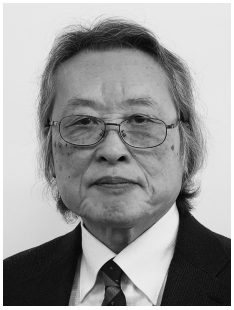
Japan Academy Prize to:

Shigeru KURATANI
Senior Visiting Scientist, RIKEN Center for Biosystems Dynamics Research (BDR)
Part-time Lecturer, Graduate School of Medical and Dental Sciences, Institute of Science Tokyo



for "Developmental Studies to Elucidate the Mechanism of Morphological Evolution in Vertebrates"

Outline of the work:

How have living organisms changed their forms over time? This fundamental question lies at the heart of evolutionary biology. Dr. Shigeru Kuratani has dedicated his career to addressing this question, particularly by investigating evolutionary phenomena involving significant modifications in anatomical patterns. Through his pioneering work, he has made remarkable discoveries that have profoundly contributed to the understanding of morphological evolution.

One of the most pivotal events in vertebrate evolution is the acquisition of jaws, a prime example of a pattern transformation. The jawed vertebrates (Gnathostomes) are believed to have evolved from jawless ancestors. To elucidate this evolutionary transition, Dr. Kuratani chose the lamprey—a modern jawless vertebrate—as a model organism and conducted a detailed comparative analysis of its embryonic development against jawed vertebrates such as chickens and mice. His research revealed that, although the same genetic toolkit is employed for oral apparatus formation, the spatial expression of these genes differs. Furthermore, the mesenchymal materials forming the mouth structure are not identical between these groups. Based on these findings, Dr. Kuratani proposed the heterotopy hypothesis, which suggests that the evolutionary acquisition of jaws resulted from a shift in gene expression locations. Heterotopy refers to the change of development in position during evolution. Dr. Kuratani provided the first example of this in vertebrates through his research on the evolution of jaws.

Additionally, Dr. Kuratani was the first in the world to successfully obtain hagfish embryos under laboratory conditions. By studying their development, he demonstrated that both lampreys and hagfish share embryonic stages reminiscent of ancestral vertebrates. This finding led to a redefinition of the morphological characteristics of cyclostomes (jawless vertebrates) and provided insights into the early evolution of vertebrate organ structures.

Another major contribution by Dr. Kuratani is his work on the evolutionary origin of the turtle shell. Unlike a simple thickened outer skin, the dorsal part of the shell incorporates ribs, and the scapula is uniquely positioned inside the ribcage rather than outside, as seen in most vertebrates. This alteration in relative anatomical positioning has long puzzled

researchers. To investigate this, Dr. Kuratani studied the development of the softshell turtle and discovered a unique folding mechanism of the body wall during embryogenesis, which is absent in other amniotes (mammals, birds, and reptiles). He further found that, while ribs normally extend ventrally through the lateral body wall in amniote embryos, turtle ribs grow outward, eventually covering the scapular primordium. He concluded that this rib overgrowth and body wall folding were crucial to the emergence of the turtle's distinctive body plan. Furthermore, he pointed out that the fossil species *Odontochelys*, an ancestral form of modern turtles, represents an intermediate stage in this developmental process. This observation provided empirical support for the idea that embryonic development recapitulates certain aspects of evolutionary history, reinforcing the link between ontogeny and phylogeny.

Dr. Kuratani's research group has also made significant strides in evolutionary developmental biology by conducting large-scale genomic analyses of vertebrate embryos. Using high-performance computing, they compared gene expression patterns across species and provided molecular evidence for the "developmental hourglass model." This model posits that the most evolutionarily conserved stage in vertebrate embryogenesis is the organogenesis phase. Their findings not only confirmed a key evolutionary principle but also suggested that certain developmental patterns are constrained by molecular limitations, underpinning the conservation of anatomical homologies across species.

His groundbreaking research has reshaped academic knowledge in the field, merging classical comparative zoology with modern empirical biology. His contributions have been widely recognized in prestigious textbooks, including *Campbell Biology* and M. J. Benton's *Vertebrate Paleontology (4th Edition)*.

Furthermore, Dr. Kuratani's research extends beyond vertebrate embryology to human anatomy and paleontology. His group has elucidated the evolutionary history of mammalian middle ear structures, facial development, and diaphragm formation. Additionally, they have successfully determined the cranial morphology and phylogenetic position of *Palaeospondylus*, a long-enigmatic Devonian vertebrate fossil.

Beyond his research, Dr. Kuratani has played a leading role in the global scientific community. In 2015, recognizing Japan's crucial role in disseminating zoological research internationally, he founded the journal *Zoological Letters*, where he continues to serve as Editor-in-Chief. His leadership is also demonstrated by frequent invitations to deliver keynote speeches at international conferences.

In conclusion, Dr. Shigeru Kuratani has pioneered the field of evolutionary developmental morphology, achieving multiple breakthroughs while maintaining a prominent presence on the global stage. His achievements make him a highly deserving recipient of this award.

List of Main Publications

Dr. Kuratani has published 251 original and review papers. The main papers related to his research are as follows:

1. Hirasawa, T., Hu, Y., Giles, S., Uesugi, K., Hoshino, M., Manabe, M., and Kuratani, S. (2022). Morphology of *Palaeospondylus* shows affinity to tetrapod ancestors. ***Nature*** **606**: 109–112.
2. Higuchi, S., Sugahara, F., Oisi, Y., Pascual Anaya, J., Takagi, W., and Kuratani, S. (2019). Inner ear development in cyclostome and the evolution of vertebrate semicircular canals. ***Nature*** **565**: 347–350.
3. Pascual-Anaya, J., Sato, I., Paps, J., Yandong, R., Sugahara, F., Higuchi, S., Takagi, W., Ruiz-Villalba, A., Ota, K. G., Wang, W., and Kuratani, S. (2018). Hagfish and lamprey Hox genes reveal conservation of temporal colinearity in vertebrates. ***Nat. Ecol. Evol.*** **2**: 859–866.
4. Sugahara, F., Pascual-Anaya, J., Oisi, Y., Kuraku, S., Aota, S., Adachi, N., Takagi, W., Hirai, T., Sato, N., Murakami, Y., and Kuratani, S. (2016). Evidence from cyclostomes for complex regionalization of the ancestral vertebrate brain. ***Nature*** **531**: 97–100.
5. Kitazawa, T., Takechi, M., Hirasawa, T., Hirai, T., Narboux-Nême, N., Kume, H., Oikawa, S., Maeda, K., Miyagawa-Tomita, S., Kurihara, Y., Hitomi, J., Levi, G., Kuratani, S., and Kurihara, H. (2015). Developmental genetic bases behind the independent origin of the tympanic membrane in mammals and diapsids. ***Nat. Commun***. **6**: 6853.
6. Kuratani, S. (2013). Evolution. A muscular perspective on vertebrate evolution. ***Science*** **341**: 139–140.
7. Hirasawa, T., Nagashima, H., and Kuratani, S. (2013). The endoskeletal origin of the turtle carapace. ***Nat. Commun.*** **4**: 2107.
8. Wang, Z.*, Pascual-Anaya, J.*, Zadissa, A., Li, W., Niimura, Y., Huang, Z., Li, C., White, S., Xiong, Z., Fang, D., Wang, B., Ming, Y., Chen, Y., Zheng, Y., Kuraku, S., Pignatelli, M., Herrero, J., Nozawa, M., Juan Wang, J., Zhang, H., Yu, L., Shigenobu, S., Wang, J., Liu, J., Flicek, P., Searle, S., Wang, J., Kuratani, S., Yin, Y., Aken, B., Zhang, G., and Irie, N. (*equal contributions) (2013). The draft genomes of soft-shell turtle and green sea turtle yield insights into the development and evolution of the turtle-specific body plan. ***Nat. Genet.*** **45**: 701–706.
9. Oisi, Y., Ota, K. G., Kuraku, S., Fujimoto, S., and Kuratani, S. (2013). Craniofacial development of hagfishes and the evolution of vertebrates. ***Nature*** **493**: 175–180.
10. Ota, K. G., Fujimoto, S., Oisi, Y., and Kuratani, S. (2011). Identification of vertebra-like elements and their possible differentiation from sclerotomes in the hagfish. ***Nat. Commun.*** **2**: 373.
11. Irie, N. and Kuratani, S. (2011). Comparative transcriptome analysis reveals vertebrate

phylotypic period during organogenesis. ***Nat. Commun.*** **2**: 248.

12. Nagashima, H., Sugahara, F., Takechi, M., Ericsson, R., Kawashima-Ohya, Y., Narita, Y. and Kuratani, S. (2009). Evolution of the turtle body plan by the folding and creation of new muscle connections. ***Science*** **325**: 193–196.
13. Kuraku, S., Takio, Y., Tamura, K., Aono, H., Meyer, A., and Kuratani, S. (2008). Non-canonical role of *Hox14* by its expression pattern in lamprey and shark. ***Proc. Natl. Acad. Sci. U.S.A.*** **105**: 6679–6683.
14. Ota, K. G., Kuraku, S., and Kuratani, S. (2007). Hagfish embryology with reference to the evolution of the neural crest. ***Nature*** **446**: 672–675.
15. Shigetani, Y., Sugahara, F., Kawakami, Y., Murakami, Y., Hirano, S., and Kuratani, S. (2002). Heterotopic shift of epithelial-mesenchymal interactions for vertebrate jaw evolution. ***Science*** **296**: 1316–1319.
16. Kuratani, S. (1997). Spatial distribution of postotic crest cells defines the head/trunk interface of the vertebrate body: embryological interpretation of peripheral nerve morphology and evolution of the vertebrate head. ***Anat. Embryol.*** **195**: 1–13.