THE "COSTOCLAVICULAR SYNDROME"

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While the symptoms which may arise from pressure on the neurovascular bundle as it passes from the thoracic inlet to the arm, although many and varied, are well known and easily recognizable, there is no general agreement on either the site or the mechanics of the compression. There is no doubt that earlier writings have over-simplified the position, and only in recent years does it seem to have been realized that there is no one cause of pressure common to all cases.

The present study is based on: (1) the findings at 120 operations undertaken for the relief of pressure on the neurovascular bundle of the arm; (2) examination of the effects of posture of the shoulder girdle on the radial pulse in a series of 120 medical students; (3) the evidence obtained by dissection of 30 bodies.

Operation Findings

These are based on the records of 120 patients who were operated upon by one of us (E. D. T.) between 1908 and the present time for symptoms of pressure on the neurovascular bundle of the arm. Of the 120 cases there were 16 in which the customary symptoms were accompanied, and to a great extent overshadowed, by complications. The remaining 104 cases were of the ordinary textbook type.

The Complicated Cases

Fourteen of these showed extensive arterial thrombosis, and in the other two the outstanding complaint was a profuse hyperhidrosis of the hands. In all the cases of thrombosis a well-developed cervical rib was present, but in no single case was any deformity, narrowing, or periarteritis found in the artery where it lay on the rib. In 12 patients the thrombosis extended no higher than to some point between the bifurcation of the brachial artery and the lower border of the pectoralis major. In only two cases was the thrombosis found to extend upwards towards the cervical rib. In neither of these did it reach the rib, but began 1 cm. distal to it in an aneurysmal dilatation of the vessel with much periarteritis.

In two patients the hyperhidrosis of the hands was profuse enough to prevent them following their employment. In one of these the cause was a well-formed cervical rib, and in the other a taut fibro-cartilaginous band representing the forward end of a rudimentary cervical rib.

The Uncomplicated Cases

In 12 of the 104 cases pressure on the lowest trunk of the plexus was due to a strong taut band springing from the pointed tip of a small cervical rib. This band passes downwards and forwards in the anterior border of the scalenus medius. If the anaesthetist is asked to deepen the breathing the lowest trunk is seen to be lifted up by the band; it has in fact in most cases a permanent notch at the point of contact.

A condition which was very similar was found in another 8 cases. The insertion of the scalenus medius was carried forward further than normal, with the result that the lowest trunk and the artery were not in contact with the rib but were raised by the V formed on one side by the lateral tendinous edge of the scalenus anterior and on the other by the sharp anterior border of the scalenus medius. In all these cases a partial detachment of both muscles resulted in cure. In 2 cases, both girls aged 14, the cause of pressure was a large cancellous boss arising at the point where a well-developed cervical rib reached the first thoracic rib. In 8 patients resection of an apparently normal first thoracic rib cured the trouble. In two at least of these there was a distinct scoliosis of the cervico-dorsal spine. In 5 patients no adequate cause was found. They were unrelieved by operation, and may have been instances of "brachial neuritis" or of "prolapsed disk."

The remaining 69 cases showed "cervical" ribs in various stages of development. In none of these cases save 3 was there any naked-eye evidence that either plexus or artery had been damaged by pressure of the clavicle. In the majority the lowest trunk, when freed, showed a permanent notch made by the upper edge of the rib, across which it had been tightly stretched. In 3 cases there was an aneurysmal dilatation of the third stage of the subclavian artery starting 1 cm. distal to the rib. With two such cases already mentioned, this gives 5 cases of dilatation in 120 patients—a proportion which is in close accord with Halsted's (1916) report of 25 instances in 525 patients.

Previous writers have stated that these "cervical" ribs are in some patients true first thoracic ribs in a deformed and rudimentary state. This observation can be confirmed by taking antero-posterior skiagrams by the moving mandible technique. This permits an accurate count of the cervical vertebrae, and should be done in all cases of suspected cervical rib.

Constriction of Axillary Artery by the Median Nerve

A young man aged 23 complained that when his left arm was hanging down by the side he felt numbness and tingling in the hand. This not only gave him much trouble at his work but had led to his being invalided out of the Army. It was noted that depression of the shoulder obliterated the radial pulse but left the third stage of the subclavian artery unaffected.

At operation no cause was found in the neighbourhood of the first rib. A second incision was made below the clavicle through which the axillary artery and adjacent nerves were freely exposed. It was then seen that on downward traction of the arm the artery was compressed by the grip of the two heads of the median nerve and that all pulsation ceased below this point. The opportunity of two incisions, one above and one below the clavicle, was taken to determine what pressure the clavicle could exert on the first rib. A piece of drainage tubing of a calibre equal to that of the artery was threaded between the wounds and behind the clavicle parallel to and in front of the vessel, with the shoulder in the normal position. On depression of the shoulder the tube fell out because the

clavicle moved away from the rib. In this patient, a broad-shouldered well-built man, there could be no possibility of pressure on the neurovascular bundle in depression of the shoulder.

From the above findings in 120 interventions it is clear that no one happening—e.g., clavicular pressure—can explain all cases of pressure lesions of the plexus.

Movements of the Shoulder in Relation to the Radial Pulse

It is an old observation that in certain positions of the shoulder the radial pulse is diminished or completely arrested. Some writers have taken for granted that the cause of this interference is costoclavicular pressure. For instance, Falconer and Weddell (1943) state that "more than one postural manœuvre involving the shoulder girdle may result in compression of the subclavian vessels." But it is not the subclavian artery that is compressed. A simple observation will show that there is a normal pulse in the first stage of the axillary artery well below the clavicle and that the clavicle has nothing to do with the arrest of the pulse in the arm on pure depression of the shoulder. From this point of view we examined a large series of medical students.

In the extensive literature of cervical rib difficulties arise from a lack of exact definition of the position of the arm and shoulder. In what follows we mean by "depression" a position of the arm held vertically by the side in the posture of carrying a heavy bag, and by "retraction" we imply a displacement of the shoulder backwards, a bracing back of the shoulder as in "throwing a chest." The results are set out in the accompanying Table. From this it is

Table Showing the Effect of Different Postures of the Shoulder in 240 Arms with the Subject in the Erect Position

	Depression of Shoulder	Retraction (Bracing Back) of Shoulder	Extension of Neck (Adson's Manœuvre)	Abduction of Arm		Adduction of Arm Against Resistance
				90°	180°	
70 males (i.e., 140 arms):						
No effect on radial pulse	56	53	118	131	75	18
Radial pulse diminished	68	70	20	6	42	38
Radial pulse obliterated	16	17	2	3	23	84
50 females (i.e., 100 arms):						
No effect on radial pulse	30	23	94	91	35	9
Radial pulse diminished	48	64	6	6	35	16
Radial pulse obliterated	22	13	0	3	30	75

seen that in depression of the shoulder there were 116 instances of diminution and 38 of arrest of the radial pulse—i.e., the radial pulse showed some alteration in 64%. In retraction of the shoulder there were 134 instances of diminished and 30 of arrested pulse—i.e., the radial pulse was modified in 68%. In abduction of the arm to 90° the effect is but slight; in only 18 cases—i.e., 7.5%—was any difference noted. In abduction to 180° the proportion of cases in which some alteration was found rose to 54%.

The results when the subject attempts adduction against resistance are of special interest. Whereas in passive abduction to 90° the percentage of alteration is as low as 7.5, when the arm is actively adducted there is a steep rise to 90%. This seems to indicate that some muscular action has come into play. The subject will be referred to later. If the same observations are made with the subjects recumbent it is found that there is no difference in the results from depression of the shoulder in the erect and recumbent positions. This finding suggests that the cause is purely mechanical and unaffected by gravity. In the recumbent position the effects on the pulse in abduction to 180° are noticeably slighter. This may be due to the effect of gravity.

Anatomy of the Axillary Artery

Bearing in mind the fact that the arrest of the pulse is in the axillary artery this region was dissected in 18 bodies. In 12 out of 18 dissections the axillary artery at the level of the second rib took an abrupt lateral turn for 1.5 cm. and then again changed direction to pass directly down into the arm. The trunks of the plexus were arranged round the first part of the artery in the following manner: the superior trunk was placed postero-lateral, the middle trunk posterior, and the inferior trunk postero-medial to the vessel. The lateral and medial heads of the median nerve were given off the plexus just at the point where the artery made its S turn opposite the second rib. They lay one in front and the other behind the artery, embracing it in a scissor-like grip which when the shoulder was depressed by traction on the arm could be seen to constrict the vessel. In the remaining 6 subjects the lateral curve of the vessel occurred opposite the first rib. Thus the superior trunk lay anteriorly, the middle trunk postero-medially, and the inferior trunk medially to the artery. The two heads of the median nerve are, in this type, so disposed that they cannot constrict the vessel however much the shoulder is depressed.

The above relationships differ from those usually described owing to the fact that our dissections were made with the arm close alongside the trunk. In the usual position for dissection—i.e., abduction to 90°—the S bend of the vessel is straightened out. The heads of the median nerve are in relation to the third part of the artery when the arm is abducted but to the junction of the first and second parts when the arm is by the side of the body.

The evidence afforded by the operation described above and by observations from our dissections would seem to suggest that the arrest of the radial pulse in depression of the shoulder is due to compression of the artery by the heads of the median nerve. It is not without significance that these postures caused changes in the pulse in two-thirds of the students and that a relationship in which such constriction was mechanically possible was found in 12 of 18 bodies.

The explanation of the arrest of the radial pulse in abduction is not easy. Dissection shows that with the arm alongside the body the neurovascular bundle lies at a distance of 3 to 4 cm. below the coracoid process. As the arm is abducted the distance alters little, for although the bundle rises slightly the coracoid is elevated at its tip and moves backwards owing to rotation of the scapula. This movement carries the pectoralis minor upwards and backwards so that the neurovascular bundle is obliged to move slightly backwards under this muscle to reach the abducted arm. During abduction the humerus rotates laterally to prevent the impingement of the greater tuberosity against the acromion. The humeral head protrudes into the lax part of the joint capsule, causing a prominence under the tendon of the subscapularis. The neurovascular bundle as it emerges from under the pectoralis minor is pressed against the head of the humerus covered by the tendon of the subscapularis. Division of the pectoralis minor at its insertion frees the bundle, and its close apposition to the humerus is relieved.

It has already been shown that, whereas simple abduction of the arm to 90° interferes with the radial pulse in 7.5% of subjects, the ratio rises at once to 90% if the subject forcibly adducts the arm. By this action the pectoralis minor and subscapularis would be tautened to an extent sufficient to cause compression of the axillary artery. Whilst making this suggestion with reserve we would state definitely that in none of our dissections did we find any

evidence to support Wright's (1945) contention that trouble may arise from forcible contact with the coracoid process itself.

Movements of the Clavicle in Relation to the First Thoracic Rib

The relations between the clavicle and the first rib were studied in 25 bodies. In these formalinized bodies it is necessary to cut across a certain amount of muscle if full movement of the clavicle is to be obtained. To guard against the possibility that this cutting of muscle might falsify the findings, five fresh post-rigor bodies were examined in the post-mortem room. There was, however, no difference in the findings in the two sets of bodies.

When the shoulder girdle is depressed by pulling the arm downwards alongside the trunk the clavicle describes an arc moving downwards and forwards so that the further the shoulder is depressed the further forward the clavicle moves, widening the interval between the clavicle and the rib. At no point in this excursion could the clavicle be made to impinge on the subclavian artery, but the interval between the two bones is narrowest (1.5 cm.) when the clavicle lies opposite the upper border of the first rib. In order to press the clavicle directly backwards on the first rib it is necessary to open the sternoclavicular joint and to sever the intra-articular disk.

As regards the plexus itself depression of the shoulder causes the superior and middle trunks, together with the contribution from the seventh cervical nerve to the long thoracic nerve (nerve to the serratus anterior), to be tightly stretched across the tendinous edge of the scalenus medius. The inferior trunk is pulled hard down into the angle of junction of the scalenus medius and the first rib. It is not possible by this manœuvre to compress the artery against either of the scaleni. The vessel can still be moved freely from side to side in the interval between the scaleni, but the S curve is abolished.

When the shoulders are retracted the acromial end of the clavicle rises and the bone lies across the root of the neck above the level of the first rib. The clavicle now makes an angle of 30° with the first costal cartilage. In this position the tendon of the subclavius compresses the subclavian vein against the first rib, but the clavicle itself does not press on that vessel. The middle third of the clavicle pushes the neurovascular bundle backwards against the anterior border of the scalenus medius, and in the presence of a resistance—e.g., a cervical rib or an abnormally placed first rib—could compress the bundle.

The excursion of the clavicle in abduction shows little or no difference from that already described in retraction.

Discussion

The literature of brachial plexus pressure has increased considerably in recent years. This is due in part to the striking rise in the number of cases of paraesthesia of the hand and arm in middle-aged women who are overworked, underfed, and spend much time carrying shopping baskets. The general tendency is to suggest that the troubles are due to compression of the plexus between clavicle and first rib. This is a pure supposition unsupported by any anatomical evidence. Some confusion in the literature further arises from papers which base definite opinions on an insufficient number of cases or include abnormal types—e.g., scoliotics. Moreover, not enough attention has been paid to a separate analysis of the movements of depression, retraction, and abduction.

In a normal person standing in the erect position the clavicle is presumably not pressing on the bundle. The moment that pure depression of the shoulder begins the

clavicle moves away from the bundle, and the further the depression the further is the clavicle away. It seems clear, therefore, that symptoms referable to the plexus arising in depression of the shoulder are not due to pressure by the clavicle, and we believe that they are caused purely by drag on the nerve cords. In this position of the limb we have shown that the plexus is stretched taut over the edge of the scalenus medius, and this is especially likely to happen where that muscle has its attachment carried forward further than usual on the first rib.

It is otherwise with retraction and with abduction. Here the clavicle in its middle third presses the neurovascular bundle against the scalenus medius. With a normal muscle such pressure is trivial; it possibly explains those cases where prolonged abduction of the arm, as in dressing the hair, causes temporary "pins and needles." Should, however, the resistance be stiffened by a cervical rib or an abnormally high first rib the pressure might easily become more serious.

It seems likely that the patients may be divided into two groups. In one, the smaller group, the pressure is clavicular, and in this type the symptoms are those of the whole plexus pressure. They are produced by retraction and abduction, and are felt at places from the deltoid region down to the hand. In the second group the symptoms are referable predominantly to the distribution of the lowest trunk and are due to hanging up of the plexus over a cervical rib, a band, the scalenus medius, or an abnormal first rib when the shoulder is depressed. We believe this to be much the larger group.

Summary

An account is given of the findings in 120 operations and 30 dissections, with observations on 120 students.

No one mechanical cause can explain all cases. Damage by pressure of the clavicle cannot happen in pure depression of the shoulder, but is a likely event in retraction and abduction if cervical rib or abnormal first rib be present. These cases will probably show whole plexus symptoms.

The most common cause of symptoms is the hanging up of the plexus on a cervical rib or other mechanical obstacle. These cases are likely to show lowest trunk symptoms.

The phenomenon of alteration in the radial pulse on movements of the shoulder is due to causes distal to the clavicle. It has nothing to do with the costo-clavicular syndrome.

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WATER AND SALT DEPLETION*

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Comparison of Effects

The main differences are shown in Table V. Their theoretical explanation, as already suggested, appears to derive from the contrast in conditions of extracellular-fluid osmotic pressure. In pure water depletion (Fig. 4A) the extracellular fluid tends to become hypertonic and its volume to be maintained by withdrawal of water from the cells. In consequence of the relative normality of the plasma volume, oligæmic symptoms, such as lassitude,

TABLE V.—Comparison of Effects of Water and Salt Depletion

Manifestation	Pure Water Depletion	Pure Salt Depletion
Dehydration	+++ primary or simple	+++ secondary or extra-cellular
Thirst	+++	Absent
Lassitude	+++	+++
Orthostatic fainting ..	Absent till late	+++
Urine volume	Scanty	Normal till late
NaCl in urine	Often +	Always absent except in Addison's disease
Vomiting	Absent	May be +++
Cramps	+	+++
Plasma NaCl	Slight increase or normal	Diminished +++
Blood urea	+	+++
Plasma volume	Normal till late	Decreased +++
Haemococoncentration ..	Not till late and slight	+++
Blood viscosity	Normal till late	Increased +++
Blood pressure	+	Fall +++
Water absorption	Rapid	Slow
Mode of death	? due to rise of osmotic pressure	Peripheral circulatory failure

giddiness, fainting, and fall of blood pressure, are absent or do not develop until a late stage. Thirst is pronounced because of cellular desiccation. In pure salt depletion (Fig. 4B) the extracellular fluid tends to become hypotonic and so water is not sucked from the cells and there is little or no thirst. The kidneys, working to preserve isotonicity of the extracellular fluid, excrete water; therefore, while water is being ingested and absorbed, urine volume is not significantly decreased, and may be increased. The volume of the extracellular fluid falls. The decrease of plasma volume causes prominent symptoms of peripheral circulatory failure due to oligæmia and increase of blood viscosity.

Mixed Water and Salt Depletion

Pure water depletion may be defined as reduction below normal of total body water without significant reduction of

total body salt; pure salt depletion, as reduction below normal of total body salt without reduction of body water beyond that which is inevitable from loss of extracellular osmotic pressure. Mixed water and salt depletion may be defined as reduction below normal of total body water and total body salt, the water reduction being greater than that consequent upon the secondary dehydration of salt depletion. This occurs in patients in whom there have been abnormal losses of secretions *without free intake of water*; the water loss tends to outstrip salt loss because the secretions lost are either isotonic (gastric or intestinal juices) or hypotonic (saliva, sweat), and, in addition, there is extra depletion of water in the continuous unavoidable losses, averaging about 1.5 litres daily, which occur from the skin and lungs and in the urine. Patients suffering from mixed depletion, as above defined (water loss in excess), have a mixture of the symptoms of pure water and of pure salt depletion. This is because the extracellular-fluid volume is diminished, due to the reduction in total sodium and chlorine, but there is also a tendency for the shrunken extracellular fluid to be hypertonic owing to the disproportionate water loss. The tendency to hypertonicity causes some withdrawal of water from the cells. The clinical picture, therefore, is such that patients show the circulatory and other features due to reduction of extracellular-fluid volume, but are also thirsty, have dry mouths, and have early oliguria.

Any condition causing secretion losses unaccompanied by adequate water intake will result in mixed depletion. Cases of acute vomiting provide the commonest examples. In protracted vomiting, such as occurs in pyloric stenosis, the effects of salt depletion tend to dominate the picture because water intake usually goes on until the late stages, so that there is a prolonged phase of selective drain of chlorine and sodium. Estimations of plasma concentrations of sodium and chlorine are even more fallacious as indicators of total loss of these ions in mixed depletion (water loss in excess) than in pure salt depletion, because of the tendency to hypertonicity in the diminished extracellular fluid. In any case, plasma chlorine estimations in vomiting, as already pointed out, are no guide to the concentration of sodium ions, because of the much greater loss of chlorine than of sodium (see Fig. 8). In mixed depletion due to vomiting it is possible for the concentration of sodium ions, largely partnered by HCO_3 , and the plasma osmotic pressure to be raised when the concentration of chlorine ions is decreased. In severe diarrhoea without vomiting (see Fig. 8) the converse may be true. The concentration of chlorine ions may be a little lower, or normal, or even raised while the concentration of sodium ions is decreased. Rogers (1921) found serum chlorides in cases of cholera before treatment to be as high as 0.79%.

Occurrence of Pure and Mixed Depletions in Practice

Pure water depletion is frequent in the circumstances already described; pure salt depletion or mixed water and salt depletion, however, are still more common because of the many causes of vomiting and diarrhoea. It is necessary to enumerate only a few of these causes to realize the frequency with which water and salt may be lost from the body. For example, vomiting may occur from gastritis, gastro-enteritis, appendicitis, pyloric or intestinal obstruction, and peritonitis; associated with pregnancy, after administration of anaesthetics, in alcoholism, in uraemia, in diabetic ketosis, in sea-sickness; and in such intracranial conditions as concussion, meningitis, cerebral tumours, and cerebral vascular lesions. Diarrhoea may occur from enteritis and colitis, from dysentery and cholera, from pancreatic insufficiency, in sprue, from ulcerative and neoplastic conditions of the intestines, and in patients in whom

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