Investigations of Early Workers in the Field of Cranial and Facial Growth*

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This review of the work of the early investigators of the phenomena of bone growth of the head and face is an attempt to present the picture as those men saw and understood these problems. Because of the generality and broadness of their writings, it is easy to modify or misconstrue their actual knowledge and theories on bone growth.

Often it is very difficult to place accurately the date of birth of a science or the inception of a revolution in human thought and learning. True the facts herein contained have been gathered from history, and that history cannot be changed at this late date. The year 1736 seems to stand out as the very beginning of our present day conception of the "problem of bone growth," for, until that year, like "Topsy of Uncle Tom's Cabin" fame, bone just grew. Human beings grew from infancy to adult life, but the how or wherefore that entered into the phenomena of bone growth apparently escaped investigation.

In that year a young surgeon, John Belchier by name, was entertained by a certain calico printer in London, England, and all unsuspectingly his host provided Belchier with the key to a method of studying the sites of bone growth. This calico printer, being somewhat economical, either by nature or by necessity, had been in the habit of feeding the madder stained bran from his dye vats to his pigs. In due time these pigs were killed and served on his table. He had observed certain red stains in cross sections of the bones in this pork, but other than perceiving the expressions of consternation on the faces of his guests when served, he seems to have gained nothing from his experiences.

However, his young surgeon friend proceeded to carry on several experiments through feeding of madder to experimental animals and proved that it was madder and not something else which had stained the bones of

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these animals. Belchier also found that even the densest bones were stained. With that he considered his investigations closed. Even Belchier did not recognize a "problem of bone growth."

There were two outstanding anatomists and surgeons of this period who molded opinion in matters pertaining to osteology. One of these, William Cheselden (1688-1752) of England, the teacher and inspirer of Belchier, "knew all there was to be known about bone, especially the human skeleton." His "Anatomy of the Human Body," published in 1713, continued to be a textbook on that subject in England for twenty years. In 1733 he published his "Osteographia, or Anatomy of the Bones." He was made chief surgeon in Chelsea Hospital in 1737, the same year that Belchier published his paper on madder stained bone. To quote from the teachings of Cheselden: "Bones were covered by a fine membrane, which upon the skull is called pericranium, elsewhere periosteum. It serves for the muscles to slide easily upon; it is everywhere full of small blood-vessels, which enter the bones for their nourishment." "Bones grow by the continual addition of this ossifying matter; they increase till their hardness resists a further extension; and their hardness always increasing while they are growing, the increase of their growth becomes slower and slower until they cease to grow at all." "In a fractured bone, the same kind of matter, which ossified the bones at first, is thrown out from the broken ends, there is formed a mass of callus matter." Such was the conception of bone, bone repair and bone growth in the first part of the eighteenth century.

About 1737 Belchier's paper came into the hands of Henri Louis Duhamel, a young lawyer of France, then thirty-seven years old who had studied for a time in Paris but had later moved to an estate near by. Duhamel seems to have been a man of rather an inquisitive turn of mind. Observation and experiment furnished the one certain source of human knowledge, so far as he was concerned. He repeated Belchier's experiments as well as several original ones and found that bones, only, were stained by madder and that bones of young animals stained more readily than those of more mature subjects. His first paper published in 1739, showing his findings in regard to bones of madder-fed animals, added practically nothing to Belchier's work. However, he experimented further upon animals to learn what took place in mending broken bones and found that the periosteum was the chief agent or factor in producing the repairing callus, instead of the so-called "juice" secreted by the broken ends, as was the prevailing belief. His papers published in 1741, '42, and '43 showed he had made considerable progress. He found that upon alternating madder feeding with madder free diets that cross sections of the bones of his experimental animals showed alternate red and white rings; that bone was formed in layers under the periosteum of growing animals; that the medullary portion of long bones became larger and larger as the animal grew.

Duhamel believed that as the shaft of long bones increased in thickness there was also present a sort of expansion of the shaft which accounted for the enlargement of the medullary space. He attempted to prove this theory by encircling the shafts of long bones with rings of silver wire. Upon killing the animals some time later he found these rings entirely within the bone. He seems to have missed, however, the fact that absorption of bone as well as building of bone material may occur in different parts of the same bone at or about the same time. Being familiar with the fact that a bench mark cut into a tree always remained at the same height from the ground he determined to learn whether bones grew in a similar manner. By passing silver wires or rods through holes drilled into bones at measured distances apart and then remeasuring the distances between these some weeks later he found the measurements identical which proved to him the increase in length of bones occurred at or near their ends. He made mention of the epiphyseal lines but did not study their function so far as we know. We should remember that it was Duhamel a young lawyer and not a medical man who discovered there was a "problem of bone growth." He proved that "bone is stained with madder only as it is being laid down; that a bone grew in thickness by circumferential deposition of plate upon plate of bone material; that a long bone grew in length at its extremities; that the deepest layer of the periosteum was the maternal tissue of bone."

Along with William Cheselden should be mentioned Albrecht von Haller (1708-1777), a German anatomist born in Switzerland, and the second outstanding authority on anatomy and surgery of this period. Haller repeated Duhamel's experiments, both in madder feeding and in fractures, but arrived at far different conclusions. Haller believed that the periosteum played no part in the formation of bone. He noted that arteries penetrated the epiphyseal cartilage and that a point of ossification began at or very near the ends of bones far removed from periosteum. Haller believed that arteries were the bone builders of the body and could build bone anywhere within the limits of periosteum. As one commentator expresses the thought, the stage was all set for a play, even the audience was waiting, but no actors appeared on the scene.

The microscope had been invented sometime between the years 1590 and 1609, but until the latter part of the seventeenth century it remained more of a toy than an instrument to be used in scientific research. Consequently, osteoblasts, small vessels, and other minute structures were unheard of and unsuspected, as far as we know.

John Hunter (1728-1793) apparently was influenced more by Haller than by anyone else who preceded him. He repeated and elaborated upon Duhamel's experiments but arrived at still different conclusions. Hunter, following Haller's example, steadfastly maintained that periosteum had no bone building or producing power, insisting that the only function of the periosteum was to act as a "passive vascular membrane which surrounded and nourished bone." About 1754 he began his investigations on the human jaws and teeth. He noted that when a tooth was lost the corresponding socket was absorbed and disappeared; also that as the roots of the deciduous teeth were absorbed tooth-sockets were formed about the roots of the succeeding permanent teeth. Hunter seems to have been the first to record the fact that although the lower second deciduous molar was very close to the anterior border of the ramus, yet, as the permanent molars erupted, sufficient room was evolved between the site of the lower second deciduous molar and the ramus, for each additional tooth. In short, John Hunter seems to have been a very observing man and to have recorded many findings which apparently, heretofore, were unnoticed and unrecorded. Perhaps a few notes and quotations from his book, "The Natural History of the Human Teeth," might serve to show how valuable he was to the healing art.

He states that at birth the mandible is composed of two distinct bones but that these soon, after birth, unite into one at the symphysis. He goes into more detail in describing the lower jaw than the upper. The following quotation may serve to show his thought processes as well as his keen mind. "The alveolar processes of both jaws should rather be considered as belonging to the teeth, than as parts of the jaws; for they begin to be formed with the teeth, keep pace with them in their growth and decay, and entirely disappear when the teeth fall; so that, if we had no teeth, it is likely we should not only have no sockets, but not even these processes, in which the sockets are formed; and the jaws can perform their motions, and give origin to muscles, without either the teeth or alveolar processes. In short, there is such a mutual dependence of the teeth and alveolar processes on each other, that the destruction of the one seems to be always attended with that of the other."

In his reasoning as to why the "superior first and second grinders have three fangs" instead of two as in the lower, perhaps another quotation from this same book would be enlightening. "What makes it still more probable that the two first superior grinders have three fangs on account of the maxilary sinus, is, that the two grinders on each side of the upper jaw, in the child, have three fangs, and we find them underneath the antrum; but those that succeed them have only one fang, as in the lower jaw; but by that time the antrum has passed further back, or rather the arch of the jaw has projected, or shot forwards, as it were, from under the antra, so that the alveolar processes that were under the antrum at one age, are got before it in another. That the edge of every fang is turned towards the circumference of the jaw, in order to counteract the acting power, we shall see when we consider the motion of the jaw, and the use of the teeth."

In his chapter under "General comparisons between the motion of the jaw in the young and in old people" another quotation or two will serve to give us some conception of Hunter's idea of bone growth as it exists in the jaws. "In children who have not yet teeth, there does not seem to be a sliding motion in the lower jaw. The articular eminence of the temporal bone is not yet formed, and the cavity is not larger than the condyle; therefore the center of motion in the lower jaw must be in the condyle. In old people, who have lost their teeth, the center of motion appears to be in the condyles, and the motion of their jaw to be only depression and elevation. They never depress the jaw sufficiently to bring the condyle forwards on the eminence, because in them the mouth in sufficiently opened when the jaw is in natural position.

"Hence it is that in old people, the gums of the two jaws do not meet in the fore part of the mouth" (because the remaining body of the lower jaw is too far forward when the jaws are closed, for the two to make contact) "and they cannot bite at that part so well, as at the side of the jaw; and, instead of the grinding motion, which would be useless, where there are no grinders; they bruise their food rather by a simple motion upwards and downwards."

Hunter's chapter on "Growth of the Two Jaws" is one of the most interesting, from our standpoint, in this book. While it does not entirely agree with our present knowledge of bone growth, still there is a striking similarity to our conception. To quote in part from this chapter: "As a knowledge of the manner in which the jaws grow will lead to the better understanding of the shedding of the teeth, and as the jaws seem to differ in their manner of growing, from other bones, and also vary according to the age, it will be here proper to give some account of their growth.

"In the foetus three or months old, we have described the marks of four or five teeth, which occupy the whole length of the upper jaw, and all that part of the lower jaw which lies before the coronoid process, for the fifth tooth is somewhat under that process.

"These five marks become larger, and the jaw bones of course increase in all directions, but more considerably backwards; for in a foetus of seven or eight months, the marks of six teeth in each side of both jaws are to be observed, and the sixth seems to be in the place where the fifth was; so that in these last four months the jaw has grown in all directions in proportion to the increased size of the teeth, and besides has lengthened itself at its posterior end as much as the whole breadth of the socket of that sixth tooth.

"The jaw still increases in all points till twelve months after birth, when the bodies of all the six teeth are pretty well formed; but it never after increases in length between the symphysis and the sixth tooth; and from this time too, the alveolar process, which makes the anterior part of the arches of both jaws, never becomes a section of a larger circle, whence the lower part of a child's face is flatter, or not so projecting forwards as in the adult.

"After this time the jaws lengthen only at their posterior ends, so that the sixth tooth, which was under the coronoid process in the lower jaw, and in the tubercles of the upper jaw of the foetus, is at last, viz, in the eighth or ninth year, placed before these parts; and then the seventh tooth appears in the place which the sixth occupied, with respect to the coronoid process and tubercle; and about the twelfth or fourteenth year, the eighth tooth is situated where the seventh was placed. At the age of eighteen or twenty the eighth tooth is found before the coronoid process in the lower jaw and under, or somewhat before the tubercle in the upper jaw which tubercle is no more than a succession of sockets for the teeth till they are completely formed."

When we read his chapter on the formation of the alveolar process there are many passages that sound almost modernistic. "Having considered the alveolar processes in their adult, or perfect state, we shall next examine and trace them from their beginning.

"We observe the beginning of the alveolar process at a very early period. In a foetus of three or four months it is only a longitudinal groove, deeper and narrower forwards, and becoming gradually more shallow and wider backwards; instead of bony partitions, dividing that groove into a number of sockets, there are only slight ridges across the bottom and sides, with intermediate depressions, which mark the future alveoli.

"In the lower jaw the vessels and nerves run along the bottom of this alveolar cavity, in a slight groove, which afterwards becomes a complete and distinct bony canal.

"The alveolar process grows with the teeth, and for some time keeps the start of them. The ridges which are to make the partitions, shoot from the sides across the canal, at the mouth of the cell, forming hollow arches; this change happens first at the anterior parts of the jaws. As each cell becomes deeper, its mouth also grows narrower, and at length is almost, but not quite, closed over the contained tooth.

"The disposition for contracting the mouth of the cell, is chiefly in the outer plate of the bone, which occasions the contracted orifices of the cells to be nearer the inner edge of the jaw. The reason, perhaps, why the bone shoots over, and almost covers the tooth, is that the gum may be firmly supported before the teeth have come through.

"The alveoli which belong to the adult grinders are formed in another manner; in the lower jaw they would seem to be the remains of the root of the coronoid process; for the cells are formed for those teeth in the root of that process; and in proportion as the body of the bone, and the cells already formed, push forwards from under that process, the succeeding cells and their teeth are formed, and pushed forward in the same manner.

"In the upper jaw there are cells formed in the tubercles for the young grinders, which at first are very shallow, and become deeper and deeper, so as almost to inclose the whole tooth before it is ready to push its way through that enclosure and gum. There is a succession of these, till the whole three grinders are formed."

Hunter's description of the development of the tooth germs and formation of the enamel, together with ossification of the tooth as a whole, is a most detailed one. He also describes the tooth crypts and attachments of the developing tooth to the crypt walls, as well as the eruption of the teeth at the proper time.

In Hunter's description of the shedding of the teeth he shows an understanding far beyond that which might be expected. While he may have used the somewhat crude microscope of his day he apparently makes little or no mention of it at this time in his life.

However, his apparent understanding of bone growth, bone absorption, and deposition of new bone, is almost uncanny. The following interesting quotation from his chapter on "Shedding of the Teeth" gives us some idea of the advances made in knowledge pertaining to bone growth. "An opinion has commonly prevailed, that the first set of teeth are pushed out by the second; this, however, is very far from being the case; and were it so, it would be attended with a very obvious inconvenience; for, were a tooth pushed out by one underneath, that tooth must rise in proportion to the growth of the succeeding one, and stand in the same proportion above the rest. But this circumstance never happens; neither can it, for, the succeeding teeth are formed in new and distinct sockets, and generally the incisors and the cuspidati of the second set are situated on the inside of the corresponding teeth of the first set; and we find, that in proportion to the growth of the succeeding teeth, the fangs of the first set decay, till the whole of the fang is so far destroyed, that nothing remains but the neck, or that part of the fang to which the gum adheres, and then the least force pushes the tooth out. It would be very natural to suppose that this was owing to a constant pressure from the rising teeth against the fangs or sockets of the first set; but it is not so; for, the new alveoli rise with the new teeth, and the old teeth decay, and when the first set falls out the succeeding teeth are so far from having destroyed, by their pressure, the parts against which they might be supposed to push, that they are still inclosed and covered by a complete bony socket. From this we see that the change is not produced by a mechanical pressure, but is a particular process in the animal economy.

"I have seen two or three jaws where the second temporary grinders were shedding in the common way, without any tooth underneath; and in one jaw where both the grinders were shedding, I met the same circumstance."

Then he goes on to cite a case from his experience, of prolonged retention of a deciduous tooth which became loose when the lady was well past the age when the succeeding tooth should have been erupted and no succeeding permanent tooth ever erupted. He sums up his argument in the following manner: "These cases prove evidently that, in the shedding, the first teeth are not pushed out by the second set, but that they grow loose and fall out of their own accord. That the succeeding teeth have some influence on the shedding of the temporary set is proved by those very cases; since in one, the first mentioned, the person was above twenty years of age, and in the other the lady was thirty; and it is reasonable to believe, that the shedding of these teeth was so late in those instances from the want of the influence, whatever it is, of the new teeth. When the incisors and cuspidati of the new set are a little advanced, but long before they appear through their bony sockets there are small holes leading to them on the inside, or behind the temporary sockets and teeth; and these holes grow larger and larger till, at last, the body of the tooth passes quite through them."

Hunter seems to have been the first to realize that bone growth is in reality composed of two separate and distinct processes, namely, deposition of bone and absorption of bone, both of which may and ofttimes are carried on at one and the same time but in different sites within the same bone. He realized that as the medullary portion of bone enlarged it was due to the process of absorption occurring on the inner surface of the compact portion in the bone while at the same time new bone layers were being added to the external portions of the compact bone beneath the periosteum. This was a distinct advancement beyond the theory of Duhamel, whose idea seemed to be that while new bone material was being added to the circumference, there also occurred a sort of expansion in the compact bone, somewhat similar to the process of inflating a rubber balloon, or of adding minute particles of bone material between those already formed, which, in Duhamel's theory, accounted for the enlargement of the medullary cavity.

Hunter greatly extended madder feeding experiments beyond those of his contemporaries or his predecessors. For example, he fed two young pigs for a month on a madder diet, at which time he killed one pig but continued to feed the other on a madder free diet for an additional month before killing. He compared corresponding bones of these two animals and at certain points found portions of the madder stained bone had been absorbed while at certain other points new bone had been formed to an increased extent over the madder stained bone of the other experimental animal.

In the femur, for instance, he found that the upper surface of the neck was covered with new bone while the under surface or portion of the neck showed absorption of the madder stained area. In the mandible, that which had been the condyle and posterior border of the ramus was covered with new bone while the madder stained anterior border of the ramus was almost entirely absorbed. He sectioned all parts of bones for comparison and made many drawings in colors, which were placed in the Hunter Museum. Unfortunately most of the colorings have since faded. While your reviewer was unable to find any mention made of the changes occurring in the bodies of the mandible or maxillae still it is difficult to believe that

Hunter did not know that changes were also taking place there as well as in the ramus.

From Hunter we get our first conception of bone growth approximately coinciding with our present day knowledge, except for the fact that he, as well as other investigators up to that time, apparently had no inkling of the part played by animal cells or cellular activity in these phenomena. Still it is difficult to conceive how he was able to get so near the truth without the use of the microscope. In 1758 Hunter carried on a series of experiments which he felt proved that veins did not have the power to absorb bone although he did recognize that something or some system did have this property and he still maintained, together with his brother William, that the lymphatics were the "absorbents" of bone. But the impelling force which caused the lymphatics to absorb bone he did not know. While, at this period at least, he had missed the artisans, i.e. the living cells in bone, the wording of his conclusion could easily be said to embrace our present day knowledge of bone absorption. To quote again: "The remote cause of absorption of whole and living parts implies the existence of two conditions, the first of which is a consciousness, in that part to be absorbed, of the unfitness or impossibility of remaining under such circumstances, whatever they may be, and, therefore, they become ready for removal and submit to it with ease. The second is a consciousness of the absorbents of such a state in the parts. Both these concurring they have nothing to do but fall to work." (Collected works, Vol. 1, p. 255.)

It is almost uncanny how Hunter, with apparently no knowledge of cells or cellular life, could formulate such a conclusion that would or could, by any stretch of the imagination, embrace our present day knowledge of nearly two hundred years later. However, George Humphry, nearly sixty years after these conclusions were formulated, did supply many of the missing links and proved that Hunter's conception, in the main, was correct.

Charles White (born 1728, the same year Hunter was born), a surgeon, proved in 1768 that if the periosteum was retained in place after dead bone had been removed, that new bone would be formed. He had removed four inches of the upper portion of the humerus and four months later new bone had been produced leaving the arm only about an inch shorter than normal, but "the arms could be freely moved." White agreed with Hunter, "that when a bone was removed the arteries of the part had the power to renew it."

Syme in Edinburgh about 1840, while experimenting on dogs, removed whole segments of the radius and found that if the periosteum was retained the bone was reproduced and if a segment of bone, together with its periosteum, was removed the bone was not reproduced. When the periosteum was separated from the bone by tin foil new bone was formed between the periosteum and the tin foil, whereas if the periosteum was removed and tin foil wrapped around the bone, no new bone was formed over the tin foil.

John Goodsir (born 1814) was assistant to Syme for a time and was thoroughly familiar with Syme's work. Goodsir became one of the pioneers of the cell doctrine, then an entirely new conception of growth and repair of living tissues. With his compound achromatic microscope, Goodsir first studied the skeletons of invertebrate animal life, particularly sponges, and guessed that human skeletons grew in much the same manner. He studied cartilage cells in growing epiphyseal lines of bones and the transformation from cartilage to bone. He believed the living cells of Haversian canals were direct descendents of cartilage cells. He had proved that similar cells had built up the skeletons of sponges and concluded that a similar process entered into the building of all animal skeletons.

Goodsir observed the same kind of cells or "corpuscles," as he termed them, lining Haversian canals beneath the periosteum and within the canalicular spaces. He was the first to realize that absorption and reproduction of bone were results of living cell activity. In studying the skeletons of sponges he found that spicules composing this skeleton took on many forms but that each was built "to strengthen and keep open the water canals." These sponge spicules were formed in position, shape, and size where most needed to keep the canals open and to support the sponge in the moving water in which it lived. Goodsir concluded that bone growth and repair required at least particles of preexisting bone, as well as sufficient nourishment. He looked upon periosteum, bone cells, and particles of bone adherent to it as a "limiting membrane" to bone growth.

At almost the same time that Goodsir in Edinburgh was proving that "bone corpuscles" produced and absorbed bone tissue, Marie Jean Pierre Flourens (1794-1867) was repeating and extending Duhamel's conception that periosteum was the maternal tissue of bone, also that Hunter's conception, namely, that "absorption of bone was constantly taking place and that the substance of every living bone was constantly in a state of flux," were correct.

Louis Ollier (born 1830) microscopically examined the structure of periosteum and found, in a cross section, a "gradual transition of structure from its superficial to its deep surface." He found osteoblasts on and within the deeper portions of the periosteum and while those cells might be widely scattered in adult periosteum, that irritation of bone, for example by injury, soon increased the number of osteoblasts in that region.

From Ollier we gain almost our first recorded knowledge that experimental physiology furnishes us the foundation of our knowledge of bone behavior, whether from a surgical or an orthodontic viewpoint. Ollier found that bone grafts from young animals held better than those from adults, and we, as orthodontists, have also found that bone absorption and rebuilding is more rapid in the young than in the adult. Ollier further found that grafts of long bones held better than those of flat bones, and that bone was deposited in the region of epiphyseal discs so long as the discs remained attached to the original bone.

He carried on a great many experiments and as a result became more and more a follower of Duhamel in the belief that periosteum was the all important factor in bone growth and reproduction. By bone growth we should keep in mind his idea of a dual process occurring in bone, namely, that there is deposition of new bone material and absorption of parts, at least, of the old bone, going on at the same time. These experiments were carried on over a period of approximately ten years, beginning about 1857.

About seventy years after Goodsir's experiments were made, William Macewen "removed the shaft of the radius from a young dog, leaving merely the epiphyseal discs. In six weeks the shaft was reproduced, not from the periosteum, but from the diaphyseal discs. The point of meeting between the parts of the shaft produced from the proximal and distal discs could still be seen in the restored radius. To make certain that his interpretation was correct he removed two and one half inches from the shaft of a young dog's radius, and covered the cut ends with a metal cap. In seven weeks the caps had met."

Among these early investigators of bone growth, two theories had sprung up. Duhamel and his followers were sure of the osteogentic properties of periosteum—that periosteum formed bone, while Haller and Hunter and their followers believed just as firmly that periosteum merely limited the growth of bone. Later, when the compound microscope came into use, osteoblasts and other cells, together with cell life or cell activity, were looked upon as the producers of bone growth. It will be noted that most of these early research workers on bone growth studied the long bones rather than the bones of the head and face, with the single exception of John Hunter.

The material contained in this paper has been gathered from many sources. However, the writings of John Hunter and Sir Arthur Keith deserve particular mention. Your essayist also feels very deeply indebted to the members of the Library staff of the University of Nebraska Medical School and Creighton University Dental School for invaluable assistance in gathering the data herein presented.

Bibliography

Cheselden, William—Anatomy of the Human Body. London, 1713. Also Osteography, or Anatomy of the Bones. London, 1733-v.2.

Duhamel, Henri Louis—Nouxelles recherches concernant l'action de la garance sur, les os. Gaz. med, de Par 1840,2,s,VIII,107;161-184,2,s,IX,113-116. Nouvelles recherches sur: le develloppement des os. Ann. de la chir. franc et etrange. Par. 1841.111,257-306. Also 1843—VIII,84-98.

Goodsir, John—The mode of reproduction after death of the shaft of a long bone. In his. Anat. Path. Obs. 8 Edinb. 1845, 68-73

Haller, Albrecht von—Primae Linae Physiologiae. 1747. Elementa Physiologiae. Corporis Humani, 1757-1766. Bibliotheca Anatomica. 1774. Bibliotheca Medicinae Practicae, 1776-88.

Hunter, John—The Natural History of the Human Teeth. 1778.

Macewen, William—De la transplantation des os; experiences de transplantation osseuse inter-humanine. Compt. rend. Acad. d sc. Par. 1881, XCII; 1470-1472.

Keith, Sir Arthur—British Medical Journal, 1919, Vol. 2, 485-487.