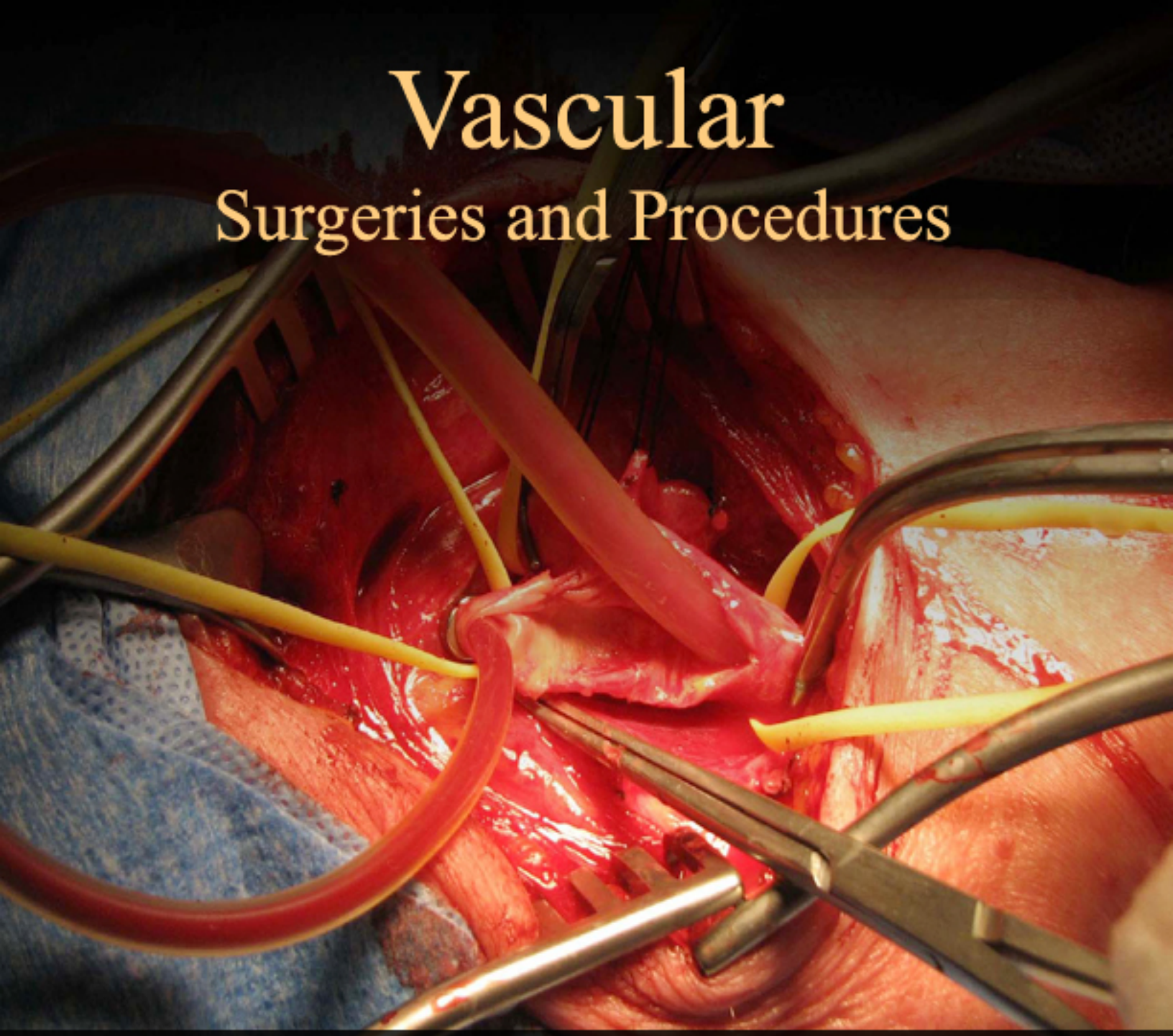
Vascular

Surgeries and Procedures



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Chapter 1

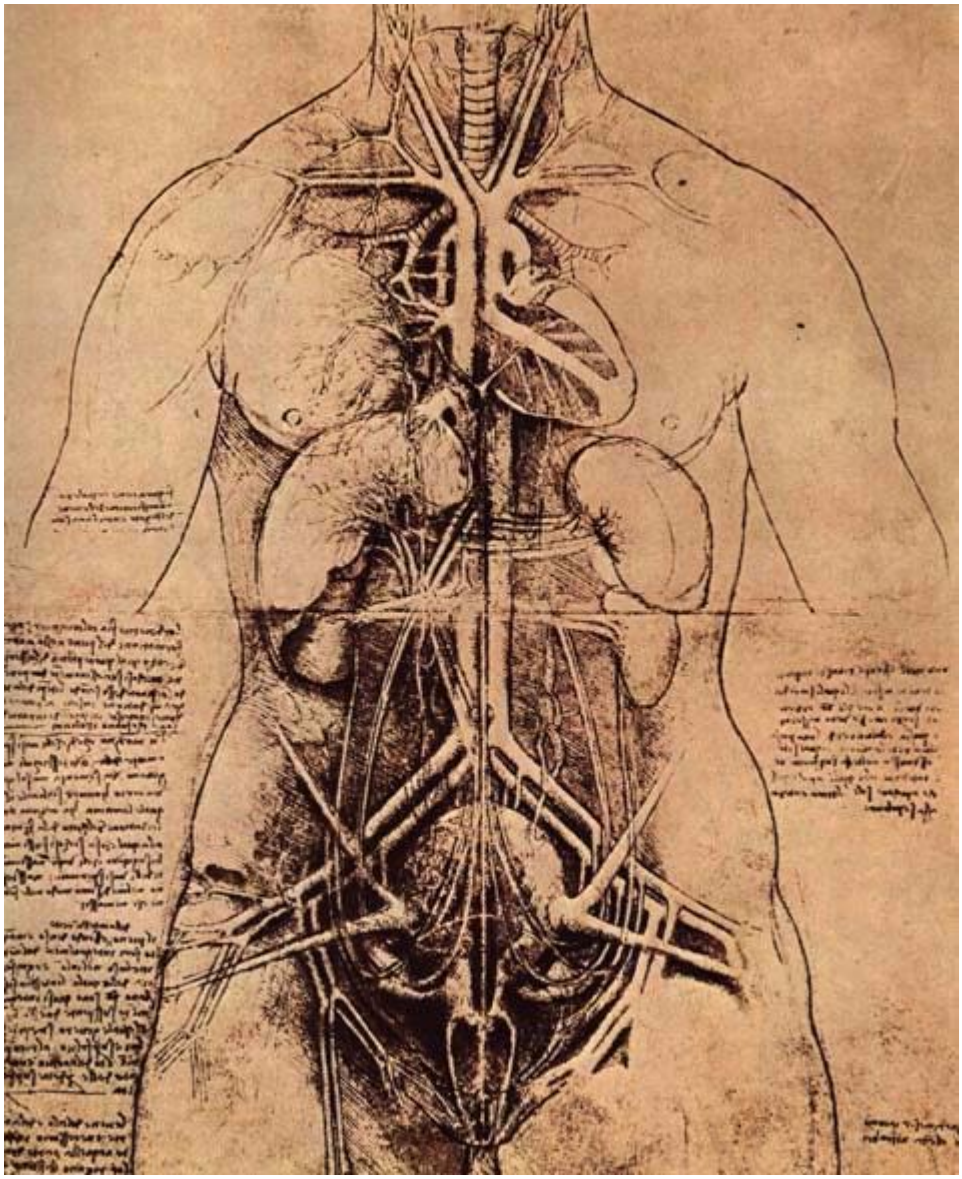
Vascular Surgery

Vascular Surgeon

Occupation	
Names	Doctor, Medical Specialist
Type	Specialty
Activity sectors	Medicine
Description	
Education required	MD or DO
Fields of employment	Hospitals, Clinics

Vascular surgery is a specialty of surgery in which diseases of the vascular system, or arteries and veins, are managed by medical therapy, minimally-invasive catheter procedures, and surgical reconstruction. The specialty evolved from general and cardiac surgery. Early pioneers of the field include Russian surgeon Nikolai Korotkov, noted for developing early surgical techniques, and Robert Paton, one of the first Australian vascular surgeons and often credited with helping the field achieve recognition as a speciality. Edwin Wylie of San Francisco was one of the early American pioneers who developed and fostered advanced training in vascular surgery and pushed for its recognition as a specialty in the United States in the 1970s. The vascular surgeon is trained in the diagnosis and management of diseases affecting all parts of the vascular system except that of the heart and brain. Cardiothoracic surgeons manage surgical disease of the heart and its vessels. Neurosurgeons manage surgical disease of the vessels in the brain (e.g. intracranial aneurysms).

The Evolution of Endovascular Surgery



Medical science has advanced significantly since 1507, when Leonardo da Vinci drew this diagram of the internal organs and vascular systems of a woman.

The specialty continues to be based on operative arterial and venous surgery but since the early 1990s has evolved greatly. There is now considerable emphasis on minimally invasive alternatives to surgery. This area of vascular surgery is called Endovascular Surgery, a term that some in the specialty append to their primary qualification as Vascular Surgeon. Endovascular and endovenous procedures can now form the bulk of a vascular surgeons practice.

The development of endovascular surgery has been accompanied by a gradual separation of vascular surgery from its origin in general surgery. Most vascular surgeons would now

confine their practice to vascular surgery and similarly general surgeons would not be trained or practice the larger vascular surgery operations or most endovascular procedures. More recently, professional vascular surgery societies and their training programme have formally separated "Vascular Surgery" into a separate specialty with its own training program, meetings, accreditation. Notable societies are Society of Vascular Surgery (SVS), USA; Australia and New Zealand Society of Vascular Surgeons (ANZ SVS). Local societies also exist e.g. Melbounrne Society of Vascular Surgeons (MVSA). Larger societies of surgery actively separate and encourage specialty surgical societies under their umbrella e.g. Royal Australasian College of Surgeons (RACS). Big text

Common Professional Associations

Associated areas of interest and operative surgical practice for vascular surgeons are access surgery for hemodialysis and peritoneal dialysis, organ harvesting for transplantation, renal transplantation, pancreatic solid organ transplantation Organ transplant.

Vascular surgeons will frequently have close associations with specialist vascular radiology clinics for a combined treatment of certain conditions. The radiologists contribute to endovascular cases management, sometimes with angioplasty and stenting, but more often in specific areas of expertise e.g. sclerotherapy for vascular anomalies and arteriovenous malformations (AVMs), coil embolisation of bleeding visceral arteries in trauma or for occlusion of tumour supplying arteries as a prelude to operation, CT-guided procedures such as lumbar chemical sympathectomy.

Common medical associations are the involvement providing surgical opinions and treatment for a multidisciplinary clinic with vascular surgeons, vascular nurses, wound management nurses, podiatrists, prosthetists, rehabilition physicians, vascular physicians, endocrinologists, etc. to manage high risk foot disease patients.

Less common operative surgical associations are: sympathectomy (ETS, Endoscopic thoracic sympathectomy), lumbar sympathectomy, Hyperhidrosis surgery); vascular access for chemotherapy etc. patients; dialysis/ECMO (extra-corporeal membrane oxygenation) for patients in Intensive Care Wards; vascular mobilisation for access associated with other specialist operations e.g. extensive orthopaedic spinal and pelvic surgery, retroperitoneal cancer dissections, renal tumour surgery.

Vascular Surgery in the Third Millennium

Arterial and venous disease treatment by angiography, stenting, and non-operative varicose vein treatment sclerotherapy, endovenous laser treatment are rapidly replacing major surgery in many first world countries. These newer procedures provide reasonable outcomes that are comparable to surgery with the advantage of short hospital stay (day or overnight for most cases) with lower morbidity and mortality rates. The durability of endovascular arterial procedures is generally good especially when viewed in the context of their common clinical usage i.e. arterial disease occurring in elderly patients and

usually associated with concurrent significant patient comorbidities especially ischaemic heart disease. The cost savings from shorter hospital stays and less morbidity are considerable but are somewhat balanced by the high cost of imaging equipment, construction and staffing of dedicated procedural suites, and of the implant devices themselves. The benefits for younger patients and in venous disease are less persuasive but there are strong trends towards nonoperative treatment options driven by patient preference, health insurance company costs, trial demonstrating comparable efficacy at least in the medium term.

A recent trend in the USA is the stand-alone day angiography facility associated with a private vascular surgery clinic, thus allowing treatment of most arterial endovascular cases conveniently and possibly with lesser overall community cost. Similar non-hospital treatment facilities for non-operative vein treatment have existed for some years and are now widespread in many countries.

An emerging trend based on such venous clinics is the treatment of varicose veins by non-vascular surgeons e.g. cosmetic physicians, phlebologists, radiologists, etc. These practices aim to offer a complete varicose and surface vein treatment without surgery.

Breadth of discipline

- Arterial diseases (especially in Diabetics)
    - Aneurysms
    - Ischemia
        - Limb ischemia
            - Acute limb ischemia
                - Thrombectomies
                - Embolectomies
                - Anti-coagulation and Thrombolysis
            - Chronic limb ischemia
                - Diabetic foot ulcers
        - Mesenteric ischemia
        - Renal ischemia
    - Extracranial cerebrovascular disease
        - Carotid Endarterectomy and other carotid surgery
        - Surgery of the vertebral system
- Venous disease
    - Deep Vein Thrombosis
    - Thrombophlebitis
    - Varicose Veins and Varicosities
    - Venous malformations
- Lymphatic disease
    - Lymphoedema

- Vascular Medicine
    - Medical disorders with a significant vascular component, for example:

    - Raynaud's syndrome
    - Scleroderma
    - Hyperhidrosis

- Migraine

Training

Previously considered a field within general surgery, it is now considered a specialty in its own right. As a result, there are two pathways for training in the United States. Traditionally, a five year general surgery residency is followed by a 1-2 year (typically 2 years) vascular surgery fellowship. An alternative path is to perform a five or six year vascular surgery residency.

Programs of training are slightly different depending on the region of the world one is in.

Country	Standards body	Professional representation	Minimum Length of training (post intern)
Australia and New Zealand	Royal Australasian College of Surgeons	Australian & New Zealand Society of Vascular Surgery (ANZSVS)	6 years
United Kingdom	Royal College of Surgeons of England, Royal College of Surgeons of Edinburgh	Vascular Society of Great Britain and Ireland	8 years
USA	Accreditation Council for Graduate Medical Education (ACGME), American Board of Surgery	American College of Surgeons Multiple vascular societies	5 years (4 via 5-year integrated Vascular Surgery Residency)

Research

Research in treating vascular disease is exploring new areas, such as minimally invasive techniques which are less risky and speed a patient's recovery time. Vascular surgeon Kenneth Ouriel studied methods like these as part of a National Institute of Health grant to study thrombosis; results from this large, multicenter randomized trial of clot busting therapy treatments were published in the New England Journal of Medicine in 1998.

Surgical procedures

By no means exhaustive, but below are a number of common procedures and indications for vascular surgeons.

Indication/disease	Procedure
Abdominal aortic aneurysm	Open AAA repair
	Endoluminal AAA repair (EVAR)
Carotid stenosis	Carotid endarterectomy
	Carotid stenting
Varicose veins	Vein stripping
	Sclerotherapy and Foam sclerotherapy or Endovenous Laser Treatment, radiofrequency vein ablation
	Ambulatory phlebectomy
Peripheral arterial occlusive disease	Angioplasty with/out Stenting
	Bypass surgery Endarterectomy Atherectomy
	Balloon embolectomy
Acute limb ischaemia	Thrombectomy
	Bypass surgery
Aortic dissection	Open repair
	Thoracic stent graft

Major Trials in Vascular Surgery

- **Edinburgh Artery Study**. *Highwire results for Edinburgh Artery Study

- **Netherland Vascular Study**.

- **Framingham heart study**. Highwire results for Framingham heart Study

- **MASS Trial**. – the Multicentre Aneurysm Screening Study (MASS) trial. Four centres (about 7000 men); screening (and treatment) vs. control group. AAA-related mortality in the screening arm reduced by about 40%; emergency ruptured AAA reducted by about 70%; disruption to elective work was reduced; and better management of risk factors and ITU/HDU beds. The overall survival benefits remain difficult to estimate, nevertheless, screening for AAA is recommended [level of recommendation: B].

- **UK Small Aneurysm Trial**: 1090 patients; AAA 4-5.5 cm; Immediate surgery vs. ultrasound surveillance (and treatment for rapid expansion or AAA >5.5); 30-day mortality after elective AAA repair is 5.8%. No difference in survival.

- **ADAM VA Cooperative Group Trial**. 73451 VA patients screened with no known hx of aneurysm; Age 50-79; AAA 4.0-5.4 cm; similar conclusion to Uk Small Aneurysm Trial.

- **Joint Vascular Research Group Trial**. 284 patients; Study the relationship between intraoperative intravenous heparinisation, blood loss during surgery and thrombotic complications. Conclusion: Intraoperative heparin, given before aortic cross clamping, is an important prophylaxic against perioperative MI in aortic aneurysm surgery.

- **HOPE (Heart Outcomes Prevention Evaluation) study** - 4046 patients with PAD. In this subgroup, there was a 22% risk reduction in patients randomized to ramipril compared with placebo,which was independent of lowering of blood pressure.

Chapter 2

Embolectomy and Vascular Bypass

Embolectomy

	Intervention: ***Embolectomy***
ICD-10 code:	
ICD-9 code:	39.74 38.0 38.1
MeSH	D017131 D017128, D017131
Other codes:	

Embolectomy is the emergency surgical removal of emboli which are blocking blood circulation. It usually involves removal of thrombi (blood clots), and is then referred to as **thrombectomy**. Embolectomy is an emergency procedure often as the last resort because permanent occlusion of a significant blood flow to an organ leads to necrosis. Other involved therapeutic options are anticoagulation and thrombolysis.

Background knowledge

Emboli are abnormal masses of material (which can be solid, liquid or gas) that are carried in the blood stream from one part of the circulation to another causing a blockage (occlusion) of a blood vessel that leads to lack of oxygen supply (ischemia) and finally infarction of tissue downstream of the embolus.

The most common type of emboli are a blood clot generated by thrombosis which has then broken off and is then transported in the blood stream.

There are two areas where emboli can form and therefore impact:

- Arterial emboli form in the left side of the heart or the main arteries, they impact in body tissues but not the lungs, commonly in the brain and the small vessels in the upper and lower limbs

- Venous emboli arise in veins (for example emboli which form from deep venous thrombosis or DVT) and these impact in the lung.

Indications

Surgical embolectomy for massive pulmonary embolism (PE) has become a rare procedure and is often viewed as a last resort. Thrombolytic therapy has become the treatment of choice.

Surgical or catheter embolectomy is normally performed in patients with pulmonary embolism (formed from venous embolisms). Embolectomy is used for patients with persisting shock despite supportive care and who have an absolute contraindication for thrombolytic therapy. And although other treatments have improved urgent surgical embolectomy or catheter embolectomy may be a life saving procedure in severe pulmonary embolism.

Embolectomies are performed for arterial embolisms in acute limb ischemia. However there are also other options, such as catheter-directed thrombolysis and anticoagulation with observation.

It can also be used for other ischemias due to embolism for example mesenteric ischemia and stroke.

Methods

Catheter embolectomy

Balloon embolectomy

Typically this is done by inserting a catheter with an inflatable balloon attached to its tip into an artery, passing the catheter tip beyond the clot, inflating the balloon, and removing the clot by withdrawing the catheter. The catheter is called Fogarty, named after its inventor Thomas J. Fogarty.

Possible complications of balloon embolectomy include intimal lesions, which can lead to another thrombosis. The vessel may also be affected by a dissection or rupture or causing cholesterol embolism from atherosclerotic plaques.

Aspiration embolectomy

Catheter embolectomy is also used for aspiration embolectomy, where the thrombus is removed by suction rather than pushing with a balloon. It is a rapid and effective way of removing thrombi in thromboembolic occlusions of the limb arteries below the inguinal ligament, as in leg infarction.

Surgical embolectomy

Surgical embolectomy is the simple surgical removal of a clot following incision into a vessel by open surgery on the artery.

Outcome

Outcome of embolectomy varies with size and location of the embolous.

In pulmonary embolism recent data shows mortality as being approximately 20%. Although this is a high mortality, it may have life-saving potential in some instances.

Vascular bypass

In medicine, a **vascular bypass** generally means an alternate or additional route for blood flow, which is created in bypass surgery, e.g. coronary artery bypass surgery by moving blood vessels or implanting synthetic tubing. Vessels frequently used for the bypass are large veins taken from the patient's leg. When and where possible, however, an artery is cut from one place and reconnected to another artery, which supplies a region that needs the blood supply more than the original site. Generally the blood flow in the receiving vessel is temporarily interrupted or reduced while the bypass is connected. To create a bypass to a critical artery, the connection can be made while blood is flowing through the receiving vessel with the ELANA operating technique.

Types of bypass surgeries

There are several different types of bypass surgeries:

- Heart bypass surgery is performed when the arteries that bring blood to the heart muscle (coronary arteries) become clogged by plaque. Such condition may lead to chest pain or heart attack.

- A bypass may be performed on peripheral arteries with occlusive disease. For example, a femoral-popliteal bypass might be used if the femoral artery was occluded.

- The cerebral artery bypass surgery is performed to reroute blood flow around a blocked or damaged artery to improve or restore blood flow to an oxygen-deprived (ischemic) area of the brain.

When several arteries are blocked and thus several bypasses are needed the procedure is called multiple bypass. The number of bypasses needed does not increase the surgery's

risks which depend on the patient's overall health. Weight and diabetes are examples of possible risks.

Care after bypass surgery

Part of the recovery after any bypass surgery includes regular visits to a physician to monitor the patient's recovery. These visits gradually decrease as the patient's health improves.

Coronary artery bypass

In the case of coronary artery bypass, patients stay in the hospital for four to six days and sometimes longer. Once the patient leaves the hospital the recovery time can vary greatly. Some patients start feeling normal after one month, while others may still experience problems up to six months after the procedure.

During the first twelve weeks after the procedure patients are advised to avoid heavy lifting as well as activities such as playing golf, tennis, or swimming while the sternum completely heals.

Since the coronary artery bypass does not represent a cure for coronary artery diseases, doctors recommend lifestyle changes that include quitting smoking, making diet changes, getting regular exercise, and lowering stress.

Cerebral artery bypass

After cerebral artery bypass, patients can return to normal activities after two to four weeks. Patients are encouraged to take short walks and gradually increase them. However, lifting weight, house work and yard work should be avoided. Also, patients are prescribed narcotic pain killers for a period of two to four weeks.

Normally a follow up visit with the neurosurgeon is scheduled for two to four weeks after surgery.

ELANA

Excimer laser assisted nonocclusive anastomosis (ELANA) is a technique in vascular surgery and neurosurgery to create a bypass without interrupting blood supply in the recipient blood vessels. This is a significant advance because the interruption of blood supply to those blood vessels (i.e., in the brain or heart) could cause a stroke or a rupture of the aneurysm.

The ELANA technique is a subtle modification of existing methods to establish a connection between blood vessels (anastomosis) to create a bypass in or to the brain. The only real differences involve how the recipient artery is opened. In conventional techniques the recipient artery is temporarily interrupted (occluded with clips) and

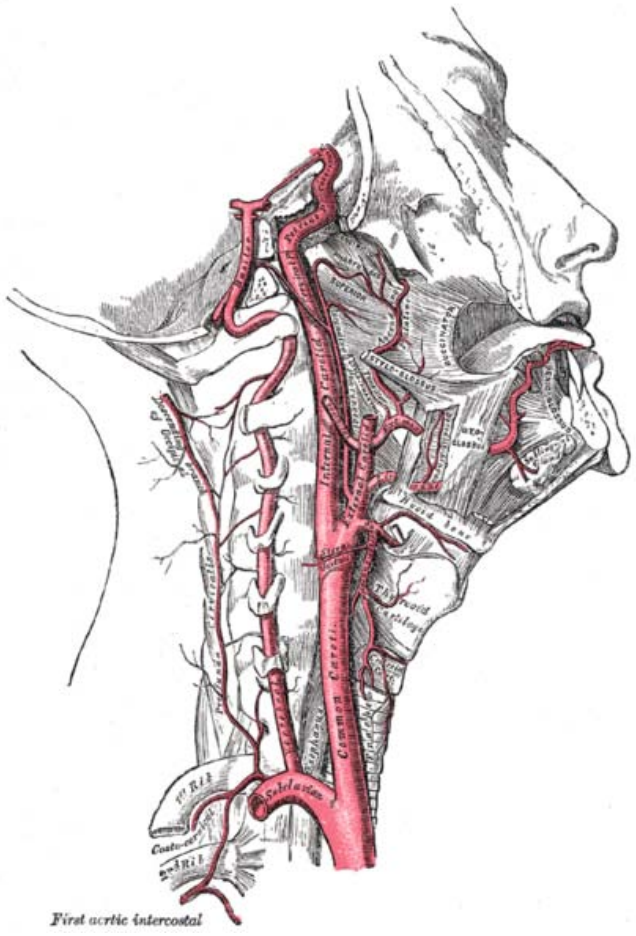
opened using microscissors or scalpel while in the ELANA technique blood flow is not interrupted and the opening (arteriotomy) is created with radiation from a 308nm Excimer Laser delivered through a catheter inserted in the vessel that will become the bypass while blood continues to flow through the artery that receives the bypass. This subtle difference, however, is very important for the safety of the procedure and eliminates the risk of ischemia to the regions supplied by the artery receiving the bypass. The technique is most valuable in neurosurgery, as brain cells are particularly sensitive to the lack of blood supply (ischemia) that would be caused by traditional methods of bypass creation. The bypasses created with the help of the ELANA can be to one of the major arteries in the brain (extracranial to intracranial EC-IC bypass) or between two arteries in the brain (intracranial to intracranial).

Surgeons are creating such a bypass mainly as a step in the treatment of patients with unclippable and uncoilable giant aneurysms or tumors at the skull base or to treat patients at risk of stroke who can not be treated otherwise.

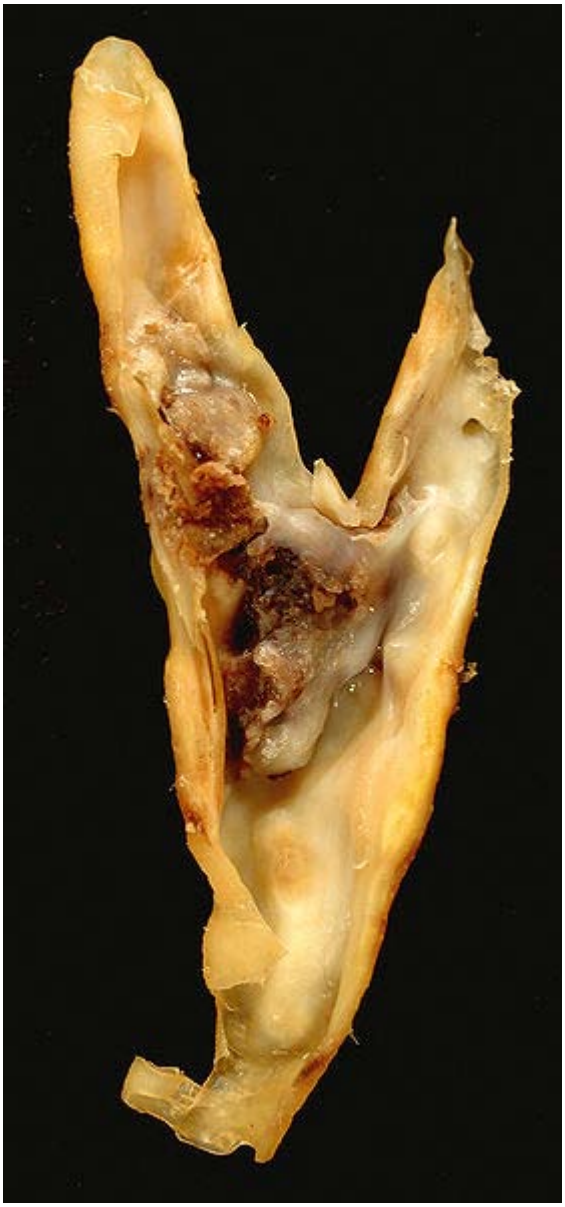
The ELANA technique has been extensively described in medical literature. It was developed in 1993 by Cornelis A.F. Tulleken, professor of neurosurgery at the University Medical Center Utrecht, the Netherlands, to find a way to treat patients with a bypass to a major cerebral artery without the risk of cerebral ischemia during the procedure. The surgery of some patients has been reported upon in the media e.g., in The New York Times in December 2006.

Chapter 3

Carotid Endarterectomy



The carotid artery is the large vertical artery in red. The blood supply to the common carotid artery starts at the arch of the aorta (left) or the subclavian artery (right). The common carotid artery divides into the internal carotid artery and the external carotid artery. Plaque often builds up at that division, and a carotid endarterectomy cuts open the artery and removes the plaque.



Section of carotid artery with plaque. Blood flows from the common carotid artery (bottom), and divides into the internal carotid artery (left) and external carotid artery (right). The atherosclerotic plaque is the dark mass on the left, which would be removed in an endarterectomy.

Carotid endarterectomy (CEA) is a surgical procedure used to prevent stroke, by correcting stenosis (narrowing) in the common carotid artery. Endarterectomy is the removal of material on the inside (*end-*) of an artery.

Atherosclerosis causes plaque to form in the carotid arteries, usually at the fork where the common carotid artery divides into the internal and external carotid artery. The plaque can build up in the inner surface of the artery (lumen), and narrow or constrict the artery. Pieces of the plaque, called emboli, can break off (i.e. embolize) and travel up the

internal carotid artery to the brain, where it blocks circulation, and can cause death of the brain tissue.

Sometimes the plaque causes symptoms first. The symptoms are temporary or transitory strokes, known as transient ischemic attacks (TIAs). By definition, TIAs last less than 24 hours; after 24 hours they are called strokes. Symptomatic stenosis has a high risk of stroke within the next 2 days. National Institute for Health and Clinical Excellence (NICE) guidelines recommend that patients with moderate to severe (50-99% blockage) stenosis, and symptoms, should have "urgent" endarterectomy within 2 weeks.

When the plaque doesn't cause symptoms, patients are still at higher risk of stroke than the general population, but not as high as patients with symptomatic stenosis. The incidence of stroke, including fatal stroke, is 1–2% per year. The surgical mortality of endarterectomy ranges from 1–2% to as much as 10%. Two large randomized clinical trials have demonstrated that carotid surgery done with a 30 day stroke and death risk of 3% or less will benefit asymptomatic patients with ≥60% stenosis who are expected to live at least 5 years after surgery. Surgeons are divided over whether asymptomatic patients should be treated with medication alone or should have surgery.

In endarterectomy, the surgeon opens the artery and removes the plaque. A newer procedure, endovascular angioplasty and stenting, threads a catheter up from the groin, around the aortic arch, and up the carotid artery. The catheter uses a balloon to expand the artery, and inserts a stent to hold the artery open. In several clinical trials,the 30-day incidence of heart attack, stroke, or death was significantly higher with stenting than with endarterectomy (9.6% vs. 3.9%)

The Carotid Revascularization Endarterectomy versus Stenting Trial (CREST) funded by the National Institutes of Health (NIH) reported that the results of stents and endarterectomy were comparable. However, the European International Carotid Stenting Study (ICSS) found that stents had almost double the rate of complications.

Procedure

The internal, common and external carotid arteries are clamped, the lumen of the internal carotid artery is opened, and the atheromatous plaque substance removed. The artery is closed, hemostasis achieved, and the overlying layers closed. Many surgeons lay a temporary shunt to ensure blood supply to the brain during the procedure. The procedure may be performed under general or local anaesthesia. The latter allows for direct monitoring of neurological status by intra-operative verbal contact and testing of grip strength. With general anaesthesia indirect methods of assessing cerebral perfusion must be used, such as electroencephalography (EEG), transcranial doppler analysis and carotid artery stump pressure monitoring. At present there is no good evidence to show any major difference in outcome between local and general anaesthesia.

Minimally-invasive procedures have been developed, by threading catheters through the femoral artery, up through the aorta, then inflating a balloon to dilate the carotid artery,

with a wire-mesh stent and a device to protect the brain from embolization of plaque material. The FDA has approved 5 carotid stent systems as safe and effective in patients at increased risk of complications for neck surgery. In the SAPPHIRE study, Yadav concluded that this procedure, known as carotid stenting, was non-inferior to carotid endarterectomy in total adverse events, and lowered event rates for major stroke, cranial nerve palsy, and myocardial infarction, in patients at high risk for surgery. It is the consensus of experts in the field that carotid artery stenting should be considered an option for patients who require carotid artery revascularization to prevent stroke and who are at increased risk of having surgical complications.

History

The endarterectomy procedure was developed and first done by the Portuguese surgeon Joao Cid dos Santos in 1946, when he operated an occluded superficial femoral artery, at the University of Lisbon. Later, surgical intervention to relieve atherosclerotic obstruction of the carotid arteries was successfully performed by Dr. Michael DeBakey in 1953 for the first time, at the Methodist Hospital in Houston, TX. The first case to be recorded in the medical literature was in The Lancet in 1954. and the surgeon was Felix Eastcott, a consultant surgeon and deputy director of the surgical unit at St Mary's Hospital, London UK. A reprint of his article together with a modern commentary can be found on-line .Since then, evidence for its effectiveness in different patient groups has accumulated. In 2003 nearly 140,000 carotid endarterectomies were performed in the USA (Halm).

Indications

The aim of CEA is to prevent the adverse sequelae of carotid artery stenosis secondary to atherosclerotic disease, i.e. stroke. As with any prophylactic operation, careful evaluation of the relative benefits and risks of the procedure is required on an individual patient basis. Peri-operative combined mortality and major stroke risk is 2–5%.

Carotid stenosis is diagnosed with ultrasound doppler studies of the neck arteries, magnetic resonance angiography (MRA) or computed tomography angiography (CTA). The circle of Willis typically provides a collateral blood supply. Surgical management of symptomatic stenoses has a much higher therapeutic index with regard to asymptomatic lesions.

The North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the European Carotid Surgery Trial (ECST) are both large randomized class 1 studies which have helped define current indications for carotid endarterectomy. The NASCET found that for every six patients treated, one major stroke would be prevented at two years (i.e. a number needed to treat (NNT) of six) for symptomatic patients with a 70–99% stenosis, where percent stenosis was defined as:

$$\text{percent stenosis} = (1 - (\text{minimal diameter}) / (\text{poststenotic diameter})) \times 100\%.$$

Symptomatic patients with less severe carotid occlusion (50–69%) had a smaller benefit, with a NNT of 22 at five years (Barclay). In addition, co-morbidity adversely affects the outcome; patients with multiple medical problems have a higher post-operative mortality rate and hence benefit less from the procedure. For asymptomatic patients (those without TIA or strokes) the European asymptomatic carotid surgery trial (ACST) found that asymptomatic patients may also benefit from the procedure, but only the group with a high grade stenosis (60% or more). For maximum benefit patients should be operated on soon after a TIA or stroke, preferably within the first month.

Contra-indications

The procedure cannot be performed in case of:

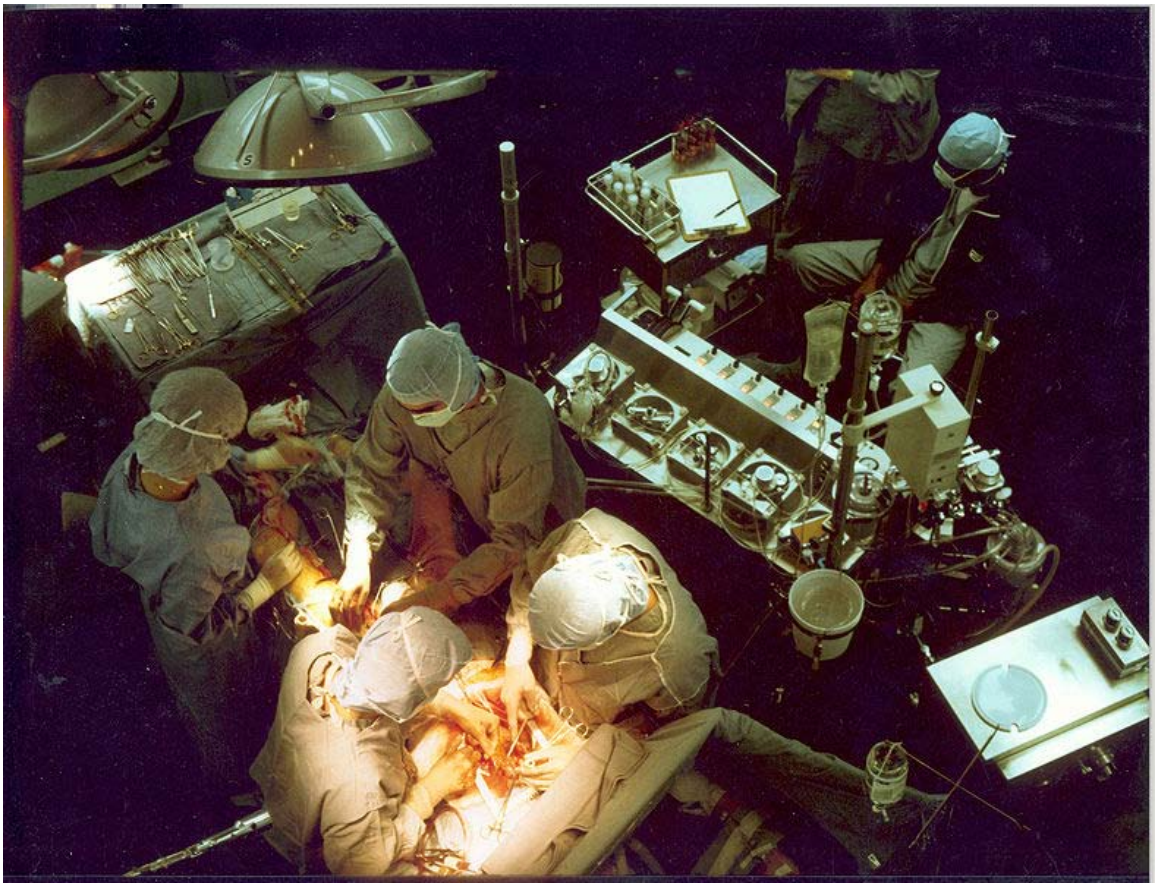
- Complete internal carotid artery obstruction (because there is no benefit to treating chronic occlusion).
- Previous stroke on the ipsilateral side with heavy sequelae, because there is no benefit in preventing what has already happened, or risking making it worse.
- Patient deemed unfit for the operation by the anaesthesiologist.

Complications

About 3% of asymptomatic and 6% of symptomatic patients are expected to suffer stroke or death as a result of either the surgery or carotid stenting. Other surgical complications include Hemorrhage of the wound bed which is potentially life-threatening, as swelling of the neck due to hematoma could compress the trachea. Rarely, the hypoglossal nerve can be damaged during surgery. This is likely to result in fasciculations developing on the tongue and paralysis of the affected side: on sticking it out, the patients tongue will deviate toward the affected side. Another rare but potentially serious complication is hyperperfusion syndrome because of the sudden increase in perfusion of the vasculature distal to stenosis.

Chapter 4

Cardiopulmonary Bypass



A heart–lung machine (upper right) in a coronary artery bypass surgery.

Cardiopulmonary bypass (CPB) is a technique that temporarily takes over the function of the heart and lungs during surgery, maintaining the circulation of blood and the oxygen content of the body. The CPB pump itself is often referred to as a **heart–lung**

machine or "the pump". Cardiopulmonary bypass pumps are operated by perfusionists in association with surgeons who connect the pump to the patient's body. CPB is a form of extracorporeal circulation.

Uses of cardiopulmonary bypass

Cardiopulmonary bypass is commonly used in heart surgery because of the difficulty of operating on the beating heart. Operations requiring the opening of the chambers of the heart require the use of CPB to support the circulation during that period.

CPB can be used for the induction of total body hypothermia, a state in which the body can be maintained for up to 45 minutes without perfusion (blood flow). If blood flow is stopped at normal body temperature, permanent brain damage normally occurs in three to four minutes — death may follow shortly afterward. Similarly, CPB can be used to rewarm individuals suffering from hypothermia.

Extracorporeal membrane oxygenation (ECMO) is a simplified form of CPB sometimes used as life-support for newborns with serious birth defects, or to oxygenate and maintain recipients for organ transplantation until new organs can be found.

CPB mechanically circulates and oxygenates blood for the body while bypassing the heart and lungs. It uses a heart–lung machine to maintain perfusion to other body organs and tissues while the surgeon works in a bloodless surgical field. The surgeon places a cannula in right atrium, vena cava, or femoral vein to withdraw blood from the body. The cannula is connected to tubing filled with isotonic crystalloid solution. Venous blood that is removed from the body by the cannula is filtered, cooled or warmed, oxygenated, and then returned to the body. The cannula used to return oxygenated blood is usually inserted in the ascending aorta, but it may be inserted in the femoral artery. The patient is administered heparin to prevent clotting, and protamine sulfate is given after to reverse effects of heparin. During the procedure, hypothermia is maintained; body temperature is usually kept at 28ºC to 32ºC (82.4–89.6ºF). The blood is cooled during CPB and returned to the body. The cooled blood slows the body's basal metabolic rate, decreasing its demand for oxygen. Cooled blood usually has a higher viscosity, but the crystalloid solution used to prime the bypass tubing dilutes the blood.

Surgical procedures in which cardiopulmonary bypass is used

- Coronary artery bypass surgery
- Cardiac valve repair and/or replacement (aortic valve, mitral valve, tricuspid valve, pulmonic valve)
- Repair of large septal defects (atrial septal defect, ventricular septal defect, atrioventricular septal defect)
- Repair and/or palliation of congenital heart defects (Tetralogy of Fallot, transposition of the great vessels)
- Transplantation (heart transplantation, lung transplantation, heart–lung transplantation)

- Repair of some large aneurysms (aortic aneurysms, cerebral aneurysms)
- Pulmonary thromboendarterectomy
- Pulmonary thrombectomy

History

A heart lung machine dating from 1958

Dr. Clarence Dennis led the team that conducted the first known operation involving open cardiotomy with temporary mechanical takeover of both heart and lung functions on April 5, 1951 at the University of Minnesota Hospital. The patient did not survive due to an unexpected complex congenital heart defect. This followed four years of laboratory experimentation with dogs with a unit called the *Iron Heart*. A team of scientists at

Birmingham University (including Eric Charles a Chemical Engineer) were among the pioneers of this technology.

The first successful open heart procedure on a human utilizing the heart lung machine was performed by John Gibbon on May 6, 1953 at Thomas Jefferson University Hospital in Philadelphia. He repaired an atrial septal defect in an 18-year-old woman.

The oxygenator was first conceptualised in the 17th century by Robert Hooke and developed into practical extracorporeal oxygenators by French and German experimental physiologists in the 19th century. Bubble oxygenators have no intervening barrier between blood and oxygen, these are called 'direct contact' oxygenators. Membrane oxygenators introduce a gas-permeable membrane between blood and oxygen that decreases the blood trauma of direct-contact oxygenators. Much work since the 1960s focused on overcoming the gas exchange handicap of the membrane barrier, leading to the development of high-performance microporous hollow-fibre oxygenators that eventually replaced direct-contact oxygenators in cardiac theatres.

Components of cardiopulmonary bypass

Cardiopulmonary bypass consists of two main functional units, the pump and the oxygenator which remove oxygen-deprived blood from a patient's body and replace it with oxygen-rich blood through a series of hoses.

Tubing

The components of the CPB circuit are interconnected by a series of tubes made of silicone rubber or PVC.

Pumps

Roller pump

The pump console usually comprises several rotating motor-driven pumps that peristaltically "massage" tubing. This action gently propels the blood through the tubing. This is commonly referred to as a roller pump, or peristaltic pump.

Centrifugal pump

Many CPB circuits now employ a centrifugal pump for the maintenance and control of blood flow during CPB. By altering the speed of revolution (RPM) of the pump head, blood flow is produced by centrifugal force. This type of pumping action is considered to be superior to the action of the roller pump by many because it is thought to produce less blood damage (Hemolysis, etc.).

Oxygenator

The oxygenator is designed to transfer oxygen to infused blood and remove carbon dioxide from the venous blood. Cardiac surgery was made possible by CPB using bubble oxygenators, but membrane oxygenators have supplanted bubble oxygenators since the 1980s.

Another type of oxygenator gaining favour recently is the heparin-coated blood oxygenator which is believed to produce less systemic inflammation and decrease the propensity for blood to clot in the CPB circuit.

Cannulae

Multiple cannulae are sewn into the patient's body in a variety of locations, depending on the type of surgery. A venous cannula removes oxygen deprived blood from a patient's body. An arterial cannula is sewn into a patient's body and is used to infuse oxygen-rich blood. A cardioplegia cannula is sewn into the heart to deliver a cardioplegia solution to cause the heart to stop beating.

Venous	Arterial	Cardioplegia
Right atrium	Proximal aorta, distal to the cross-clamp	Proximal aorta, proximal to the cross-clamp
Vena cavae	Femoral artery	Coronary sinus (retrograde delivery)
Femoral vein	Axillary artery	Coronary ostia
	Distal aorta	Bypass grafts (during CABG)
	Apex of the heart	

Cardioplegia

A CPB circuit consists of a systemic circuit for oxygenating blood and reinfusing blood into a patient's body (bypassing the heart); and a separate circuit for infusing a solution into the heart itself to produce cardioplegia (i.e. to stop the heart from beating), and to provide myocardial protection (i.e. to prevent death of heart tissue).

Operation

A CPB circuit must be primed with fluid and all air expunged before connection to the patient. The circuit is primed with a crystalloid solution and sometimes blood products are also added. The patient must be fully anticoagulated with an anticoagulant such as heparin to prevent massive clotting of blood in the circuit.

Complications

CPB is not benign and there are a number of associated problems:

- Postperfusion syndrome (also known as Pumphead)
- Hemolysis
- Capillary leak syndrome
- Clotting of blood in the circuit – can block the circuit (particularly the oxygenator) or send a clot into the patient.
- Air embolism
- Leakage – a patient can rapidly exsanguinate (lose blood perfusion of tissues) if a line becomes disconnected.
- 1.5% of patients that undergo CPB are at risk of developing Acute Respiratory Distress Syndrome.

As a consequence, CPB is only used during the several hours a cardiac surgery may take. Most oxygenators come with a manufacturer's recommendation that they are only used for a maximum of 6 hours, although they are sometimes used for up to 10 hours, with care being taken to ensure they do not clot off and stop working. For longer periods than this, an ECMO (extra-corporeal membrane oxygenation) or VAD (ventricular assist device) circuit is used, which can be in operation for up to 31 days – such as in this Taiwanese case, for 16 days, after which the patient received a heart transplant.

CPB may contribute to immediate cognitive decline. The heart-lung blood circulation system and the connection surgery itself release a variety of debris into the bloodstream, including bits of blood cells, tubing, and plaque. For example, when surgeons clamp and connect the aorta to tubing, resulting emboli may block blood flow and cause mini strokes. Other heart surgery factors related to mental damage may be events of hypoxia, high or low body temperature, abnormal blood pressure, irregular heart rhythms, and fever after surgery.

Chapter 5

Atherectomy and Peripheral Vascular Examination

Atherectomy

Atherectomy is a minimally invasive surgical method of removing, mainly, atherosclerosis from a large blood vessel within the body. Today, it is generally used to effectively treat peripheral arterial disease of the lower extremities. It has also been used to treat coronary artery disease, albeit ineffectively.

Procedure

Unlike angioplasty and stents, which push plaque into the vessel wall, atherectomy involves removing the plaque burden within the vessel. Increasing the vessel lumen by removing the plaque burden improves downstream wound healing, reduces claudication and pushes amputation levels more distal. While atherectomy is usually employed to treat arteries it can be used in veins and vein grafts as well.

Atherectomy falls under the general category of percutaneous revascularization, which implies re-canalizing blocked vasculature via a needle puncture in the skin. The most common access point is near the groin through the common femoral artery (CFA). However, wire and catheter access can occur from wherever a doctor is willing to stick. Other common places are the brachial artery, radial artery, popliteal artery, dorsalis pedis, and others.

Advantages

The procedure is considered less invasive than endarterectomy, which involves the surgical cut down and removal of plaque from the inner wall of a diseased vessel.

The advantages of atherectomy when compared to endarterectomy include less procedure time, ease of use, faster patient recovery, decreased systemic complications, repeatability in light of new occlusions. It also serves as a chance for non-surgical candidates.

The advantages of atherectomy when compared to balloons (angioplasty) and stenting are less vessel barotrauma, no foreign object (stent metal) left in the body and leaving all future options open for the patient at the treated site.

SilverHawk

A common and widely adapted type of atherectomy to treat peripheral arterial disease is directional plaque excision. The SilverHawk or TurboHawk, by FoxHollow, is the only device which does this. Studies have proven its effectiveness in the removal of plaque, the increase of blood flow and the luminal gain of the vessel. Long term results also suggest favorability.

The device uses a small circular blade to shave off the plaque and an attached nosecone to capture the plaque to remove it from the body.

The SilverHawk was invented by John Simpson. Simpson sold the technology to FoxHollow who in turn was purchased by ev3. In July 2010, ev3 was purchased by Covidien.

Peripheral vascular examination

In medicine, the **peripheral vascular examination** is a series of maneuvers to elicit signs of peripheral vascular pathology. It is performed as part of a physical examination, or when a patient presents with leg pain suggestive of a cardiovascular pathology.

The exam includes several parts:

- Position/Lighting/Draping
- Inspection
- Palpation
- Auscultation
- Special maneuvers

Position/Lighting/Draping

Position - patient should be lying in the supine position and the bed or examination table should be flat. The patient's hands should remain at her sides with her head resting on a pillow.

Lighting - adjusted so that it is ideal.

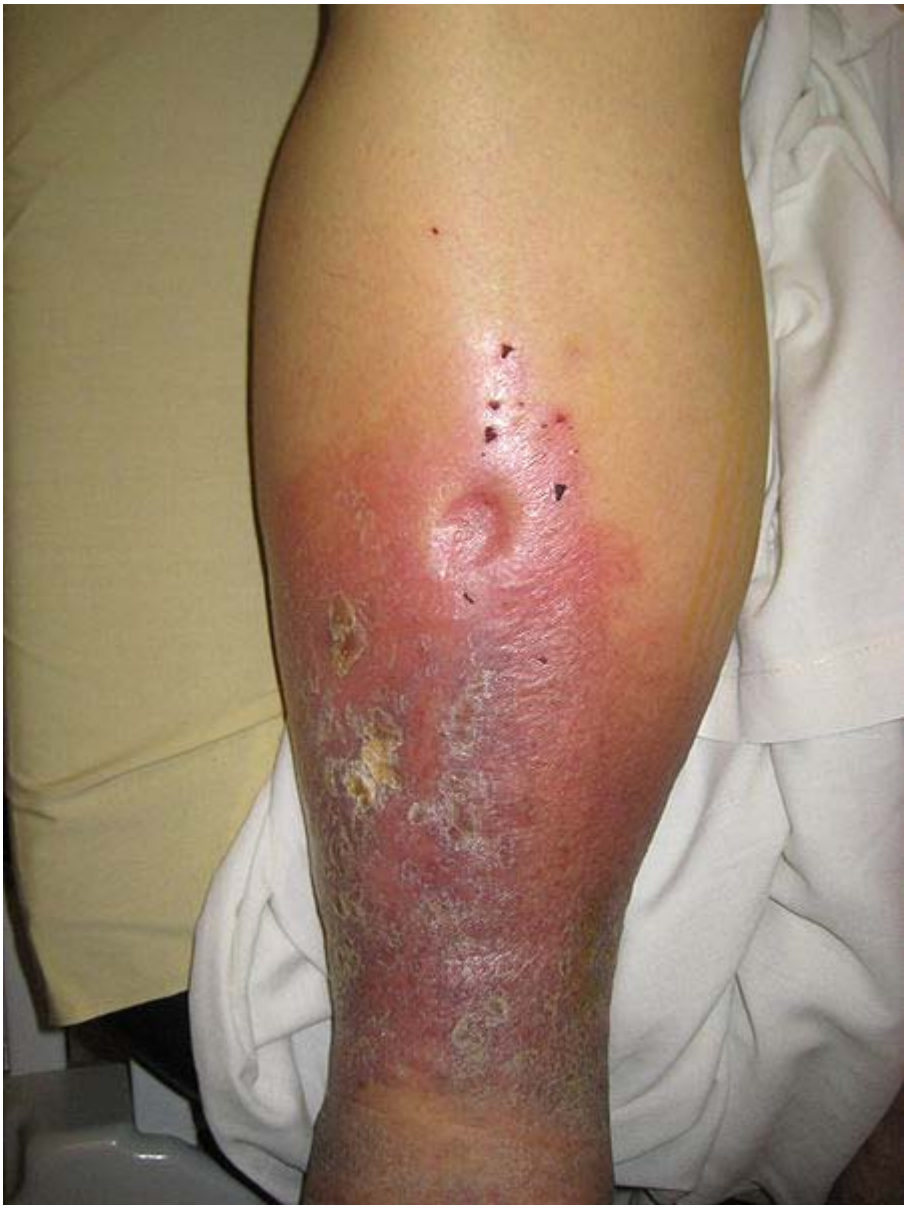
Draping - the legs should be exposed, the private groin and thigh covered. Drapes are usually placed between the legs.

Inspection

On inspection the physician looks for signs of:

- trauma
- previous surgery (scars)
- muscle wasting/muscle asymmetry
- edema (swelling)
- erythema (redness)
- ulcers - arterial ulcers tend to be on the borders / sides of the foot, neuropathic ulcers on the plantar surface of the foot, venous ulcers tend on be on the medial aspect of the leg superior to the medial malleolus.
- hair - hair is absent in peripheral vascular disease (PVD)
- shiny skin - seen in PVD

Palpation



Example of pitting edema in a patient with hepatic failure

- Temperature - cool suggest poor circulation, sides should be compared
- Pitting edema - should be tested for in dependent locations - dorsum of foot, if present then on the shins. If the patient has been in bed for a longer period of time one should check the sacrum.
- Capillary refill - should be less than 3 seconds.

Arterial pulses

- Dorsalis pedis artery pulse - on dorsal surface of the foot, running lateral to the tendon of the first toe
- Posterior tibial artery pulse - posterior and inferior to the medial malleolus
- Popliteal artery pulse - behind the knee, typically done with both hands
- Femoral artery pulse - in the femoral triangle / halfway between the ASIS and pubic symphysis

Auscultation

- for femoral artery bruits

Special maneuvers

- Ankle-brachial pressure index (ABPI) assesses peripheral vascular disease
- Venous refill with dependency (should be less than 30 seconds) - the vein should bulge outward within 30 seconds of elevation for one minute.

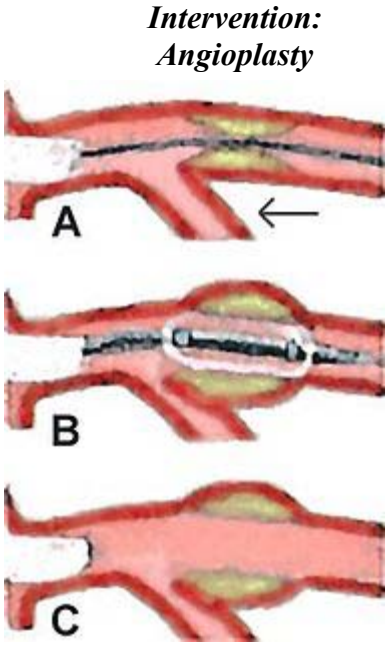
- Buerger's Test (assessment of arterial sufficiency):
  With the patient supine, note the colour of the feet soles. They should be pink. Then elevate both legs to 45 degrees for more than 1 minute. Observe the soles. If there is marked pallor (whiteness), ischemia should be suspected. Next check for rubor of dependency. Sit the patient upright and observe the feet. In normal patients, the feet quickly turn pink. If, more slowly, they turn red like a cooked lobster, suspect ischemia.

- Brodie-Trendelenburg Test (assessment of valvular competence if varicose veins are present):
  One leg at a time. With the patient supine, empty the superficial veins by 'milking' the leg in the distal to proximal direction. Now press with your thumb over the saphenofemoral junction (2 cm below and 2 cm lateral to the pubic tubercle) and ask the patient to stand while you maintain pressure. If the leg veins now refill rapidly, the incompentence is located below the saphenofemoral junction, and vice versa. This test can be repeated using pressure at any point along the leg until the incompetence has been mapped out.

Chapter 6

Angioplasty and Carotid Stenting

Angioplasty



Balloon angioplasty.

ICD-10 code:

ICD-9 code: 00.6 36.0 39.50

MeSH D017130

Other codes:

Angioplasty is the technique of mechanically widening a narrowed or obstructed blood vessel, typically as a result of atherosclerosis. An empty and collapsed balloon on a guide

wire, known as a balloon catheter, is passed into the narrowed locations and then inflated to a fixed size using water pressures some 75 to 500 times normal blood pressure (6 to 20 atmospheres). The balloon crushes the fatty deposits, opening up the blood vessel for improved flow, and the balloon is then collapsed and withdrawn.

The word is composed of the medical combining forms of the Greek words αγγειος *aggeîos* meaning "vessel" and πλαστός *plastós* meaning "formed" or "moulded". Angioplasty has come to include all manner of vascular interventions typically performed in a minimally invasive or *percutaneous* method.

History

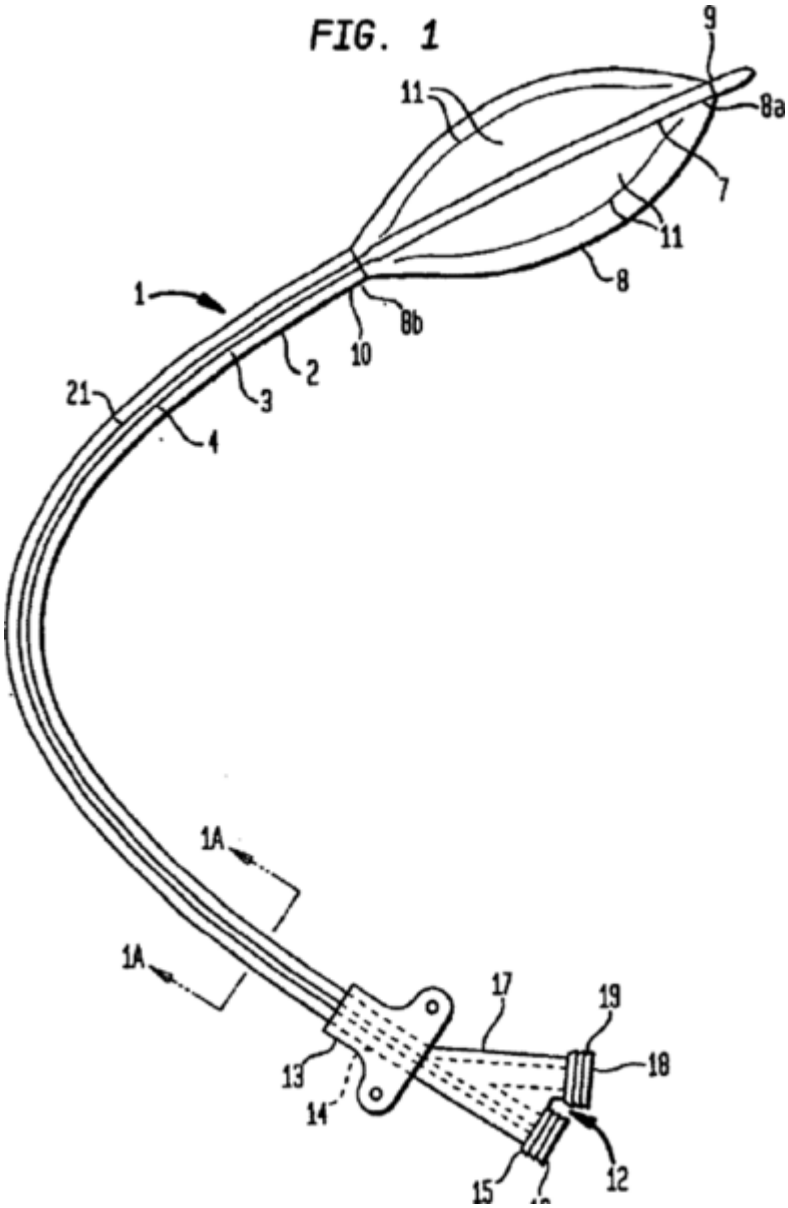


Diagram of a balloon catheter.

Angioplasty was initially described by interventional radiologist Charles Dotter in 1964. Dr. Dotter pioneered modern medicine with the invention of angioplasty and the catheter-delivered stent, which were first used to treat peripheral arterial disease. On January 16, 1964, Dotter percutaneously dilated a tight, localized stenosis of the superficial femoral artery (SFA) in an 82-year-old woman with painful leg ischemia and gangrene who refused leg amputation. After successful dilation of the stenosis with a guide wire and coaxial Teflon catheters, the circulation returned to her leg. The dilated artery stayed open until her death from pneumonia two and a half years later. Charles Dotter is commonly known as the "Father of Interventional Radiology" and was nominated for the Nobel Prize in medicine in 1978.

The first coronary angioplasty on an awake patient was performed by German cardiologist Andreas Gruentzig in September 1977.

Causes of Coronary Artery Disease

Blockages in the arteries may be caused by hypertension, diabetes, sedentary lifestyle, smoking, high cholesterol levels, diets high in saturated fats, and cardiovascular disease. Removing blockages is done with angioplasty.

Angioplasties are safer than bypass surgery and according to statistics less than 1% of people die from complications after this procedure. Complications that may occur after or during an angioplasty are the following:

- Tearing of the artery resulting in total blockage and possible myocardial infarction - this can usually be repaired with a stent
- A dislodged clot may cause a stroke in some circumstances (in less than 1% of patients who undergo angioplasties);
- Bleeding or bruising where the catheters were inserted;
- Kidney problems, especially in people with underlying kidney disease and diabetes - this is caused by the iodine contrast dye used for the X-ray; intravenous fluids and medications can be given before and after the procedure to try to reduce this risk.
- Arrhythmia (irregular heartbeat);
- Allergic reaction to the dye given during the angioplasty;
- Myocardial infarction happens in 3 to 5% of the cases;
- The need for emergency coronary artery bypass grafting during the procedure (2-4 percent of people). This may occur if an artery closes down instead of opening up;
- Restenosis is one of the most common complications of angioplasties and it consists in the gradual re-narrowing of the blood vessels within the next several weeks to months after the procedure. There are certain conditions that increase the risk of developing this complication and these are hypertension, diabetes, angina or kidney disease.
- Blood clots (in-stent thrombosis) can form within stents hours or months after angioplasty and they may cause myocardial infarction.

The risks carried by angioplasty are greater in patients older than 75 years, patients who suffer from diabetes or kidney disease or who have extensive heart disease or blot clots in the heart arteries. Also, patients with poor pumping function in their hearts and women are considered to have an increased risk for complications.

Complications such as myocardial infarction, stroke or kidney problems are however among the rarest. The death rate among patients who have angioplasty is very small, about 0.1% (compared to 1% to 2% for routine bypass surgery).

All in all, the risks are relatively low and acceptable in most cases when one balances the potential benefit against the expected risk (risk-benefit ratio).

Controversy

The value of angioplasty in rescuing someone having a heart attack (by immediately alleviating an obstruction) is clearly defined in multiple studies, but studies have failed to find reduction in hard endpoints for angioplasty vs. medical therapy in stable angina patients. The artery-opening procedure can temporarily alleviate chest pain, but does not contribute to longevity. The "vast majority of heart attacks do not originate with obstructions that narrow arteries".

A more permanent and successful way to prevent heart attacks in patients at high risk is to give up smoking, increase exercise and take "drugs to get blood pressure under control, drive cholesterol levels down and prevent blood clotting".

After the procedure

After angioplasty, most of the patients are monitored overnight in the hospital but if there are no complications, the next day, patients are sent home.

The catheter site is checked for bleeding and swelling and the heart rate and blood pressure are monitored. Usually, patients receive medication that will relax them to protect the arteries against spasms. Patients are typically able to walk within two to six hours following the procedure and return to their normal routine by the following week.

Angioplasty recovery consists in avoiding physical activity for several days after the procedure. Patients are advised to avoid any type of lifting, babysitting grandchildren or other strenuous physical activity for a week. Patients will need to avoid physical stress or prolonged sport activities for a maximum of two weeks after a delicate balloon angioplasty.

Patients with stents are usually prescribed an anticoagulant, clopidogrel which is taken at the same time with acetylsalicylic acid. These medications are intended to prevent blood clots and they are usually taken for at least the first months after the procedure is performed. In most cases, patients are administrated this type of medication for 1 year.

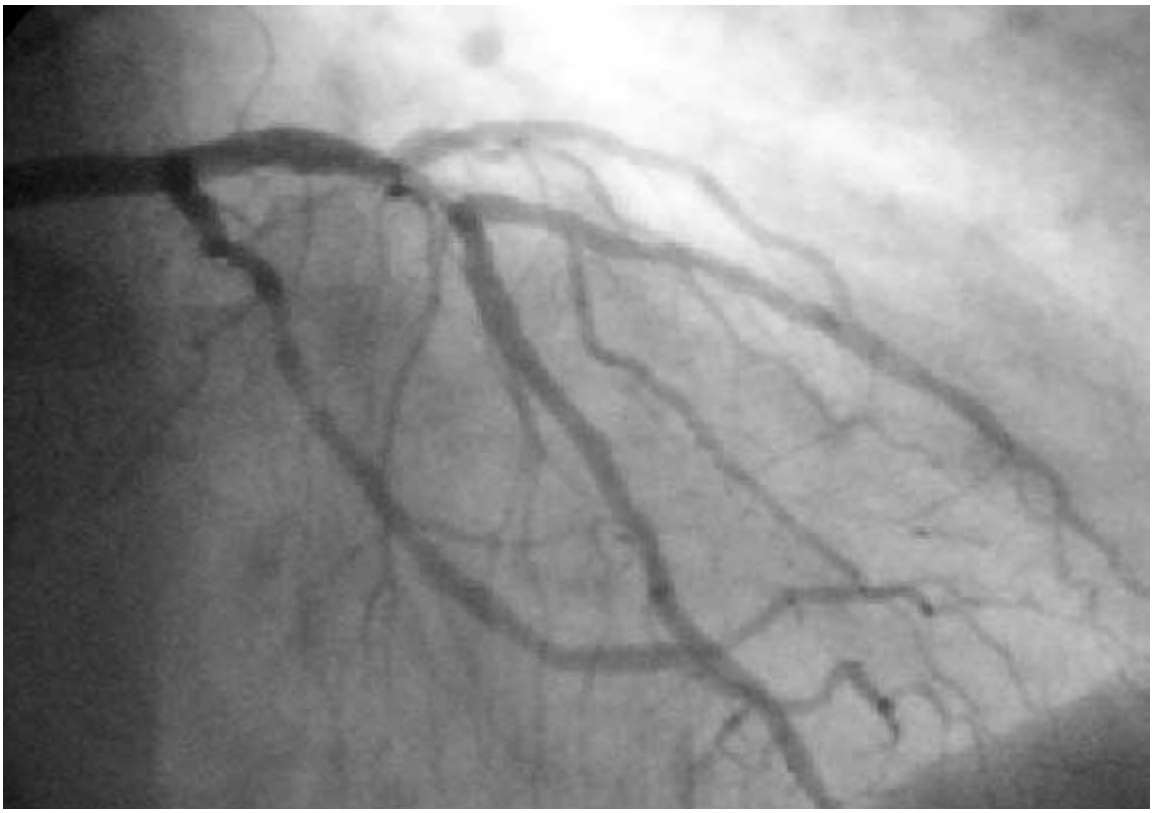
Also, patients who are doing dental work are advised to cancel it because there is a risk of endocarditis, an infection of the heart.

Patients who experience swelling, bleeding or pain at the insertion site, develop fever, feel faint or weak, notice a change in temperature or color in the arm or leg that was used or have shortness of breath or chest pain should immediately seek medical advice..

Peripheral angioplasty

Peripheral angioplasty refers to the use of a balloon to open a blood vessels outside the coronary arteries. It is commonly done to treat atherosclerotic narrowings of the abdomen, leg and renal arteries. PA can also be done to treat narrowings in veins, etc. Often, peripheral angioplasty is used in conjunction with peripheral stenting and atherectomy.

Coronary angioplasty



A coronary angiogram (an X-ray with radio-opaque contrast in the coronary arteries) that shows the left coronary circulation. The distal left main coronary artery (LMCA) is in the left upper quadrant of the image. Its main branches (also visible) are the left circumflex artery (LCX), which courses top-to-bottom initially and then toward the centre-bottom, and the left anterior descending (LAD) artery, which courses from left-to-right on the image and then courses down the middle of the image to project underneath the distal

LCX. The LAD, as is usual, has two large diagonal branches, which arise at the centre-top of the image and course toward the centre-right of the image.

Percutaneous coronary intervention (**PCI**), commonly known as **coronary angioplasty** is a therapeutic procedure to treat the stenotic (narrowed) coronary arteries of the heart found in coronary heart disease. These stenotic segments are due to the build up of cholesterol-laden plaques that form due to atherosclerosis. PCI is usually performed by an interventional cardiologist.

Treatment with PCI for patients with stable coronary artery disease reduces chest pain, but does not reduce the risk of death, myocardial infarction, or other major cardiovascular events when added to optimal medical therapy.

Renal artery angioplasty

Atherosclerotic obstruction of the renal artery can be treated with angioplasty of the renal artery (percutaneous transluminal renal angioplasty, PTRA). Renal artery stenosis can lead to hypertension and loss of renal function.

Carotid angioplasty

Carotid artery stenosis is treated with angioplasty and stenting for high-risk patients in many hospitals.

Cerebral arteries angioplasty

In 1983, the Russian neurosurgeon Zubkov and colleagues reported the first use of transluminal balloon angioplasty for vasospasm after aneurysmal SAH.

Carotid stenting

Carotid artery stenting (CAS) is an endovascular, catheter-based procedure which unblocks narrowings of the carotid artery lumen to prevent a stroke. Carotid artery stenosis can present with no symptoms (diagnosed incidentally) or with symptoms such as transient ischemic attacks (TIAs) or cerebrovascular accidents (CVAs, strokes). The largest clinical trial to date, CREST, compared stenting to surgery on the collective incidence of any stroke, any heart attack or death. They found that there was no significant differences out to four years of follow-up between surgery and carotid stenting when counting all three, but CAS has a higher risk of stroke or death than open surgery . Overall, younger patients (<70 years old) had better outcomes with stenting than with surgery, which was a surprising finding as CAS is supposed to be less invasive. Patients

had fewer heart attacks with stenting, but they did have more minor strokes. There was no difference between surgery or stenting for major (disabling) strokes.

Prior to this, several European trials have reported results in symptomatic carotid artery stenosis patients comparing surgery and stenting. The SPACE trial, conducted in Germany, Austria, and Switzerland found no difference in outcomes between surgery and stenting. They also noted that younger (< 67 years old) patients had better outcomes with stenting. They noted that more experienced centers had better results than inexperienced centers.

The EVA-3s trial was stopped early due to an early finding that stenting was too dangerous. The trial was criticized that they used experienced surgeons and inexperienced stent physicians, so that the results may have been affected by the training of operators. Future trials ensured that the endovascular arms had more experienced endovascular operators, as seen in the CREST and SAPPHIRE trial .

An interim report from ICSS demonstrates no overall difference between surgery and stenting for both major strokes and death, but again did show more minor strokes (resolved within 30 days) with stents and open surgery was safer than CAS in the treatment of symptomatic carotid artery disease. A study was carried out in seven of the centers participating in ICSS to assess the incidence of ischemic brain lesions (silent infarcts) detected by diffusion-weighted MRI. They found that 73% of patients undergoing CAS with distal filter protection showed new ischemic lesions after the procedure versus 17% of those undergoing CEA.

Recently physicians have questioned the ethics and validity of European trials comparing a mature carotid surgical procedure to carotid stenting performed by inexperienced physicians. In CREST, physicians performed procedures on a trial basis and were then permitted to enroll patients once their expertise in the carotid stent procedure could be confirmed. Conversely, some may wonder if it may be unethical to continue to perform stenting in all patients (instead of those who are at higher risk for surgery) in an effort to learn how to make a new technology functional.

Procedure

- Informed consent obtained and local anaesthetic administered
- Preparation of both groins with antiseptic and draped
- Puncture into femoral artery and access through short sheath
- Guidewire passed through aorta and into arch
- Arch aortogram obtained if not previously performed to confirm suitability to continue
- Carotid and cerebral angiogram performed
- Long access sheath placed after cannulation of common carotid artery (CCA)
- Guidewire passed through area of carotid narrowing
- Placement of embolic protection device above the area of narrowing

- Angioplasty of carotid narrowing, but more commonly proceed straight to deployment of stent into area of narrowing
- Angioplasty post stent deployment
- Removal of protection device, guidewires and sheath
- Aftercare of groin puncture site

Indications

Carotid stenting is preferred therapy in patients who are increased risk for carotid surgery. High risk features include medical comorbidities (severe heart disease, heart failure, severe lung disease, age > 75/80, etc) and anatomic features (contralateral carotid occlusion, radiation therapy to the neck, prior ipsilateral carotid artery surgery, intra-thoracic or intracranial carotid disease) that make surgery difficult or risky.

Anatomic high surgical risk: Contralateral carotid occlusion Contralateral laryngeal palsy Post-radiation treatment Previous CEA recurrent stenosis High cervical ICA lesions CCA lesions below the clavicle Severe tandem lesions

Co-morbid high surgical risk: Congestive Heart Failure (Class III/IV), and/or known severe left ventricular dysfunction <30% Open-heart surgery within 6 weeks Recent myocardial infarction (>24 hours and <4 weeks) Unstable angina (CCS class III/IV) Synchronous severe cardiac and carotid disease requiring open heart surgery and carotid revascularization Severe pulmonary disease to include any of the following: Chronic oxygen therapy Resting P02 of < 60 mmHg Baseline hematocrit > 50% FEV1 or DLCO < 50% of normal Abnormal stress test Age greater than 80 years

Using the criteria of successful trials, candidates are either symptomatic (TIA or stroke) patients with >50% stenosis of the carotid artery, or are asymptomatic with >80% stenosis of the internal carotid artery.

Carotid stenting may be considered an alternative to carotid surgery in average surgical risk patients, albeit with a higher risk of death or stroke as seen in the SAPPHIRE and CREST trials .

Features that favor carotid stenting include non-atherosclerotic cause of the stenosis (fibrodysplasia, radiation, early post-surgical stenosis or flap) an experienced center and experienced physician performing the procedure. Features that make stent placement more difficult include significant aortic arch tortuosity, thrombus containing lesions, occluded carotid artery, heavily calcified vessels, symptomatic patients and very tortuous and twisting vessels. None of these affect open, surgical endarterectomy.

Patient Selection Warnings

Lesion Characteristics: Patients with evidence of intraluminal thrombus thought to increase the risk of plaque fragmentation and distal embolization. Patients whose lesion(s) may require more than two stents. Patients with total occlusion of the target

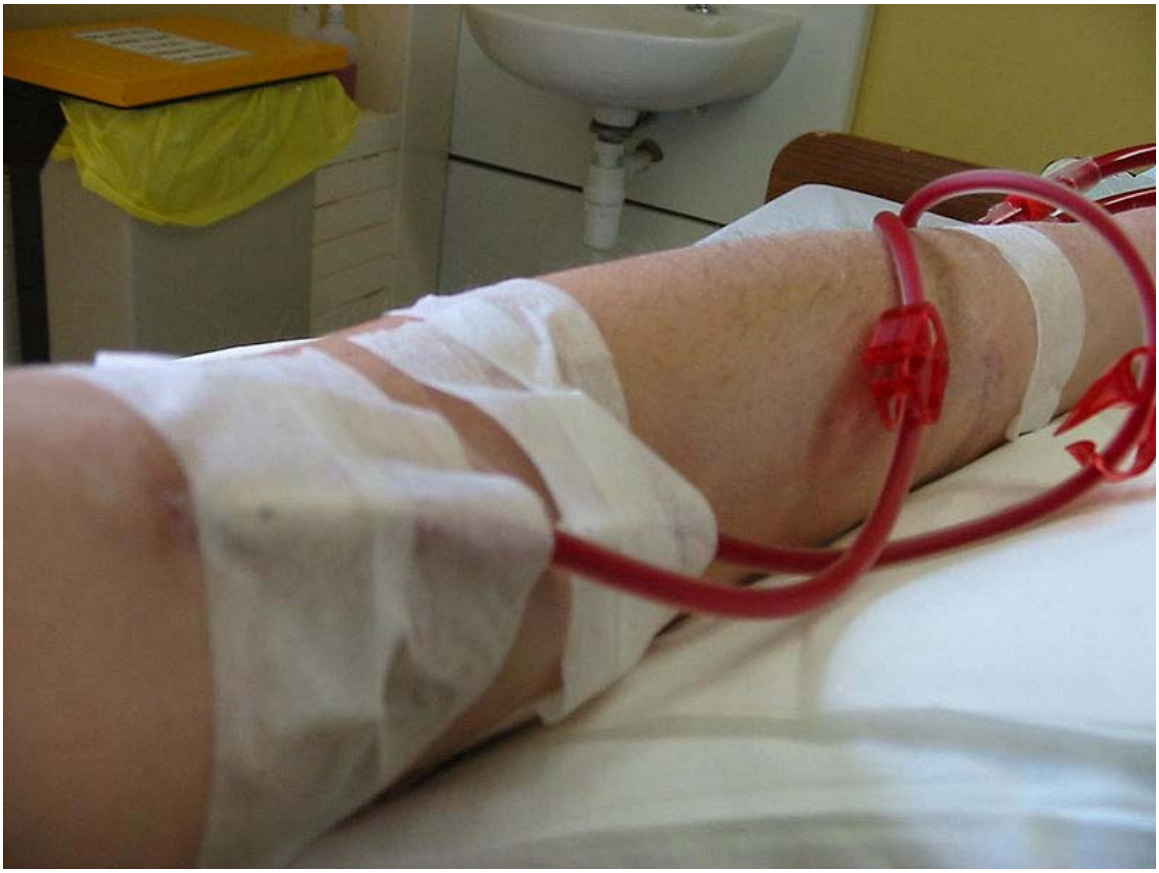
vessel. Patients with highly calcified lesions resistant to PTA. Concurrent treatment of bilateral lesions.

Access Characteristics: Patients with known peripheral vascular, supra-aortic or internal carotid artery tortuosity that would preclude the use of catheter-based techniques. Patients in whom femoral or brachial arterial access is not possible

Patient Characteristics: Patients experiencing acute ischemic neurologic stroke or who experienced a large stroke within 48 hours. Patients with an intracranial mass lesion (i.e., abscess, tumor, or infection) or aneurysm (>9mm). Patients with arterio-venous malformations of the territory of the target carotid artery. Patients with coagulopathies. Patients with poor renal function, who, in the physician's opinion, may be at high-risk for a reaction to contrast medium. Pregnant patients or patients under the age of 18.

Chapter 7

Hemodialysis



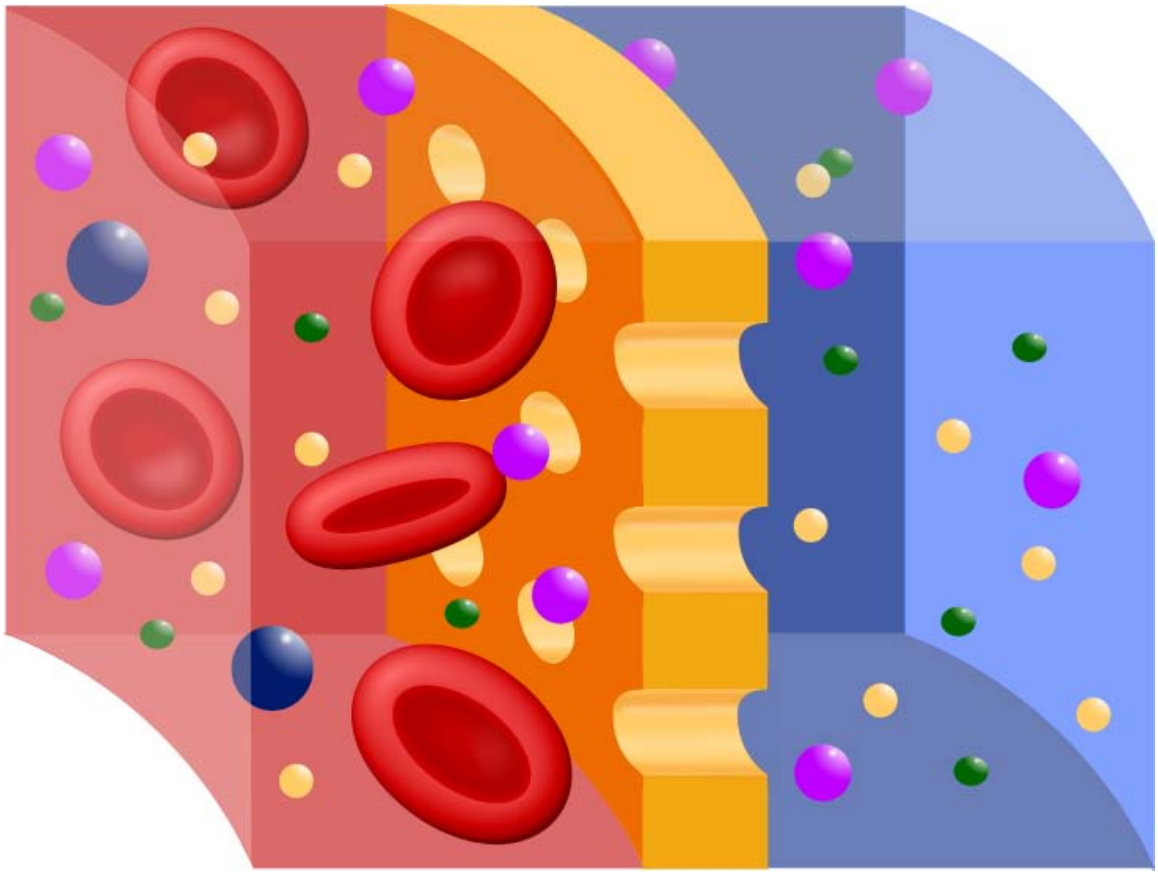
Hemodialysis in progress

Hemodialysis machine

In medicine, **hemodialysis** (also **haemodialysis**) is a method for removing waste products such as creatinine and urea, as well as free water from the blood when the kidneys are in renal failure. Hemodialysis is one of three renal replacement therapies (the other two being renal transplant; peritoneal dialysis).

Hemodialysis can be an outpatient or inpatient therapy. Routine hemodialysis is conducted in a dialysis outpatient facility, either a purpose built room in a hospital or a dedicated, stand alone clinic. Less frequently hemodialysis is done at home. Dialysis treatments in a clinic are initiated and managed by specialized staff made up of nurses and technicians; dialysis treatments at home can be self initiated and managed or done jointly with the assistance of a trained helper who is usually a family member.

Principle



Semipermeable membrane

The principle of hemodialysis is the same as other methods of dialysis; it involves diffusion of solutes across a semipermeable membrane. Hemodialysis utilizes counter current flow, where the dialysate is flowing in the opposite direction to blood flow in the extracorporeal circuit. Counter-current flow maintains the concentration gradient across the membrane at a maximum and increases the efficiency of the dialysis.

Fluid removal (ultrafiltration) is achieved by altering the hydrostatic pressure of the dialysate compartment, causing free water and some dissolved solutes to move across the membrane along a created pressure gradient.

The dialysis solution that is used may be a sterilized solution of mineral ions or comply with Britich Pharmacopea. Urea and other waste products, potassium, and phosphate diffuse into the dialysis solution. However, concentrations of sodium and chloride are similar to those of normal plasma to prevent loss. Sodium bicarbonate is added in a higher concentration than plasma to correct blood acidity. A small amount of glucose is also commonly used.

Note that this is a different process to the related technique of hemofiltration.

History

Many have played a role in developing dialysis as a practical treatment for renal failure, starting with Thomas Graham of Glasgow, who first presented the principles of solute transport across a semipermeable membrane in 1854. The artificial kidney was first developed by Abel, Rountree and Turner in 1913,, the first hemodialysis in a human being was by Hass (February 28, 1924) and the artificial kidney was developed into a clinically useful apparatus by Kolff in 1943 - 1945. This research showed that life could be prolonged in patients dying of renal failure.

Dr. Willem Kolff was the first to construct a working dialyzer in 1943. The first successfully treated patient was a 67-year-old woman in uremic coma who regained consciousness after 11 hours of hemodialysis with Kolff's dialyzer in 1945. At the time of its creation, Kolff's goal was to provide life support during recovery from acute renal failure. After World War II ended, Kolff donated the five dialyzers he had made to hospitals around the world, including Mount Sinai Hospital, New York. Kolff gave a set of blueprints for his hemodialysis machine to George Thorn at the Peter Bent Brigham Hospital in Boston. This led to the manufacture of the next generation of Kolff's dialyzer, a stainless steel Kolff-Brigham dialysis machine.

By the 1950s, Willem Kolff's invention of the dialyzer was used for acute renal failure, but it was not seen as a viable treatment for patients with stage 5 chronic kidney disease (CKD). At the time, doctors believed it was impossible for patients to have dialysis indefinitely for two reasons. First, they thought no man-made device could replace the function of kidneys over the long term. In addition, a patient undergoing dialysis suffered from damaged veins and arteries, so that after several treatments, it became difficult to find a vessel to access the patient's blood.

Dr. Nils Alwall: The original Kolff kidney was not very useful clinically, because it did not allow for removal of excess fluid. Dr. Nils Alwall encased a modified version of this kidney inside a stainless steel canister, to which a negative pressure could be applied, in this way effecting the first truly practical application of hemodialysis, which was done in 1946 at the University of Lund. Alwall also was arguably the inventor of the arteriovenous shunt for dialysis. He reported this first in 1948 where he used such an arteriovenous shunt in rabbits. Subsequently he used such shunts, made of glass, as well as his canister-enclosed dialyzer, to treat 1500 patients in renal failure between 1946 and 1960, as reported to the First International Congress of Nephrology held in Evian in September 1960. Alwall was appointed to a newly-created Chair of Nephrology at the University of Lund in 1957. Subsequently, he collaborated with Swedish businessman Holger Crafoord to found one of the key companies that would manufacture dialysis equipment in the past 50 years, Gambro. The early history of dialysis has been reviewed by Stanley Shaldon .

Dr. Belding H. Scribner working with a surgeon, Dr. Wayne Quinton, modified the glass shunts used by Alwall by making them from Teflon. Another key improvement was to connect them to a short piece of silicone elastomer tubing. This formed the basis of the

so-called Scribner shunt, perhaps more properly called the Quinton-Scribner shunt. After treatment, the circulatory access would be kept open by connecting the two tubes outside the body using a small U-shaped Teflon tube, which would shunt the blood from the tube in the artery back to the tube in the vein .

In 1962, Scribner started the world's first outpatient dialysis facility, the Seattle Artificial Kidney Center, later renamed the Northwest Kidney Centers. Immediately the problem arose of who should be given dialysis, since demand far exceeded the capacity of the six dialysis machines at the center. Scribner decided that the decision about who would receive dialysis and who wouldn't, would not be made by him. Instead, the choices would be made by an anonymous committee, which could be viewed as one of the first bioethics committees.

Prescription

A prescription for dialysis by a nephrologist (a medical kidney specialist) will specify various parameters for a dialysis treatment. These include frequency (how many treatments per week), length of each treatment, and the blood and dialysis solution flow rates, as well as the size of the dialyzer. The composition of the dialysis solution is also sometimes adjusted in terms of its sodium and potassium and bicarbonate levels. In general, the larger the body size of an individual, the more dialysis he/she will need. In the North America and UK, 3-4 hour treatments (sometimes up to 5 hours for larger patients) given 3 times a week are typical. Twice-a-week sessions are limited to patients who have a substantial residual kidney function. Four sessions per week are often prescribed for larger patients, as well as patients who have trouble with fluid overload. Finally, there is growing interest in short daily home hemodialysis, which is 1.5 - 4 hr sessions given 5-7 times per week, usually at home. There also is interest in nocturnal dialysis, which involves dialyzing a patient, usually at home, for 8–10 hours per night, 3-6 nights per week. Nocturnal in-center dialysis, 3-4 times per week is also offered at a handful of dialysis units in the United States.

Side effects and complications

Hemodialysis often involves fluid removal (through ultrafiltration), because most patients with renal failure pass little or no urine. Side effects caused by removing too much fluid and/or removing fluid too rapidly include low blood pressure, fatigue, chest pains, leg-cramps, nausea and headaches. These symptoms can occur during the treatment and can persist post treatment; they are sometimes collectively referred to as the dialysis hangover or dialysis washout. The severity of these symptoms is usually proportionate to the amount and speed of fluid removal. However, the impact of a given amount or rate of fluid removal can vary greatly from person to person and day to day. These side effects can be avoided and/or their severity lessened by limiting fluid intake between treatments or increasing the dose of dialysis e.g. dialyzing more often or longer per treatment than the standard three times a week, 3–4 hours per treatment schedule.

Since hemodialysis requires access to the circulatory system, patients undergoing hemodialysis may expose their circulatory system to microbes, which can lead to sepsis, an infection affecting the heart valves (endocarditis) or an infection affecting the bones (osteomyelitis). The risk of infection varies depending on the type of access used (see below). Bleeding may also occur, again the risk varies depending on the type of access used. Infections can be minimized by strictly adhering to infection control best practices.

Heparin is the most commonly used anticoagulant in hemodialysis, as it is generally well tolerated and can be quickly reversed with protamine sulfate. Heparin allergy can infrequently be a problem and can cause a low platelet count. In such patients, alternative anticoagulants can be used. In patients at high risk of bleeding, dialysis can be done without anticoagulation.

First Use Syndrome is a rare but severe anaphylactic reaction to the artificial kidney. Its symptoms include sneezing, wheezing, shortness of breath, back pain, chest pain, or sudden death. It can be caused by residual sterilant in the artificial kidney or the material of the membrane itself. In recent years, the incidence of First Use Syndrome has decreased, due to an increased use of gamma irradiation, steam sterilization, or electron-beam radiation instead of chemical sterilants, and the development of new semipermeable membranes of higher biocompatibility. New methods of processing previously acceptable components of dialysis must always been considered. For example, in 2008, a series of first-use type or reactions, including deaths occurred due to heparin contaminated during the manufacturing process with oversulfated chondroitin sulfate.

Longterm complications of hemodialysis include amyloidosis, neuropathy and various forms of heart disease. Increasing the frequency and length of treatments have been shown to improve fluid overload and enlargement of the heart that is commonly seen in such patients.

Listed below are specific complications associated with different types of hemodialysis access.

Access

In hemodialysis, three primary methods are used to gain access to the blood: an intravenous catheter, an arteriovenous (AV) fistula and a synthetic graft. The type of access is influenced by factors such as the expected time course of a patient's renal failure and the condition of his or her vasculature. Patients may have multiple accesses, usually because an AV fistula or graft is maturing and a catheter is still being used. The creation of all these three major types of vascular accesses requires surgery.

Catheter

Catheter access, sometimes called a CVC (Central Venous Catheter), consists of a plastic catheter with two lumens (or occasionally two separate catheters) which is inserted into a large vein (usually the vena cava, via the internal jugular vein or the femoral vein) to

allow large flows of blood to be withdrawn from one lumen, to enter the dialysis circuit, and to be returned via the other lumen. However, blood flow is almost always less than that of a well functioning fistula or graft.

Catheters are usually found in two general varieties, tunnelled and non-tunnelled.

Non-tunnelled catheter access is for short-term access (up to about 10 days, but often for one dialysis session only), and the catheter emerges from the skin at the site of entry into the vein.

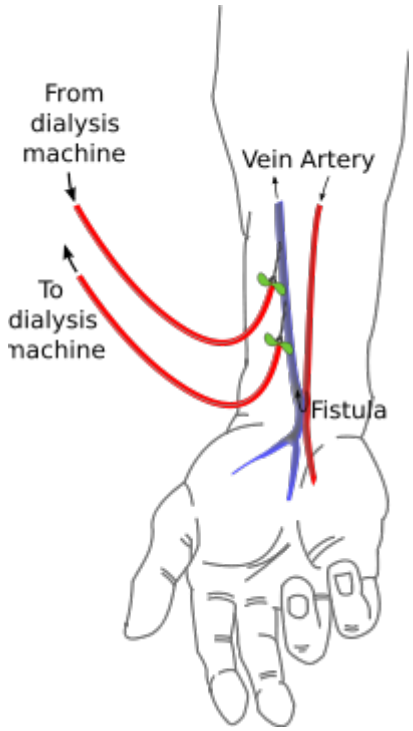
Tunnelled catheter access involves a longer catheter, which is tunnelled under the skin from the point of insertion in the vein to an exit site some distance away. It is usually placed in the internal jugular vein in the neck and the exit site is usually on the chest wall. The tunnel acts as a barrier to invading microbes, and as such, tunnelled catheters are designed for short- to medium-term access (weeks to months only), because infection is still a frequent problem.

Aside from infection, venous stenosis is another serious problem with catheter access. The catheter is a foreign body in the vein and often provokes an inflammatory reaction in the vein wall. This results in scarring and narrowing of the vein, often to the point of occlusion. This can cause problems with severe venous congestion in the area drained by the vein and may also render the vein, and the veins drained by it, useless for creating a fistula or graft at a later date. Patients on long-term hemodialysis can literally 'run out' of access, so this can be a fatal problem.

Catheter access is usually used for rapid access for immediate dialysis, for tunnelled access in patients who are deemed likely to recover from acute renal failure, and for patients with end-stage renal failure who are either waiting for alternative access to mature or who are unable to have alternative access.

Catheter access is often popular with patients, because attachment to the dialysis machine doesn't require needles. However, the serious risks of catheter access noted above mean that such access should be contemplated only as a long-term solution in the most desperate access situation.

AV fistula



A radiocephalic fistula.

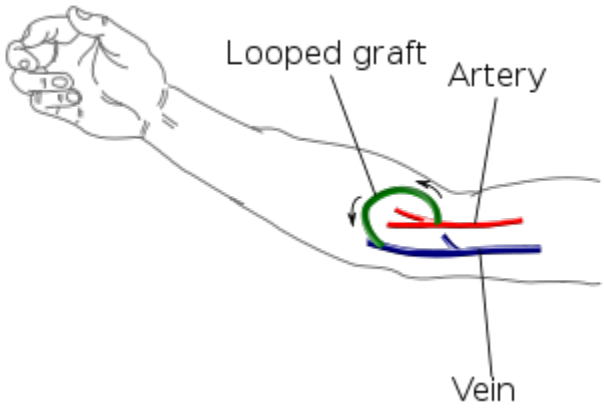
AV (arteriovenous) fistulas are recognized as the preferred access method. To create a fistula, a vascular surgeon joins an artery and a vein together through anastomosis. Since this bypasses the capillaries, blood flows rapidly through the fistula. One can feel this by placing one's finger over a mature fistula. This is called feeling for "thrill" and produces a distinct 'buzzing' feeling over the fistula. One can also listen through a stethoscope for the sound of the blood "whooshing" through the fistula, a sound called *bruit*.

Fistulas are usually created in the nondominant arm and may be situated on the hand (the 'snuffbox' fistula'), the forearm (usually a **radiocephalic** fistula, or so-called Brescia-Cimino fistula, in which the radial artery is anastomosed to the cephalic vein), or the elbow (usually a brachiocephalic fistula, where the brachial artery is anastomosed to the cephalic vein). A fistula will take a number of weeks to mature, on average perhaps 4–6 weeks. During treatment, two needles are inserted into the fistula, one to draw blood and one to return it.

The advantages of the AV fistula use are lower infection rates, because no foreign material is involved in their formation, higher blood flow rates (which translates to more effective dialysis), and a lower incidence of thrombosis. The complications are few, but if a fistula has a very high blood flow and the vasculature that supplies the rest of the limb is poor, a steal syndrome can occur, where blood entering the limb is drawn into the fistula and returned to the general circulation without entering the limb's capillaries. This results in cold extremities of that limb, cramping pains, and, if severe, tissue damage. One long-term complication of an AV fistula can be the development of an aneurysm, a

bulging in the wall of the vein where it is weakened by the repeated insertion of needles over time. To a large extent the risk of developing an aneurysm can be reduced by carefully rotating needle sites over the entire fistula, or using the "buttonhole"(constant site) technique. Aneurysms may necessitate corrective surgery and may shorten the useful life of a fistula. To prevent damage to the fistula and aneurysm or pseudoaneurysm formation, it is recommended that the needle be inserted at different points in a rotating fashion. Another approach is to cannulate the fistula with a blunted needle, in exactly the same place. This is called a 'buttonhole' approach. Often two or three buttonhole places are available on a given fistula. This also can prolong fistula life and help prevent damage to the fistula.

AV graft



An arteriovenous graft.

AV (arteriovenous) grafts are much like fistulas in most respects, except that an artificial vessel is used to join the artery and vein. The graft usually is made of a synthetic material, often PTFE, but sometimes chemically treated, sterilized veins from animals are used. Grafts are inserted when the patient's native vasculature does not permit a fistula. They mature faster than fistulas, and may be ready for use several weeks after formation (some newer grafts may be used even sooner). However, AV grafts are at high risk to develop narrowing, especially in the vein just downstream from where the graft has been sewn to the vein. Narrowing often leads to clotting or thrombosis. As foreign material, they are at greater risk for becoming infected. More options for sites to place a graft are available, because the graft can be made quite long. Thus a graft can be placed in the thigh or even the neck (the 'necklace graft').

Fistula First project

AV fistulas have a much better access patency and survival than do venous catheters or grafts. They also produce better patient survival and have far fewer complications compared to grafts or venous catheters. For this reason, the Centers for Medicare & Medicaid (CMS) has set up a Fistula First Initiative , whose goal is to increase the use of AV fistulas in dialysis patients.

There is ongoing research to make bio-engineered blood vessels, which may be of immense importance in creating AV fistulas for patients on hemodialysis, who do not have good blood vessels for creation of one. It involves growing cells which produce collagen and other proteins on a biodegradable micromesh tube followed by removal of those cells to make the 'blood vessels' storable in refrigerators.

Types

There are three types of hemodialysis: conventional hemodialysis, daily hemodialysis, and nocturnal hemodialysis. Below is the adaption and summary from a brochure of The Ottawa Hospital.

Conventional hemodialysis

Chronic hemodialysis is usually done three times per week, for about 3-4 hours for each treatment, during which the patient's blood is drawn out through a tube at a rate of 3-400 cc/min. The tube is connected to a 15, 16, or 17 gauge needle inserted in the dialysis fistula or graft, or connected to one port of a dialysis catheter. The blood is then pumped through the dialyser, and then the processed blood is pumped back into the patient's bloodstream through another tube (connected to a second needle or port). During the procedure, the patient's blood pressure is closely monitored, and if it becomes low, or the patient develops any other signs of low blood volume such as nausea, the dialysis attendant can administer extra fluid through the machine. During the treatment, the patient's entire blood volume (about 5000 cc) circulates through the machine every 15 minutes.

Daily hemodialysis

Daily hemodialysis is typically used by those patients who do their own dialysis at home. It is less stressful (more gentle) but does require more frequent access. This is simple with catheters, but more problematic with fistulas or grafts. The "buttonhole technique" can be used for fistulas requiring frequent access. Daily hemodialysis is usually done for 2 hours six days a week.

Nocturnal hemodialysis

the procedure of nocturnal hemodialysis is similar to conventional hemodialysis except it is performed six nights a week and six-ten hours per session while the patient sleeps.

Advantages and disadvantages

Advantages

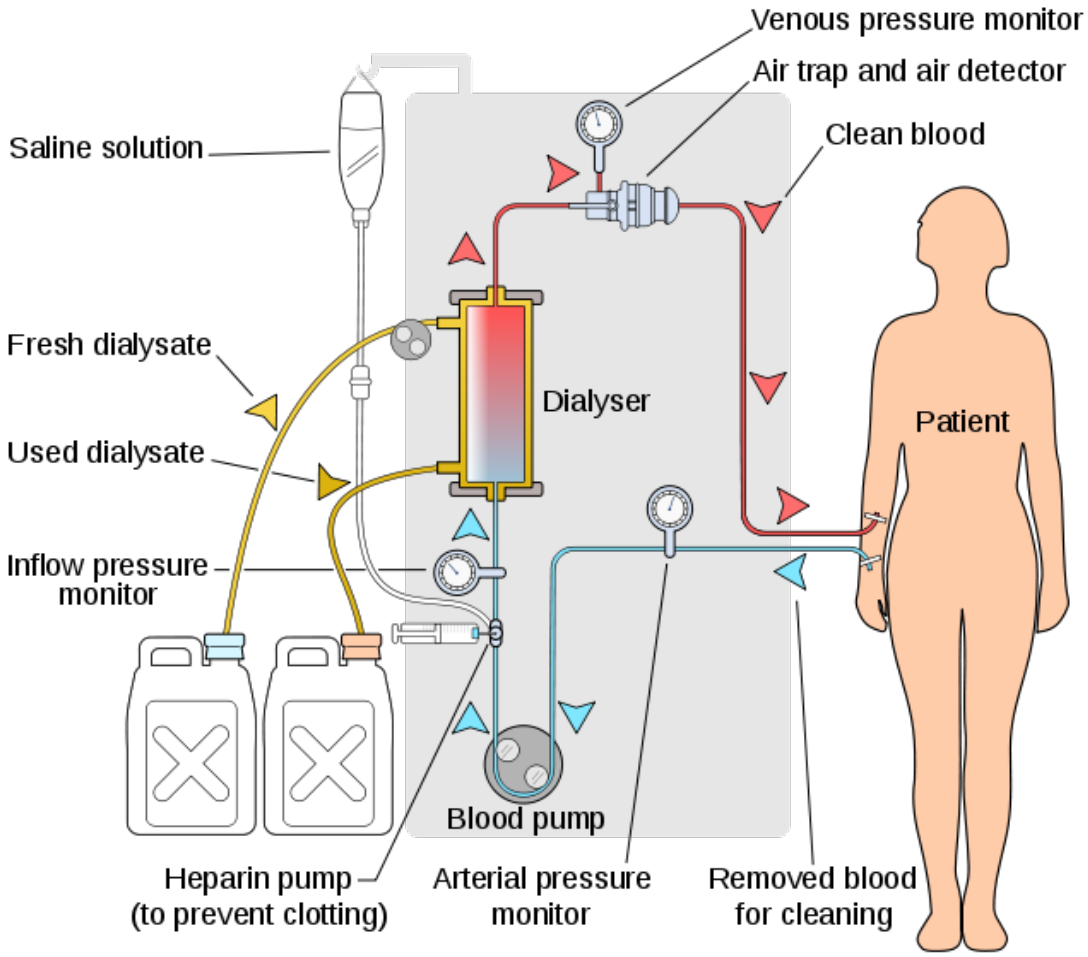
- Low mortality rate
- Better control of blood pressure and abdominal cramps
- Less diet restriction

- Better solute clearance effect for the daily hemodialysis: better tolerance and fewer complications with more frequent dialysis

Disadvantages

- Restricts independence, as people undergoing this procedure cannot travel around because of supplies' availability
- Requires reliable technology such as high water quality and electricity
- Requires more supplies like dialysis machines
- The procedure is complicated and requires that care givers have more knowledge
- Requires time to set up and clean dialysis machines, and expense with machines and associated staff

Equipment



Schematic of a hemodialysis circuit

The hemodialysis machine pumps the patient's blood and the dialysate through the dialyzer. The newest dialysis machines on the market are highly computerized and continuously monitor an array of safety-critical parameters, including blood and dialysate

flow rates; dialysis solution conductivity, temperature, and pH; and analysis of the dialysate for evidence of blood leakage or presence of air. Any reading that is out of normal range triggers an audible alarm to alert the patient-care technician who is monitoring the patient. Manufacturers of dialysis machines include companies such as Fresenius, Gambro, Baxter, B. Braun, NxStage and Bellco.

Water system

A hemodialysis unit's dialysate solution tanks

An extensive water purification system is absolutely critical for hemodialysis. Since dialysis patients are exposed to vast quantities of water, which is mixed with dialysate concentrate to form the dialysate, even trace mineral contaminants or bacterial endotoxins can filter into the patient's blood. Because the damaged kidneys cannot perform their intended function of removing impurities, ions introduced into the bloodstream via water can build up to hazardous levels, causing numerous symptoms or death. Aluminum, chloramine, fluoride, copper, and zinc, as well as bacterial fragments and endotoxins, have all caused problems in this regard.

For this reason, water used in hemodialysis is carefully purified before use. Initially it is filtered and temperature-adjusted and its pH is corrected by adding an acid or base. Then it is softened. Next the water is run through a tank containing activated charcoal to adsorb organic contaminants. Primary purification is then done by forcing water through a

membrane with very tiny pores, a so-called reverse osmosis membrane. This lets the water pass, but holds back even very small solutes such as electrolytes. Final removal of leftover electrolytes is done by passing the water through a tank with ion-exchange resins, which remove any leftover anions or cations and replace them with hydroxyl and hydrogen molecules, respectively, leaving ultrapure water.

Even this degree of water purification may be insufficient. The trend lately is to pass this final purified water (after mixing with dialysate concentrate) through a dialyzer membrane. This provides another layer of protection by removing impurities, especially those of bacterial origin, that may have accumulated in the water after its passage through the original water purification system.

Once purified water is mixed with dialysate concentrate, its conductivity increases, since water that contains charged ions conducts electricity. During dialysis, the conductivity of dialysis solution is continuously monitored to ensure that the water and dialysate concentrate are being mixed in the proper proportions. Both excessively concentrated dialysis solution and excessively dilute solution can cause severe clinical problems.

Dialyzer

The dialyzer is the piece of equipment that actually filters the blood. Almost all dialyzers in use today are of the hollow-fiber variety. A cylindrical bundle of hollow fibers, whose walls are composed of semi-permeable membrane, is anchored at each end into potting compound (a sort of glue). This assembly is then put into a clear plastic cylindrical shell with four openings. One opening or blood port at each end of the cylinder communicates with each end of the bundle of hollow fibers. This forms the "blood compartment" of the dialyzer. Two other ports are cut into the side of the cylinder. These communicate with the space around the hollow fibers, the "dialysate compartment." Blood is pumped via the blood ports through this bundle of very thin capillary-like tubes, and the dialysate is pumped through the space surrounding the fibers. Pressure gradients are applied when necessary to move fluid from the blood to the dialysate compartment.

Membrane and flux

Dialyzer membranes come with different pore sizes. Those with smaller pore size are called "low-flux" and those with larger pore sizes are called "high-flux." Some larger molecules, such as beta-2-microglobulin, are not removed at all with low-flux dialyzers; lately, the trend has been to use high-flux dialyzers. However, such dialyzers require newer dialysis machines and high-quality dialysis solution to control the rate of fluid removal properly and to prevent backflow of dialysis solution impurities into the patient through the membrane.

Dialyzer membranes used to be made primarily of cellulose (derived from cotton linter). The surface of such membranes was not very biocompatible, because exposed hydroxyl groups would activate complement in the blood passing by the membrane. Therefore, the basic, "unsubstituted" cellulose membrane was modified. One change was to cover these

hydroxyl groups with acetate groups (cellulose acetate); another was to mix in some compounds that would inhibit complement activation at the membrane surface (modified cellulose). The original "unsubstituted cellulose" membranes are no longer in wide use, whereas cellulose acetate and modified cellulose dialyzers are still used. Cellulosic membranes can be made in either low-flux or high-flux configuration, depending on their pore size.

Another group of membranes is made from synthetic materials, using polymers such as polyarylethersulfone, polyamide, polyvinylpyrrolidone, polycarbonate, and polyacrylonitrile. These synthetic membranes activate complement to a lesser degree than unsubstituted cellulose membranes. Synthetic membranes can be made in either low- or high-flux configuration, but most are high-flux.

Nanotechnology is being used in some of the most recent high-flux membranes to create a uniform pore size. The goal of high-flux membranes is to pass relatively large molecules such as beta-2-microglobulin (MW 11,600 daltons), but not to pass albumin (MW ~66,400 daltons). Every membrane has pores in a range of sizes. As pore size increases, some high-flux dialyzers begin to let albumin pass out of the blood into the dialysate. This is thought to be undesirable, although one school of thought holds that removing some albumin may be beneficial in terms of removing protein-bound uremic toxins.

Membrane flux and outcome

Whether using a high-flux dialyzer improves patient outcomes is somewhat controversial, but several important studies have suggested that it has clinical benefits. The NIH-funded HEMO trial compared survival and hospitalizations in patients randomized to dialysis with either low-flux or high-flux membranes. Although the primary outcome (all-cause mortality) did not reach statistical significance in the group randomized to use high-flux membranes, several secondary outcomes were better in the high-flux group . A recent Cochrane analysis concluded that benefit of membrane choice on outcomes has not yet been demonstrated . A collaborative randomized trial from Europe, the MPO (Membrane Permeabilities Outcomes) study, comparing mortality in patients just starting dialysis using either high-flux or low-flux membranes, found a nonsignificant trend to improved survival in those using high-flux membranes, and a survival benefit in patients with lower serum albumin levels or in diabetics.

Membrane flux and beta-2-microglobulin amyloidosis

High-flux dialysis membranes and/or intermittent on-line hemodiafiltration (IHDF) may also be beneficial in reducing complications of beta-2-microglobulin accumulation. Because beta-2-microglobulin is a large molecule, with a molecular weight of about 11,600 daltons, it does not pass at all through low-flux dialysis membranes. Beta-2-M is removed with high-flux dialysis, but is removed even more efficiently with IHDF. After several years (usually at least 5-7), patients on hemodialysis begin to develop complications from beta-2-M accumulation, including carpal tunnel syndrome, bone

cysts, and deposits of this amyloid in joints and other tissues. Beta-2-M amyloidosis can cause very serious complications, including spondyloarthropathy, and often is associated with shoulder joint problems. Observational studies from Europe and Japan have suggested that using high-flux membranes in dialysis mode, or IHDF, reduces beta-2-M complications in comparison to regular dialysis using a low-flux membrane.

Dialyzer size and efficiency

Dialyzers come in many different sizes. A larger dialyzer with a larger membrane area (A) will usually remove more solutes than a smaller dialyzer, especially at high blood flow rates. This also depends on the membrane permeability coefficient K_0 for the solute in question. So dialyzer efficiency is usually expressed as the K_0A - the product of permeability coefficient and area. Most dialyzers have membrane surface areas of 0.8 to 2.2 square meters, and values of K_0A ranging from about 500 to 1500 mL/min. K_0A, expressed in mL/min, can be thought of as the maximum clearance of a dialyzer at very high blood and dialysate flow rates.

Reuse of dialyzers

The dialyzer may either be discarded after each treatment or be reused. Reuse requires an extensive procedure of high-level disinfection. Reused dialyzers are not shared between patients. There was an initial controversy about whether reusing dialyzers worsened patient outcomes. The consensus today is that reuse of dialyzers, done carefully and properly, produces similar outcomes to single use of dialyzers .

Nursing care for hemodialysis patient

Adapt from nephrology nursing practice recommendations developed by Canadian Association of Nephrology and Technology (CANNT) based on best available evidence and clinical practice guidelines, a nephrology nurse should perform:

Hemodialysis Vascular Access: Assess the fistula/graft and arm before, after each dialysis or every shift: the access flow, complications Assess the complication of central venous catheter: the tip placement, exit site, complications document and notify appropriate health care provider regarding any concerns. educates the patient with appropriate cleaning of fistula/graft and exit site; with recognizing and reporting signs and symptoms of infection and complication.

Hemodialysis adequacy: Assesses patient constantly for signs and symptoms of inadequate dialysis. Assesses possible causes of inadequate dialysis. Educations patients the importance of receiving adequate dialysis.

Hemodialysis treatment and complications: Performs head to toe physical assessment before, during and after hemodialysis regarding complications and access's security. Confirm and deliver dialysis prescription after review most update lab results. Address any concerns of the patient and educate patient when recognizing the learning gap.

Medication management and infection control practice: Collaborate with the patient to develop a medication regimen. Follow infection control guidelines as per unit protocol.

Chapter 8

Hemofiltration

In medicine, **hemofiltration**, also **haemofiltration**, is a renal replacement therapy similar to hemodialysis which is used almost exclusively in the intensive care setting. Thus, it is almost always used for acute renal failure. It is a *slow continuous* therapy in which sessions usually last between 12 to 24 hours and are usually performed daily. During hemofiltration, a patient's blood is passed through a set of tubing (a *filtration circuit*) via a machine to a semipermeable membrane (the *filter*) where waste products and water are removed. Replacement fluid is added and the blood is returned to the patient.

The Principle of Hemofiltration

As in dialysis, in hemofiltration one achieves movement of solutes across a semi-permeable membrane. However, solute movement with hemofiltration is governed by convection rather than by diffusion. With hemofiltration, dialysate is not used. Instead, a positive hydrostatic pressure drives water and solutes across the filter membrane from the blood compartment to the filtrate compartment, from which it is drained. Solutes, both small and large, get dragged through the membrane at a similar rate by the flow of water that has been engineered by the hydrostatic pressure. So convection overcomes the reduced removal rate of larger solutes (due to their slow speed of diffusion) seen in hemodialysis.

Replacement fluid composition

An isotonic replacement fluid is added to the blood to replace fluid volume and electrolytes. The replacement fluid must be of high purity, because it is infused directly into the blood line of the extracorporeal circuit. The replacement hemofiltration fluid usually contains lactate or acetate as a bicarbonate-generating base, or bicarbonate itself. Use of lactate can occasionally be problematic in patients with lactic acidosis or with severe liver disease, because in such cases the conversion of lactate to bicarbonate can be impaired. In such patients use of bicarbonate as a base is preferred.

Hemodiafiltration

Hemofiltration is sometimes used in combination with hemodialysis, when it is termed hemodiafiltration. Blood is pumped through the blood compartment of a high flux dialyzer, and a high rate of ultrafiltration is used, so there is a high rate of movement of water and solutes from blood to dialysate that must be replaced by substitution fluid that is infused directly into the blood line. However, dialysis solution is also run through the dialysate compartment of the dialyzer. The combination is theoretically useful because it results in good removal of both large and small molecular weight solutes.

Intermittent vs. continuous modes of therapy

These treatments can be given intermittently, or continuously. The latter is usually done in an intensive care unit setting.

On-line intermittent hemofiltration (IHF) or hemodiafiltration (IHDF)

Either of these treatments can be given in outpatient dialysis units, three or more times a week, usually 3-5 hours per treatment. IHDF is used almost exclusively, with only a few centers using IHF. With both IHF or IHDF, the substitution fluid is prepared on-line from dialysis solution by running dialysis solution through a set of two membranes to purify it before infusing it directly into the blood line. In the United States, regulatory agencies have not yet approved on-line creation of substitution fluid because of concerns about its purity. For this reason, hemodiafiltration is almost never used in an outpatient setting in the United States as of 2007. Use of sterile, pre-packaged substitution fluid would be cost-prohibitive in the current economic environment.

Continuous hemofiltration (CHF) or hemodiafiltration (CHDF)

Hemofiltration is most commonly used in an intensive care unit setting, where it is either given as 8-12 hours treatments, so called SLEF (slow extended hemofiltration), or as CHF (continuous hemofiltration also sometimes called continuous veno-venous hemofiltration (CVVH)) or Continuous Renal Replacement Therapy (CRRT). Hemodiafiltration (SLED-F or CHDF or CVVHDF) also is widely used in this fashion. In the United States, the substitution fluid used in CHF or CHDF is commercially prepared, prepackaged, and sterile (or sometimes is prepared in the local hospital pharmacy), avoiding regulatory issues of on-line creation of replacement fluid from dialysis solution.

With slow continuous therapies, the blood flow rates are usually in the range of 100-200 ml/min, and access is usually achieved through a central venous catheter placed in one of the large central veins. In such cases a blood pump is used to drive blood flow through the filter. Native access for hemodialysis (eg AV fistulas or grafts) are unsuitable for CHF because the prolonged residence of the access needles required might damage such accesses.

Is on-line intermittent hemodiafiltration (IHDF) better than regular hemodialysis?

There is controversy about whether intermittent on-line hemodiafiltration (IHDF) gives better results than hemodialysis in an outpatient setting. In Europe, several observational studies have compared outcomes in patients getting dialysis with those getting IHDF. These have suggested a lower mortality rate and other favorable outcomes in patients getting IHDF vs. those getting ordinary hemodialysis. However, the issue is not settled at this time, because the required randomized controlled clinical trials have not been done. Another problem has been that in several of the trials done, IHDF was compared to dialysis using low-flux (small pore) membranes, and the benefit found may have been due more to the use of a high-flux membrane than to the addition of convective transport (filtration) to dialysis. A recent Cochrane database review of available trials could not find a definite benefit of either IHF or IHDF vs. hemodialysis in terms of outcomes.

Chapter 9

Ankle Brachial Pressure Index

The **Ankle Brachial Pressure Index** (**ABPI**), known more commonly as an ABI, is the ratio of the blood pressure in the lower legs to the blood pressure in the arms. Compared to the arm, lower blood pressure in the leg is an indication of blocked arteries (peripheral vascular disease). The ABI is calculated by dividing the systolic blood pressure at the ankle by the systolic blood pressures in the arm.

Method

A Doppler ultrasound blood flow detector, commonly called Doppler Wand or Doppler probe, and a sphygmomanometer (blood pressure cuff) are usually needed. The blood pressure cuff is inflated proximal to the artery in question. Measured by the doppler wand, the inflation continues until the pulse in the artery ceases. The blood pressure cuff is then slowly deflated. When the artery's pulse is re-detected through the doppler probe the pressure in the cuff at that moment indicates the systolic pressure of that artery.

The higher systolic reading of the left and right arm brachial artery is generally used in the assessment. The pressures in each foot's posterior tibial artery and dorsalis pedis artery are measured with the higher of the two values used as the ABI for that leg.

$$ABPI_{Leg} = \frac{P_{Leg}}{P_{Arm}}$$

Where P_{Leg} is the systolic blood pressure of dorsalis pedis or posterior tibial arteries
and P_{Arm} is the highest of the left and right arm brachial systolic blood pressure

The ABPI test is a popular tool for the non-invasive assessment of PVD. Studies have shown the sensitivity of ABPI is 90% with a corresponding 98% specificity for detecting hemodynamically significant (Serious) stenosis >50% in major leg arteries, defined by angiogram.

However, ABPI has known issues:

- ABPI is known to be unreliable on patients with arterial calcification (hardening of the arteries) which results in less or incompressible arteries, as the stiff arteries produce falsely elevated ankle pressure, giving false negatives). This is often found in patients with diabetes melitus (41% of PAD patients have diabetes), renal failure or heavy smokers. ABPI values < 0.9 & >1.3 should be investigated further regardless.
- Performing ABPI is time consuming.
- Resting ABPI is insensitive to mild PAD. Treadmill tests (6 minute) are sometimes used to increase ABPI sensitivity, but this is unsuitable for patients who are obese or have co-morbidities such as Aortic aneurysm, and increases assessment duration.
- Lack of protocol standardisation, which reduces intra-observer reliability.
- Skilled Operators are required for consistent, accurate results.

These issuesd have rendered ABI unpopular in primary care, due to the perceived difficulties and time taken. However, technology is emerging that allows for the oscillometric calculation of ABI. This is achieved by doing simultaneous readings of blood pressure at the levels of the ankle and upper arm using specially calibrated oscillometric modules. Several Manufactureres have devices on the market. The main interest in the introduction of an oscillometric system to measure ABI is that it standardizes the method and makes the measurement of ABI accessible to all doctors.

Interpretation of results

In a normal subject the pressure at the ankle is slightly higher than at the elbow (there is reflection of the pulse pressure from the vascular bed of the feet, whereas at the elbow the artery continues on some distance to the wrist). The ABPI is the ratio of the highest ankle to brachial artery pressure and an ABPI of greater than 0.9 is considered normal (Free from significant PAD).

However, an ABPI value greater than 1.3 is considered abnormal, and suggests calcification of the walls of the arteries and incompressible vessels, reflecting severe peripheral vascular disease.

Provided that there are no other significant conditions affecting the arteries of the leg, the following ABPI ratios can be used to predict the severity of PAD as well as assess the nature and best management of various types of leg ulcers:

ABPI value	Interpretation	Action	Nature of ulcers, if present
above 1.2	Abnormal Vessel hardening from PVD	Refer routinely	Venous ulcer use full compression bandaging
1.0 - 1.2	Normal range	None	
0.9 - 1.0	Acceptable		

0.8 - 0.9	Some arterial disease	Manage risk factors	
0.5 - 0.8	Moderate arterial disease	Routine specialist referral	Mixed ulcers use reduced compression bandaging. Claudication may be present at values less than 0.6.
under 0.5	Severe arterial disease	Urgent specialist referral	Arterial ulcers no compression bandaging used. Pain at rest may be present at values less than 0.25.

Predictor of atherosclerosis mortality

Studies in 2006 suggests that an abnormal ABPI may be an independent predictor of mortality, as it reflects the burden of atherosclerosis.

Chapter 10

Sclerotherapy

Sclerotherapy is a procedure used to treat blood vessels or blood vessel malformations (vascular malformations) and also those of the lymphatic system. A medicine is injected into the vessels, which makes them shrink. It is used for children and young adults with vascular or lymphatic malformations. In adults, sclerotherapy is often used to treat varicose veins and hemorrhoids.

Sclerotherapy is one method, along with surgery, radiofrequency and laser ablation, for treatment of varicose veins and venous malformations. In ultrasound-guided sclerotherapy, ultrasound is used to visualize the underlying vein so the physician can deliver and monitor the injection. Sclerotherapy is often done under ultrasound guidance after venous abnormalities have been diagnosed with duplex ultrasound. Sclerotherapy under ultrasound guidance and using microfoam sclerosants has been shown to be effective in controlling reflux from the sapheno-femoral and sapheno-popliteal junctions. However, some authors believe that sclerotherapy is not suitable for veins with reflux from the greater or lesser saphenous junction, or veins with axial reflux.

Historical aspects

Sclerotherapy has been used in the treatment of varicose veins for over 150 years. Like varicose vein surgery, sclerotherapy techniques have evolved during that time. Modern techniques including ultrasonographic guidance and foam sclerotherapy are the latest developments in this evolution.

Goldman says that the first reported attempt at sclerotherapy was by D Zollikofer in Switzerland, 1682 who injected an acid into a vein to induce thrombus formation. Both Debout and Cassaignaic reported success in treating varicose veins by injecting perchlorate of iron in 1853. Desgranges in 1854 cured 16 cases of varicose veins by injecting iodine and tannin into the veins. This was approximately 12 years after the probable advent of great saphenous vein stripping in 1844 by Madelung. However, due to high rates of side-effects with the drugs used at the time, sclerotherapy had been practically abandoned by 1894. With the improvements in surgical techniques and anaesthetics over that time, stripping became the treatment of choice.

Work continued on alternative sclerosants in the early 20th century. During that time carbolic acid and perchlorate of mercury were tried and whilst these showed some effect in obliterating varicose veins, side-effects also caused them to be abandoned. Prof. Sicard and other French doctors developed the use of sodium carbonate and then sodium salicylate during and after the First World War. Quinine was also used with some effect during the early 20th century. At the time of Coppleson's book in 1929, he was advocating the use of sodium salicylate or quinine as the best choices of sclerosant.

Further work on improving the technique and development of safer more effective sclerosants continued through the 1940s and 1950s. Of particular importance was the development of sodium tetradecyl sulfate (STS) in 1946, a product still widely used to this day. George Fegan in the 1960s reported treating over 13,000 patients with sclerotherapy, significantly advancing the technique by focussing on fibrosis of the vein rather than thrombosis, concentrating on controlling significant points of reflux, and emphasizing the importance of compression of the treated leg. The procedure became medically accepted in mainland Europe during that time. However it was poorly understood or accepted in England or the United States, a situation that continues to this day amongst some sections of the medical community.

The next major development in the evolution of sclerotherapy was the advent of duplex ultrasonography in the 1980s and its incorporation into the practise of sclerotherapy later that decade. Knight was an early advocate of this new procedure and presented it at several conferences in Europe and the United States. Thibault's article was the first on this topic to be published in a peer-reviewed journal.

The work of Cabrera and Monfreaux in utilising foam sclerotherapy along with Tessari's "3-way tap method" of foam production further revolutionised the treatment of larger varicose veins with sclerotherapy.

Methods

Injecting the unwanted veins with a sclerosing solution causes the target vein to immediately shrink, and then dissolve over a period of weeks as the body naturally absorbs the treated vein.

Sclerotherapy is the "gold standard" and is preferred over laser for eliminating large spider veins (telangiectasiae) and smaller varicose leg veins. Unlike a laser, the sclerosing solution additionally closes the "feeder veins" under the skin that are causing the spider veins to form, thereby making a recurrence of the spider veins in the treated area less likely. Multiple injections of dilute sclerosant are injected into the abnormal surface veins of the involved leg. The patient's leg is then compressed with either stockings or bandages that they wear usually for two weeks after treatment. Patients are also encouraged to walk regularly during that time. It is common practice for the patient to require at least two treatment sessions separated by several weeks to significantly improve the appearance of their leg veins.

Sclerotherapy can also be performed using microfoam sclerosants under ultrasound guidance to treat larger varicose veins, including the great and small saphenous veins. After a map of the patient's varicose veins is created using ultrasound, these veins are injected whilst real-time monitoring of the injections is undertaken, also using ultrasound. The sclerosant can be observed entering the vein, and further injections performed so that all the abnormal veins are treated. Follow-up ultrasound scans are used to confirm closure of the treated veins, and any residual varicose veins can be identified and treated.

Foam sclerotherapy

Foam sclerotherapy is a technique that involves injecting “foamed sclerosant drugs” within a blood vessel using a syringe. The sclerosant drugs (Sodium Tetradecyl Sulfate or polidocanol) are mixed with air or a physiological gas (carbon dioxide) in a syringe or by using mechanical pumps. This increases the surface area of the drug. The foam sclerosant drug is more efficacious than the liquid one in causing sclerosis (thickening of the vessel wall and sealing off the blood flow), for it does not mix with the blood in the vessel and in fact displaces it, thus avoiding dilution of the drug and causing maximal sclerosant action. It is therefore useful for longer and larger veins. Experts in foam sclerotherapy have created “tooth paste” like thick foam for their injections, which has revolutionized the non-surgical treatment of varicose veins and venous malformations, including Klippel Trenaunay syndrome.

Clinical evaluations

A study by Kanter and Thibault in 1996 reported a 76% success rate at 24 months in treating saphenofemoral junction and great saphenous vein incompetence with STS 3% solution. Padbury and Benveniste found that ultrasound guided sclerotherapy was effective in controlling reflux in the small saphenous vein. Barrett et al. found that microfoam ultrasound guided sclerotherapy was "effective in treating all sizes of varicose veins with high patient satisfaction and improvement in quality of life".

A Cochrane Collaboration review of the medical literature concluded that "the evidence supports the current place of sclerotherapy in modern clinical practice, which is usually limited to treatment of recurrent varicose veins following surgery and thread veins." A second Cochrane Collaboration review comparing surgery to sclerotherapy concluded that sclerotherapy has greater benefits than surgery in the short term but surgery has greater benefits in the longer term. Sclerotherapy was better than surgery in terms of treatment success, complication rate and cost at one year, but surgery was better after five years. However, the evidence was not of very good quality and more research is needed.

A Health Technology Assessment found that sclerotherapy provided less benefit than surgery, but is likely to provide a small benefit in varicose veins without reflux from the sapheno-femoral or sapheno-popliteal junctions. It did not study the relative benefits of surgery and sclerotherapy in varicose veins with junctional reflux.

The European Consensus Meeting on Foam Sclerotherapy in 2003 concluded that "Foam sclerotherapy allows a skilled practitioner to treat larger veins including saphenous trunks". A second European Consensus Meeting on Foam Sclerotherapy in 2006 has now been published.

Complications

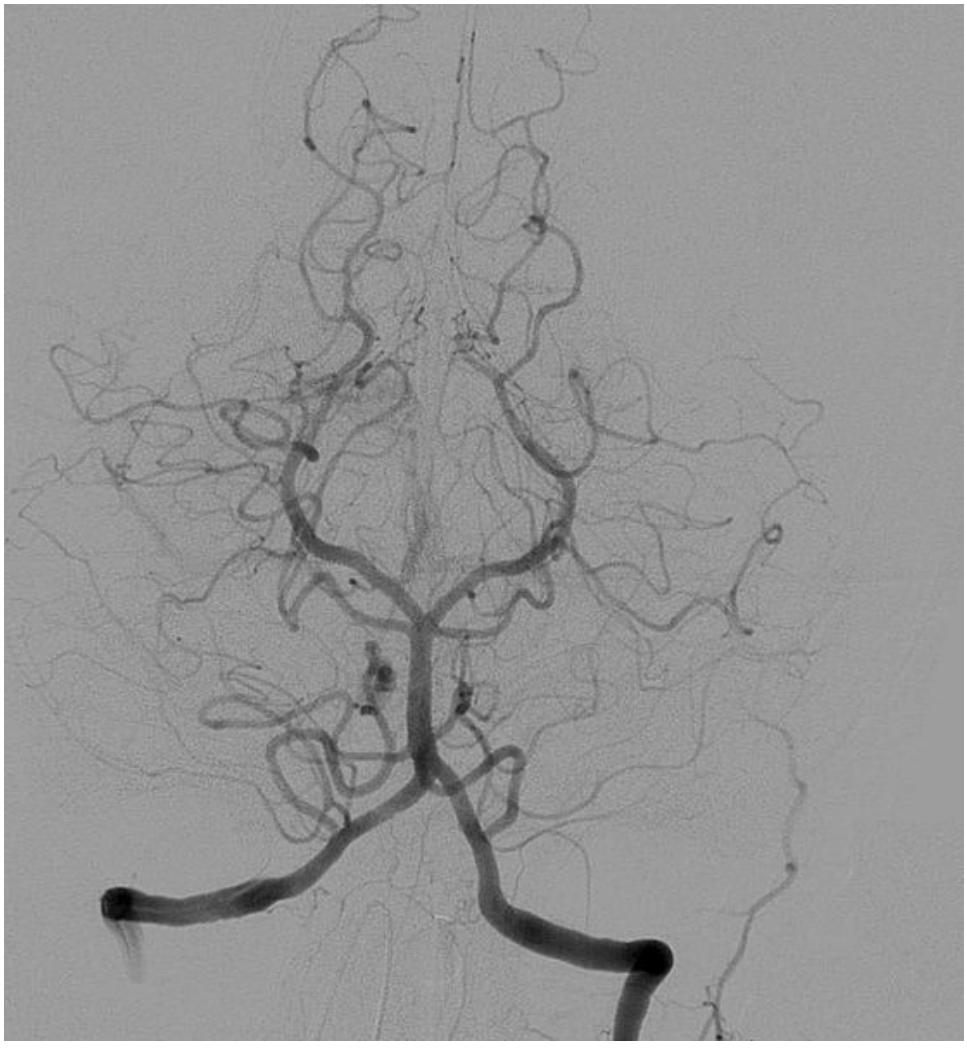
Complications, while rare, include venous thromboembolism, visual disturbances, allergic reaction , thrombophlebitis, skin necrosis, and hyperpigmentation.

If the sclerosant is injected properly into the vein, there is no damage to the surrounding skin, but if it is injected outside the vein, tissue necrosis and scarring can result. Skin necrosis, whilst rare, can be cosmetically "potentially devastating", and may take months to heal. It is very rare when small amounts of dilute (<0.25%) sodium tetradecyl sulfate (STS) is used, but has been seen when higher concentrations (3%) are used. Blanching of the skin often occurs when STS is injected into arterioles (small artery branches). Telangiectatic matting, or the development of tiny red vessels, is unpredictable and usually must be treated with repeat sclerotherapy or laser..

Most complications occur due to an intense inflammatory reaction to the sclerotherapy agent in the area surrounding the injected vein. In addition, there are systemic complications that are now becoming increasingly understood. These occur when the sclerosant travels through the veins to the heart, lung and brain. A recent report attributed a stroke to foam treatment , although this involved the injection of an unusually large amount of foam. More recent reports have shown that bubbles from even a small amount of sclerosant foam injected into the veins quickly appears in the heart, lung and brain. The significance of this is not fully understood at this point and large studies show that foam sclerotherapy is safe. Sclerotherapy is fully FDA approved in the USA.

Chapter 11

Angiography



Angiogram showing a transverse projection of the vertebrobasilar and posterior cerebral circulation.

Angiography or **arteriography** is a medical imaging technique used to visualize the inside, or lumen, of blood vessels and organs of the body, with particular interest in the arteries, veins and the heart chambers. This is traditionally done by injecting a radio-opaque contrast agent into the blood vessel and imaging using X-ray based techniques such as fluoroscopy. The word itself comes from the Greek words *angeion*, "vessel", and *graphein*, "to write or record". The film or image of the blood vessels is called an *angiograph*, or more commonly, an *angiogram*.

The term *angiography* is strictly defined as based on projectional radiography; however, the term has been applied to newer vascular imaging techniques such as CT angiography and MR angiography. The term *isotope angiography* has also been used, although this more correctly is referred to as isotope perfusion scanning.

History

The technique was first developed in 1927 by the Portuguese physician and neurologist Egas Moniz at the University of Lisbon to provide contrasted x-ray cerebral angiography in order to diagnose several kinds of nervous diseases, such as tumors, coronary heart disease and arteriovenous malformations. He is usually recognized as one of the pioneers in this field. Moniz performed the first cerebral angiogram in Lisbon in 1927, and Reynaldo Cid dos Santos performed the first aortogram in the same city in 1929. With the introduction of the Seldinger technique in 1953, the procedure became markedly safer as no sharp introductory devices needed to remain inside the vascular lumen.

Technique

Mobile X-ray machine

Depending on the type of angiogram, access to the blood vessels is gained most commonly through the femoral artery, to look at the left side of the heart and the arterial system or the jugular or femoral vein, to look at the right side of the heart and the venous system. Using a system of guide wires and catheters, a type of contrast agent (which shows up by absorbing the x-rays), is added to the blood to make it visible on the x-ray images.

The X-ray images taken may either be still images, displayed on a image intensifier or film, or motion images. For all structures except the heart, the images are usually taken

using a technique called digital subtraction angiography (DSA). Images in this case are usually taken at 2 - 3 frames per second, which allows the radiologist to evaluate the flow of the blood through a vessel or vessels. This technique "subtracts" the bones and other organs so only the vessels filled with contrast agent can be seen. The heart images are taken at 15-30 frames per second, not using a subtraction technique. Because DSA requires the patient to remain motionless, it cannot be used on the heart. Both these techniques enable the radiologist or cardiologist to see stenosis (blockages or narrowings) inside the vessel which may be inhibiting the flow of blood and causing pain.

Uses

Coronary angiography

One of most common angiograms performed is to visualize the blood in the coronary arteries. A long, thin, flexible tube called a catheter is used to administer the x-ray contrast agent at the desired area to be visualized. The catheter is threaded into an artery in the forearm, and the tip is advanced through the arterial system into the major coronary artery. X-ray images of the transient radiocontrast distribution within the blood flowing within the coronary arteries allows visualization of the size of the artery openings. Presence or absence of atherosclerosis or atheroma within the walls of the arteries cannot be clearly determined.

Microangiography

Microangiography is commonly used to visualize tiny blood vessels.

Neuro-vascular angiography

Another increasingly common angiographic procedure is neuro-vascular digital subtraction angiography in order to visualise the arterial and venous supply to the brain. Intervention work such as coil-embolisation of aneurysms and AVM gluing can also be performed.

Peripheral angiography

Angiography is also commonly performed to identify vessel narrowing in patients with leg claudication or *cramps*, caused by reduced blood flow down the legs and to the feet; in patients with renal stenosis (which commonly causes high blood pressure) and can be used in the head to find and repair stroke. These are all done routinely through the femoral artery, but can also be performed through the brachial or axillary (arm) artery. Any stenoses found may be treated by the use of atherectomy.

Other

Other angiographic uses include the diagnosis of retinal vascular disorders, such as diabetic retinopathy and macular degeneration.

Complications

Coronary angiography

Coronary angiographies are common and major complications are rare. These include Cardiac arrhythmias, kidney damage, blood clots (which can cause heart attack or stroke), hypotension and pericardial effusion. Minor complications can include bleeding or bruising at the site where the contrast is injected, blood vessel damage on the route to the heart from the catheter (rare) and allergic reaction to the contrast.

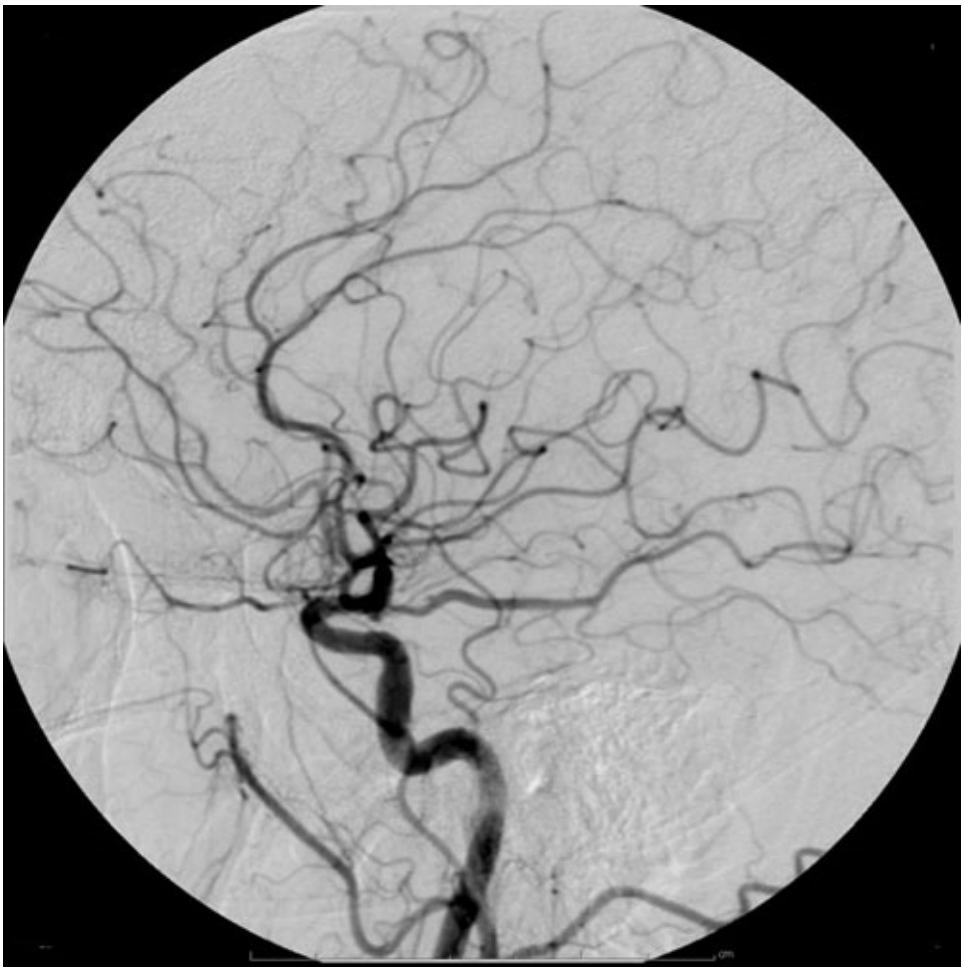
Cerebral angiography

Major complications in Cerebral Angiography are also rare but include stroke, an allergic reaction to the anaesthetic other medication or the contrast medium, blockage or damage to one of the access veins in the leg, or thrombosis and embolism formation. Bleeding or bruising at the site where the contrast is injected are minor complications, delayed bleeding can also occur but is rare.

Chapter 12

Digital Subtraction Angiography and Cerebral Angiography

Digital subtraction angiography



Example of iodine-based contrast in cerebral angiography

Digital subtraction angiography (**DSA**) is a type of fluoroscopy technique used in interventional radiology to clearly visualize blood vessels in a bony or dense soft tissue environment. Images are produced using contrast medium by subtracting a 'pre-contrast image' or the *mask* from later images, once the contrast medium has been introduced into a structure. Hence the term 'digital *subtraction* angiography'.

Applications

DSA is primarily used to image blood vessels. It is useful in the diagnosis and treatment of:

- Arterial and venous occlusions, including carotid artery stenosis, pulmonary embolisms and acute limb ischaemia.
- Arterial stenosis, which is particularly useful for potential renal donors in detecting renal artery stenosis.
- Cerebral aneurysms and arterio-venous malformations (AVM).

DSA and Fluoroscopy

In traditional angiography images are acquired by exposing an area of interest with time-controlled x-rays while injecting contrast medium into the blood vessels. The image obtained would also include all overlying structure besides the blood vessels in this area. This is useful for determining anatomical position and variations but unhelpful for visualising blood vessels accurately.

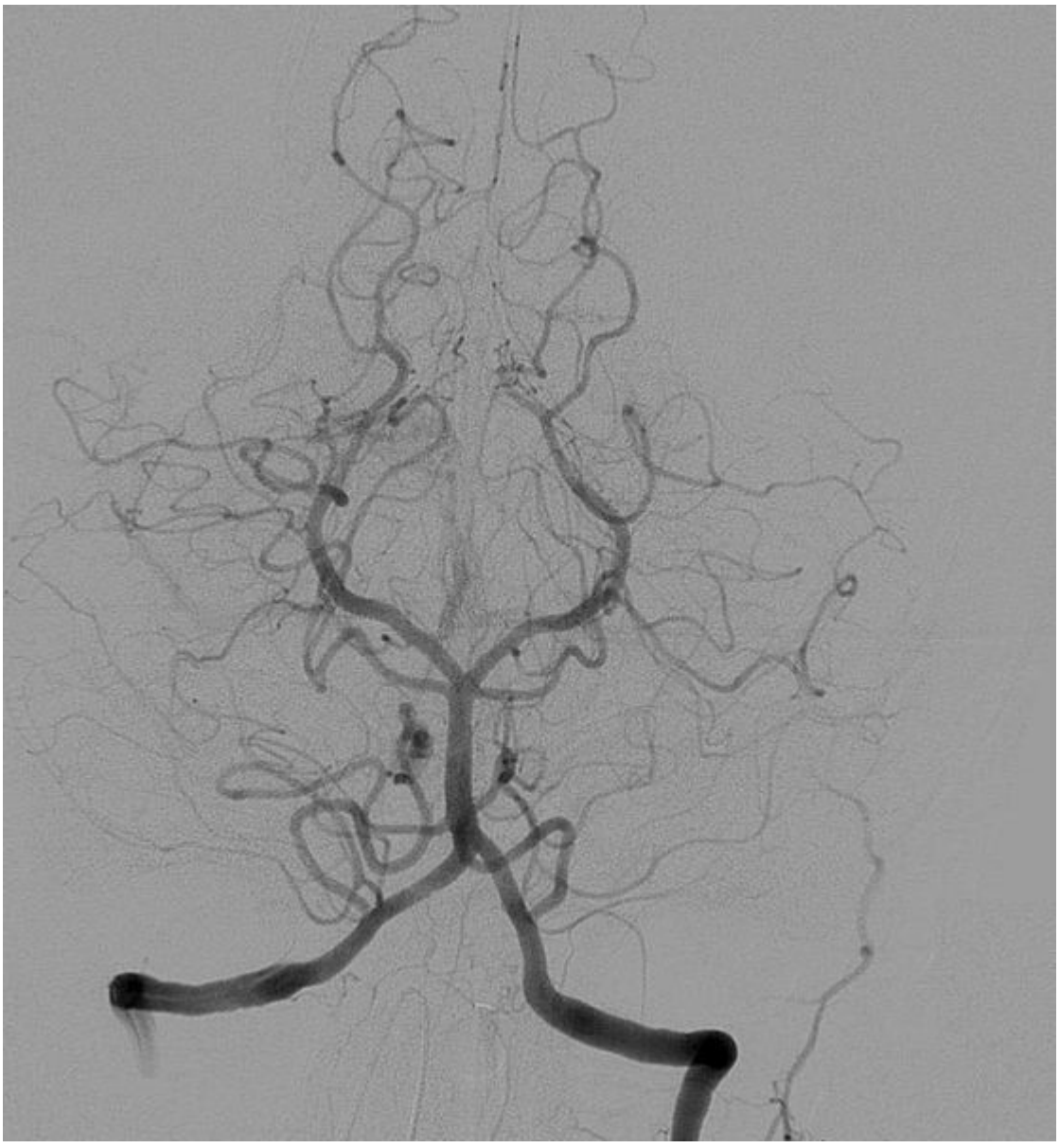
In order to remove these distracting structures to see the vessels better, first a mask image is acquired. The mask image is simply an image of the same area before the contrast is administered. The radiological equipment used to capture this is usually an image intensifier, which will then keep producing images of the same area at a set rate (1 - 6 frames per second), taking all subsequent images away from the original 'mask' image. The radiologist controls how much contrast media is injected and for how long. Smaller structures require less contrast to fill the vessel than others. Images produced appear with a very pale grey background, which produces a high contrast to the blood vessels, which appear a very dark grey.

The images are all produced in real time by the computer, as the contrast is injected into the blood vessels.

The future

DSA is being used less and less routinely in imaging departments. It is being taken over by computed tomography angiography (CTA), which can produce 3D images through a test which is less invasive and stressful for the patient.

Cerebral angiography



Cerebral angiogram showing a transverse projection of the vertebrobasilar and posterior cerebral circulation.

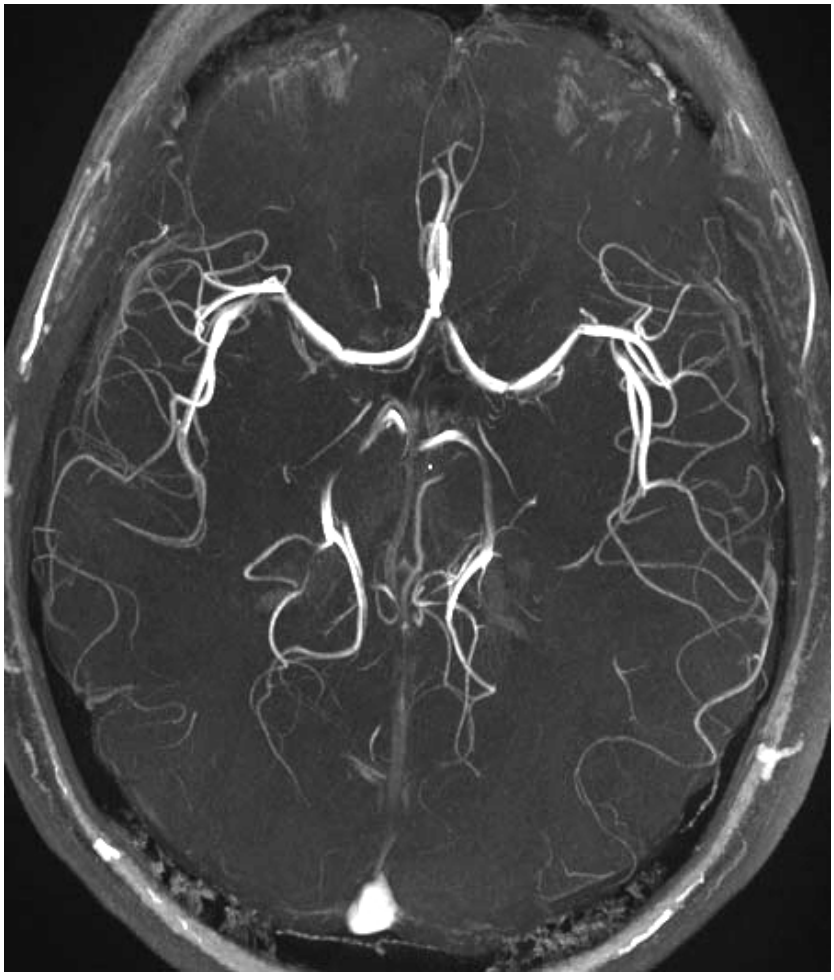
Cerebral angiography is a form of angiography which provides images of blood vessels in and around the brain, thereby allowing detection of abnormalities such as arteriovenous malformations and aneurysms. It was pioneered in 1927 by Egas Moniz, who also helped develop thorotrast for use in the procedure.

Typically a catheter is inserted into a large artery (such as the femoral artery) and threaded through the circulatory system to the carotid artery, where a contrast agent is injected. A series of radiographs is taken as the contrast agent spreads through the brain's arterial system, then a second series as it reaches the venous system.

For some applications this method may yield better images than less invasive methods such as computed tomography angiography and magnetic resonance angiography. In addition, cerebral angiography allows certain treatments to be performed immediately, based on the its findings. If, for example, the images reveal an aneurysm, metal coils may be introduced through the catheter already in place and maneuvered to the site of aneurysm; over time these coils encourage formation of connective tissue at the site, strengthening the vessel walls.

Chapter 13

Magnetic Resonance Angiography



Time-of-flight MRA showing the circle of Willis in the brain. Note the "venetian blinds" artifact visible as the multiple pseudo-stenosis on both the left and right middle cerebral artery

Magnetic resonance angiography (MRA) is a group of techniques based on Magnetic Resonance Imaging (MRI) to image blood vessels. Magnetic resonance angiography is used to generate images of the arteries in order to evaluate them for stenosis (abnormal narrowing), occlusion or aneurysms (vessel wall dilatations, at risk of rupture). MRA is often used to evaluate the arteries of the neck and brain, the thoracic and abdominal aorta, the renal arteries, and the legs (called a "run-off").

Acquisition

A variety of techniques can be used to generate the pictures, based on flow effects or on contrast (inherent or pharmacologically generated).

Standard

- **Contrast enhanced** (CE-MRA): Injection of MRI contrast agents is currently the most common method of acquiring MRA. The contrast medium is injected into a vein, and images are acquired during the first pass of the agent through the arteries. Provided that the timing is correct, this may result in images of very high quality. An alternative is to use a contrast agent that does not, as most agents, leave the vascular system within a few minutes, but remains in the circulation up to an hour (a '"blood-pool agent"'). Since longer time is available for image acquisition, higher resolution imaging is possible. A problem, however, is the fact that both arteries and veins are enhanced at the same time.
- **Time-of-flight** (TOF) or **Inflow angiography**, uses a short echo time and flow compensation to make flowing blood much brighter than stationary tissue. As flowing blood enters the area being imaged it has seen a limited number of excitation pulses so it is not saturated, this gives it a much higher signal than the saturated stationary tissue. As this method is dependent on flowing blood, areas with slow flow (such as large aneurysms) or flow that is in plane of the image may not be well visualized. This is most commonly used in the head and neck and gives detailed high resolution images.
- **Phase-contrast** (PC-MRA): the phase of the MRI signal is manipulated by special bipolar gradients (varying magnetic fields) that is preset to a maximum expected flow velocity. An image acquisition that is reverse of the bipolar gradient is then acquired and the difference of the two image is calculated. Static tissues such as muscle or bone will subtract out, however moving tissues such as blood will acquire a different phase since it moves constantly through the gradient, thus also giving its speed of the flow. Since phase-contrast can only acquire flow in one direction at a time, 3 separate image acquisitions in all three directions must be computed to give the complete image of flow. Despite the slowness of this method, the strength of the technique is that in addition to imaging the flowing blood, quantitative measurements of blood flow occur at the same time.

Research

- **Fresh blood imaging** (FBI): An imaging technique using fast or super fast spin echo sequences (FSE/SFSE). Takes advantage of the longer T2 relaxation of blood compared to surrounding tissue. The images are acquired by fast spin echo sequences that can be synchronized with heart beats.
- **4D Dynamic MR Angiography** (4D-MRA): The first images, before enhancement, serve as a subtraction mask to extract the vascular tree in the succeeding images. Allows to divide arterial and venous phases of a blood-groove with visualisation of its dynamics. Time of research is much less in comparison with other methods MRA.
- **BOLD venography** or **Susceptibility weighted imaging**: This method exploits the susceptibility differences between tissues and uses the phase image to detect these differences. The magnitude and phase data are combined (digitally, by an image-processing program) to produce an enhanced contrast magnitude image which is exquisitely sensitive to venous blood, hemorrhage and iron storage. The imaging of venous blood with SWI is a blood-oxygen-level dependent (BOLD) technique which is why it was (and is sometimes still) referred to as BOLD venography. Due to its sensitivity to venous blood SWI is commonly used in traumatic brain injuries (TBI) and for high resolution brain venographies.

Similar procedures to flow effect based MRA can be used to image veins. Called *Magnetic resonance venography* (MRV) this can be achieved by exciting a plane inferiorly while signal is gathered in the plane immediately superior to the excitation plane, and thus imaging the venous blood which has recently moved from the excited plane. Differences in tissue signals, can also be used for MRA. This method is based on the different signal properties of blood compared to other tissues in the body, independent of MR flow effects. This is most successfully done with balanced pulse sequences such as TrueFISP or bTFE. BOLD can also be used in stroke imaging in order to assess the viability of tissue survival.

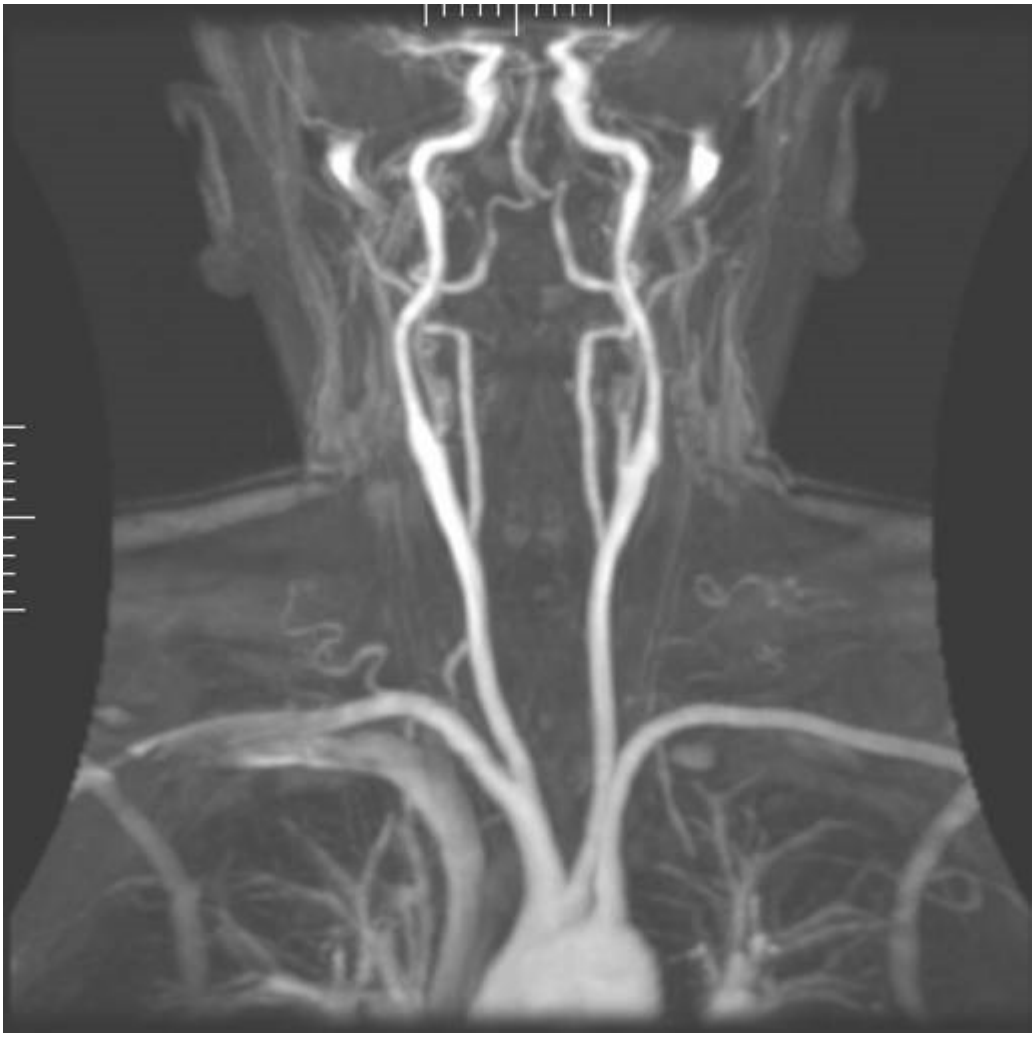
Artifacts

MRA techniques in general are sensitive to turbulent flow, which can cause proton spins to rapidly dephased thus causing a significant loss of signal. This can cause mis-diagnosis of stenosis. Other types of MRA related artifacts include:

- **Phase-contrast**:
  - *Phase wrapping*: caused by the under estimation of maximum blood velocity in the image. The fast moving blood about maximum set velocity for phase-contrast MRA gets aliased and the flow direction is reversed instead
  - *Maxwell terms*: caused by the switching of the gradients field in the main field B0. This cause the over magnetic field to be distort and give inaccurate phase information for the flow.
- **Time-of-Flight**:

- *Laminar flow*: In certain vessels, the blood flow is slower on the vessel walls than near the center. This causes some of the blood near the walls to become saturated further upstream in the vessel.
- *Venetian blinds*: Since the technique acquires images in slabs, non-uniform flip angles due to uneven distribution of the sinc pulses resulting in non-uniform signal intensity

Visualization



Maximum intensity projection of an MRA covering from the top of the heart to just below the circle of Willis

Occasionally, MRA directly produces (thick) slices that contain the entire vessel of interest. More commonly, however, the acquisition results in a stack of slices representing a 3D volume in the body. To display this 3D dataset on a 2D device such as a computer monitor, some rendering method has to be used. The most common method is *Maximum intensity projection* (MIP), where the computer simulates rays through the volume and selects the highest value for display on the screen. The resulting images

resemble conventional catheter angiography images. If several such projections are combined into a cine loop or QuickTime VR object, the depth impression is improved, and the observer can get a good perception of 3D structure. An alternative to MIP is direct volume rendering where the MR signal is translated to properties like brightness, opacity and color and then used in an optical model.

Clinical use

MRA has been successful in studying many arteries in the body, including cerebral and other vessels in the head and neck, the aorta and its major branches in the thorax and abdomen, the renal arteries, and the arteries in the lower limbs. For the coronary arteries, however, MRA has been less successful than CT angiography or invasive catheter angiography. Most often, the underlying disease is atherosclerosis, but medical conditions like aneurysms or abnormal vascular anatomy can also be diagnosed.

An advantage of MRA compared to invasive catheter angiography is the non-invasive character of the examination (no catheters have to be introduced in the body). Another advantage, compared to CT angiography and catheter angiography, is that the patient is not exposed to any ionizing radiation. Also, contrast media used for MRI tend to be less toxic than those used for CT angiography and catheter angiography, with less people having any risk of allergy. Also far less is needed to be injected into the patient. The greatest drawbacks of the method are its comparatively high cost and its somewhat limited spatial resolution. The length of time the scans take can also be an issue, with CT being far quicker. It is also ruled out in patients who are unsafe for MRI (such as having a pacemaker or metal in the eyes or certain surgical clips).

Chapter 14

Cardioplegia

Cardioplegia is intentional and temporary cessation of cardiac activity, primarily for cardiac surgery.

Overview

The word cardioplegia means cardio-the heart and plegia- paralysis. Technically this means arresting or stopping the heart so that surgical procedures can be done in a still and bloodless field. Most commonly however, the word cardioplegia refers to the solution used to bring about asystole of the heart, or heart paralysis.

The four main goals of hypothermic cardioplegia are:

1. Immediate and sustained electromechanical quiescence
2. Rapid and sustained homgenous myocardial cooling
3. Maintenance of therapeutic additives in effective concentrations
4. Periodic washout of metabolic inhibitors

The most common procedure for accomplishing asystole is infusing cold cardioplegic solution into the coronary circulation. This process protects the myocardium, or heart muscle, from damage during the period of ischemia.

To achieve this, the patient is first placed on cardiopulmonary bypass. This device, otherwise known as the heart-lung machine, takes over the function of gas exchange by the lung and blood circulation by the heart. Subsequently the heart is isolated from the rest of the blood circulation by means of an occlusive cross-clamp placed on the ascending aorta proximal to the innominate artery. During this period of heart isolation the heart is not receiving any blood flow, and thus no oxygen for metabolism. As the cardioplegia solution distributes to the entire myocardium the ECG will change and eventually asystole will ensue. Cardioplegia lowers the metabolic rate of the heart muscle thereby preventing cell death during the ischemic period of time.

Physiology

Cardioplegic solution is the means by which the ischemic myocardium is protected from cell death. This is achieved by reducing myocardial metabolism through a reduction in cardic work load and by the use of hypothermia.

Chemically, the high potassium concentration present in most cardioplegic solutions decreases the membrane resting potential of cardiac cells. The normal resting potential of ventricular myocytes is approximately -90mV. When extracellular cardioplegia displaces blood surrounding myocytes, the cell depolarizes more readily, i.e. at a less negative membrane potential. The depolarization causes contraction, intracellular calcium is sequestered by the sarcoplasmic reticulum via ATP dependent Ca++ pumps, and the cell relaxes (diastole). However the high potassium concentration of the cardioplegia extracellular prevents repolarization. The resting potential on ventricular myocardium is about -84mV at a extracellular K+ of 5.4 mmol/l. Raising the K+ to 16.2 mmol/l raises the resting potential to -60mV, a level at which muscle fibers are inexcitable to ordinary stimuli. When the resting potential approaches -50mV, sodium channels are inactivated resulting in in a diastolic arrest of cardiac activity. Membrane inactivation gates, or **h** Na+ gates, are voltage dependent. The less negative the membrane voltage, the more **h** gates that tend to close. If partial depolarization is produced by a gradual process such as elevating the level of extracellular K+, then the gates have ample time to close and thereby inactivate some of the Na+ channels. When the cell is partially depolarized, many of the Na+ channels are already inactivated, and only a fraction of these channels are available to conduct the inward Na+ current during phase 0 depolarization.

Interestingly the use of two other cations, Na+ and Ca++, also can be used to arrest the heart. By removing extracellular Na+ from perfusate the heart will not beat because the action potential is dependent upon extracellular Na ions. However the removal of Na+ does not alter the resting membrane potential of the cell. Likewise removal of extracellular Ca++ results in a decreased contractile force, and eventual arrest in diastole. An example of a low [K+] low [Na+] solution is HTK (Histidine-tryptophan-ketoglutarate). Conversely increasing extracellular Ca++ enhances contractile force. Elevating Ca++ to a high enough level results in cardiac arrest in systole. This unfortunate irreversible event is referred to as "stone-heart" or rigor.

Hypothermia is the other key component of most cardioplegic strategies. It is employed as another means to further lower myocardial metabolism during periods of ischemia. The Van't Hoff equation allow calculation that oxygen consumption will drop by 50% for every 10°C reduction in temperature. This Q10 (temperature coefficient) effect combined with a chemical cardiac arrest can reduce myocardial oxygen consumption (MV02) by 97%.

and then ***cold cardioplegia*** is given into the heart through the aortic root. Blood supply to the heart arises from the aorta root through coronary arteries. is in diastole thus ensuring that the heart does not use up the valuable energy stores (ATP- adenosine triphosphate) .

Blood is commonly added to this solution in varying amounts from 0-100%. Blood acts a buffer and also supplies nutrients to the heart during ischemia.

Once the procedure on the heart vessels (CABG- coronary artery bypass grafting) or inside the heart like valve replacement or correction of congenital heart defect etc. is over the cross-clamp is removed and the isolation of the heart is terminated so that normal blood supply to the heart is restored and the heart starts beating again.

The cold fluid (usually at 4 °C) ensures that the heart cools down to an approximate temperature of around 15–20 °C thus slowing down the metabolism of the heart and thereby preventing damage to the heart muscle. This is further augmented by the cardioplegia component which is high in potassium

When solution is introduced into the aortic root (with an aortic cross-clamp on the distal aorta to limit systemic circulation), this is called antegrade cardioplegia. When introduced into the coronary sinus it is called retrograde cardioplegia.

Ingredients

- St. Thomas' Solution
- Bretschneider Solution
- Univ of Wisconson Solution
- Custodiol HTK
- Celsior

There are many cardioplegic solutions of varying additives. The only vital additive in most solutions is potassium chloride in a 20-30 mmol/L concentration range. Other additives such as mannitol, sodium bicarbonate, procaine, et cetera, are of secondary importance. Below are several generic crystalloid cardioplegia solutions.

Induction

Sodium Bicarbonate 8.4% 31.25 mEq
Potassium Chloride 35 mEq
Mannitol 25% 3.75 g
Isolyte-S pH 7.4 133 mL

Add prior to use with induction:
Lidocaine 2% 62.5 mg
Nitroglycerin 500 mcg
Albumin 25% 12.5 g

Reperfusate

Mannitol 20% 37.5 mL
Isolyte-S pH 7.4 291.75 mL
CPD 30 mL
MSA/MSG 0.92M 70 mL

Add prior to use:
Sodium bicarbonate 62.5 mEq (62.5 mL)
Lidocaine 2% 125 mg (6.2 mL)
Nitroglycerin 1000 mcg (0.2 mL)

Ringers

Ringer's Solution 1000 mL
Potassium Chloride 20 mEq
Magnesium Chloride 32 mEq
Mannitol 20% 10 g
Sodium Bicarbonate 8.4% 6.5 mEq

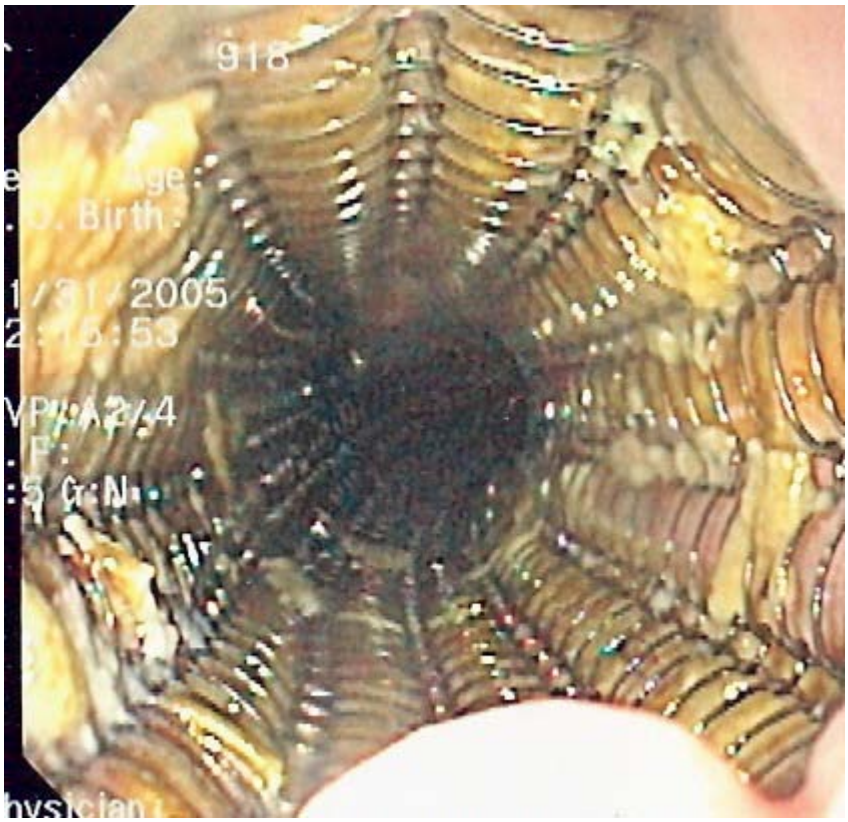
Add prior to use:
Procaine 10% 2.73 mL

Maintenance

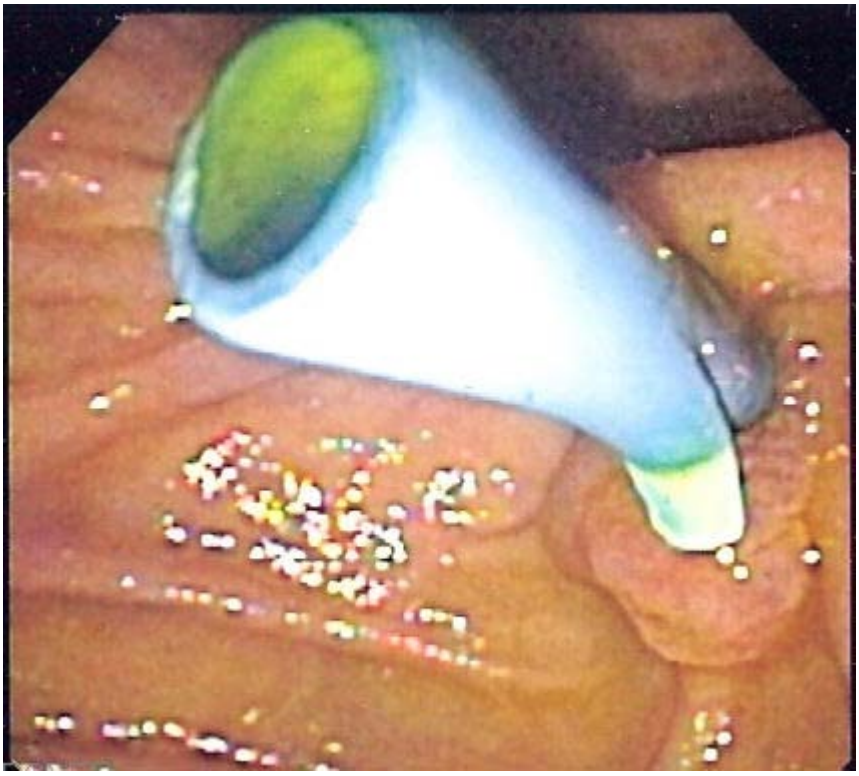
Sodium Bicarbonate 8.4% 125 mEq
Potassium Chloride 25 mEq
Mannitol 25% 15 g
Isolyte-S pH 7.4 802 mL

Chapter 15

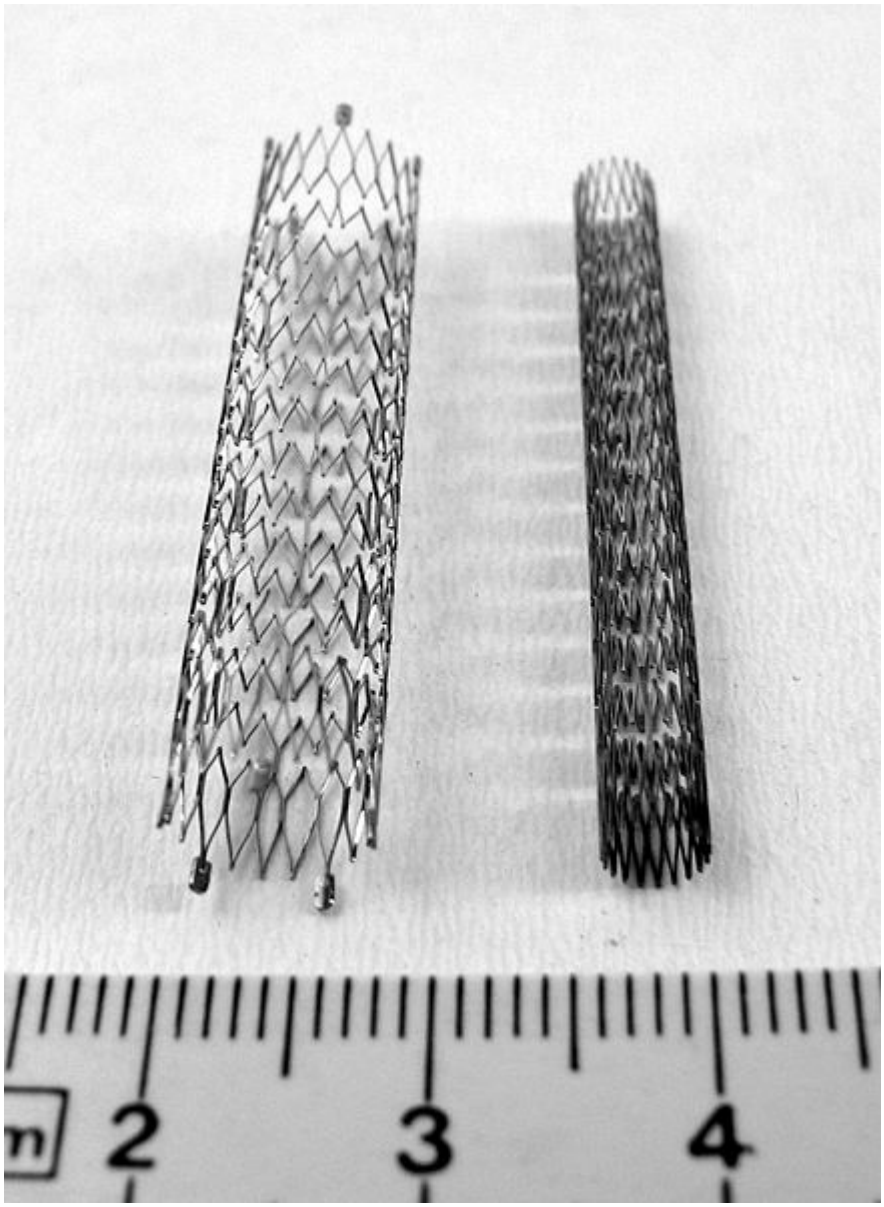
Stent



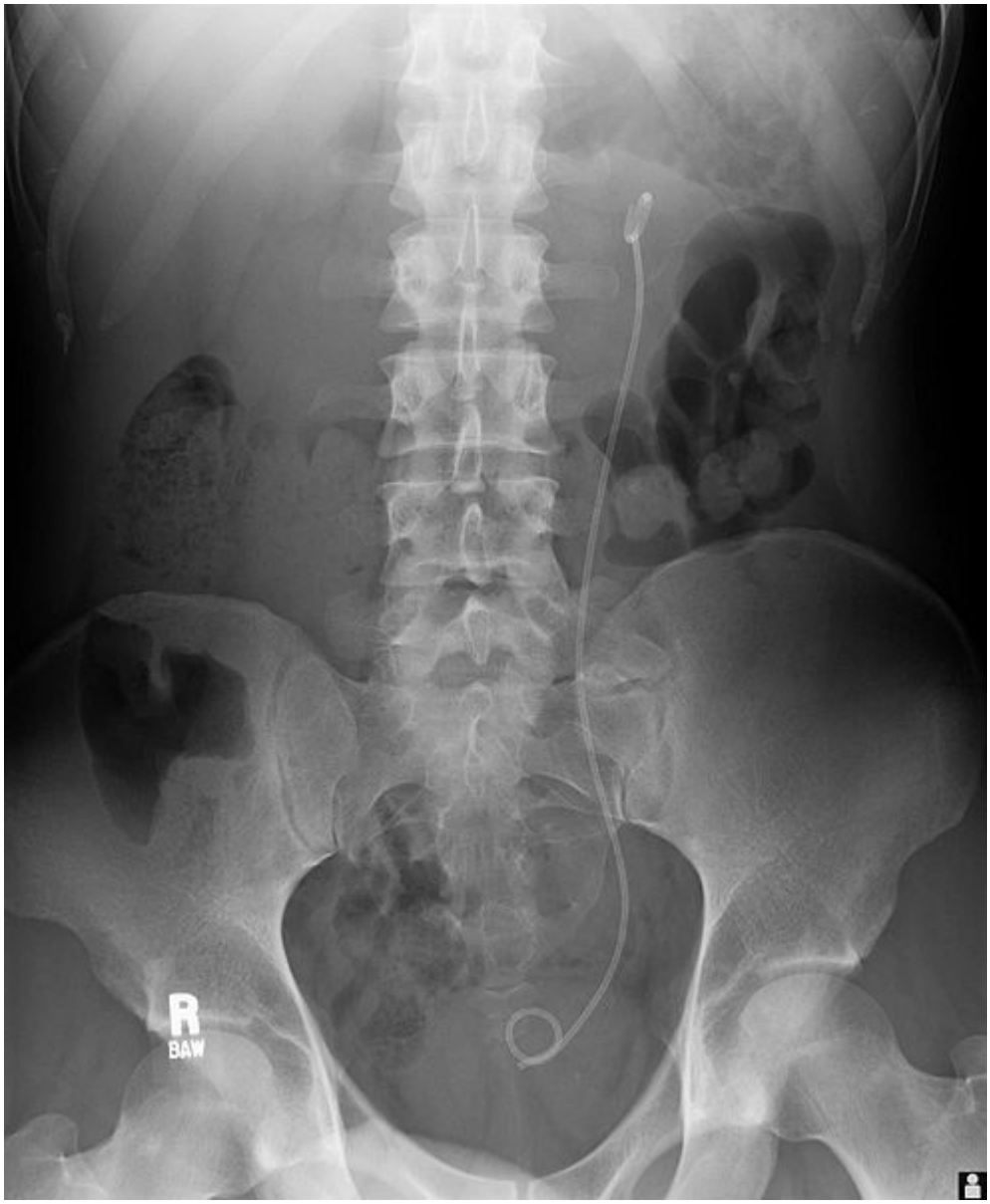
Endoscopic image of self-expanding metallic stent in an esophagus, which was used to palliatively treat esophageal cancer.



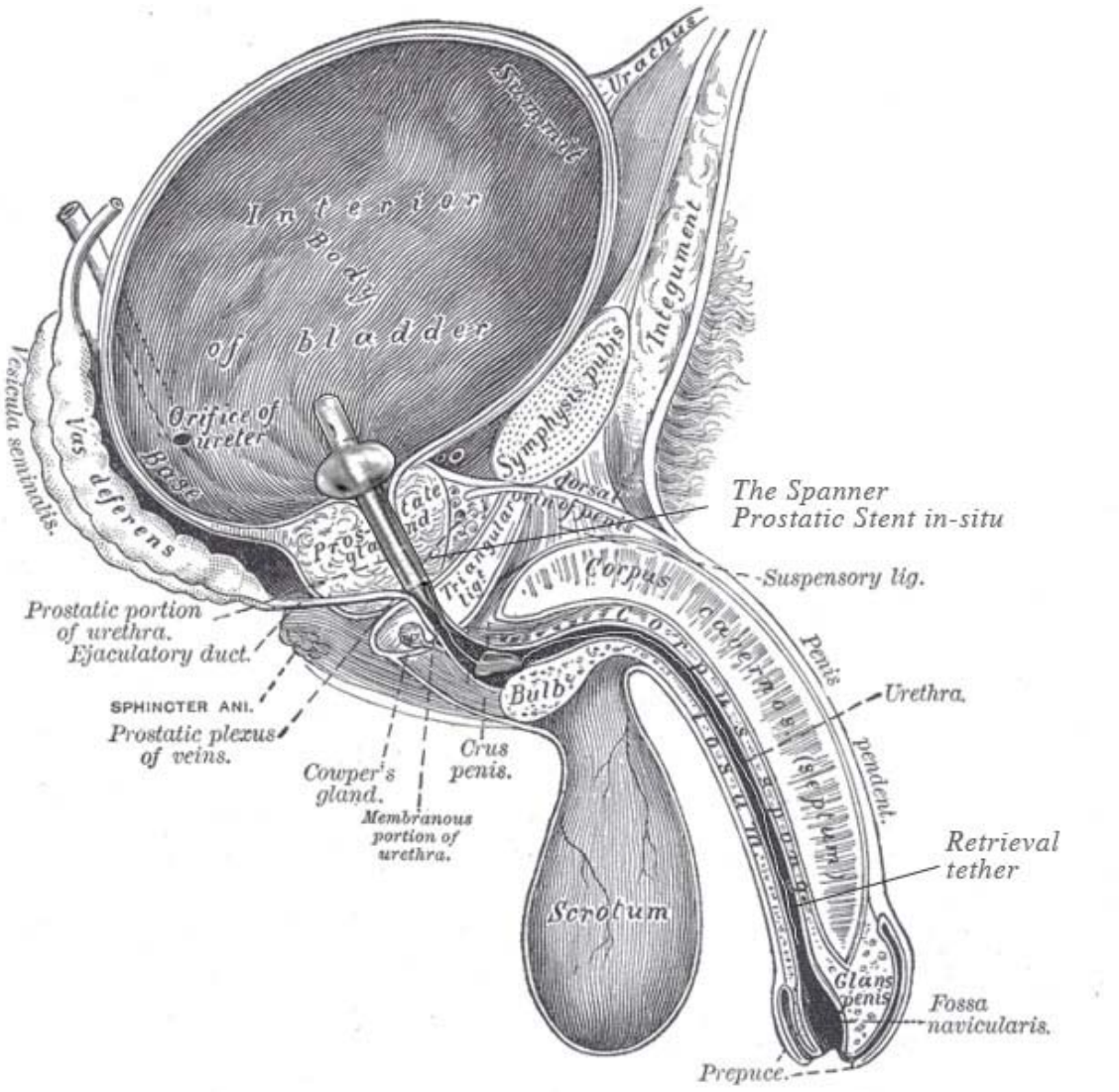
Endoscopic image of biliary stent seen protruding from ampulla of Vater at the time of duodenoscopy



Stents for peripheral vessels



Example of a uretal stent used to alleviate hydronephrosis of the kidney



Example of a stent / catheter used in the prostate to treat an enlarged prostate and help obstructed urination

Example of a Stent used in an Endovascular aneurysm repair

In medicine, a **stent** is an artificial 'tube' inserted into a natural passage/conduit in the body to prevent, or counteract, a disease-induced, localized flow constriction. The term may also refer to a tube used to temporarily hold such a natural conduit open to allow access for surgery.

Etymology

The origin of the word *stent* remains unsettled. The verb *stenting* was used for centuries for the process of stiffening garments (a usage long obsolete, per the *Oxford English Dictionary*) and some believe this to be the origin. Others attribute the noun *stent* to Jan F. Esser, a Dutch plastic surgeon who in 1916 used the word to describe a dental

impression compound invented in 1856 by the English dentist Charles Stent (1807–1885), which Esser employed to craft a form for facial reconstruction. The full account is described in the *Journal of the History of Dentistry*. According to the author, from the use of Stent's compound as support for facial tissues grew the eventual use of stent to open various bodily structures. Worth noting though is that the first "stents" used in medical practice were initially called "Wallstents".

Types of stent

Coronary arteries

The most widely known stent use is in the coronary arteries with a bare-metal stent, a drug-eluting stent or occasionally a covered stent.

Coronary stents are placed during a percutaneous coronary intervention procedure, also known as an angioplasty.

Urinary tract

Ureteral stents are used to ensure the patency of a ureter, which may be compromised, for example, by a kidney stone. This method is sometimes used as a temporary measure, to prevent damage to a blocked kidney, until a procedure to remove the stone can be performed. Indwelling times of 12 months or longer are indicated to hold ureters open, which are compressed by tumors in the neighbourhood of the ureter or by tumors of the ureter itself. In many cases these tumors are inoperable and the stents are used to ensure drainage of urine through the ureter. If drainage is compromised for longer periods, the kidney can be damaged. The main complications with ureteral stents are dislocation, infection and blockage by encrustation. Recently stents with coatings (e.g. heparin) were approved to reduce infection, encrustation and therefore stent exchanges.

Urethral/Prostatic stent

A urethral or Prostatic stent might be needed if a man is unable to urinate. Often this situation occurs when an enlarged prostate pushes against the urethra, blocking the flow of urine. The placement of a stent can open the obstruction. Recent scientific breakthroughs have now meant using a Prostatic stent is a viable method of dis-obstructing the prostate. Stents can be temporary or permanent. Temporary stents can be placed in the Urologist's office in a manner similar to placing a Foley catheter taking less than 10 minutes and using only Lidocaine jelly. Clinical results show the temporary stent is effective and well tolerated. Permanent stents are mostly placed on an outpatient basis under local or spinal anesthesia and usually take about 30 minutes. Clinical results show occurrences of migration, painful wearing and difficult removal.

Prostatic/sphinchter stents can be used for draining the bladder in patient with urethra obstruction, or nerve damages to the nerves controlling the bladder. Stents could be placed in the prostate, across the outer and inner sphinchter to achieve a good drainage of

the bladder. The patient will need to use diapers, incontinence pants/plastic pants, or a external collection device (external catheter) to collect the urine.

Vascular

Stents are used in a variety of vessels aside from the coronary arteries.

Peripheral vascular

Stents may be used as a component of peripheral artery angioplasty.

Stent graft

A **stent graft** is a tubular device, which is composed of special fabric supported by a rigid structure, usually metal. The rigid structure is called a stent. An average stent on its own has no covering, and therefore is usually just a metal mesh. Although there are many types of stent, these stents are used mainly for vascular intervention.

The device is used primarily in endovascular surgery. Stent grafts are used to support weak points in arteries, such a point commonly known as an aneurysm. Stent grafts are most commonly used in the repair of an abdominal aortic aneurysm, in a procedure called an EVAR. The theory behind the procedure is that once in place inside the aorta, the stent graft acts as a false lumen for blood to travel through, instead of flowing into the aneurysm sack.

Other

- CHD Stent
- Esophageal stent
- Duodenal Stent
- Colonic Stent
- Biliary Stent
- Pancreatic Stent