8. *The pulmonary vascular resistance* ranged between 10 and 45 units (800 to 3,600 dynes sec./cm.⁵), and averaged 22 units in patent ductus, 20 units in Eisenmenger's complex, and 17 units in atrial septal defect. When considering the resistance, due allowance should be made for the smaller blood flows of infants and small children.

9. *The arterial oxygen saturation* (femoral in cases of patent ductus) averaged between 77 and 82% in all groups, and was remarkably close to the mean in three-quarters of all cases.

[The second part, together with a list of references, will appear in our next issue.]

ARTERIAL OCCLUSION COMPLICATING THORACIC OUTLET COMPRESSION SYNDROME

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It is well known that a cervical rib, a fibrous band in the anterior border of the scalenus medius, or an enlargement on the first rib may cause symptoms of vascular disease in the upper limb, but it is less well appreciated that the result may be a major amputation, ischaemic contracture of the fingers, or ischaemic muscle pain in the forearm and hand. Three cases have been recorded in the literature in which proximal spread of arterial thrombosis had reached the bifurcation of the innominate artery and caused hemiplegia. We believe that this complacency may be attributed to the excellent collateral circulation in the upper limb, which in the more minor lesions leads to minimal symptoms and spontaneous recovery; to the still widely held theory of a nervous origin for these symptoms, leading possibly to inadequate examination of the patients' vessels; and to the paucity of cases of major arterial occlusion due to cervical rib recorded in the literature. The admission of six such patients to this unit within the past 12 months, however, suggests that the incidence of these major occlusions may be higher than is generally realized.

In 1911 Todd, having noticed that the lowest trunk of the brachial plexus is intimately related to a cervical rib more often than is the subclavian artery, suggested that vascular symptoms associated with such a rib might be due to paralysis of the sympathetic fibres running in this trunk. With increasing knowledge of the function of the autonomic system, Telford and Stopford (1931) rightly pointed out that the colour changes induced are those of overactivity, not of paralysis, of the sympathetic fibres. By administration of ergot they induced endarteritis and thrombosis of the vessels in the combs of cocks and concluded that if arterial "spasm" be continued for a long period occlusion of the affected vessels can occur, and that irritation of the sympathetic fibres crossing the cervical rib in the lowest trunk of the brachial plexus would thus explain all the vascular features seen in these patients, including disappearance of the brachial pulse. Moreover, they showed by a series of dissections that in some subjects the sympathetic fibres are aggregated into a bundle in the lower

part of this trunk, and argued that only in such a patient could these fibres be irritated, thus explaining the much greater incidence of neurological than of vascular symptoms associated with cervical rib.

Lewis and Pickering (1934) exposed the shortcomings of this theory by pointing out, firstly, that chronic irritation of a nerve trunk results in paralysis, not stimulation, of the fibres, and that there appears to be no reason why autonomic fibres should behave differently; and, secondly, that in cases of cervical rib the patients with vascular symptoms rarely have neurological features, whereas on the basis of this theory mixed cases should be regularly seen. Their own patient showed periarterial fibrosis, and it was demonstrated at operation that the subclavian artery was nipped between the abnormal rib and the clavicle when the arm was abducted. They suggested, therefore, that in these cases damage to the subclavian artery is followed by local mural thrombosis and that all the vascular features can be explained by embolism or by spreading thrombosis. Eden (1939) strongly supported this theory with the evidence of two further cases, and we submit that our experiences can be explained on no other basis. Support for this theory is also to be found in the not infrequent occurrence of a systolic murmur over the subclavian artery in these patients, indicating turbulence in the blood flow at this point.

Brachial Artery Occlusion

In patients with occlusion of the brachial artery a careful history revealed that a sudden onset of ischaemic symptoms in the hand and forearm was followed by a gradual recovery which may have been marred by one or more further acute episodes. On examination a powerful brachial pulse ceased abruptly in the vicinity of the lower border of the pectoralis major or the middle of the arm, points corresponding approximately to the origins from the brachial artery of major collateral vessels. After treatment, or even spontaneously, pulsation may return in the radial artery, though not in the lower brachial artery. These are the typical history and findings of a brachial embolus, which affords a much more convincing explanation of such a clear-cut picture than does a series of events consequent on sympathetic irritation. Injury may play a part in liberating an embolus, as illustrated by Cases 1 and 2, and may be a single blow or the repeated minor traumata associated with a particular occupation.

Case 1

A man aged 46 gave the history that following a fall on to his outstretched left hand at the end of February, 1957, the hand had suddenly become "numb," painful, cold, and white. On March 3 at another hospital a left upper thoracic ganglionectomy was performed, following which he noticed a pulsating swelling in his neck but no improvement of his hand. On March 17 he again had sudden severe pain in his hand, with marked pallor and coldness, and a brachial embolectomy was attempted but with only transient success.

He was admitted to our wards on June 28 with gangrene of the tips of the thumb and index and middle fingers and ischaemic atrophy of the hand. All the interphalangeal joints were almost fixed and movements at the metacarpophalangeal joints were greatly restricted by ischaemic contractures. The hand was white when elevated, cyanosed when dependent. The pulsation in the neck was the subclavian artery, which showed no aneurysm but was more prominent following division of the scalenus anterior at the sympathectomy. The brachial pulse ceased abruptly at the middle of the arm. X-ray examination showed no cervical rib, but a large boss on the first rib in the region of the subclavian groove.

At operation on July 10 the left first rib was removed, following which the colour and temperature of the hand

slowly improved, but when last seen there had been little improvement in the movement of his fingers.

Comment.—The sequence of events in this case appears to have been mural thrombosis of the subclavian artery, dislodgment by the fall of an embolus which lodged at the brachial bifurcation, and consecutive thrombosis to involve collaterals on March 17, removal of this clot being followed by thrombosis. The end-result is loss of the tips of the thumb and index and middle fingers and of 75% of the function of the hand.

Case 2

A man aged 22 was transferred to our ward from another hospital on May 11, 1957. In November, 1956, he used a Kanga drill at work for a day and a half, but thereafter did not use it again, as it caused considerable discomfort in his right upper limb. In December he suddenly developed pain in the right hand and numbness and tingling of the fingers, but spontaneous recovery began a few hours later. At the beginning of May, 1957, he experienced pain of sudden onset in his right hand and forearm, which became white and cold as high as the elbow, but, anticipating spontaneous cure as on the previous occasion, he did not seek advice for several days, by which time established gangrene of the fingers was found. He was at once admitted to hospital, where a brachial plexus block was performed and tolazoline hydrochloride injected intra-arterially. These measures had little effect and he was immediately transferred to St. Mary's Hospital.

On admission he complained of pain in the hand at rest, with severe pain in the forearm on movement of the fingers or wrist. The limb was cold and blue from the elbow downwards with diminution of sensation to pinprick and complete loss to light touch. There was dry gangrene of the three middle fingers and of the terminal phalanges of the little finger and thumb. The axillary pulse was strong but ceased abruptly at the lower border of the pectoralis major muscle. X-ray examination revealed a complete cervical rib.

The limb was cooled by exposure to a stream of air from an electric fan and vasodilatation encouraged by applying heat to the body and remaining limbs and by the administration of alcohol. Heparin was given intravenously to diminish the risk of arterial thrombosis in those vessels still patent. These measures produced little change in the appearance of the limb but averted spread of gangrene. On May 13 the cervical rib was excised with its periosteum and upper thoracic ganglionectomy performed. Post-operatively reflex vasodilatation and anticoagulant therapy were continued, and gradually the area of threatened gangrene receded distally. Amputation was postponed until July 24, when a line of demarcation was well established and it was possible to save the proximal part of the hand and portions of the thumb and little finger as a basis for later fashioning of a claw hand.

Comment.—This case also shows how a warning embolus may be followed by a more serious one with disastrous results. It also points the moral that amputation in embolic vascular disease should be delayed until the gangrenous tissue is clearly demarcated, for the line is almost invariably much more distal than the initial appearance would suggest. On admission the general impression was that nothing could save this young man from a formal below-elbow amputation.

Case 3

A girl of 15 years was admitted to hospital on January 26, 1957. Eight months previously she had developed tingling in the right hand and fingers and had noticed that the hand became white and painful if held above her head. Six weeks before admission the tip of her little finger became blue, as did the middle one shortly afterwards. Two weeks before admission she developed sudden severe pain in the forearm and hand, which became cold and white and later became cyanosed.

On admission the right forearm and hand were colder than the left and there was gangrene of the tips of the middle and little fingers. The whole hand was a dusky blue colour and little movement of the fingers was possible. On the right side of the neck a cervical rib was palpable with a prominent subclavian artery, over which a systolic murmur was clearly heard. No pulsation could be felt below the middle of the arm, at which point the brachial pulse ceased abruptly.

On January 28 a complete cervical rib was removed and upper thoracic ganglionectomy performed. The hand immediately became much warmer, finger movements rapidly improved, and the gangrenous areas became demarcated.

Comment.—This case also illustrates the probability of further embolism if the first one is ignored, but fortunately in this case the result was less serious.

Case 4

A man aged 46 was operated upon elsewhere in February, 1956, for bilateral inguinal hernia and developed post-operative pulmonary collapse. Serial chest x-ray films revealed that during this period he sustained a stress fracture of the right first rib near the scalene tubercle. Just before Christmas, 1957, he noticed considerable aching in his right forearm during shaving, and he had to rest several times during this operation with the arm hanging down, but as he often suffered from rheumatic myalgic pains he was not unduly alarmed. As symptoms persisted, however, he reported to his surgeon at the end of January, 1958, and was referred to us with the correct diagnosis, for examination showed that the brachial pulse ceased abruptly just below the lower border of the pectoralis major and x-ray examination for cervical rib revealed a large mass of callus on the first rib. On admission to hospital on February 25 we confirmed these findings, but, in addition, pulsation had returned in the radial artery and a pulsating collateral vessel was found in front of the medial epicondyle of the humerus.

At operation on March 3 the subclavian artery was found to have a soft friable wall, and in fact ruptured when depressed by a finger. Upper thoracic ganglionectomy was performed after suture of the artery, but it was deemed wiser not to interfere with the first rib. Post-operatively the hand was warmer and was no longer cyanosed when dependent.

Case 5

A woman aged 32 was awakened by sudden severe pain along the inner border of the forearm and hand and she noticed that the hand quickly became cold and white. Attempts to use the hand increased the pain. The condition improved gradually during the next two weeks, but on raising the arm above the head the hand still became white and numb.

On admission to hospital at this stage in February, 1952, the left hand and forearm were paler and colder than the right and no pulsation was palpable below the middle of the arm. Cervical ribs were palpable on both sides of the neck with prominent subclavian arteries overlying them.

At operation the subclavian artery on the left side was found to be constricted between the scalenus anterior and the abnormal rib. Division of the muscle was followed by a marked increase in pulsation of the third part of the vessel. A complete cervical rib was excised and upper thoracic ganglionectomy performed. Post-operatively the hand became warm and pink and pulsation returned in the radial artery. Unfortunately it has not been possible to see this patient since her discharge from hospital.

Subclavian Artery Thrombosis

Complete occlusion of the subclavian artery is less common than embolism in these patients, but may occur as a consequence of local mural thrombosis in one of two ways. Firstly, the thrombus may increase in size until it

occludes the vessel. If this process occurs gradually one would expect the collateral circulation to increase steadily with decrease of the flow in the main vessel, and the distal vessels to remain patent. Symptoms would develop gradually and probably would remain minimal. On the other hand, rapid occlusion of the subclavian artery would cause symptoms of sudden onset with gradual improvement as the collateral vessels dilated. Stammers (1950) records such a case. Secondly, a brachial bifurcation embolus could be followed by consecutive thrombosis, in which case a sudden onset of symptoms would be followed by deterioration, either steadily or spasmodically, depending on the rate of spread of thrombosis. It is in this group that the risk of gangrene is greatest, for the major collateral channels are occluded at their origins from the main artery. Reviewing 29 cases which they were able to trace in the literature, Schein *et al.* (1956) point out that two out of four patients under 35 years sustained major amputations, and 11 of the 29 had minor amputations.

Case 6

A woman aged 37 was admitted to hospital in September, 1957. In 1947 she had noticed a hard swelling above the left clavicle which had been removed at another hospital but had recurred. At this time she had been told that she had an extra rib. In January, 1957, tingling in the fingers of the left hand, with a feeling of numbness, and pain in the forearm and hand on use developed, and the hand became cold. All these features began simultaneously and suddenly and she noticed that if she used cold water the hand rapidly became blue, but a pink colour was restored by warmth. Since January the symptoms had become gradually worse and the hand constantly blue and cold.

On examination there was a palpable left cervical rib with a visible subclavian pulse medial to it. There was no palpable pulse beyond the rib and the axillary artery could be felt as a solid cord as far as the lower border of the pectoralis major. The hand was cold and blue, the grip weak, ischaemic pain came on rapidly, and there was impaired sensation of the fingers.

At operation on September 18 the subclavian artery was found to be thrombosed from the point at which it crossed a cervical rib. The rib was removed and upper thoracic ganglionectomy performed. Post-operatively the hand became warm and pink but no pulsation had returned to the distal vessels when the patient was discharged from hospital.

Comment.—The original operation in 1947 was excision of a cervical rib, presumably subperiosteal as the rib reformed, and the subclavian artery thrombosis may have been induced by the operative trauma. The interval of 10 years between operation and the onset of vascular symptoms, however, suggests that it was spontaneous. It is clear that subsequently thrombosis had spread distally to the upper arm.

Case 7

A man aged 55 was admitted to hospital on September 10, 1957. Four months previously he had dropped a cup of tea because his right hand had suddenly become weak, and soon afterwards his fingers began to tingle. Since that time he had noticed difficulty in using his right hand, numbness of his fingers, and pain in his forearm and hand on use. More recently the hand became blue but the other features remained unchanged.

On examination the right hand was cold and the fingers were blue. No pulsation could be felt in the limb or root of the neck. X-ray examination revealed a short cervical rib on the right side.

At operation the subclavian artery was found to be acutely kinked and narrowed over a stout cord-like structure passing from the end of the cervical rib to the first rib, and was thrombosed from this point distally. The rib and cord were excised and upper thoracic ganglionectomy was per-

formed. Post-operatively the hand became pink and warmer, but the tingling persisted in the fingers. Use of the hand was being regained slowly two weeks later.

Comment.—The severity of the initial symptoms suggests that they were due to a brachial embolus from the obviously traumatized subclavian artery, which in turn became thrombosed either by consecutive thrombosis or, less likely, by spread of the intramural clot, consequent on the reduced blood flow through the vessel.

Vascular Symptoms Associated with Cervical Rib

The majority of cervical ribs cause no symptoms, but their owners are no less liable to other disease than are their fellows. Consequently it is not surprising that patients are sometimes seen with both vascular symptoms and cervical ribs which are no more than coincidental.

Case 8

A woman aged 70 was admitted to hospital in the afternoon of October 11, 1957. At lunch her hand became suddenly cold and white and the least movement of her fingers caused acute pain in the forearm.

Examination revealed that the right hand and forearm were colder and paler than the left, the brachial pulse ceased at the elbow, and there was no radial pulse. X-ray examination showed bilateral incomplete cervical ribs. The limb was kept cool, the body heated, vasodilatation encouraged with brandy and tolazoline hydrochloride, and anti-coagulants were given to limit thrombosis. Symptomatic recovery proceeded steadily and the radial pulse became palpable on October 18.

One month later the patient was readmitted with congestive heart failure, and it appears likely that the source of the brachial embolus was a myocardial infarct.

Case 9

A man of 75 years was referred to the out-patient department with gangrene of the tips of his middle and little fingers. The radial pulse was palpable and the hand warm, but the affected fingers were cold and blue. X-ray examination revealed bilateral cervical ribs. The diagnosis of digital artery thrombosis due to atherosclerosis was made and recovery ensued without active treatment.

Case 10

A girl of 19 years was admitted to hospital on December 6, 1956, with a typical history of Raynaud's phenomenon in the hands, and complaining also of cold feet and blue legs. On examination all the peripheral pulses were palpable, the subclavian arteries were elevated on cervical ribs, and over the left one a systolic murmur was clearly heard. X-ray examination confirmed the presence of bilateral complete cervical ribs.

At operation the left subclavian artery presented a palpable thrill and was nipped between the rib and a band passing over the vessel. The ribs were excised and upper thoracic ganglionectomy was performed.

Comment.—This girl had the sympathicotonic conditions of Raynaud's phenomenon of the hands and also cyanosis of the legs in association with cervical ribs. Nevertheless, the subclavian murmur and the operative findings strongly suggest that mural thrombosis had developed as a result of the rib on the left side, and it may be that timely operation has prevented embolus or major thrombosis. When last seen in January, 1958, the upper limbs were symptom-free and the pulses normal.

Discussion

Normally the subclavian artery passes from the thorax to the arms in a smooth curve over the broad surface of the first rib. The effect of a cervical rib is to raise the artery in the neck, thus sharpening the curve, and it now crosses the comparatively narrow surface of the cervical rib or the

narrow rigid band connecting the tip to the first rib. Any drag on the arm, therefore, will angulate the artery over a rigid structure, and a common complaint of these patients is inability to carry a heavy package on the affected side. Case 7 illustrates this point well, and it affords a probable explanation of the attacks of Raynaud's phenomenon which form the only symptoms of an occasional patient with cervical rib. Eden (1939) described a case in which scalenotomy was ineffective in relieving symptoms and a second operation was required for removal of the underlying rib, and Smith (1940) recorded a case of subclavian artery thrombosis due to kinking of the vessel by a fibrous band in the anterior border of the scalenus medius.

Clearly, then, angulation alone by an abnormal structure may be sufficient in time to damage the vessel, but there is evidence obtained at operation in such patients that the artery may also be subjected to further compression between the abnormal structure and the overlying scalenus anterior or clavicle. Case 5 is an example of this, and Lewis and Pickering (1934) were able to demonstrate the nipping of the subclavian artery between a cervical rib and the clavicle in their patient when the arm was abducted. Patterson (1940) describes an interesting case in which symptoms occurred on the second side three years after operation on the first, and it was seen at operation that the artery was greatly compressed between a cervical rib and the scalenus anterior. Division of the muscle afforded only partial relief of the compression, but the artery became 40% larger when the rib was removed.

Periarterial fibrosis may or may not be present in these cases, but appears to afford no indication of the severity of damage to the artery. In Case 4, for example, little or no fibrosis was present, yet the artery was soft and dilated and so friable that it ruptured at the touch of a finger. Stammers (1950) had a similar experience, and Adson (1947) reported two cases of rupture of the artery after scalenotomy, one as the operation was being concluded and the second on the twelfth post-operative day. That Telford (Telford and Mottershead, 1947) found no periarteritis in many of his cases cannot, therefore, be used to support his theory.

It has been suggested as an objection to the occlusive explanation of vascular symptoms in these cases that ligation of the subclavian artery distal to the thyrocervical trunk causes no symptoms and hence a mural thrombus should not do so. In fact, it does not, until either it becomes a complete occlusion or is cast off as an embolus, when symptoms of some duration are produced. Transient Raynaud attacks are due to intermittent occlusion of the artery by increased angulation or compression. Hyperhidrosis is quoted as evidence in favour of Telford and Stopford's (1931) theory, but this is an uncommon symptom in cervical rib patients with vascular features and we see sporadically patients with hyperhidrosis but no evidence of cervical rib. It is our opinion that when the two conditions occur in the same patient they are not cause and effect but are purely coincidental.

Whichever theory one believes, there can be no doubt that once vascular symptoms appear the rib should be removed. To add upper thoracic ganglionectomy takes only a few extra minutes, and in our opinion should always be done to secure rapid and maximal dilatation of the collateral vessels around the block in the main channels. Theoretically, one should also excise the affected segment of subclavian artery to prevent further emboli or thrombosis, and replace it with a homograft to restore normal blood flow, and this is advocated by Schein *et al.* (1956). We believe, however, that these advantages are largely theoretical. In cases of brachial embolus the distal vessel is blocked and a graft will do no more to improve the circulation to the hand and forearm than a sympathectomy. After removal of the traumatizing rib it is probable that the mural thrombus will organize, that the risk of a further embolus is small, and hence there is little to be gained by thromboendarterectomy. On the other hand, there is an appreciable incidence of thrombosis of grafts in vessels of this size,

particularly if end to end; the collateral circulation in this region is excellent and we believe the extent and duration of the operation are not justified by the slight improvement to be expected over a sympathectomy.

The ideal would be to remove the cervical rib before vascular complications occur, but, as the great majority of these ribs never cause symptoms, clearly some selection would be required. We suggest that the presence of a murmur over the subclavian artery indicates turbulence in the blood flow due to the rib (or to athero-sclerosis) and that in such a patient serious consideration should be given to the advisability of operation. Telford and Mottershead (1947) have shown that so many normal persons can obliterate the radial pulse by various postural manoeuvres that these are quite valueless in cases of cervical rib. Adson's deep-breathing test, however, does not fall into this class, for it depends on the action of the scalenus anterior as an accessory muscle of respiration, and obliteration of the radial pulse by this means suggests compression of the subclavian artery between a cervical rib and the muscle. We suggest that, while this does not in itself constitute an indication for operation, such a patient should be watched for the development of a subclavian murmur or of vascular symptoms, and operation advised should either appear.

Summary

Attention is drawn to the serious results which may ensue if vascular symptoms in association with a thoracic outlet compression syndrome pass unrecognized or are disregarded; for, though they may be coincidental, not infrequently they provide the initial evidence of damage to the subclavian artery. The end-result may be loss of fingers, ischaemic contracture of forearm and hand, or a major amputation, following occlusion of the main vascular channels by embolism or thrombosis; examples of each are described.

Further evidence of the purely vascular origin of these symptoms as distinct from an indirect autonomic effect is presented.

Treatment is briefly discussed and suggestions are made for the selection of those patients with cervical ribs in whom vascular complications may arise and for whom excision of the rib should be advised.

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Two new training films for nurses, on lifting patients, have been made by the Ministry of Health, with the help of the Central Office of Information. The first deals with the lifting of patients in hospital, and demonstrates diagrammatically with an animated skeleton the effect on the body of a good and bad lift, and how the latter can cause injury. Two basic ways of lifting are shown, the usual hospital one, and the shoulder (or Australian) lift. The second, which is primarily to help district nurses and health visitors, could also be of use to relatives who are nursing patients at home. Various everyday situations are illustrated, including the lifting by a district nurse of a helpless patient in a low bed, and in a double bed, in cramped surroundings and without other help. Both these films are 16 mm. and can be hired from the Central Film Library, Government Building, Bromyard Avenue, Acton, London, W.3, at 5s. for the first day and 1s. for subsequent days. The films may be purchased for £10 12s. 6d. for Part I and £8 10s. for Part II.