Symmetry Breaking in Our Body – Mystery of Homochirality in Biomolecules

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Humans can be divided into three types: right–handed people, left–handed people, and mixed–handed people. In general, right–handed people are dominant in any countries, any era, and readers of this article as well. What does determine the handedness of humans? Many researchers have tackled this question and suggested several explanations, such as the brain hemisphere region of labor, the genetic inheritance, the experience during unborn babies, and the environmental effects. However, the actual origin of handedness is not yet elucidated.

This kind of “dominant handedness” happened at nanoscale: amino acids are almost always left–handed, and sugars are almost always right–handed. In chemistry, the handedness of molecules is called chirality. Molecules are called chiral if they cannot be superposed on their mirror image by any combination of rotations and

translations, and isomers relating the chirality are called enantiomers. Chirality is an important concept especially in biochemistry and pharmacy because enantiomers show the completely different bioactivities. For example, thalidomide, a drug, in the left–handed form acts as a medicine but in the right–handed form causes birth defects. L–forms (left–handed) of glutamic acids is used as a flavor enhancer of foods whereas D–forms (right–handed) is bitter and not tasty at all. Notably, almost all amino acids take L–forms in the natural world. This uniformity of chirality in the natural world is called as “homochirality”. The curious and fascinating point is that how the homochirality is established because the chirality of molecules is randomly determined under non–special conditions.

Humans found chirality 200 years ago and scientists managed to understand, control, and use the chirality of molecules. The first discovery goes back to 1815. Jean-Baptiste Biot, a French scientist, found optical rotation of the polarized light by passing the light through a specific organic solution. Louis Pasteur, the father of vaccination, firstly separated enantiomers in 1848 by checking the shape of crystals with eyes. The concept of chirality was supposed at that time, but the term *chirality* was named by Lord Kelvin, the father of absolute temperature, in 1894. Since then, chirality became a common sense in the field of physics, biology, pharmacy, and chemistry. Physicists have

explained the mechanism of optical rotation by electromagnetics or quantum mechanics. Biologists have revealed the relationship between chirality and biological activity. Pharmacists have developed novel drugs by controlling chirality of molecules. Chemists have separated enantiomers in natural products and developed the chiral-selective synthesis. Several studies about chirality were awarded in the Nobel Prize. Dr. Ryōji Noyori won the Nobel Prize in Chemistry in 2001 for the study of chiral selective catalytic reactions and Dr. Satoshi Ōmura won the Nobel Prize in Physiology or medicine in 2015 for the isolation and structural determination of useful chiral natural products. Thus, scientists have understood and controlled chirality well. However, the origin of homochirality in the natural world is still unknown and exists as a dark problem in science.

As for the origin of homochirality, many mechanisms have been proposed.[1] In general, these models consist of three steps: symmetry breaking to induce the small enantiomeric imbalance, amplification of the imbalance, and transmission to another molecules. Amplification and transmission were already accomplished by synthetic chemists *in vitro*. The amplification was demonstrated by a chiral autocatalyst, which promotes the formation of itself. It was demonstrated that the small amount of one enantiomer of an enantiomeric pair acts as an autocatalyst.[2] Transmission of

homochirality to another molecules is exactly same as the chiral selective catalytic reaction as studied by Dr. Noyori.[3] Synthetic chemists can generate both left–handed, dominant in the natural world, and right–handed amino acids. These mechanisms of amplification and transmission seem to be plausible, although it is not known how it works for the actual compounds present in the natural world.

For the origin of symmetry breaking, many possibilities have been suggested. One of the explanations is the transmission from other asymmetric factors such as electroweak interaction, circularly polarized light, rotation of Earth, and statistical fluctuations during synthesis. Some scientists assume the extraterrestrial origin based on the discovery of the enantiomeric imbalance in the Murchison meteorite, one of the most studied meteorites.[4] The existence of circularly polarized light from aligned interstellar dust particles supported the assumption.[5] More simple explanation would be the natural selection – a key mechanism of the evolution may be valid for the establishment of homochirality because the difference in chirality resulted in the different bioactivity and the different possibility to survive. Joint research of biologists, chemists, physicists, and paleontologists about computational simulation or *in vitro* replicating experiments of the primitive Earth may give an insight into the feasibility and the time scale of these possibilities.

The origin of homochirality is deeply related to the evolution of life. Life is thought to be born 4 billion years ago as a result of chemical evolution from methane to complicated biomolecules. The development of homochirality have functionalized biomolecules and evolved the complexity of life for a long time. The understanding of homochirality will help to interpret the mechanism and diversity of life.

Furthermore, related studies will disclose the nature of chirality and lead to the development of materials such as pharmaceuticals and optical devices based on chirality. Versatile methods to control the chirality of molecules will fasten the production and the discovery of novel pharmaceuticals. Optical devices controlling optical rotation by chiral molecules may innovate the conventional communication system by increasing the amount of information included in the light. The answer to the mystery of homochirality is not the answer to the mystery of handedness of humans, but it will have a broad impact on wide area of sciences and enrich our life by improving material sciences.

References

1. F. Jafarpour, T. Biancalani, and N. Goldenfeld “Noise-induced symmetry breaking far from equilibrium and the emergence of biological homochirality” *Phys. Rev. E.*

2017, *95*, 032407.

2. T. Shibata, H. Morioka, T. Hayase, K. Choji, and K. Soai “Highly Enantioselective Catalytic Asymmetric Automultiplication of Chiral Pyrimidyl Alcohol” *J. Am. Chem. Soc.* **1996**, *118*, 471.

3. A. Miyashita, A. Yasuda, H. Takaya, K. Toriumi, T. Ito, T. Souchi, and R. Noyori “Synthesis of 2,2'-bis(diphenylphosphino)-1,1'-binaphthyl (BINAP), an atropisomeric chiral bis(triaryl)phosphine, and its use in the rhodium(I)-catalyzed asymmetric hydrogenation of .alpha.-(acylamino)acrylic acids” *J. Am. Chem. Soc.* **1980**, *102*, 7932.

4. M. H. Engel and B. Nagy “Distribution and enantiomeric composition of amino acids in the Murchison meteorite” *Nature*, **1982**, *296*, 837.

5. U. Meiernrich “Amino acids and the asymmetry of life: caught in the act of formation” Springer, **2008**, 123-124.