which might even, when provoked, become a little biting. It took time and some skill to penetrate an outer film of reserve which arose from innate modesty and shyness, but once beneath that protective covering, one readily discovered in him a simple, idealistic and gifted person of many sides, possessed of an almost miraculous power to stimulate students to put forth their best efforts. His memory and example will long survive in the achievements of his students and associates, in the broad ideas which he disseminated, and in the admiration and affection which he inspired.

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FRANKLIN PAINE MALL: A REVIEW OF HIS SCIENTIFIC ACHIEVEMENT[1]

To those who are familiar with the history of medicine in this country, it is a matter of common knowledge that at the time Dr. Mall began his career, thirty years ago, anatomy in America had no scientific standing—a mere tool of surgery with but a single method, that of dissection. He left it where it must be in any community where medicine is progressive, one of its greatest sciences. He left it richly endowed with technical methods, a science so truly fundamental that workers in every other branch of medicine are constantly and increasingly returning to it, both for methods and for results. The vision of this change must have been his while he was yet a student for he wrote in one of his letters:

> My aim is to make scientific medicine a life work. If opportunities present, *I will*. This has been my plan ever since I left America and not until of late (since having received encouragement) have I expressed myself. I shall no doubt meet many stumbling blocks, but they are anticipated.

Sweeping aside the traditions of the dissecting room, he first created conditions under which this change could develop, and then devoted himself to scientific achievement and to the type of teaching in which he was profoundly interested. It was one of his oft-repeated maxims that the best and perhaps the only great way to teach is by example. With the ideal of scientific work as his goal, he has left us an example so rich in ideas, so varied in technical methods and so representative of the range of anatomy and embryology, that a study of his work is both an inspiration and an education.

His first undertaking in the field of research serves well to illustrate his independence of thought which, to those who knew him, was most striking. During the winter of 1885 he began his scientific work under His at Leipzig, who gave to him a problem connected with the gill-arches in the chick. In this study he came to the conclusion, now generally held, that the thymus arises from the endoderm of the pharynx, notwithstanding the fact that His held the view that it came from ectoderm. This work was given to His as Dr. Mall was leaving for Baltimore and was accepted for publication. In the next number of the journal of which His was editor, there appeared a second communication from the latter, strengthening his own point of view, but announcing that a different opinion would be published by one of his pupils in the next number. When Dr. Mall's article appeared, it was with a damaging footnote by His, to the effect that the independent character of the results was obvious. Two years later His restudied the region in a human embryo and found that Dr. Mall's conclusions were correct. He gave due acknowledgment of this in an open letter to

[1] Address given at a meeting in memory of Franklin Paine Mall held at the Johns Hopkins University, February 3, 1918.

Dr. Mall in the same journal, in which he states frankly, "Sie haben gegen mich Recht." This letter cemented a lifelong friendship, as can be readily seen from correspondence accompanying Dr. Mall's article on "An Estimate of the Work of His."

During the winter of 1885, His suggested that Dr. Mall work under the great physiologist, Ludwig. As Ludwig's laboratory was always full, the opportunity was slow in coming; indeed, as Dr. Mall wrote home, he was leaving Leipzig with no hope; his trunk was even on the way to the station when the letter came that the opportunity he so much desired was his. So great was the influence of Ludwig over his mind, character and future work, that it is impossible to overestimate it. He himself summed it up in these words: "To that master I owe much—all." Ludwig assigned to him the study of the villus of the intestine. His first impression of his new problem, as gathered from one of his letters home, was that here was a subject which had occupied the minds of the greatest anatomists of the past century. Repeatedly throughout Dr. Mall's writings there is to be found that expression of regard for the work of great minds. Widely read in his own subject, it was of the works which have lived that he made a profound study.

In Ludwig's laboratory Dr. Mall learned the methods of injecting blood-vessels and lymphatics, and his studies on the vascular system of the intestine and stomach are familiar to every student of medicine. Under the influence of Ludwig, his work was characterized by a very strong physiological bent. Indeed it may be said that his work was physiology in the hands of one with an intense interest in structure.

In some of the foreign universities it was the custom for a new incumbent of a chair to deliver an address giving, as it were, a "prophecy" or a "program" of his future work. Such a program was the famous address of His on accepting a chair in the Swiss University of Basel. In some such way the article of Dr. Mall on the stomach, published in the first volume of the Johns Hopkins Hospital Report, gives his program of the way he proposed to study anatomy. This paper lays a foundation for what may be called physiological anatomy. He studied the stomach from every aspect and with a wide range of methods. Here is the beginning of his brilliant work on the fibers of the connective tissues; here the studies on the normal contraction-wave of smooth muscle and the experiments on the reversal of those waves. In his paper on the stomach is this brief note:

> Recently I have found that irritation of the splanchnic nerve causes contraction of the mesenteric vein.

He probably first made this observation in Ludwig's laboratory and subsequently proved that the portal vein is supplied with vasomotor nerves, a valuable discovery in physiology.

The most important idea of this early work from the standpoint of anatomy is that of structural units, which Dr. Mall conceived from the study of the villus. The theory reaches its best expression in Dr. Mall's articles on the liver and spleen. It is that organs are made of ultimate histological units, represented in the vascular system by the capillary bed which intervenes between a terminal artery and its corresponding vein. Thus the size of the unit is determined by the length of the capillary. These units are grouped together into lobules. They are not only of great structural significance, since an organ is to be considered as a multiplication of them, but they are also of significance to physiology since such units are equal in

function. This equality of size and function comes from the laws of growth; when a unit increases in size so that the length of its capillaries increases beyond the norm, a new artery develops, the single unit splitting into two.

In his study on the spleen Dr. Mall brings out best the relation of all the tissues of an organ to its function. Thus he showed by experiments that the vessels of the spleen are emptied by the contraction of the bands of muscle on the trabeculae and that the fibers of these same trabeculae are so arranged as to distend the veins and compress the arteries as the muscles contract.

One of his valuable contributions is the study of the structure of the heart. He grasped the significance of the work of Krehl, which he said bore the stamp of Ludwig. In this work it is to be seen that the atrio-ventricular rings are tendons of origin for the bands of heart-muscle. In 1900 he gave the study of the bands of heart-muscle to John Bruce MacCallum, who unraveled the ventricles of the heart in the embryo pig into superficial and deep spiral bands with their origin and insertion in two tendons, the atrio-ventricular rings and the chordae tendineae. As a tribute to this brilliant work, Dr. Mall completed the study on the adult human heart after MacCallum's death, reducing the problem to the following simple terms: To understand the beat of the heart one must figure out how a muscular bag is constructed so as to empty itself. We have Dr. Mall's specimens in the laboratory showing how the spiral bands contract with each beat of the heart in the exact familiar pattern of wringing out a rag.

Another line of work which interested him greatly was the study of the brain. Here he was drawn to the anthropological side. Dr. Hrdlicka, the anthropologist in Washington, had said to him that the brain of a negro could be distinguished from that of a white man and with this in mind Dr. Mall made a comparative study of the brains in the anatomical collection, comparing them by weights, the complexity of their convolutions and other criteria. Realizing that no man can free himself of prejudice, he charted all of his data by means of numbers, filling in the race and sex only after the charts were complete. In this way he showed that the crude, present-day methods are inadequate for scientific deductions regarding the relation of the brain to race and sex. Of the criteria on race, there remains only the difference in the shape of the brain corresponding to the well-known shape of the head.

In his anatomical studies Dr. Mall has enriched his science with a wide range of methods. Our laboratory is full of examples of beautiful injections, corrosions of blood vessels, preparations of connective tissue made by maceration, cleared embryos to show the development of the skeleton and many others. His own methods of work in the laboratory are of great interest and he frequently discussed the influence of Ludwig in this connection. Contrary to the usual type, Dr. Mall was far more active mentally than physically. I have known him to think and plan with the greatest care so that a bit of routine might be simplified. Thus it was his habit to think out every detail of an experiment before he undertook it; he never employed the system of trying a thing out without adequate preparation or of approximating his methods through errors. For this reason he made but one experiment a day. If it failed, he would not repeat it until the next day, thus giving himself ample time to think out the reasons of his failure.

He was intolerant of the collection of unanalyzed material. His interest in technical procedures was only in their bearing

upon solving problems; it lay in understanding principles rather than in multiplying evidence.

We have outlined Dr. Mall's work in anatomy as it grew out of his study in Ludwig's laboratory. But he was not only an anatomist, he was also an embryologist. In 1891 he published an account of a normal human embryo, now placed in the fourth week of development. He made a most careful and accurate study of all of its systems, illustrated by the surface form, by models and casts. This was the first human embryo ever modeled in America and at that time it was the most complete account of any human embryo in existence. In this study he announced several discoveries, for example, that the Eustachian tube and the middle ear arise from the first branchial arch. The effect of this work on Dr. Mall is to be seen in these words in one of his publications:

> I always think in human anatomy in relation to this embryo.

Dr. Huber has said that this study has served as a model for all future work of its type. It did more for, like his work on the stomach, it represents as it were, Dr. Mall's program in embryology. This specimen forms the foundation of the priceless collection of over two thousand human embryos which Dr. Mall later gave the department of embryology of the Carnegie Institution of Washington. It was perfect, beautifully fixed and sectioned. When he had finished the description of it he offered it as a tribute to his teacher, His. His returned it, with several others of his own, expressing the wish that they might be the nucleus for a much larger collection. How richly has this gift borne fruit in the development of the science of embryology!

In the study of embryonic development, three names stand out in logical sequence, von Baer, His, Mall. Neither His nor Dr. Mall were concerned with the phenomena of maturation, fertilization or the cleavage stages, in the development of the embryo, but the latter has characterized the work of His as laying a foundation for histogenesis. In like manner the work of Dr. Mall in normal embryology may be summed up in the term organogenesis. He has traced the growth of organs up to their adult stage. He has laid the foundation for a complete anatomical survey of the human embryo in all stages of its development. Here, for example, belong his studies on diaphragm and the ventral abdominal walls and more strikingly his studies on the development of the loops of the intestine. These he followed from their beginning up to their position in the adult, he then determined their normal position in the adult by studies in the dissecting room, and by experiments on animals he showed that both the intestine and the omentum seek their normal position when disturbed. Of this work His wrote:

> Your satisfaction in your work will be lasting, because you have brought light into a field which was so obscure. The thing which has been lacking in all of our studies on development up to this time has been observations on the transition between the early embryonic and fetal stages up to the form of the adult. For the intestine you have given the entire study from the beginning up to the end, and I regard it a great step in advance.

It is in connection with the development of the vascular system that Dr. Mall made some of his most significant contributions to embryology. One of the most important points in the study of the embryo just mentioned was solving the problem of the primitive ventral branches of the aorta. This he did by showing that the vessels which are the forerunners of the celiac axis arise as far forward as the first dorsal segment and by indicating the method by which they shift back to their position in the adult. This work has since been repeated

with more specimens, but not analyzed with more insight. I recall in connection with these more elaborate subsequent studies on this subject, one of Dr. Mall's characteristic comments: "I can never become interested in the mere collection of new examples after a principle has once been thoroughly established." In connection with the study of the development of the vascular system the two lines of thought embodied in Dr. Mall's earlier work converge. These two generalizations I understand to be, first, that he approached anatomy from the standpoint of how structure is adapted to function, a different idea from that of the study of pure morphology, and secondly, that he saw the value of organogenesis to the study of anatomy. He carried over to embryology the methods of injecting blood-vessels and lymphatics in use for the adult and thereby made possible a complete account of the spread of vessels in the embryo. In the study of the vascular system he emphasized again and again the value of the study of an organ as a whole. Trained by the man who invented the microtome and himself making many improvements on it, he reacted strongly against those anatomists who study only sections. He was interested in the architecture of an organ; to use one of his own phrases he had "a feeling for structure." Indeed, he has often said that if he were to choose a career again, it would be that of an architect. His gift in anatomy, like the gift of the sculptor or the architect, was the power to visualize structure in three dimensions. Thus, one can understand his pleasure in the studies of the architecture of the vessels of organs, given not in indefinite terms, but showing the exact pattern of all vessels, the number and the relations of the orders of arteries from the main to the terminal branches. Thus he has left us a rich heritage of corrosions of the vessels of various organs which is worthy of a place in the great scientific museums of the world.

During the later years of his life, Dr. Mall became more and more interested in the problems associated with his collection; that is to say, in the type of problems for which institutes for research are founded, those that depend upon that analysis of large amounts of material and the cooperation of experts along closely allied lines. These problems touch more and more closely clinical medicine and social welfare. Such, for example, is the study of abnormal embryos, leading up to the analysis of their frequency and causes, the normal curve of growth, the determination of the age of the embryo and the causes of sterility and abortion. He first became interested in the study of abnormal embryos through separating the normal from the abnormal in his collection. His first general account of abnormal embryos was in the volume of the Johns Hopkins Hospital Reports published in honor of Dr. Welch in 1900. Eight years later he published a monograph on monsters, of which Morgan wrote:

> The recent publication by Mall on the causes underlying the origin of human monsters marks an epoch in the study of teratology in this country, for he has treated the subject with a breadth of view and a wealth of illustration rarely found in the handling of this complex question. Mall has brought to the task a profound knowledge of the older literature of the subject, an appreciation of the most modern results in experimental teratology, and a thorough familiarity at first hand with the subject of human monsters. The physician and anatomist are brought into close touch with work generally supposed to be outside their proper field; and on the other hand, the student of malformations in the lower animals will be made to appreciate the inexhaustible supply of human materials with which the anatomist and physician are familiar.

In this study and during the last six years, Dr. Mall has given a masterly analysis of the causes of monsters. He has shown

that from the earliest ages of the world's history the study of monsters has been one of the capital problems of anatomy, medicine and natural history; that the belief in supernatural causes gave way to the theory of maternal impressions, and that this must now give way to a scientific analysis of their causes. Dr. Mall recognized that a few abnormalities, polydactyly, for example, are germinal and can not be produced experimentally; but that monsters are not due to germinal or hereditary causes, but are produced from normal embryos by influences which are to be sought in their environment. The cause of monsters, he has indicated, lies buried in the non-committal term of faulty implantation. In his recent paper on cyclopia he has fully analyzed the meaning of recent experimental embryology. He showed that as soon as Stockard succeeded in experimenting with eggs in such a way as to produce cyclopian monsters at will, the explanation of the process was at hand, for the work demonstrated that a slight change in chemical environment, acting at a critical time, caused cyclopia. Dr. Mall studied the cyclopian monsters in his collection, one of which is at a stage where a complete analysis could be made, and in conclusion he says:

> It seems to me that the studies based upon our collection of embryos, as well as recent investigations in experimental embryology, set at rest for all time the question of the causation of monsters. It has been my aim to demonstrate that the embryos found in pathological human ova and those obtained experimentally in animals are not analogous or similar, but identical. A double monster or a cyclopian fish is identical with the same condition in human beings. In all cases monsters are produced by external causes acting upon the ovum.

Thus, most localized abnormalities and monsters, of which he gives a wealth of illustrations, can be traced back to the faulty nutrition of the embryo at early critical stages, and the effects can be followed with every grade of intensity, from complete degeneration of the ovum to monsters which survive to term. One of his most interesting deductions is that in some forms of faulty implantation there results a dissociation of the tissues of the embryo, so that they grow exactly as do the cells in the experiments with tissue cultures, without the correlating forces which check and integrate the organs in normal development. It is to my mind a significant example that this work has been carried on during the years given to the organization of a new institute, that is to say that Dr. Mall so planned the work of administration that it did not check research. It is not too much to say that this work of Dr. Mall's opens up a new field, and that it has already formed a broad foundation on which all future study of abnormalities must rest. Such was the work with which he was engaged at the time of his death. In his vision of an institute for embryological research, he saw that the two great lines of work in which he was most interested could be brought to a successful conclusion within a reasonable limit of time. First, that the full development of the study of organogenesis could give us a completely rationalized anatomy; second, that there is a group of problems such as the determination of the curve of growth, the study of abnormalities and their causes, normal and abnormal implantation which may perhaps be brought together under the heading of the study of the laws of growth, which lie beyond the powers of a single individual and thus must be attacked through organized research. Often he said during the latter months of his life: "My work is mapped out for the next ten years." Fortunately in his "Plea for an institute of human embryology" and in some unpublished manuscripts some of these plans are

recorded; but for the loss of those coming years that would have given us his greatest achievements, those achievements for which his whole life has been the preparation, no philosophy can console us. About a month before his death he put the question to me: "What would you say had been the effect of the Carnegie Institute of Embryology upon this laboratory?" to which I replied: "It has lifted the research of the place from a somewhat amateurish to a more professional state." Never shall I forget the pleasure in his face as he replied: "It is exactly what I wished to do." Such was his aim, such the ideal from which he had never swerved from the very beginning of his career.

No account of Dr. Mall's scientific work is complete without a mention of his contribution in the training of others. Of teaching he had the highest ideal. He once said: "What higher title could there be than that of a great teacher?" That he himself was one of the world's great teachers will be realized when his influence in the development of medical education in this country is adequately analyzed. To the general problems of education he gave deep thought and great originality. His own teaching was characterized by two broad principles, which were followed in his laboratory; first, that each student might approach his work in the spirit of a discoverer. Second, that since in each class there may be those who are destined to become the intellectual leaders of the next generation, liberty in education is essential in order that the strong personality might develop. In regard to the meaning of liberty in education, I shall venture to be specific in two points: He held that in the planning of courses in the laboratory, the directions for work should not be so minute and specific as to eliminate a student's initiative; and that his time should not be so completely filled with prescribed work that he could not follow his own bent in some line.

Dr. Mall's methods of training others were unique—so bound up with his own rare personality that none could copy, and few describe them. He had a gift, perhaps a genius for stimulating thought. Rarely indeed by question, the quiz he never used; it was more in the nature of an occasional suggestion, the acuteness of which impressed one more and more profoundly as one pondered over it. Perhaps his most fundamental quality was his rare generosity. I recall distinctly an instance in which a student had worked carefully and accurately with him without, however, understanding the meaning or the value of his observations. The student became discouraged and had decided to give up the work when Dr. Mall asked for his notes, and later published a very interesting paper under the student's name. This incident is the more interesting in connection with one of Dr. Mall's letters, written in the early days of the medical school when he was homesick for the laboratory of Leipzig. He told therein that before leaving Leipzig he had given some incomplete studies to Ludwig, evidently expecting him to use them in his own work, but that Ludwig had added experiments and published all under Dr. Mall's name. He then concluded, "Can you blame any one for wanting to return to one who would do things like that?" Ludwig, he wrote, was entirely without selfishness, and that when he tried to thank him for all he had done, he replied, "Pass it on." This indeed became the great watchword of Dr. Mall's life. Most freely did he give his ideas and his energies to his students. You will find no joint research with his students, for all that he gave them he meant to be theirs. He demanded in return the development of high standards of

work. In fact, perhaps the most lasting effect which he made upon the minds of his followers was the value of scientific standards and the meaning of ideals in research. He never gave first-hand praise; the only encouragement which a student received was a genuine interest in his work shown in such a way that the student came to find enjoyment where Dr. Mall found his—in the work itself. Many of his informal talks in the laboratory were on general topics or on principles rather than the specific development of research, and so general, so whimsical were these discussions that their meaning was lost entirely upon more than one student.

In directing departments there are certain leaders who train the students only in their own problems, giving little scope for independent work. Dr. Mall on the contrary was keen to give opportunities to those who could develop an independent line of research. Thus, for example, in his laboratory he developed the method of tissue-culture. Again, though his own work did not lead him into the newer fields of cytology, he saw to it that this work was represented. An even more striking example is that he was the first to see that the methods of anthropology might be applied with great value to the study of embryology; hence he brought into the department of embryology professional anthropologists thereby widening the scope of the science of embryology.

Closely bound up with his own scientific achievements is the part he played in the development of scientific publications in this country. According to his own account when he started out he hoped that the excellent *Journal of Morphology* would care for all the more complete publications of the laboratory, but it became hampered financially and finally suspended publication in 1903. During a term of years, those in the laboratory well remember that he constantly discussed the feasibility of establishing a new journal. At a meeting of the Anatomists held in Baltimore in 1900, a committee was formed to launch the *American Journal of Anatomy* and its first number appeared the following November. In 1906 followed the *Anatomical Record,* both published first in Baltimore. In 1908, when the *Journal of Morphology* was revived by the Wistar Institute of Anatomy, it was with Dr. Mall's work on monsters as its first number. More striking still as an example of Dr. Mall's ideas of developing scientific publications in this country, are the new Contributions to Embryology, published by the Carnegie Institution of Washington. His originality, far-seeing vision and courage for undertaking new enterprises could not be better illustrated than in connection with these journals.

In his introduction to the article on His, Dr. Mall wrote these words:

> The ancient science of anatomy has been perpetuated during many centuries by great men who have dedicated their lives to it. The list is a long one, for the development of science has been slow and progressive from the earliest ages up to the present time; we find in it, on the one hand, some of the names of the greatest who ever lived—Aristotle, Vesalius—on the other, the names of those who rank as leaders of a generation, Bichat, His.

With Bichat and His belongs the name of Mall. His name will be associated with the strongly physiological bent of modern anatomy, with the laying of a broad foundation of organogenesis in embryology, and with the vision of a broadening of the scope of embryology so as to bring it into relation with the problems of clinical medicine and social welfare. In America, his place is unique; it goes without saying that he was our greatest anatomist. More than any other man in American medicine, he had led his generation into the way of research.

FLORENCE R. SABIN