannosaurus are due to ontogeny or individual variation. And given that there are striking similarities between "*Nanotyrannus*" specimens and adult *Tyrannosaurus* specimens(Carr 1999), it is most parsimonious to assume that former is the junior synonym of the latter.

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