Popular Science Monthly/Volume 12/April 1878/The Source of Muscular Power

THE SOURCE OF MUSCULAR POWER.

THE advance of modern research has brought the sciences of physics, chemistry, and physiology, into very close relations, and as the two former have given great help to the latter, many are looking to see all physiological problems finally resolved on physical and chemical principles. Much is to be expected from the future, but sanguine anticipations should not be allowed to misinterpret existing facts. Prof. Austin Flint, Jr., has been much occupied in investigating the living system as a dynamical engine, and has published the results of his experimental inquiries in a little volume, entitled "The Source of Muscular Power." He has made an important contribution to the subject of animal mechanics, and his views will be so interesting, alike to the physiologist and the general student, that a summary of his argument will be appreciated by the readers of the MONTHLY.

Since it has been ascertained that the force derived from chemical action which will raise the temperature of a pound of water 1° Fahr. will, under another form of manifestation, lift 772 pounds one foot high, 772 foot-pounds have been regarded as the force-equivalent of 1° of heat. In other words, if the burning or oxidation of a certain definite weight of matter will raise the temperature of one pound of water 1° Fahr., the force-value of this matter is said to be 772 foot-pounds.

In the animal economy, certain matters are taken in and consumed as food; matters are discharged from the body in the form of excretions, such as the constituents of the urine; a certain amount of heat is produced in the body in order to maintain the animal temperature, to supply the loss of heat dependent upon radiation from the surface; a certain amount of force is exerted in the processes of circulation of the blood and in the respiratory movements, and a certain amount of work is performed by muscular action. If it be assumed that the oxidation of matter in the animal economy involves, of necessity, either the production of heat or of force, an answer to the following question becomes at once of great importance as regards our ideas of the immediate source of muscular power:

Is the food directly oxidized in the perfected and adult animal organism, the result of this oxidation being heat and force, and is this the single source of muscular power, or is the perfected animal organism, particularly as regards the muscular system, itself consumed gradually as a result of muscular work, the waste of muscular tissue being represented by the excretions, and such waste being repaired constantly by food? To state this question in simpler terms, is the muscular system a part of a machine that consumes food as fuel in the production of force, not wearing its own substance to any considerable extent, or does the muscular system use its own substance in the production of force?

Before 1866, the following ideas, formulated by Liebig, Lehmann, and others, were pretty generally accepted by physiologists:

The muscular substance, which constitutes about two-fifths of the weight of the entire body, is composed mainly of matters containing carbon, hydrogen, oxygen, and nitrogen, in contradistinction to the fats, which contain only carbon, hydrogen, and oxygen. The most important excrementitious matter thrown off by the kidneys is urea, which contains carbon, hydrogen, oxygen, and nitrogen. The amount of urea excreted is to be regarded, to a certain extent, as a measure of the physiological wear of the muscular system, which wear is increased by muscular exertion, there being a corresponding increase in the excretion of urea by the kidneys. This wear of the muscular system is being constantly repaired by the nitrogenized elements of food. In discussing, then, this question, physiologists have come to speak of the excretion of nitrogen as measuring, more or less accurately, the physiological wear of the muscular system.

In 1866, two German physiologists, Fick and Wislicenus, ascended one of the Alpine peaks, and measured the influence of this unusual muscular exertion upon the excretion of nitrogen. As it is well known that the quantity of nitrogenized food, such as meat, eggs, etc., influences the amount of nitrogen excreted by the kidneys, these observers confined themselves to a diet without nitrogen during the ascent and for a number of hours immediately preceding and following. They found that the amount of nitrogen eliminated by the kidneys was diminished during the muscular exertion by about one-third. From these experiments, they concluded that muscular exercise does not increase the elimination of nitrogen, but rather diminishes it; and from this time dates the proposition, which is now adopted by many physiologists, that the muscular system is a machine which consumes food as fuel, and does not wear its own substance to any very great extent in the production of force. Fick and Wislicenus advanced the view that "the substances, by the burning of which force is generated in the muscles, are not the albuminous constituents of the tissues, but non-nitrogenous substances, either as fats or hydrates of carbon."

Such a doctrine as that advanced by Fick and Wislicenus, according to Prof. Flint, is not logical and is opposed to many well-known physiological facts. The arguments he advances against it are the following;

1. Physiological experiments should be made under strictly natural or physiological conditions of the system. A non-nitrogenized diet is not natural. No man would attempt to perform a feat of muscular endurance under a diet composed exclusively of fat, starch, and sugar, which was the exclusive diet of Fick and Wislicenus.

2. Lehmann has shown that an exclusively non-nitrogenized diet, of itself, without any variation in muscular exercise, will reduce the excretion of nitrogen by the kidneys more than one-half. Pavy has shown the same effects of non-nitrogenized food upon the system without any variation in muscular exercise.

3. Fick and Wislicenus do not show that extraordinary muscular exertion, with a non-nitrogenized diet, diminishes the excretion of nitrogen below the point to which it would be reduced by the diet itself, without muscular work; for they made no comparative experiments with a non-nitrogenized diet and no unusual exercise.

In view of these facts, the conclusion arrived at by Prof. Flint is, that the experiments of Fick and Wislicenus fail to show that muscular exercise diminishes, or even does not increase, the elimination of nitrogen, which is the very essence of their argument.

In 1870, Prof. Flint made a series of elaborate experiments upon Weston, during a walk of three hundred and seventeen and one-half miles in five consecutive days. Recognizing the fact that the elimination of nitrogen bears a certain relation to the nitrogen of the food, in these experiments, Prof. Flint estimated the nitrogen of the food and calculated the proportion of nitrogen excreted to the nitrogen ingested, which had never been done in any previous experiments upon the physiological effects of muscular exercise. His observations were continued for five days before the walk, the five days of the walk, and five days after the walk. Prof. Flint, or his assistants, were with Weston, day and night, for the entire fifteen days. Every article of food was weighed or measured, and its nitrogen carefully estimated, as was the nitrogen excreted. The variations in body-weight, temperature, etc., were also taken. No accident occurred, and the observations were absolutely complete. The most important general results of these experiments were the following:

For the five days before the walk, the average daily exercise being eight and one-fifth miles, the average proportionate excretion of nitrogen by the kidneys was 86.58 parts for every 100 parts of nitrogen of food.

For the five days of the walk, the average daily exercise being sixty-three and one-half miles, the average proportionate excretion of nitrogen by the kidneys was 143.98 parts for every 100 parts of nitrogen of food.

For the five days after the walk, the average daily exercise being two and one-fifth miles, the average proportionate excretion of nitrogen by the kidneys was 77.03 parts for every 100 parts of nitrogen of food.

These facts showed conclusively that, in this instance, at least, the extraordinary exertion of walking three hundred and seventeen and one-half miles in five consecutive days very largely increased the proportionate excretion of nitrogen by the kidneys.

The source of the excess of nitrogen excreted during the walk must have been the excessive wear of muscular tissue engendered by the extraordinary exertion, which was not repaired by the food. This is rendered almost certain by the following calculation:

At the beginning of the walk, Weston was in good condition, with little or no fat, and he weighed 119.20 pounds. "At the end of the five days' walk, the weight had been reduced from 119.20 to 115.75 pounds, showing a loss of 3.45 pounds. According to Payen, three parts of nitrogen represent one hundred parts of fresh muscular tissue. The total quantity of nitrogen discharged during these five days was 1,811.62 grains. The total nitrogen of food during the same period amounted to 1,173.82 grains, giving an excess of 637.80 grains of nitrogen discharged over the nitrogen of food. The 637.80 grains of nitrogen, according to Payen's formula, would represent 21,260.00 grains, or 3.037 pounds of muscular tissue. The actual loss of muscular tissue was 3.45 pounds, and the loss unaccounted for, amounting to only 0.413 of a pound, is very small. It might be fat or water, or the difference might be due to inaccuracies in the estimates of the nitrogen of food, which, of necessity, were approximative."

In 1876, Dr. Pavy, of London, made a series of experiments upon Perkins, a pedestrian, and upon Weston, similar to those made by Prof. Flint upon Weston, in 1870. The following were the general results of these observations:

Perkins walked sixty-five and one-half miles in twenty-four hours. During this time, he excreted 190.37 parts of nitrogen by the kidneys for every 100 parts of nitrogen of food. For twenty-four hours of rest, several days after this walk, Perkins excreted 76.58 parts of nitrogen by the kidneys for every 100 parts of nitrogen of food.

Observations were made upon Weston for eleven days of walking, as follows: 1. A walk of one hundred and eighty and one-half miles in two consecutive days; 2. A walk of two hundred and sixty-three miles in seventy-five consecutive hours; 3. A walk of four hundred and fifty miles in six consecutive days. The proportionate excretion of nitrogen was estimated for these periods of exercise, and was also calculated for eight days of rest. The daily average excretion of nitrogen for the eight days of rest was 60.90 parts for every 100 parts of nitrogen of food. The daily average excretion of nitrogen for the eleven days of walking was 87.34 parts for every 100 parts of nitrogen of food—an increased proportion of 43.44 per cent. These experiments, like those of Prof. Flint, show a very great increase in the proportionate excretion of nitrogen produced by the excessive and prolonged muscular exertion.

Dr. Pavy admits, as the result of his own experiments, the simple fact that muscular exercise increases the proportionate excretion of nitrogen, but he does not accept the view advanced by Prof. Flint, that the muscular system, in exerting force, consumes its own substance, and that this substance is repaired by food. Dr. Pavy made a series of calculations, in connection with his experiments, comparing the force-value of the excess of nitrogen excreted during exercise over the nitrogen excreted during rest with the work actually performed in walking. He attempted to show that the force represented by this excess of nitrogen excreted would not account for the work accomplished. These calculations of Dr. Pavy involve formulas for reducing miles walked to foot-pounds, and estimates of the force exerted in respiratory movements, the action of the heart, etc. Prof. Flint, in his essay, gives an elaborate review of these calculations, and objects to many of the formulæ as necessarily inaccurate. It is impossible, in a short abstract, to give a satisfactory account of Prof. Flint's argument upon these points. The following are the conclusions arrived at by Prof. Flint, as the result of the various experiments which he has discussed:

"I. While the various elements of food burned in oxygen out of the body will produce a definite amount of heat which may be calculated as equivalent to a definite number of foot-pounds of force, the application of this law to the changes which food or certain of the constituents of the body undergo in the living organism is uncertain and unsatisfactory, for the following reasons:

"(*a.*) There is no proof that the elements of food undergo the same changes in the living body as when burned in oxygen, or that definite amounts of heat or force are necessarily manifested by their metamorphoses in such a way that they can be accurately measured.

"(*b.*) Assuming that the elements of food contain a definite amount of locked-up force, to measure the part of this force which is expended in muscular work, it is indispensable to be able to estimate accurately the force used in circulation, respiration, and the various nutritive processes, and to measure the heat evolved which maintains the standard animal temperature and which compensates the heat lost by evaporation from the general surface. It does not seem that any accurate idea can be formed of the amount of force used in circulation and respiration, and the estimates made by different observers of authority present variations sometimes of more than one hundred per cent. Such estimates are usually made in view of some dynamic theory, and they are based upon physiological data which are necessarily uncertain and subject to wide and frequent variations. No approximate estimate, even, can be made of the actual amount of heat produced within the living organism, except, perhaps, during a condition of nearly absolute muscular repose. The only way in which this could be done would be to deduct the force used in muscular work, circulation, respiration, and the nutritive processes, from the heat-value or force-value of the food. These elements of the question being uncertain, an accurate estimate of the heat produced becomes impossible, as, at the best, the only definite quantity in the problem is the total heat-value or force-value of food.

"(*c.*) To compare an amount of muscular work actually performed with the estimated force-value of food, apart from the impossibility of arriving at an accurate estimate of the amount of food consumed in circulation, respiration, the nutritive processes, and the production of heat, which is a necessary element in the problem, the work actually performed in walking a certain distance must be reduced to foot-pounds or foot-tons. The formula for this is so uncertain that no such reduction can be made which can be assumed to be even approximatively correct.

"II. The method of calculating the possible amount of force of which the body is capable, by using as the sole basis for this calculation the force-value of food, must be abandoned until the various necessary elements of the problem can be made sufficiently accurate to accord with the results of experiments upon the living body. Until that time arrives, physiologists should rely upon the positive results obtained by experiments rather than upon calculations made from uncertain data and under the influence of special theories. In case of fatal disagreement between any theory and definite experimental facts, the theory must be abandoned, provided the facts be incontestable.

"III. Experiments show that the estimated force-value of food, after deducting the estimated force used in circulation, respiration, the nutritive processes, and in the production of heat, will sometimes account for a small fraction only of muscular work actually performed, this work being reduced to foot-tons by the uncertain process to which I have already alluded. The errors in these calculations are manifestly so considerable that the calculated results seem to be of little value, while the experimental fact that a certain amount of work has been accomplished must remain.

"IV. It must be admitted that, under ordinary and normal conditions of diet and muscular exercise, the weight of the body being uniform, the ingress and egress of matter necessarily balance each other. If this balance be disturbed by diminishing the supply of food below the requirements of the system for its nutrition and for muscular work, the body necessarily loses weight, a certain portion of its constituent parts being consumed and not repaired. If the balance be disturbed by increasing the muscular work to the maximum of endurance and beyond the possibility of complete repair by food, the body loses weight. The probable source of muscular power may be most easily and satisfactorily studied by disturbing the balance between consumption and repair by increasing the work. In this, it is rational to assume that the processes of physiological wear of the tissues are not modified in kind, but simply in degree of activity.

"V. Experiments show that excessive and prolonged muscular exercise may increase the waste or wear of certain of the constituents of the body to such a degree that this wear is not repaired by food. Under these conditions, there is an increased discharge of nitrogen, particularly in the urine. This waste of tissue may be repaired if food can be assimilated in sufficient quantity, but in my experiments it was not repaired. The most important question to determine experimentally in this connection is with regard to the influence of excessive and prolonged muscular exercise upon the excretion of nitrogen. It is shown experimentally that such exercise always increases the excretion of nitrogen to a very marked degree, under normal conditions of alimentation; but the proportionate quantity to the nitrogen of food is great when the nitrogen of food remains the same as at rest, and is not so great, naturally, when the nitrogen of food is increased. In the latter case, the excessive waste of the tissues is in part, or it may be wholly, repaired by the increased quantity of food. Experiments upon excessive exertion with a non-nitrogenous diet are made under conditions of the system that are not physiological; and the want of nitrogen in the food in such observations satisfactorily accounts for the diminished excretion of nitrogen.

"VI. By systematic exercise of the general muscular system or of particular muscles, with proper intervals of repose for repair and growth, muscles may be developed in size, hardness, power, and endurance. The only reasonable theory that can be offered in explanation of this process is the following: While exercise increases the activity of disassimilation of the muscular substance, a necessary accompaniment of this is an increased activity in the circulation in the muscles, for the purpose of removing the products of their physiological wear. This increased activity of the circulation is attended with an increased activity of the nutritive processes, provided the supply of nutriment be sufficient, and provided also, that the exercise be succeeded by proper periods of rest. It is in this way only that we can comprehend the process of development of muscles by training; the conditions in training being exercise, rest following the exercise, and appropriate alimentation, the food furnishing nitrogenized matters to supply the waste of the nitrogenized parts of the tissues. This theory involves the idea that muscular work consumes a certain part of the muscular substance, which is repaired by food. The theory that the muscles simply transform the elements of food into force directly, these elements not becoming at any time a part of the muscular substance, is not in accordance with the facts known with regard to training.

"VII. All that is known with regard to the nutrition and disassimilation of muscles during ordinary or extraordinary work teaches that such work is always attended with destruction of muscular substance, which may not be completely repaired by food, according to the amount of work performed and the quantity and kind of alimentation.

"VIII. In my experiments upon a man walking three hundred and seventeen and one-half miles in five consecutive days, who at the beginning of the five days had no superfluous fat, the loss of weight was actually 3.45 pounds, while the total amount of nitrogen discharged from the body in excess of the nitrogen of food taken for these five days, assuming that three parts of nitrogen represent one hundred parts of muscular substance, as has been shown by analysis to be the fact, represented 3.037 pounds of muscular substance. This close correspondence between the actual loss of weight and the loss that should have occurred, as deduced from a calculation of the nitrogen discharged in excess of the nitrogen of food, seems to show very clearly that, during these five days of excessive muscular work, a certain amount of muscular substance was consumed which had not been repaired, and that this loss could be calculated with reasonable accuracy from the excess of nitrogen excreted.

"IX. Finally, experiments upon the human subject show that the direct source of muscular power is to be looked for in the muscular system itself. The exercise of muscular power immediately involves the destruction of a certain amount of muscular substance, of which the nitrogen excreted is a measure. Indirectly, nitrogenized food is a source of power, as, by its assimilation by the muscular tissue, it repairs the waste and develops the capacity for work; but food is not directly converted into force in the living body, nor is it a source of muscular power, except that it maintains the muscular system in a proper condition for work. In ordinary daily muscular work, which may be continued indefinitely, except as it is restricted by the conditions of nutrition and the limits of age, the loss of muscular substance produced by work is balanced by the assimilation of alimentary matters. A condition of the existence of the muscular tissue, however, is that it cannot be absolutely stationary, and that disassimilation must go on to a certain extent, even if no work be done. This loss must be repaired by food to maintain life. A similar condition of existence applies to every highly-organized part of the body and marks a broad distinction between a living organism and an artificially constructed machine, which latter can exert no motive power of itself, and can develop no force that is not supplied artificially by the consumption of fuel or otherwise."

Prof. Flint, in an appendix, has added a calculation of the non-nitrogenized food taken by Weston during his five days' walk, in order "to answer the possible objections of those who may contend that, in his discussion, lie should have included the heat-producing and force-producing power of non-nitrogenized alimentary substances." This calculation is briefly as follows:

Force-value of nitrogenized food		2,858.79	foot-tons.
" "	loss of weight of the body.	1,764.52	" "
" "	non-nitrogenized food, in excess of that required to produce 17,787 heat-units (the amount of animal heat) produced in five days.	597.75	" "
	Total.	5,221.06	" "
Deduct the estimated force used in circulation and respiration.		1,339.29	" "
Force remaining for muscular work.		3,881.77	" "

"The actual work represented by walking three hundred and seventeen and one-half miles is estimated at 4,321.33 foot-tons. This leaves 439.56 foot-tons of work which cannot be accounted for in any way, according to the estimates of the observers quoted, leaving a deficiency of a little more than ten per cent.

"These calculations show the fallacy of such estimates, and the impossibility of accounting for work actually performed, even when we include the heat-value and the force-value of non-nitrogenized food."

The estimates of the force used in circulation and respiration, and of the heat produced by the body, were all calculated for a condition of rest, and they are much less than the estimates that should be made for a period of excessive muscular exercise.