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ARTERIAL

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MISCONCEPTIONS REGARDING ARTERIAL ELASTICITY.

BY

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MISCONCEPTIONS REGARDING ARTERIAL ELASTICITY.[1]

A PROPER grasp of physical principles is an indispensable preliminary to the study of the complex problems of physiology and pathology, and this is impossible unless the terms in use be correctly employed. Laxity in the use of these terms is common enough and leads to many misunderstandings; but this want of exactitude is venial when contrasted with the flagrant abuse which has sometimes to be deplored. Whether arising from ignorance or carelessness the misuse of scientific terminology is greatly to be regretted, and the aim of this paper is to bring forward a startling example of such misconceptions as are apt to have their origin in the one or the other. The instance to be cited is connected with elasticity, than which no property of matter is more commonly misunderstood. Before approaching the immediate subject of this paper, which may be said to be a kind of object lesson, it is necessary to consider the exact meaning of the term elasticity. In order to have clear and definite notions upon which to proceed the definitions of the great writers on physics must be consulted, and as the fountain-head of knowledge in this department Lord Kelvin and Professor Tait may with confidence be selected. "Elasticity of matter," says Lord Kelvin,[2] "is that property in virtue of which a body requires force to change its bulk or shape and requires a continued application of the force to maintain the change, and springs back when the force is removed, and if left at rest without the force does not remain at rest except in its previous bulk and shape." "Elasticity, in the correct use of the term, implies that property in a body in virtue of which it recovers, or tends to recover, from a deformation." Such is the definition of

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[1] A paper read before the Edinburgh Pathological Club, July 15th, 1896.

[2] Kelvin: Encyclopædia Britannica, ninth edition. Edinburgh, 1877, vol. vii., p. 796.

Professor Tait,[3] who in another part of the same work from which this quotation has been made says further: "A substance is said to be elastic when, on being left free, it recovers wholly or partially from a deformation."[4] Elasticity, therefore, is the property by means of which a body that has been distorted by any force returns to its original bulk and shape on the removal of that force. This conception necessarily involves several considerations: (1) there must be a force or stress to produce distortion or strain; (2) there must be resistance to the stress which causes the strain; (3) the stress must be continuously maintained in order to keep up permanent strain; (4) there must be a return more or less to the original bulk and form on the removal of the stress; (5) as long as the stress is sustained there must be an opposite or counter-stress, often termed the restitution pressure; and (6) in a perfectly elastic body, supposing such to be conceivable, the restitution pressure does not lessen with time.

The relation of the distorting force or stress to the amount of distortion or strain was considered by Hooke,[5] and his celebrated law, "Ut tensio sic vis," is commonly translated into every-day language by the statement, as given by Professor Tait,[6] "Strain is proportional to stress." We may attempt to express this idea in exact terms. If P be the measure of any stress and p that of the corresponding strain, then $P = Kp$ where K depends on the nature of the body. K is greater when the strain is smaller for any given stress, and it therefore is a measure of the resistance of the substance to the particular kind of stress denoted by P. The co-efficient of resistance is equal to the reciprocal of the co-efficient of distortability. If K = resistance and p = strain, then $K = \frac{1}{p}$ and $p = \frac{1}{K}$. This serves as a measure of resistance to change of bulk or form, but it affords no real assistance in estimating elasticity, and it is only possible to gauge the limits of elasticity of any body by the amount of strain from which it can perfectly recover. Such is obviously the meaning of the two writers from whom the definitions already quoted have been

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[3] Tait: Properties of Matter, p. 32. Edinburgh, 1885.

[4] Op. cit., p. 142.

[5] Hooke: Lectures de Potentiâ Restitutivâ, or of Spring, London, 1678, p. 1.

[6] Tait: Op. cit., p. 195.

obtained, and the conception is rendered more precise by some examples given by Lord Kelvin, which may now be referred to. "The limits of elasticity of metals, stones, crystals, woods, are so narrow that the distance between any two neighbouring points of the substance never alters by more than a small proportion of its own amount without the substance either breaking or experiencing a permanent set, and therefore the angle between two lines meeting in any point of the substance and passing always through the same matter is never altered by more than a small fraction of the radian before the body either breaks or takes a permanent set."[7]

As a contrast to the behaviour of such substances he gives the following example: "On the other hand, gelatinous substances, such as indiarubber and elastic jellies, have very wide limits of elasticity. A vulcanised indiarubber band, for instance, is capable of being stretched again and again to eight times its length, and returning always to nearly its previous condition when the stress is removed. A shape of transparent jelly presents a beautiful instance of great degrees of distortion with seemingly very perfect elasticity."[8] The conclusion to which such facts lead is that it is impossible to measure elasticity by means of resistance. A substance may have very small limits of resistance to stress and yet be possessed of wide limits of elasticity. This is the true conception, equally removed from the two common misconceptions, firstly, that elasticity means resistance, and, secondly, that it is equivalent to distortability. Elasticity can only be estimated by the amount of recovery from distortion, and the greater the distortion from which a body can recover the greater is the elasticity of the body.

Upon elasticity depend many of the physiological functions of the body, more especially in connexion with the circulatory organs. The arteries are highly endowed with this quality. Arterial elasticity is the property by means of which the energy of the heart is stored up. With every pulsation of the heart there is a corresponding increase of blood pressure and arterial potential which, during cardiac diastole, rhythmically becomes kinetic. Blood pressure and arterial tension may therefore be regarded as reciprocal. One point connected with this subject has not perhaps, from the physiological point of view, received the attention which it has deserved. When the arterial wall has been distended by the

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[7] Kelvin: Op. cit., p. 800.

[8] Op. cit., p. 801.

heart beat and the distending force or pressure has been removed, the artery regains its original form; but during the process of restitution the kinetic energy of the vessel causes it to pass rapidly through its mean form, so that it suffers an alteration in the opposite direction—that is, it becomes smaller than its mean. But, again, a restitution pressure is developed, and the wall returns again through its mean position. This is repeated and vibrations are produced as a result of elasticity. In the aorta, when the swift flow of the blood suddenly stops, a negative, or perhaps more correctly a less degree of positive, pressure makes its appearance in the vessel in consequence of the inertia of the blood, and at the same time the restitution pressure in the wall of the aorta causes it to become smaller. The shrinkage is carried beyond the mean size of the aorta, but again the restitution pressure comes into play, the vessel expands and aids the negative pressure in drawing back towards the heart the column of blood. Successive movements of this kind go on until the wall attains its mean position.

As is well known, soft animal tissues do not behave like inorganic substances in respect of elasticity, and Hooke's law is by no means so applicable to them as to inorganic substances. The distortability of animal tissues gradually diminishes in proportion to the stress. Werthheim[9] showed that the curve of distortability, constructed by taking the weights employed to lengthen a piece of tissue as the abscissa and the elongations as the ordinates, is concave towards the abscissa line, whereas with a metal wire the curve is practically straight. This has been abundantly proved by Professor Roy[10] with regard to the arteries, and further, as Professor Tigerstedt[11] puts it, the elastic coefficient of the arteries is not constant but varies with the pressure.

About fourteen years ago Professor Roy conducted a most interesting series of experiments, already referred to, upon the elastic properties of the arterial wall. Some of the results which he obtained are not immediately connected with the subject of this communication, but as they throw a flood of light upon the bearings of organic to inorganic elasticity they are all worthy of the fullest attention. In

[9] Werthheim: Annales de Chimie et Physiologie, xii., 1841, pp. 385, 581, and 610, and xxi., 1847, p. 385.

[10] Roy: Journal of Physiology, iii., 1881, p. 125.

[11] Tigerstedt: Lehrbuch der Physiologie des Kreislaufs, s. 318, 1893.

his researches upon the thermo-elastic properties of animal tissues he found that these differ entirely from those of most inorganic substances. When a metal is compressed it becomes warmer, and when it is stretched it become colder; every animal tissue gives opposite results. His experiments were performed with the thermopile and galvanometer, and he found that the temperature of all animal tissues rises on stretching and falls again when they are relaxed. The production of restitution pressure is therefore accompanied by the generation of heat. The variation of temperature increased directly with the weights employed. Conversely, he has also proved that when heat is applied animal substances contract and that when they are allowed to cool they again expand. Animal tissues, therefore, are like bismuth, exceptions to the general rule that heat causes expansion and cold contraction, and they therefore resemble caoutchouc. These results have not such direct bearing upon the matter to be more especially discussed, but inasmuch as they are of vital importance in observing certain differences between the elastic properties of animal tissues and inorganic substances they cannot well be passed over. As regards the relation between internal pressure and the cubic capacity of the arteries Professor Roy investigated the degree in which a portion of artery expands with each successive increase in the internal pressure. The method employed was to enclose a portion of artery, so arranged that it could be distended by any internal pressure, in a small vessel containing olive oil, the variation of whose contents were recorded. The intra-arterial pressure was raised by increments of 10 mmHg until a pressure of from 100 to 200 mmHg was attained. The increments of capacity increase in proportion to the increments of arterial pressure until a certain point is reached, after which they diminish, and the most interesting result is that the arterial walls are most distensible at pressures corresponding more or less exactly to their normal blood pressure. Investigations upon veins show a very different relation between internal pressure and cubic capacity, inasmuch as the maximum distensibility occurs with pressures immediately above zero. Zwaardemaker[12] found that with regard to the arteries the results of Professor Roy's researches were in close accord with the conclusions to which he was led by a series of investigations made by himself.

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12 Zwaardemaker: Nederlandsch Tijdschrift voor Geneeskunde, II. R., xxiv. B., 61 S., 1888.

Another interesting point ascertained by investigating the amount of stretching is that, in the case of transverse strips of the aorta, the removal of the intima and adventitia produces almost no change, and the resistance and curve obtained with the media alone is practically the same as that obtained before the removal of the intima and adventitia. With longitudinal strips of the aorta the case is entirely different, and in these the removal of the intima as well as of the adventitia produces marked changes. Such are the facts in young healthy subjects. In the case, however, of persons of advanced age the resistance of the different layers of the aorta undergoes a considerable change, which is of pathological interest as bearing upon the rupture of vessels and the production of aneurysm. In such elderly persons the removal of the intima does not leave the resistance of transverse strips unchanged, but the curve falls more rapidly than before, especially the light weights. The removal of the adventitia also has considerable influence.

The influence of age on the elastic properties of the arteries is very great. The ratio of expansion in youth and early adult life—i.e., to the age of from twenty to thirty—is practically the same, but it is very different in the case of advanced age. Here the amount of expansion to pressure is greatly reduced. The effect of disease upon the arteries was very fully investigated by Professor Roy, and in the case of dogs suffering from wasting fevers he found that the arteries were more distensible with lower intra-vascular pressures and that with increasing marasmus the point of maximum distensibility with unit variation of internal pressure is reached with lower pressures. He holds that the pathological change in the elasticity of the arteries consists in their remaining abnormally wide at zero pressure, their walls having received a permanent set, so that only a part of the curve given by normal arteries remains. With regard to man, he found that this pathological change in the elastic properties of the arteries is extremely common, being found in every case in which death was preceded by lingering disease, while in the case of those dying suddenly the curve was practically identical with that of the healthy animal. In all these experiments the extent of distortion, from which there was perfect restoration to previous form and bulk, has been correctly taken as a measure of the amount of elasticity. These facts have been for long a favourite subject of study with me, and it filled me with consternation to find in the most recent work on pathology which has appeared in the

English language, the translation of Professor Thoma's "General Pathology and Pathological Anatomy" by Dr. Bruce, that these almost universally accepted facts appeared to me to be controverted. Without further preface let me quote the passage to which exception must be taken: "During life the diminution of the elasticity of the arteries shows itself by a soft distensile pulse and a sphygmographic tracing with a very high dicrotic rise, which is unduly far removed from the apex of the wave. The distance of the apex of the dicrotic rise from that of the pulse wave indicates in these conditions that the pulse wave is somewhat slowly propagated in the blood stream. At the same time, murmurs which are synchronous with the pulse are heard in the large arteries—the femoral, for example. This seems to be a consequence of the rapid change of the vascular tension which the high pulse wave produces. Arterial murmurs are thus of great importance for the pathology of the circulation. Lastly, I may point out that in many cases the appearance of a pulse in the retinal arteries on ophthalmoscopic examination is to be ascribed to a diminution of the elasticity of their wall. In all the above-mentioned cases, however, no severe general disturbance of the circulation usually appears. There is rather, as I have shown, a tendency to an alteration of the structure of the walls of the artery. In consequence of the greater tension to which the weakened walls of the arteries and veins are subjected by the blood stream their lumen dilates. Since, however, the amount of blood which flows through a section of an artery in a given time is determined chiefly by the condition of the capillaries, the widening of the arteries produces only a moderate increase in the amount of blood which flows through, so that at the same time the rapidity of the blood stream is reduced in the widened vessel. A retardation of the stream is produced, and this, as I have been able to show, is the immediate cause of a new formation of connective tissue in the intima of the widened artery. This, again, diminishes the lumen of the artery, and the latter is thus readapted to the blood stream. The new formation of the connective tissue in the intima renders the vessel more firm, so that it appears more rigid and less yielding (arterio-sclerosis, phlebo-sclerosis, angio-sclerosis). The elasticity of the wall of the vessel, and therefore the resistance which it offers to stretching, is considerably increased, often to such an extent that the pulsatile movements within it are reduced. The pulsating blood stream of the artery now flows in a channel, the wall of which possesses more or less the properties of a rigid tube. This involves an increase of the resistance to the stream which must not be undervalued. The heart is at first able to overcome this by strengthening its contraction. Gradually the thickness of the wall of the left ventricle becomes considerably increased, but the increased activity required of the heart exposes it to the danger of insufficiency of its action. This in many cases leads to a fatal termination."

In the passage just quoted there are many contradictory statements which seem to indicate some deplorable misconceptions, and lest it might be thought that my friend and colleague, Dr. Bruce, is in any degree responsible for the singular confusion of ideas pervading the passage, it is only right to say that his translation has been executed with a fidelity worthy of a better cause. "During life," says Professor Thoma, "the diminution of the elasticity of the arteries shows itself by a soft, distensile pulse and a sphygmographic tracing with a very high dicrotic rise, which is unduly far removed from the apex of the wave. The distance of the apex of the dicrotic rise from that of the pulse wave indicates in these conditions that the pulse wave is somewhat slowly propagated in the blood stream." Such a statement as this deserves the closest examination. It seems as if the author judged elasticity, not by the amount of strain which can be borne and restitution pressure produced, but solely by the amount of resistance to stress. As we have already seen, Professor Roy and other workers in this field correctly measure elasticity by the amount of distortion which can be undergone, followed by return to normal form; and how a soft, distensile pulse and a sphygmographic tracing with a very high dicrotic rise can be produced by a diminution of the elasticity of the arteries entirely passes my comprehension. Again, let us hear Professor Thoma. "Lastly," he says, "I may point out that in many cases the appearance of a pulse in the retinal arteries on ophthalmoscopic examination is to be ascribed to a diminution of the elasticity of their wall." Here the author is on safer ground, but he happens to have crossed to the other side of the hedge from that on which he stood when we compare the first passage referred to with that just quoted. The appearance of a pulse in the retinal arteries shows that the arterial system is either somewhat like a system of rigid tubes with an intermittent flow, or it exemplifies the point made out by Roy, previously referred to, that the arterial system is too wide for the quantity of blood.

But these are minor degrees of misconception when compared with an astounding statement which follows. "In consequence," the author states, "of the great distension to which the weakened walls of the arteries and veins are subjected by the blood-stream their lumen dilates. Since, however, the amount of blood which flows from a section of an artery in a given time is determined chiefly by the condition of the capillaries, the widening of the arteries only produces a moderate increase in the amount of blood which flows through, so that at the same time the rapidity of the blood-stream is reduced in the widened vessel A retardation of the stream is produced, and this, as I have been able to show, is the immediate cause of a new formation of connective tissue in the intima of the widened artery. This again diminishes the lumen of the artery, and the latter is thus re-adapted to the blood stream. The new formation of the connective tissue in the intima renders the vessel more firm, so that it appears more rigid and less yielding. The elasticity of the wall of the vessel, and therefore the resistance which it offers to stretching, is considerably increased, often to such an extent that the pulsatile movements within it are reduced." The perusal of this amazing statement must leave the reader in a condition little less than pitiable. He will infallibly be left in doubt whether the author or himself has been deprived of the faculty of reason. Professor Thoma assuredly "walketh in a vain show." How, in the name of everything that is reasonable, can the elasticity of the wall of the vessel be increased by a new formation of connective tissue rendering the vessel at once more rigid and less yielding?

In what has been said it has been my endeavour to keep well within the limits of a just and even generous judgment. My own tendencies are at all times more appreciative than critical, yet, while fully recognising the great services to circulatory pathology rendered by Professor Thoma, it seems my bounden duty to point out what is certainly a grave misconception of physical facts as well as an unfortunate misuse of physical terms. The passage which has been arraigned forms a curious commentary upon a sentence in the author's preface. "Since the beginning of my career," Professor Thoma says, "I have endeavoured to investigate the mechanical laws which govern pathological processes, and accordingly have spent much time in the preliminary study of mechanics and mathematics." It is indeed difficult to reconcile this autobiographical statement with the results specially referred to. In the preceding criticism there has been no intention on my part to scoff at the unfortunate blunders which have been criticised. "A smile for a friend and a sneer for the world"—the motto assumed for the youthful hero of romance by a gifted author[13]—may be a useful rule in the field of politics, but it has no place in science, for in all our discussions and controversies our sole aim is to arrive at the truth.

Edinburgh.

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[13] Lord Beaconsfield: Vivian Grey, Book ii., Chap. iii.

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