Ian A. Trail
Andrew N. M. Fleming
Editors

Disorders of the Hand

Volume 1: Hand Injuries

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Preface

In recent years there have been significant advances in the understanding and treatment of disorders of the hand and wrist. This has resulted in a significant improvement in the quality of life for many patients. The authors who have produced this text were chosen as they are hand surgeons who have led many of these exciting developments in the management of both elective and trauma hand surgery. All are internationally respected.

The topics covered are well illustrated with images, radiographs and line drawings and provide practical guidance on surgical procedures. The references at the end of each chapter have been chosen as they are either classic papers or are the most relevant to modern surgical management.

Thus we hope that we have produced a book that will enable improved care for current patients with hand and wrist complaints and inspire surgeons to think in greater detail about treatment options that will provide even better care in the future.

Finally, we would like to thank all the contributors as well as Diane Allmark for her help, but also our families for their patience and support.

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Finally we would like to thank our secretaries, particularly Diane Allmark, and respective families who, for longer than we dare think, have put up with us reading and re-reading manuscripts on what they think is only a small part of the body!

Contents

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Blood Vessels

1

Henk Giele and Richard Barton

Keywords
Vascular injuries • hand and upper limb • ischemia

Introduction

Vascular disorders of the upper extremity encompass a broad range of pathology with diverse clinical presentations and management options. The consequences of vascular insufficiency may be critical to the point of producing cell death or subcritical events that damage tissue but fall short of generating necrosis. They occur as a result of a structural abnormality (laceration, thrombosis, embolism) or as a consequence of inappropriate physiological control mechanisms or both. Ultimately any symptoms that are a consequence of vascular disorders result from a failure to provide adequate nutritional blood flow to the extremity.

In each case a thorough understanding of the vascular anatomy and an index of suspicion borne out of the knowledge of possible diagnosis is essential to the efficient evaluation and management. In this chapter we discuss the vascular anatomy of the upper limb and the physiological control mechanisms of blood flow. The evaluation, investigation and management of vascular disorders consequent to traumatic, compressive, occlusive, vasospastic, tumour and systemic processes are each outlined separately.

An appropriate level of understanding of the incidence and nature of these anomalies will help to ensure correct interpretation of investigations and define a correct diagnosis in what can occasionally be confusing or even contradictory symptoms and signs.

The upper limb arterial system, via collaterals, anastamosing networks and physiological control mechanisms often has effective compensatory capacity in the face of vascular disorders. It is the hand, which functions as the 'end organ' that is ultimately the source of symptoms.

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Anatomy

A surgeon's understanding of the vascular anatomy of the upper limb, common anatomic variations and the typical pattern of collateral flow are essential in the assessment and management of suspected vascular injury.

Arterial System

The upper limbs are supplied by a right and left subclavian artery that becomes the axillary artery as it passes the outer edge of the first rib and enters the apex of the axilla.

Clinical Pearl – 5 Branches of the Subclavian Artery (Mnemonic VIT*amin* C&D)

V – Vertebral
I – Internal thoracic
T – Thyrocervical trunk (inferior thyroid, suprascapular, transverse cervical)
C – Costocervical trunk (first intercostal, deep cervical)
D – Dorsal scapular artery

The axillary artery extends to the inferior border of the teres major muscle where it enters the periphery and becomes the brachial artery. The axillary artery has three parts according to its relationship to the pectoralis minor (medial, deep, and inferior) and six named branches, the supreme thoracic, thoracoacromial axis, lateral thoracic artery, subscapular trunk and the anterior and posterior circumflex humeral vessels (the mnemonic is Sixties Teens Love Sex And Pot or Screw The Lawyers Save A Patient or She Tastes Like Sweet Apple Pie). Apart from the thoracic vessels these are important for collateral flow around the shoulder.

Clinical Pearl – 6 Branches of the Axillary Artery (Mnemonic)

Sixties – supreme thoracic
Teens – thoraco-acromial axis
Love – lateral thoracic
Sex – subscapular trunk
And – anterior and
Pot – posterior circumflex humeral

The brachial artery enters the flexor compartment in the medial arm and proceeds superficially in this space towards the elbow, gradually spiralling more anterior until it lies midway between the humeral epicondyles in the antecubital fossa. It bifurcates near the neck of the radius into radial and ulnar arteries. Major branches are the profunda brachii and superior and inferior ulnar collaterals. The profunda brachii branches first and follows the radial nerve to run posterior, then lateral to the humerus, and ends as anterior and posterior branches that communicate with the radial recurrent and interosseous recurrent vessels at the cubital anastamosis around the elbow joint. The superior and inferior ulnar collateral branches pass posterior and anterior to the medial epicondyle respectively to join the ulnar recurrent vessels distally. All these branches providing major sources of collateral flow across the elbow.

The radial artery appears as a direct continuation of the brachial artery. It takes a more superficial course than the ulnar artery in the proximal forearm, initially travelling deep to the bicipital aponeurosis and brachioradialis but superficial to pronator teres, flexor digitorum superficialis and flexor pollicis longus, along its path to the wrist. At the proximal wrist, it gives off the superficial palmar artery and a volar carpal branch before proceeding dorsally beneath the first extensor compartment tendons. In the snuffbox it gives rise to the dorsal carpal branch and the first dorsal metacarpal artery before diving between the two heads of the first dorsal interosseous muscle and entering the palm as the deep palmar arch.

The ulnar artery passes beneath pronator teres and the fibrous arch of flexor digitorum superficialis; it joins the ulnar nerve at the junction of the middle and proximal thirds of the forearm, on the surface of the flexor digitorum profundus muscle belly. The ulnar neurovascular bundle proceeds distally to the wrist where it lies immediately deep and radial to the flexor carpi ulnaris tendon. It gives rise to a dorsal cutaneous branch 2–5 cm proximal to the pisiform and a palmar and dorsal carpal branch at the wrist. It enters the hand by crossing superficial to the transverse carpal ligament through Guyon's canal within which it gives a deep palmar branch and continues as the superficial palmar arch.

The common interosseous artery originates from the ulnar within a few centimetres of the elbow and almost immediately divides into anterior and posterior branches. These lie deep on either side of the interosseous membrane enroute to the wrist. They communicate via perforating branches, which pierce the membrane, and then unite distally where branches connect with palmar and dorsal carpal arches, providing a collateral pathway to the hand.

Within the hand and wrist there is a system of arterial arches, which provide multiple interconnecting anastamotic networks and collateralisation. They demonstrate significant anatomic variance, particularly on the radial side of the hand. The most proximal of these arches contains volar and dorsal carpal segments that encircle the wrist. It has contributions from each of the radial, ulnar and interosseous arteries. The volar carpal arch sends branches distally into the hand to anastamose with the deep palmar arch. Dorsal metacarpal arteries two to four arise from the dorsal carpal arch and proceed distally on their respective interossei, communicating via perforating vessels with the palmar circulation at the metacarpal heads. They bifurcate into dorsal digital branches to supply adjacent sides of all four fingers.

The superficial palmar arch is a direct continuation of the ulna artery beyond the flexor retinaculum. It lies in contact with the deep surface of the palmar aponeurosis running transversely at the level of the abducted thumb. From its convexity arise digital branches- a proper digital artery to the ulna side of the little finger and three common digital arteries, to the second, third and fourth web spaces.

The deep palmar arch is a continuation of the radial artery, having entered the palm by passing between the two heads of the first dorsal interosseous muscle and onwards between the oblique and transverse heads of adductor pollicis. The deep palmar arch travels across the palm at a level proximal to the superficial arch, deep to the flexor tendons. In the classic pattern, it gives rise to the palmar blood supply of the thumb via its first branch, the first palmar metacarpal artery or arteria princeps pollicis. This passes distally along the first metacarpal bone and divides into two palmar digital branches of the thumb at the metacarpal head. The radialis indicis supplies the radial aspect of the index finger and variably arises directly from the deep arch or as a common trunk with the arteria princeps pollicis or from the superficial palmar arch. The deep palmar arch also produces three further palmar metacarpal arteries, which pass distally to anastamose with the dorsal metacarpal arteries at the level of the metacarpal heads and the common palmar digital vessels of the superficial arch. All five digits therefore receive arterial inflow from both the radial and ulna arteries via the deep and superficial arches.

The two palmar arterial arches may be incomplete. The superficial arch is most commonly completed by the superficial palmar branch of the radial artery but may also be completed via a persistent median artery or from a branch of the deep palmar arch. The deep palmar arch is less variable and is completed by the deep branch of the ulna artery in 98.5 % of hands [1].

The common digital arteries give rise to two proper digital arteries. These travel along the contiguous sides of all four fingers, dorsal to the digital nerves, between Grayson's and Cleland's ligaments. They have multiple anastamotic connections along their path. These include three transverse palmar arches located at the level of the necks of the proximal and middle phalanges and just distal to the profundus insertion. The digital artery supplies the metacarpal and interphalangeal joints and each has two dorsal branches, which anastamose with the dorsal digital arteries.

In the thumb there are two constant communicating branches of the palmar digital arteries. The first is at the level of the proximal phalangeal neck, the second lies across the distal part of the oblique pulley of the flexor sheath. Distally, the pulp arcade runs between the insertion of the flexor tendon and the bony tuft of the distal phalanx. Similar to the fingers there are further branches from the digital arteries to the interphalangeal joint, dorsal thumb, nail bed and flexor sheath.

Some arterial anatomical variations have already been discussed; certainly the point has been made about the high incidence of variability on the radial side of the hand. The dominant supply to the thumb, being the ulnar palmar digital vessel will only arise from the first palmar metacarpal artery approximately 60 % of the time, it is otherwise supplied from the first dorsal metacarpal artery, superficial palmar arch or superficial branch of the radial artery. Despite this wide variety of origin, once it has reached the level of the ulnar sesamoid, the ulnar palmar digital artery will follow a constant and superficial course in all thumbs [2].

The most common abnormality above the wrist is a high branching radial artery from the brachial artery. When this occurs it is more likely to be from a high proximal position than from the lower part of the brachial artery, it is common, occurring in approximately 12 % of arms [1]. Peculiarities of the radial artery in the forearm are uncommon, but typically relate to a more superficial position of the vessel, such as lying on the surface of brachioradialis, instead of under its medial border and lying above the first and or third extensor compartments at the wrist. Less commonly the ulnar artery may also vary in its origin, occasionally arising 5–7 cm below the elbow, but more frequently from higher on the brachial artery. With a proximal origin the artery will typically lie in a more superficial position over the flexor muscles in the forearm.

A persistent median artery has a reported incidence between 4.4 and 27 % [3]. During embryogenesis the median artery branches from the interosseous (axis) artery and follows the median nerve in the forearm and into the hand. It provides the dominant blood supply to the distal half of the upper extremity in the first few months of foetal life. In the normal course of development the median artery regresses and usually disappears as the radial and ulnar arteries develop. When present after embryogenesis the persistent median artery accompanies the median nerve through the carpal tunnel on its ventral surface, where it may join the superficial palmar arch or end as one or two palmar digital arteries.

Venous System

The venous system is defined by superficial and deep veins linked by perforating vessels. Valves in each of these systems prevent retrograde flow and the flow of blood from deep to superficial. Deep veins are numerous and accompany arteries in the form of venae commitantes and also lie within muscle bellies. Large superficial veins on the back of the hand form the dorsal venous network. This network contributes significantly to the venous drainage of the palm and this then coalesces on the radial side into the cephalic vein and on the ulnar side into the basilic vein. These two vessels serve as the dominant superficial drainage routes along the lateral and medial aspects of the upper limb.

The cephalic vein gives rise to the median cubital vein distal to the elbow, which receives branches from the deep system and diverges proximo-medially to reach the basilic vein. Above the elbow the cephalic vein runs lateral to biceps, along the deltopectoral groove and perforates the clavipectoral fascia to drain into the axillary vein. The basilic vein runs up the medial border of the limb, perforating the deep fascia halfway up the upper arm and joins the brachial veins to become the axillary vein. The standard pattern of superficial veins in the forearm also includes a median vein that drains the flexor surface of wrist and forearm and joins either the basilic or median cubital vein. There are frequent variations to this pattern [4].

Lymphatic System

The lymphatic glands and vessels of the upper extremity are divided into superficial and deep [5].

The scant superficial glands comprise the supratrochlear and deltopectoral groups; they number only a few in each group. The supratrochlear group are situated above the medial epicondyle of the humerus, medial to the basilic vein. The deltopectoral glands lie adjacent to the cephalic vein in the deltopectoral groove, just inferior to the clavicle. The superficial lymphatic vessels accompany the cephalic, median and basilic veins. This system is in free communication with the deep lymphatics whose glands lie predominantly in the axilla. There may be some scattered deep glands along the course of the arteries in the forearm and the brachial artery in the arm. The axillary glands typically number 20–30 and in surgical terms are described as being in levels one to three. Level I glands lie distal to pectoralis minor, level II glands lie deep to the pectoralis minor and level III glands are in the apex of the axilla, proximal to pectoralis minor [6].

Physiology

The microvascular system of the hand functions to deliver the nutritional requirements of the tissue and to provide flow through the arteriovenous anastamosis that participate in temperature regulation. The nutritional flow required to maintain tissue viability is typically only 10–20 % of the potential blood flow, leaving the remainder to pass through the thermoregulatory beds. This system has considerable capacity and undergoes large fluctuations in volume, under the control of environmental influences, local factors and metabolic demands as well as circulating mediators and centrally controlled sympathetic tone.

Local metabolic demands, mediated through oxygen levels and metabolites, influences microcirculatory blood flow to maintain adequate nutritional requirements.

Endothelial cells are intimately involved in the regulation of vascular tone via the synthesis and release of cytokines, growth factors, prostaglandins and other bioactive macromolecules. Some are mediators of vasodilatation such as prostacyclin and nitric oxide and others, such as endothelin-1 are vasoconstrictors.

The sympathetic nervous system contributes to vaso-regulation via the alpha adrenergic receptors of the vascular smooth muscle which cause vasoconstriction. The nerve fibers travel in perivascular tissue and penetrate the arterial and venous walls of the hand and forearm.

Evaluation of Vascular Disorders of the Upper Limb

History and Presentation

The clinical presentation of upper limb vascular disorders range from significant ischaemic symptoms such as pain, finger tip ulceration or gangrene, to mild symptoms suggestive of inadequate, subcritical blood flow; claudication, peripheral cold intolerance, altered sensation and skin colour changes.

Patients present with symptoms of acute onset or having developed signs and symptoms progressively over time. Acute necrosis or open wounds are relatively easy to assess, but when the complaints are chronic, and mild or intermittent then diagnosis is more difficult and reliant on investigations.

The patient may reveal a history of recent trauma or describe chronic occupational or recreational exposure to repetitive hand injury and vibration. If the condition is non-traumatic a broad past medical history must include the search for atheromatous disease, cardiac ischaemia and arrhythmia, malignancy, diabetes, systemic connective tissue disorders, drug exposure, tobacco use and family history of blood dyscrasias. An element of peripheral vascular disease may be present prior to the injury or indeed render the vessel more susceptible or less tolerant of injury. In chronic or delayed presentations, one should enquire about aggravating and relieving factors, such as activity, arm position and environmental or emotional stressors.

Examination

Examination includes the entire upper limb and neck and aims to determine the adequacy of the vascular system and identify sites of possible vascular compromise. Inspection can reveal open wounds, joint dislocation, deformity, but also more subtle observations of skin colour change, hair loss, scars, fingertip atrophy, necrosis or ulceration, splinter haemorrhages and fungal infections of the nails.

On palpation one should detect temperature differences, skin texture, hair growth, capillary refill and the quality of pulses. The site of previous injury may reveal the mass of an aneurysm, fistula or haematoma.

There are a number of useful clinical tests that should be carried out during the consultation. Allen's test is used to determine the patency of the dual blood supply and quality of collateral circulation of the hand or digit [7]. When assessing the ulnar and radial arteries the examiner compresses both vessels at the wrist and asks the patient to open and close the hand until it turns pale. The vessels are then released sequentially and reperfusion across the hand is observed. The test is repeated reversing the order of artery release. Delayed perfusion or failure to reperfuse indicates reduced flow in the vessel released.

If the pulses cannot be palpated they may be searched for using the hand held Doppler probe. However presence of the Doppler signal should not reassure one to the extent of avoiding intervention, as a completely occluded artery can still display an audible Doppler signal.

Investigation

The appropriate set of investigations is determined by the clinical presentation, history and examination findings. An open wound, fracture or dislocated joint with loss of pulses and compromised distal vascularity requires no further investigation, other than surgical exploration and reduction.

However in chronic cases, investigations may be required and along with specific upper limb vascular investigations it may be relevant to perform blood tests such as ESR, Rheumatoid factor and antinuclear antibodies. Other considerations, particularly if embolisation is suspected, include ECG and cardiac echocardiogram. A number of patients will benefit from a referral to other disciplines such as rheumatology, cardiology or vascular surgery.

Vascular testing aims to determine the structural configuration of the upper limb vessels and their functional capability to respond to stress. Often a combination of vascular studies is necessary to help differentiate between occlusion and vasospastic disorders and determine their relative importance when both occur together.

In most circumstances plain radiography is the starting point. It is useful in characterising phleboliths, vascular calcification, foreign bodies, and the presence of any osseous abnormalities. Vascular imaging using ultrasound, CT and MRI has greatly increased the diagnostic ability of radiologists [8].

Doppler ultrasound is easily accessible and inexpensive. It is able to differentiate venous from arterial flow, assess flow haemodynamics and vessel lumen morphology. A normal vessel produces a triphasic waveform and progresses to monophasic in a vessel with abnormal flow characteristics. Pulse-echo imaging uses sound to produce a two dimensional representation of the vessel wall. It is, however, operator dependent and is unable to fully evaluate upper limb arterial inflow.

Colour duplex imaging can provide structural and functional information about a vessel. It demonstrates the direction and velocity of flow with varying intensity of either a red or blue colour on the monitor. This non-invasive technique is cost efficient and repeatable. It is useful to differentiate between tumours of the upper extremity such as differentiating ganglia from aneurysms. It can also localise the site of vascular obstruction.

Plethysmography, or digital pulse volume recording, is a technique that quantitates flow by detecting volume change in the limb or digit and can measure the response in blood flow to changes in temperature. It produces characteristic pulse volume recordings that can be used to differentiate a fixed arterial obstruction or narrowing from vasospastic disease. It is further helpful in the evaluation of vasospastic disease by predicting the results of surgical sympathectomy by observing the response of a cold, vasoconstricted digit blocked with local anaesthetic. The anaesthetised digit mimics the physiological conditions achieved following sympathectomy, so an improvement in the signs suffered under environmental stress is a positive predictor of operative success.

Cold stress testing provides an evaluation of the response of the digital vessels to physiologic stress by monitoring cutaneous perfusion and