Renewed complaints in patients after coronary artery bypass grafting

Bijlsma, Pieter

Renewed Complaints in Patients after Coronary Artery Bypass Grafting: Coronary Angiographic Findings

A radiological approach based on Computer Data Analysis

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met een samenvatting in het Nederlands.

Stellingen

1. Het gebruik van clips in de coronaire bypass chirurgie leidt tot een significant lagere graft patency en dient daardoor met klem te worden ontraden.

2. Bij het vervaardingen van een goed te beoordelen coronairangiogram is het gebruik van een Aluminium filter, aan de röntgenbuiszijde, vooral in de RAO-projectie, een onmisbaar onderdeel van de technische installatie.

3. Het pendelend contrastverloop, getij-fenomeen genoemd, is in een coronair arterie waaraan een bypass is gehecht, alleen zichtbaar indien de betreffende coronairarterie nog in open verbinding staat met de aorta.

4. Indien de, peroperatief, gemeten stroomsnelheid van het bloed in een graft kleiner is dan 40 ml/min, blijkt het aantal afgesloten grafts tweemaal zo groot te zijn.

5. De graft patency van IMA grafts is hoger dan die van veneuze grafts.

6. Bij pre-operatief aangetoonde akinesie van de apex cordis blijkt tweederde der grafts later ernstige of totale stenosering te vertonen.

7. Van de pre-operatief vastgestelde stenosen, kleiner dan 25%, blijkt, post-operatief, tweederde groter dan 50% te zijn geworden.

8. Het catheteriseren van een veneuze bypass kan aanleiding geven tot een spasme.

9. Bezuinigen op de Dotter methode bij de behandeling van vaatvernauwingen is patient-onvriendelijk en leidt tot kostenstijging.

10. Totale afsluiting van een iliacaal of femoropopliteaal traject is geen contra-indicatie voor recanalisatie en dilatatie.

11. Voor het aantonen van intra-articulaire afwijkingen van het kniegewricht geniet dubbelcontrast-arthrografie de voorkeur boven MRI.

12. Polly Grey, de mascotte en het geheime wapen van het F-16 322 squadron te Leeuwarden, zal niet bij de onderhandelingen tot wederzijdse vermindering van kernwapens worden betrokken.

13. Dynamische computertomografie met behulp van de ultrafast scanner, de cine CT genoemd, geeft meer en snellere patiënteninformatie dan de conventionele computertomografie en draagt daardoor bij tot een beter inzicht in de dynamiek van ziekteprocessen.

14. Percutane transluminale angioplastiek - de Dotter methode - is de gouden standaard bij het beoordelen van andere vasculaire interventie methoden.

15. Bij de behandeling van een verkalkte afsluiting in het femoropopliteale traject is het gebruik van laser angioplasty de eerste keuze van behandeling.

Bergen (NH), 6 april 1988 — P. Bijlsma

RIJKSUNIVERSITEIT GRONINGEN

Renewed Complaints in Patients after Coronary Artery Bypass Grafting: Coronary Angiographic Findings

A radiological approach based on Computer Data Analysis

PROEFSCHRIFT

ter verkrijging van het doctoraat
in de Geneeskunde
aan de Rijksuniversiteit Groningen
op gezag van de Rector Magnificus Dr. S.K. Kuipers
in het openbaar te verdedigen op Woensdag 6 april 1988
des namiddags te 4.00 uur

door

Pieter Bijlsma

geboren te Leeuwarden

1988
Drukkerij van Ketel te Schagen

Eerste promotor : Prof. dr. C.J.P. Thijn
Tweede promotor : Prof. dr. C.B.A.J. Puylaert

Eerste referent : Dr. P.K. Blanksma
Tweede referent : Dr. G.H.M. Landman

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Aan Ank

Aan Roald
Igor
Mascha

Voorwoord

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CONTENTS

RENEWED COMPLAINTS IN PATIENTS AFTER CORONARY ARTERY BYPASS GRAFTING;
CORONARY ANGIOGRAPHIC FINDINGS.

A radiological approach based on computer data analysis.

Chapter 1.

Introduction and objectives to the study.

The rapid development of coronary artery surgery has partly been made possible by improvements in the field of coronary angiography which is still the "golden standard".
As a result, it is possible to make a medically appropriate selection of the patients who have to undergo a coronary artery bypass grafting operation (CABG) or a percutaneous coronary angioplasty (PTCA).
In addition to the diagnosis of coronary arterial abnormalities, which are regarded as the principal cause of angina pectoris and the assesment of the left ventricle function, more and more coronary angiographic examinations are being carried out in order to evaluate the results of coronary artery surgery and PTCA.

The evaluation of the CABG results has led to the present study.

Several studies have been carried out elsewhere on a mixed population of patients, both with and without complaints, in which the survival studies are central. The ideal approach would be to compare CABG patients without complaints with CABG patients who still do have complaints or do have a recurrence of angina pectoris. Since the post-operative coronary angiographic examination is not entirely without risk, at the time of this study this examination has been carried out mainly on patients with complaints. Our group of patients was classified in accordance with the categories indicated by the New York Heart Association (NYHA).

In this study 303 CABG patients who returned with complaints were examined. For this purpose, both the pre-operative and the post-operative coronary angiograms were compared with each other, as were the pre-operative and the post-operative left ventriculograms.

The first objective of this study was to investigate whether changes have occurred in the native coronary arteries which have been bypassed as well as in the grafts used.

The progression of coronary artery pathology is therefore an important part of this study.
The graft patency evaluation is closely related to the previous study and has been carried out intensively. Patency rate, related to the different types of grafts; time-patency relation; patency rate, related to the various coronary

artery segments to which the grafts have been stitched; patency rate versus NYHA classification.
Left ventricular function evaluation, both pre- and post operative, has been carried out as well.

The second objective was to investigate what influences are of importance in relation to the different operation techniques as well as in relation to the graft patency for both these techniques.
In the 303 patients of this study two different operation techniques have been used, namely the operation technique in which the lateral branches of the venous bypass are clamped off with metallic clips and the operation technique in which these branches have been tied off with suture material.

The third objective in this study was to investigate the availability of computer date analysis in the classification of the abnormalities of coronary arteries, grafts and left ventricular function.
An appropriate program was especially designed for this study.
An immense number of figures became available by using computer data analysis. Out of these figures some examples have been made to demonstrate the usefullness of the computer analysis.

The fourth objective was to investigate the left ventricular function, postoperatively. In the literature investigation of both the coronary arteries and left ventricle function is often combined (Chesebro et al./Campeau et al.) in coronary artery disease.

A few chapters are devoted to aspects of importance for coronary angiography, anatomy of the coronary arteries, some haemodynamic aspects of the coronary artery circulation, the method of coronary angiographic interpretation, technical aspects of coronary angiography and radiation protection. a more detailed description is also given of the use of contrast media in coronary angiography and the influence these agents can give to the images. In this way I composed a short manual for the radiologists interested in cardiovascular radiology.

Abbreviations.

CAD	=	coronary artery disease.
CAG	=	coronary arteriography.
CABG	=	Coronary Artery Bypass Grafting.
LCA	=	Left Coronary Artery.
RCA	=	Right Coronary Artery.
LM	=	Left Main (=trunk of LCA).
LAD	=	Left Anterior Descending artery.
CX	=	Circumflex artery.
MO	=	Margo Obtuse branch.
D	=	Diagonal branch.
IM	=	Inter Mediate branch.
S	=	Septal branch.
SN	=	Sinus Nodal branch.
CP	=	Conus Pulmonal branch.
AM	=	Acute Marginal branch.
RPD	=	Right Posterior Descending branch.
AVN	=	Atrial Ventricular Node branch.
RA	=	Right Atrial branch.
AP	=	Antero-Posterior projection.
RAO	=	Right Anterior Oblique.
LAO	=	Left Anterior Oblique.
LV	=	Left Ventricle.
LACx	=	Left atrial circumflex branch.
PL	=	Posterolateral branch.
CXPL	=	Posterolateral branch of the circumflex.

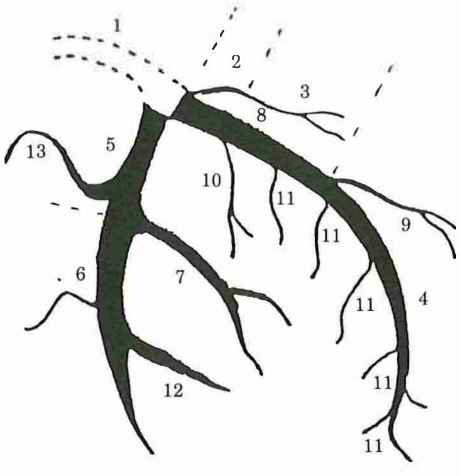


Fig.2.1 Left coronary artery
RAO projection at 30°

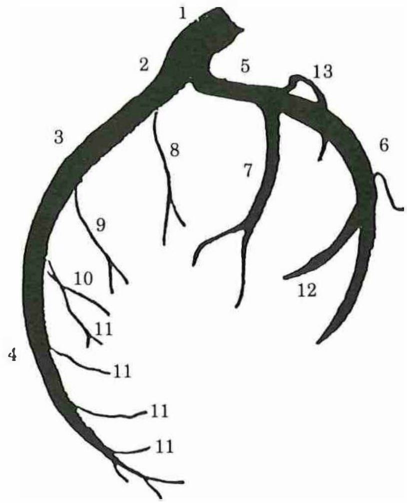


Fig.2.2 Left coronary artery
Left lateral projection

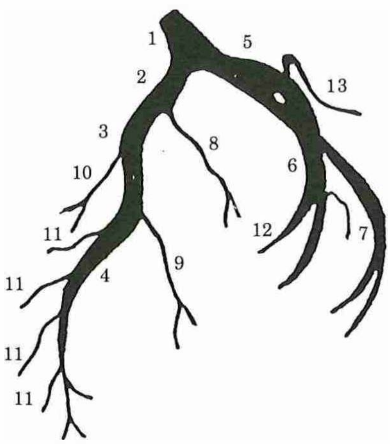


Fig.2.3 Left coronary artery
Antero-Post projection

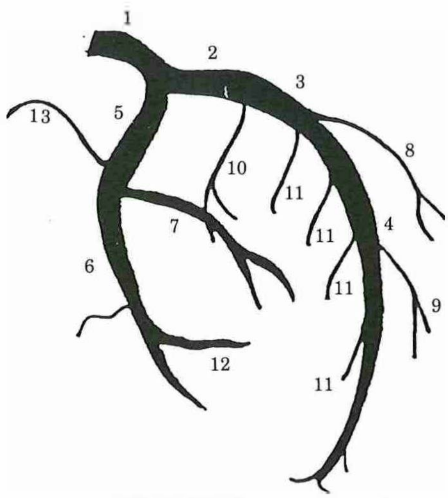


Fig.2.4 Left coronary artery
LAO projection at 60°

1. Left Main
2. Proximal LAD
3. Mid LAD
4. Distal LAD
5. Proximal circumflex artery
6. Distal circumflex artery
7. Margo obtuse artery
8. First diagonal artery
9. Second diagonal artery
10. First septal artery
11. Septal arteries
12. Postero-lateral artery

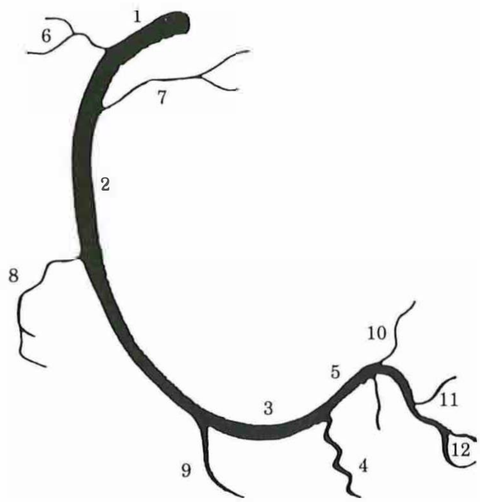


Fig.2.5 Right coronary artery
LAO projection at 45°
Caudo-cranial 15°

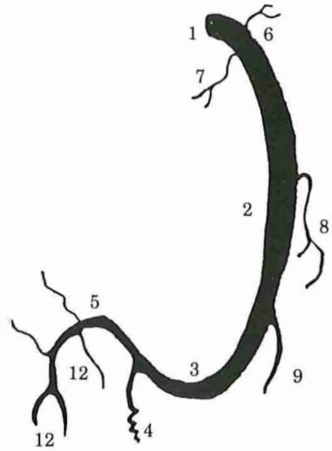


Fig.2.6 Right coronary artery
RAO at 120°,
Cranio-caudal 10°

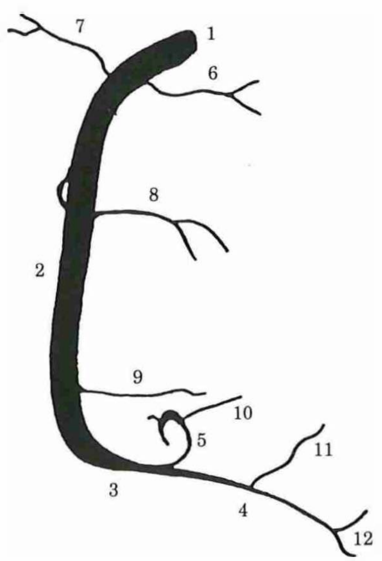


Fig.2.7 Right coronary artery
RAO projection at 45°

Right coronary artery.

1. Proximal right coronary artery
2. Mid part right coronary artery
3. Distal part right coronary artery
4. Postero descending artery
5. Retroventricular artery
6. Conus pulmonal branch
7. Sinus node branch
8. Right ventricular artery
9. Right marginal artery
10. Atrio-Ventricular artery
11. Septal arteries
12. Diaphragmatic arteries

Chapter 2

Anatomy and Pathology of the coronary arteries

A good knowledge of the anatomy of the coronary arteries is essential for being able to recognise and interpret coronary angiograms. An excellent description of the anatomy and its many variations has been given by James (1961), Gensini (1967) and Ludwig (1969). The coronary system consists of two large vessels, the right and left coronary arteries, which divide just above the aortic valves. Sometimes a small branch is seen which branches off close to the origin of the right coronary artery (conus branch).

2.1. Normal anatomy

2.1.1. RIGHT CORONARY ARTERY (RCA)

The RCA arises from the right aortic sinus (Valsalva). The ostium normally lies in the centre between two commissures of the right valve on the right side of the aorta. The artery runs over a short distance ventrally to the right and then passes between the right auricle and the pulmonary cone, arches here caudally through the right atrioventricular sulcus to the acute marginal branch and then arches dorsally to enter the crux via the sulcus. The RCA generally runs over a shorter or longer distance through the sulcus posteriorly towards the left.

Side branches

2.1.1.1. Conus pulmonal branch (CP)

This branch can divide off separately from the aorta. In the literature the presence of a separate ostium is described in varying percentages (James, Schlesinger - 50%, Halbertsma - 33%).
If the conus pulmonal branch divides from the RCA it runs ventrally and left to the conus pulmonal where it forms an anastomosis with the branch arising from the proximal part of the left anterior descending artery (LAD). If there is an obstruction in the proximal part of the RCA or the LAD this can result in a collateral connection which is sometimes called the ring of Vieussens.

2.1.1.2. Sinus nodal branch (SN)

The sinus nodal branch arises just below the path of the conus pulmonal branch. Gross (1921) found that in 60% of the cases the sinus node is supplied with blood by a branch from the RCA and in 40% by a branch from the left coronary artery (LCA). Sometimes there is a solitary origin of the sinus nodal branch from the aorta.

2.1.1.3. Right ventricular branch (RV)

The medial part of the RCA shows a division of a few branches towards the right ventricular wall, with the right ventricular branch generally being seen half way and the acute marginal branch more distally.

2.1.1.4. Atrioventricular node branch (AVN)

This branch supplies the atrioventricular node (Tawara's node). The artery divides at the crux and continues into the septum atriorum beside the base of the heart in the ventral direction (James - 1967).

2.1.1.5. Right posterior descending branch (RPD)

This branch occurs in various forms, sometimes in the terminal part of the RCA and sometimes as a side branch. Most authors report that in some 90% of the cases this branch divides from the RCA at the distal arch and continues into the posterior interventricular sulcus to the apex. A number of small vessels branch off from the RPD to the septum ventriculorum. Various anatomical variations of the course of this branch are described in the literature. The crux can be recognised by the course of the vessel. The AVN branch and the RPD divide here. The RCA is dominant (75% of the cases) if it continues to run beyond the crux, through the AV groove on the left. If the crux is supplied by the left coronary artery, the left coronary artery is dominant (10%). If both end at the crux the system is balanced (15%).

2.1.1.6. Facies diaphragmatica branches of the left ventricular wall

These run in the direction of the apex and vary in number.

2.1.1.7. Atrial branches

These are generally small and sometimes consist of three, four or five branches (Gross). There are often anastomoses with atrial branches from the LCA.

2.1.2. LEFT CORONARY ARTERY (LCA)

This artery arises from the left aortic sinus (Valsalva), in the centre between the two commissures, often with a slight ventral or dorsal deviation. The majority of the left coronary arteries arise from one ostium. Occasionally, two ostia are seen, the circumflex artery then arising independently from the aorta. The trunk of the left coronary artery runs slightly leftwards and frontally, then slightly caudally below the left auricle of the heart to the zone where the left atrioventricular sulcus and the pulmonary artery meet. Here the trunk divides into the left anterior descending branch and the circumflex artery. The bifurcation in the LAD runs through the anterior interventricular sulcus. The circumflex branch runs through the left atrioventricular groove and lies below the left auricle of the heart. Although the bifurcation is seen in some of the cases, a trifurcation is seen instead of a bifurcation fairly frequently, the branch arising between the LAD and the circumflex artery is then being called the intermediate branch. (fig. 2.8).

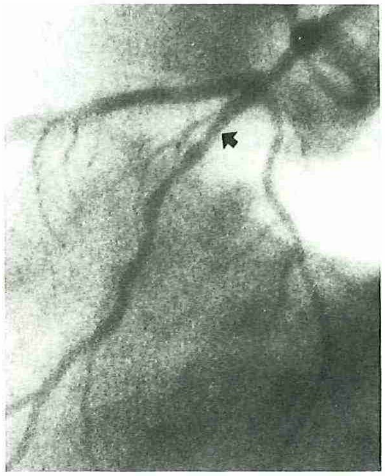


Fig.2.8 Intermediate branch

2.1.2.1. Left Anterior Descending artery (LAD)

In the coronary system as a whole, this artery is the most constant in its origin and course. The proximal part arches slightly round the pulmonary artery and then runs through the anterior interventricular sulcus to the apex. The distal part runs just to or over the apex and then arches round the facies diaphragmatica to terminate in the posterior interventricular sulcus. An anastomosis is often seen between the LAD and the RPD, which is important if one of the large vessels displays a stenosis, resulting in an important collateral connection.

2.1.2.1.1. Diagonal branches (D)

The relative importance of the diagonal branches is subject to variations. Sometimes the first diagonal branch is the most-important, sometimes the second diagonal branch is important. Sometimes there are several equally important branches. When studying coronary angiograms the parallel movement of the diagonal branches with the margo obtuse branch is an unmistakable point of identification.
In every case the LAD moves in contrary motion to the margo obtuse branch, so that a scissor-like aspect is seen. This phenomenon too, applies in every case and is a very important point of recognition for the LAD and the margo obtuse branch.

2.1.2.1.2. Septal branches

A number of vessels branch off from the LAD at an angle of ap-

approximately 90° and run directly to the septum. These are termed the septal branches. The first septal branch is generally fairly large and a number of side branches are seen which can supply the major part of the septum.
These branches frequently anastomose with the side branches of the RPD. If there is stenosis of one of the large vessels this can result in the formation of an important collateral connection.

2.1.2.2. Circumflex artery (CX)

This artery branches off at a fairly sharp angle from the trunk of the left coronary artery and runs through the left atrioventricular sulcus, generally leaving the sulcus before or just after the margo obtuse branch. The branch through the atrioventricular groove, behind the division of a large branch over the margo obtuse, is generally small or may be entirely absent. Sometimes this branch can anastomose with the right coronary artery, so that in the event of a stenosis of one of the large vessels a good collateral connection can again be formed. A number of side branches arise from the circumflex artery.

These areas are as follows:

2.1.2.2.1. The sinus nodal (SN) branch, as already described, divides off from the circumflex artery, in some 40% of the cases.

2.1.2.2.2. The left atrial circumflex (LACx) branch
This branch divides off from the proximal part and runs to the left atrium.

2.1.2.2.3. The margo obtuse branch (MO)
This branch is sometimes the only large side branch of the circumflex artery, but in a fairly large number of cases several small MO branches are seen which are then numbered respectively, from proximal to distal. In all cases, this marge obtuse branch displays a scissor-like movement with the LAD.

2.1.2.2.4. The postero-lateral (PL) branches divide off from the distal part of the circumflex artery and runs through the left atrioventricular groove. In approximately 10% of the cases a posterior descending branch also divides off from the circumflex artery and in the remaining cases this branch arises from the right coronary artery. Ludwig (1969) reports that in approximately 10% of the cases a branch also divides off from the circumflex artery towards the atrioventricular node.

2.2. Congenital abnormalities of the coronary arteries

Besides having a good knowledge of the anatomy of the coronary arteries it is also very important to recognize the congenital, anatomical variations in these arteries. In the literature, one regularly encounters case reports of an anatomical variant, in which respect it repeatedly transpires that these congenital variations are very rare. Page et al. (1974) found a percentage of 0.7% in an extensive study of coronary angiograms made in their clinic. In a study of 1,000 coronary angiograms Baltaxe and Wixson (1979) described congenital coronary vessel abnormalities in 0.9% of the cases.
They distinguish three groups of patients:

1. Patients who, besides displaying an abnormal course of the coronary vessel, also had other congenital abnormalities, including the tetralogy of Fallot (two patients).

2. Patients displaying valvular defects in addition to an abnormal course of the coronary vessel: mitral insufficiency, aortic stenosis or aortic insufficiency (four patients).

3. Patients with only an abnormal congenital coronary vessel variation without any further cardiac anomalies (three patients).

Disregarding group 3, in which only an abnormal course of the coronary arteries was seen, Baltaxe and Wixson (1979) stated that the figure for congenital anomalies is 0.3%.

2.2.1. VARIATIONS OBSERVED IN OUR DEPARTMENT

Eshchar Dwaswon et al. (1979) describe the occurance of congenital aneurysms. These coronary aneurysms are often multiple and it is striking to note how frequently they are associated with an aneurysm of the abdominal aorta.

2.2.1.1. Very rarely occurring variations

In studying over 7.000 coronary angiograms a number of very rarely occuring anatomical variants of the coronary arterial system were seen. In total, we found 14 patients in whom a congenital, abnormal coronary vessel anomaly was seen. In six patients we found the circumflex artery arising from the right sinus Valsalva, and in one of these patients an aortic stenosis had occured at a later age. Two patients displayed the RCA arising from the LCA. In one patient the LCA arose from the RCA. The conus pulmonal branch was seen arising separately from its own ostium in two patients and one patient displayed a left atrioventricular branch, together with the posterolateral branch of the circumflex (CXPL) branch from the right sinus Valsalva (Fig.2.9). In addition, one patient was seen in whom the right bronchial artery arose from the right sinus nodal branch. In a total of 7000 coronary angiograms it was found that the percentage of congenital coronary vessel anomalies was 0.2%, which corresponds reasonably well with the international literature (Baltaxe and Wixson - 1979).

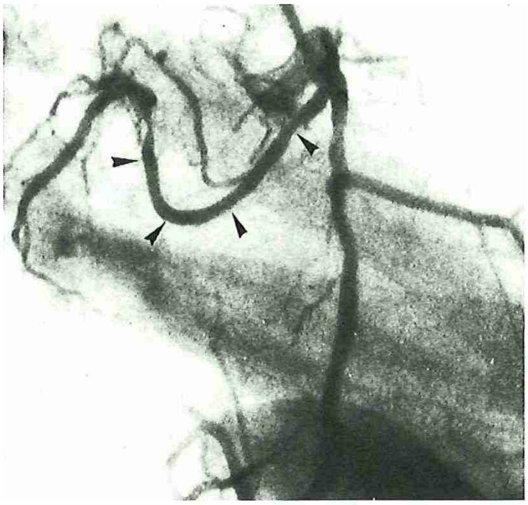


Fig.2.9 Circumflex artery arising from the right sinus Valsalva

2.2.1.2. More frequently occuring variations

It is important to know that abnormalities of more frequent occurrence and/or vessels with an abnormal path were also seen.

A trifurcation of the left coronary system was seen frequently. In these cases the LAD and the CX systems didn't arise from the main left, but from a third vessel which branches off from this division, namely the intermediate artery (IM branch). If the IM branch was present, according to Landman (1986) in nearly 50% of all coronary angiograms, one frequently saw that the first diagonal branch was either absent or was very gracile in aspect. Besides this trifurcation, a four-branch vessel was also occasionally seen arising from the main left.
The branch which then ran closest to the circumflex artery was termed the IM branch, while the branch which ran closer to the LAD was regarded as the first diagonal branch.

2.3. **Acquired variations**

2.3.1. ANEURYSMS

In some abnormal coronary angiograms an aneurysm is seen in the coronary artery, with a slight preferential localisation being observable proximally in the LAD, followed by the RCA. Daoud et al. (1963) found the opposite namely 1.4% in 694 obductions in which an aneurysm preference was seen for the RCA. Most aneurysms occur on the basis of arteriosclerosis.

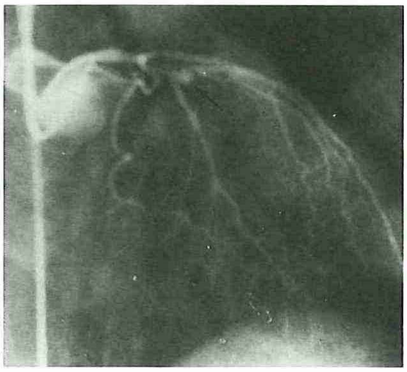


Fig. 2.10 Aneurysm in the LCA

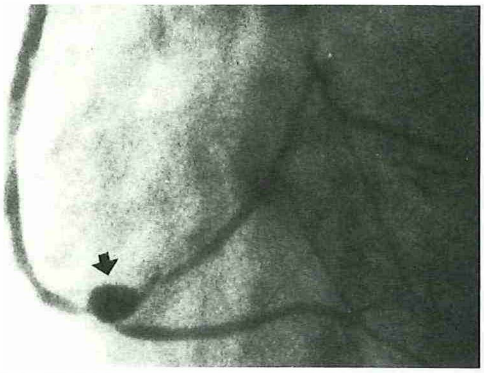


Fig. 2.11 Aneurysm in the RCA

2.3.2. SPASM

Sometimes a proximal constriction is observed in a coronary vessel at the start of selective catheterization, with a marked preference in selective catheterization of the RCA. Such a spasm is often induced by the catheter. When a spasm occurs during the coronary angiography procedure, catheterization should be temporarily interrupted, the catheter should be slightly withdrawn and nitroglycerine s.l. medication should be administered to the patient. After this, catheterization should be continued and the spasm virtually always disappears. A spasm in the main left of the LCA is extremely rare. Sometimes a spontaneous spasm is also seen. Prinzmetal et al. (1959) described this unusual form of angina pectoris at rest, now known as Prinzmetal angina.

2.3.3. BRIDGING

Myocardial bridging is a phenomenon in which an intramural part of a coronary vessel segment is narrowed during systole. During this systole a clearly reduced flow of contrast medium is seen, followed by a normal flow during diastole. This contrast movement is reminiscent of milking and in the international literature it is

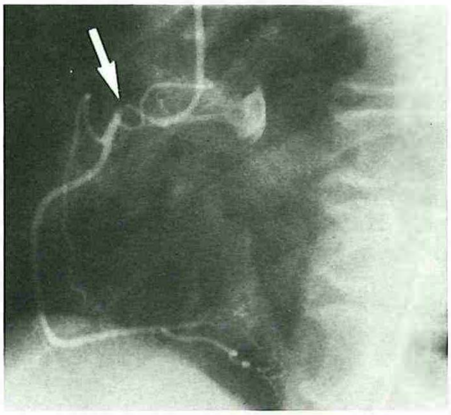


Fig. 2.12 Spasm proximal in the RCA

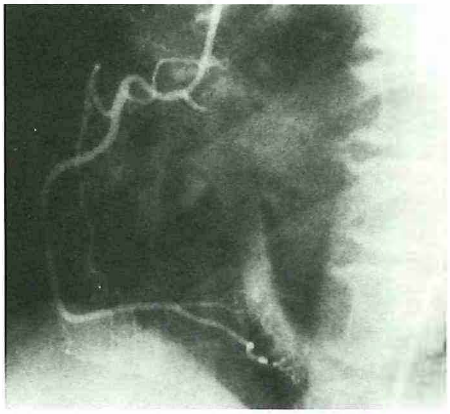


Fig. 2.13 Same RCA after catheter replacement and nitroglycerine medication

termed the milking phenomenon. This milking phenomenon has been described by various authors who have rightly pointed out that the importance of bridging was initially underestimated. Edwards (1956) describes a percentage of bridging in 5.3% of the cases, while Polacek (1951) records 85.7%, in which respect it must be pointed out that these latter figures are based on a postmortem study. During the study of coronary angiograms made in our clinic a percentage of 7.2% was found, which corresponds reasonably well with the figures of Edwards.

As mentioned above, the importance of bridging was initially underestimated since the coronary blood circulation mainly occurs in the diastole, so that during the systole this narrowing could not be expected to have any effect. Various publications by Faraqui et al. (1978), Ishimori (1979) and Bourassa (1976) do attach importance to this, in my view rightly so. In various publications they report that bridging, particularly of the LAD, can cause myocardial ischaemia, while bridging is also alleged to result in increased arteriosclerosis. International opinion about myocardial bridging is divided, but it is important to recognize this phenomenon when interpreting coronary angiograms.

2.3.4. TORTUOSITY

A very marked tortuos coronary artery system is seen in a great many coronary angiograms made in women. According to the present study, the occurrence of the tortuosity aspect of coronary arteries in over 80% of the women examined was normal. The tortuosity aspect of the coronary vessels in males was markedly lower (9.3%) and we regard this as a clear reason for using the term 'female tortuosity'. In radiodiagnostics it is well known that in the angiographic examination of other vessels, too, a marked tortuosity is seen in women, for instance of the uterine arteries. To what extent this is clinically significant is not clear. Perhaps the increase in size of the uterus during pregnancy, together with the increase of circulation blood supply has to do with this phenomenon?

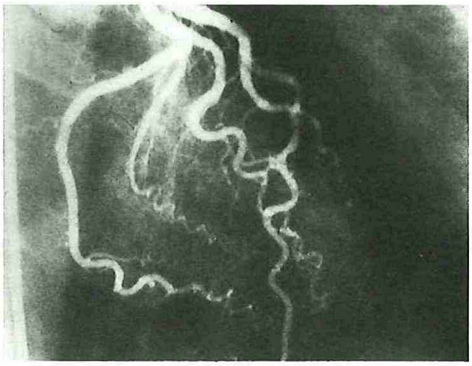


Fig. 2.14 female tortuosity of the LCA

It is well known that a number of patients with complaints which are suspected of coronary artery disease nevertheless display a normal coronary angiogram (20%). In addition, one sometimes sees very serious coronary artery abnormalitites in patients who present only slight complaints or have no complaints whatsoever. It also happens that patients with serious coronary artery abnormalities, even including closure of one of the coronary arteries, occasionally display a normal left ventricular angiogram, favoured by a good collateral system. In addition, the presence of a virtually akinetic left ventricle or a serious hypokinesis of the left ventricle accompanied by minimal coronary vessel abnormalities, is also possible.

2.4. Coronary artery disease

Degenerative disorders of the arterial wall are called arteriosclerosis. These abnormalities may be the reason for stenosis of the affected arteries and reduction of its functional capacity. Arteriosclerosis can be classified into: senile arteriosclerosis, Mönckeberg's sclerosis, arteriolosclerosis and atheromatosis (van Andel, 1979).
The abnormalities of the coronary arteries are mostly atherosclerotic lesions; for this reason only this type of arteriosclerosis will be discussed more extensively.

There are different theories regarding the origin and development of atherosclerotic lesions (Moskowitz-1950; Hueper-1929; Duguid-1949; Benditt and Benditt-1973; Ross-1976).
Most of these theories have a great deal of overlapping and are

based upon a - reaction to injury - of the vascular wall.
The details of these theories will not be discussed in this study. Most investigators (Goldstein, Brown-1980; Thomas, Lee-1979) probably subscribe this theory at the present time. However, there are widely different views regarding the type of injury, the target cell(s) and the nature of the response. In the early stages atherogenesis is characterized by excessive proliferation of intimal smooth cells and in the late stages by extensive necrosis with accumulation of lipid-rich necrotic debris.
Almost any type of injury (physical, immunological, chemical or other) to the intima results in some degree of proliferation of intimal smooth-muscle cells.

In general, the extent of proliferation and the eventual necrosis correlate positively with the serum cholesterol levels over a wide range. However, there are broad differences in response of the intimal cells among both men and experimental animals to the same cholesterol levels. Some of the different aspects will be shortly mentioned.
Studies of the earliest stages of atherogenesis in hyper-lipidemic young swine (Thomas et al., 1979) concentrated on intimal-cell masses in the abdominal aorta. These intimal-cell masses are mostly modified smooth-muscle cells and over the following 60 days of growth these smooth-muscle cells in the media increase about two fold. On a low-fat, low-cholesterol mashdiet, these cells do not increase significantly in number. If the swine are fed a hyper-lipidemic diet for 60 days, there is an overall threefold increase in intimal smooth-muscle cells. If this diet is continued for up to nearly a year, the fibrous plaques develop, with extensive accumulation of lipid-rich necrotic debris. These lipids seem to act as mitogens, with the intimal smooth-muscle cells as the target cells.

Another theory is based upon the fact that if an artery in an experimental animal is denuded of its endothelium, a large increase in the number of intimal smooth-muscle cells appears within a few days. These proliferate rapidly at first and eventually, after several months, appear to stop. Meanwhile extensive fibro-muscular plaques have developed. Without hyperlipidemia the process appears to be self-limited and necrosis seldom occurs (Ross et al., 1977). However, if the injury is repeated the process starts over and goes through another cycle.
Repeated injuries to small foci of endothelial cells can occur during life and the cumulative effect could result in atherosclerosis. In this theory hyperlipidemia is a secondary additive factor, with the primary emphasis on endothelial cell injury.

Murphy (1973) along with others have demonstrated in experimental animals that immunological injury to the endothelium can be an important factor in the atherogenesis, especially when coupled with a hyperlipidemic diet. However, there is no hard evidence at present to indicate that this is an important factor in man.

Intimal wall thickening and relative hypoxia have been proposed as possible reasons for the higher rates of death from atherosclerotic causes among cigarette smokers. Cigarette smoking is associated with some degree of carboxy hemoglobinemia which impairs, to a certain degree, the delivery of oxygen to the tissues. There seem to be some support for it from experimental animals (Wanstrup et al., 1969) but there is yet no convincing evidence that this mechanism is of importance in man.

Other theories regarding atherogenesis are those who deal with genetic factors, but virtually nothing is known about these proposed genetic factors at the present time.
Thrombosis may be important in the origin and growth of lesions and as acting as a secondary occlusive phenomenon. Duguid (1949) stimulated a great deal of investigation. However, no evidence has been found to indicate that thrombosis played a great role in the development of atherosclerotic lesions in man. Damage of DNA by cholesterol has also been mentioned as a cause of excessive births and deaths of cells, which might eventually result in atherosclerotic lesions in the intima, but at present there is insufficient evidence to evaluate this theory.
Summarizing, reaction to injury, seems to be the most important theorie at the present time.

Atheroma, thrombus and underlying haemorrhage cause luminal narrowing which can be concentric or eccentric. Minor irregularities of the vascular wall are an early manifestation of atherosclerosis, due to intima plaques.
The proliferation of the intima, which begins at birth, is not considered abnormal until the thickness of the intima is greater than that of the media. As mentioned above, the thickened intima is composed predominantly of collagen and elastic fibres but also contains smooth-muscle cells that may be lipid-filled.
The plaques occur irregularly along the length of the vessels, but frequently in more pronounced form proximally. Atherosclerosis may give different sorts of manifestations, such as: a filling defect - stenosis - diffuse narrowing - aneurysm - dilatation - ulceration - calcification.

2.5. Some haemodynamic aspects related to the progression of stenotic lesions in the coronary artery circulation

It seems appropriate to vizualize the coronary-vascular tree as being composed of large and small vessels. Coronary blood flow is determined by two major components of coronary vascular resistance, the extravascular component and a vasomotor component, respectively.

a. Extravascular component
During a normal cardiac cycle, myocardial blood flow is determined by the coronary vascular resistance, which in turn is dependent on coronary vasomotor tone and the extravascular compression generated by the ventricles. The pressure within the cardiac muscle increases in proportion to intra-ventricular pressure. Myocardial compression is minimal in the epicardial vessels and greatest in the subendothelial vessels. The extravascular component of coronary vascular resistance compresses the vessels most during systole and least during diastole. This extravascular compressional factor is more likely to affect the impedance to blood flow of the resistance vessels, particularly in the subendocardial regions (small arteries and arterioles), than conductance vessels (large epicardial arteries).

b. Vasomotor component
A vasomotor component is produced by the action and humoral stimulation of the vascular smooth muscle. Vagal cholinergic excitation leads to vasodilatation; sympathetic adrenergic activation may lead to either constriction or dilatation.
The coronary arteries vary in their composition and content of alpha-and-beta-adrenergic receptors depending on the size and diameter of the arterial segment examined. The alpha-adrenergic receptors seems to play an important constrictor role in the large coronary arteries. Coronary arteriolar tone is regulated primarily by the metabolic requirements of the myocardium (an increase in the myocardial oxygen consumtion causes coronary vasodilatation). Under normal conditions, large coronary arteries seem to play a small role in the regulation of coronary blood flow. Progressive ischemia produced by progressive atherosclerosis of large vessels causes an accumulation of vaso-active metabolites at the local microvascular level which produces vasodilatation and a reduction in the coronary circulatory reserve.

As atherosclerosis continues, the ability for the small coronary vessels to compensate for the reduction of blood flow through the large arteries is exceeded. The precapillary arterioles are dilated maximally. If, under these conditions, myocardial demand increases, blood flow can only be increased by increasing the pressure gradient or dilating the large coronary arteries. The strength of the blood flow depends on the differences in arteriovenous pressure, divided by the resistance, in which respect the arteriovenous pressure gradient is the difference between the pressure in the ascending aorta and in the coronary sinus which drains into the right atrium. The reduction of the radius in the coronary artery results in an increase in resistance which works to the fourth power.

A stenotic lesion can lead to the occurrence of eddies, particularly during the systole. In the coronary vascular system filling occurs during the diastole. Now, if via the filling of a graft blood flows from this graft into the coronary artery, mainly during the stystole, we often see a retrograde flow in the coronary arteries during this period. During the diastole, this retrograde flow is again forced distally, as a result of which blood is seen travelling to and fro in this area. (Fig.2.15-2.20).

This phenomenon which we called the tide phenomenon (Fig.2.21) is clearly observable during the injection of contrast medium, both in the coronary artery and in the graft. This to - and - fro movement can cause a sharp decrease in the blood flow in the stenotic region which will produce an increase in thrombocyte aggregation (Aldridge-1971; Bourassa et al. 1978), resulting in an increased tendency to thrombosing and deposition of atheromatous material. Various investigations, (Rees-1976; Levin-1981) and our own research have shown a clear progression in the stenosing, especially proximal to a graft anastomosis.
It was also observed that this progression involved branches such as diagonals, arising proximal to the graft anastomosis.
In the studies, mentioned above, the progression of stenosis distal to the graft anastomosis was a controversial question. In this study, progression distal to the anastomosis was found. For instance, stenotic lesions in the LAD, distal to the graft anastomosis, with luminal narrowing of up to 25% were found to change post-operatively into occlusions in 12.5% of the cases. Bourassa et al. (1978) reported a percentage of 11.6%. This progression will be discussed in greater detail later.

Depending on the vascular stitching techniques used, various complications can occur, ranging from bleedings to thrombo-embolism, in which respect a distinction is made between early and late thrombosis formation. An important part is played here by surgical techniques, the treatment of the bypass intima lesion and changes in the blood flow. In particular, changes in the blood flow depend on such aspects as the diameter of the receiving artery and bypass as well as the tension of the graft on the coronary vessel.

Generally a constriction takes place at the site of the anastomosis. In particular, U-sutures cause greater constriction than single or continious ordinary stitching. Flow through an end -to -side anastomosis is regarded as a flow through a curve, the angle formed by

the curve being very important here. The smaller this angle, the greater the radius of the implantate and the smaller the loss of pressure energy.
The more gradual the change in the flow bed, the less the change of turbulence and stasis. This can be achieved better with a side -to -side anastomosis than in an end -to -side anastomosis.
The elasticity of the vascular segment receiving the grafts plays an important role; the radial expansion in an artery is approximately 7% and one should take this into consideration when the diameter of the venous graft has to be measured.
It is obvious that a straight answer for all the haemodynamic aspects in bypassed coronary arteries is not yet available.

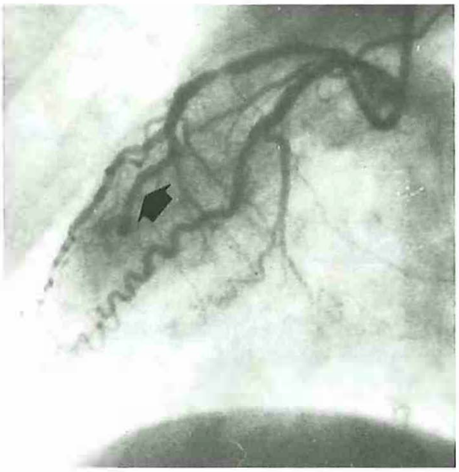


Fig.2.15 Diastolic phase, contrast filling of LAD distal.

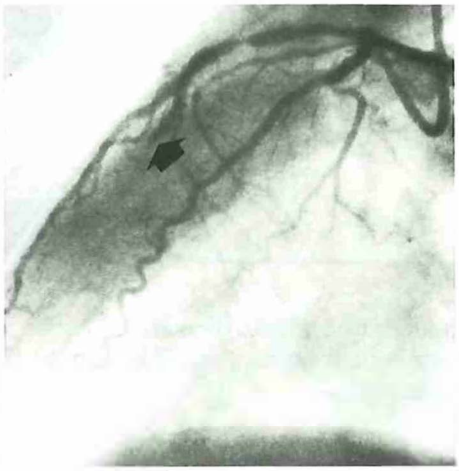


Fig.2.16 Systolic phase, contrast emptying of LAD distal.

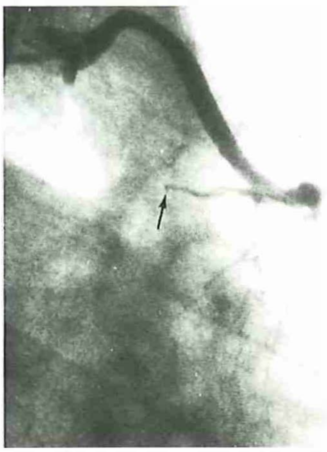


Fig.2.17 Contrast injection in S graft on LAD. Diastolic phase.

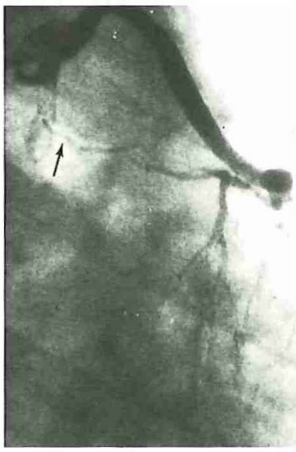


Fig.2.18 Contrast injection in S graft on LAD. Systolic phase.

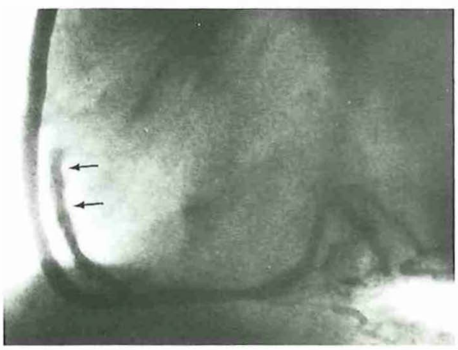


Fig.2.19 Contrast injection in S graft on RCA. Systolic phase.

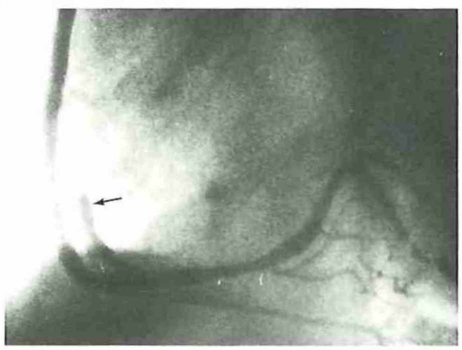
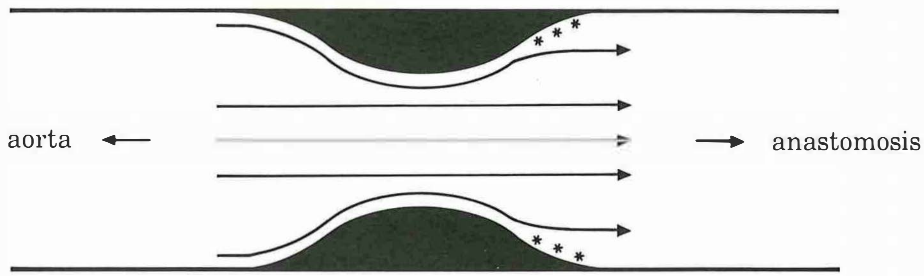
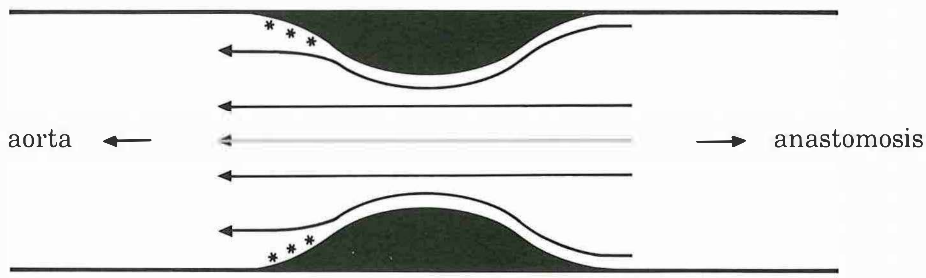


Fig.2.20 Contrast injection in S graft on RCA. Diastolic phase.



a. diastolic phase. Blood flow driven more distally into the coronary artery, through a stenotic lesion. Dead water area distal to the stenosis.



b. systolic phase. Blood flow driven more proximally causing dead water area just proximal to the stenosis.

Fig.2.21 Tide-phenomenon in a stenotic region of a coronary artery to which a graft is stitched.
****dead water region. (van Aken, 1982).*

Chapter 3

Coronary Angiography

3.1. Historical Review

According to Cournand (1975) and Grossman (1980) Claude Bernard is said to have inserted an iron wire into a horse's heart via a vein (1844). In 1929 Werner Forsmann was the first person to pass a catheter into the heart of a living person-himself. He inserted a catheter into his own left antecubital vein under fluoroscopic guidance. He then walked to the X-ray department which was on a different level, after which some X-ray exposures were made.
In the course of the years he used this technique several times on himself. His colleagues were so sceptical about this procedure, however, that he gave up, with the result that this method fell into oblivion.

Dos Santos described in 1929 the first translumbar aortography.

In 1931 Moniz, de Carvalho and Lima succeeded in visualizing the pulmonary arteries by using the Forsmann technique.

Nuvoli (1936) was the first one, who used the trans-sternal aorta puncture in patients with an aortic aneurysm, while Castellanos (1937) inserted a catheter into the superficial femoral artery up to the abdominal aorta.

In 1945 Grossman carried out animal experiments in which he injected contrast medium via a catheter, the tip of which was just above the aortic valves. In this way, the coronary vessels were visualized in a number of dogs.

Radner (1946) succeeded in visualizing the coronary vessels in man by making a trans-sternal puncture in the aorta. He injected thorotrast for this purpose. Later, he changed this method by introducing a catheter via the brachial artery and placing the tip of the catheter close to the aortic valves, so that the coronary vessels became more clearly visible.

In the fifties, a great deal of work was done by the Nobel prize winner Andre Cournand, which resulted in greatly increased interest in cardiac catheterization.
Zimmerman and Limon Lason (1950) introduced retrograde left ventricular catheterization. Di Guglielmo et al (1952) described the results of coronary vascular research in which a catheter was also introduced via the brachial artery.
Vascular examination rapidly gained momentum as a result of the method of Seldinger (1953) in which catheterization was carried out percutaneously after simple needle puncture.

Ross and Cope (1959) used trans-septal catheterization via a vein, followed in 1959 by the selective arterial catheterization technique according to Mason Sones. This method was later modified by Abrams (1962) and Judkins (1967). The latter used percutaneous, transfemoral selective catheterization. The development of the image intensifier linked to a TV monitor has also made an important contribution to the rapid developments in the field of coronary angiography. The use of angulation projections (Ludwig 1969) has also contributed to improved diagnosis of coronary arterial abnormalities.
Nowadays, either the Sones method or the Judkins method is used.

3.2. Coronary angiographic procedure

As technical data can influence the radiological data, a survey of the technical equipment, cine-angiography, catheterization methods and material is given, as wel as use of contrast media, radiation protection and interpretation and method of assessing stenosis.

3.2.1. RADIOLOGICAL EQUIPMENT

Coronary angiography, including imaging of the cardiac chambers, makes high demands on the radiological equipment, because one has to deal with a fast-moving object, together with small vessels. X-ray imaging of these structures is a highly complex process and to ensure a good understanding of this process we shall review the function of the major components required to accomplish this type of imaging.

The components required in an angiographic department include a high output generator, image intensifier, television camera and monitor, cine camera and a dedicated installation to accomplish a variety of projections, especially oblique, cranio-caudal and caudal-cranial angulations.
In our department the generator is an Optimus M 200 (Philips), especially designed for angiographic applications, which offers facilities for single-plane-operation with a 35 mm cine camera (Arriflex-R), and an image intensifier/TV fluoroscopy. For optimum cine-angiography, a three-phase, twelve-pulse generator is required. This generator has tetrode switching, giving a minimum pulse time of 0.3 miliseconds.

In our department we use an Arritechno cine camera on which a frame frequency (at a mains frequency of 50 HZ) of 25, 50, 75, 100 or 150 frames per second can be used. Duration of cine run: 10, 15, 20, 30, 40 and 60 seconds. We normally use up to 50 frames per second with a cine run duration of 10 to 15 seconds.

We used a Super Rotalix metal tube, SRM 35-100 (Philips), which is designed for high loadability, short exposure times and sustained operation. The tube envelope consists of a ceramic cathode insulator, which ensures a greater 'high voltage stability'. This tube, with a focal spot combination of 0.6 mm and 1.2 mm, can be effectively employed in cine-fluorography.
During coronary angiography of the LCA, especially in the RAO position, the lucency of the lung fields cause under-exposure, which makes it very difficult or even impossible to make good imgages of the LAD.
In our equipment, an Aluminium wedge filter (Fig.3.1.) is placed in the collimator at the X-ray tube side. This filter can be rotated 360°, thus covering the lung fields. It can also be move linearly to get it out of the image. The use of this filter gives an excellent image of the coronary vessels (Fig.3.2.-3.3) and in our opinion it is indispensable in making a reliable coronary angiogram as well as a good ventriculogram.

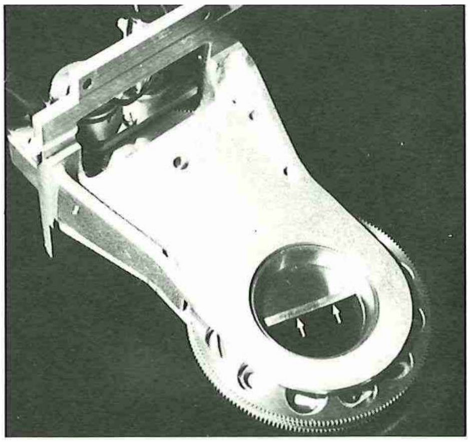


Fig.3.1 Aluminium wedge filter

3.2.2. CINE-ANGIOGRAPHY

Cine-fluorography of the coronary arteries is done at a speed of 50 frames/sec.
Left ventriculography can be imaged by using 25 frames/sec.
The rapid succession of images will minimize the risk of an important phase of movement being missed.

The optimum quality of the c.a.g. depends on choice of a small focus. The Super Rotalix X-ray tube (Philips), foci of 0.6-1.2 mm, is very well suited for this purpose. In order to limitate the irradiated volume, both for reducing scatter and the radiation dose imparted to the patient, it is self-evident to set the X-ray diaphragm to the correct size.

A grid is nearly always used to reduce the influence of scattered radiation on the image. An extra filter of about 1-3 mm A1 or of 0.05 mm Cu and 1 mm A1 is useful for keeping the patient dose as low as possible.
In our catheterization lab we make use of a poly-C (Philips) which is excellent in handling and has the options mentioned above.

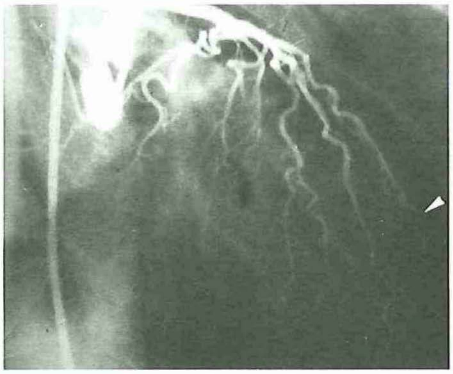


Fig.3.2. Aluminium wedge filter used during LCA angiography (RAO). D-1 well to distinguish

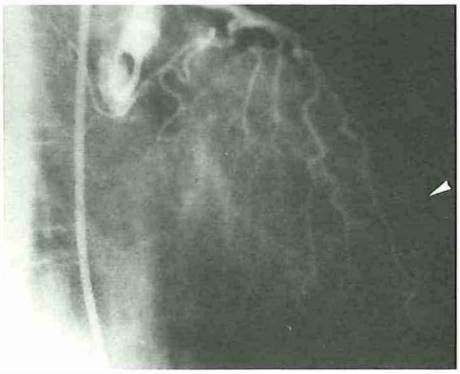


Fig.3.3. Same projection, without filter. D-1 hardly visible

3.2.3. CATHETERIZATION TECHNIQUES

In our department coronary angiography is frequently carried out using the 'El Gamal catheter', which can be catheterize both coronary vessels selectively in a very high percentage of cases (86 - 93%), the percentage in graft catheterization being 91.4%. In the procedure described by El Gamal et al. (1980) the figures then reported were on the low side as experience with this catheter was still fairly limited. At present, our cardiologists report a success percentage of approximately 90 to 93%.

Depending on the angiographer, either the Sones' or the Judkins' method is used.

3.2.3.1. Sones' method

In the selective method according to Sones arteriotomy of the brachial artery is necessary, after which a catheter is introduced into the ascending aorta. The advantage of the Sones' technique is that a fairly short route to the coronary arteries is possible, so that manoeuvring with smaller catheters results in a simplification of the procedure. A disadvantage is arteriotomy which has to be stitched afterwards, it is time consuming and sometimes an arterial occlusion can occur.

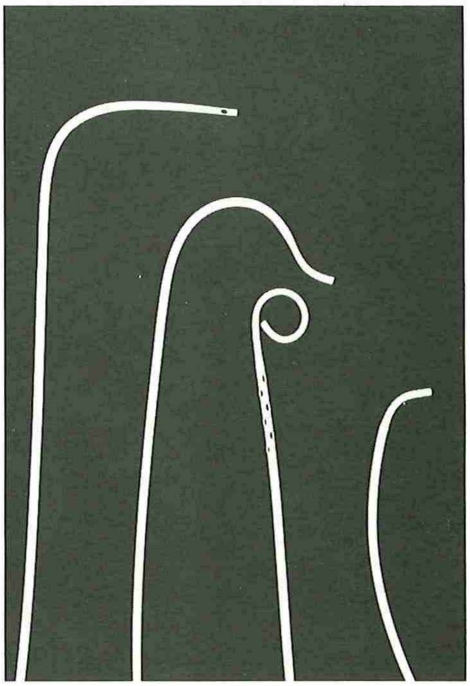


Fig.3.4. Preshaped disposable catheters, used for coronary angiography and left ventriculography.
From left to right:
El Gamal catheter
Amplatz Left
Pigtail (LV injection)
Judkins Right

3.2.3.2. Judkins' method

In this method catheterization takes place via a puncture in the femoral artery, after which the catheter is pushed up into the ascending aorta. The Judkins' method is virtually the only one used in the Catharina Hospital in Eindhoven. It is a relatively safe method for the patient involving little stress. The disadvantage is that manoeuvring with longer catheters calls for a higher degree of skill.

In particular, in the case of serious abnormalities in the pelvic vessels, manoeuvring with longer catheters can cause problems. Occasionally, therefore, we depart from this procedure and the method of Sones is used.

In our department it is customary to place a sheath in the insertion channel in the femoral artery and a somewhat thinner catheter is then introduced into this. Manoeuvrability of the catheter in the groin is then significantly improved. One disadvantage, however, is that a larger insertion opening is obtained in the femoral artery so that the probability of haematoma forming is greater. The pressure time for this puncture site is also significantly longer because of this larger opening.

The catheter to be used is connected to a three-way stopcock which has three side connections, each of which can be closed off separately. The two end inlets are used for connecting the catheter and injection syringe. The side connections are used for:

1. Measuring the intra-arterial and intraventricular pressure. This is important for the safety of the catheterizaton procedure.
2. Connecting an infusion, the so-called 'flushing mechanism' in which saline solution is used with 50 mg of heparin dissolved in it per 500 cc (= 5000 E).
3. An infusion containing contrast medium that permits rapid filling of the injection syringe. The injection syringe, which can be regulated from behind the glass lead screen, as described, is operated with a foot pedal. Because of this rapid filling method, there is no need to disconnect the injection syringe.

3.2.3.3. Catheterization of the LCA:

The patient is seen in the 45° RAO position, the catheter being placed in such a way that the tip lies in the left sinus of Valsalva. The patient is then asked to take a deep breath, as a result of which the catheter frequently shoots into the ostium.

3.2.3.4. Catheterization of the RCA:

The X-ray tube is placed in the 60° LAO position, with the catheter tip lying high and pointing towards the left coronary sinus. By means of a slow, clockwise rotation the catheter tip then generally turns into the RCA. If this is unsuccessful, the catheter is pushed up slightly so that the tip enters the right sinus. By moving it to and fro, the tip can then be slipped into the right ostium.

3.2.3.5. Catheterization of grafts:

The X-ray tube is placed in the 60° LAO position, after which the catheter tip is placed high in the ascending aorta. After this, again by slow clockwise rotation at various levels, the graft opening is searched for and the catheter is hooked on.

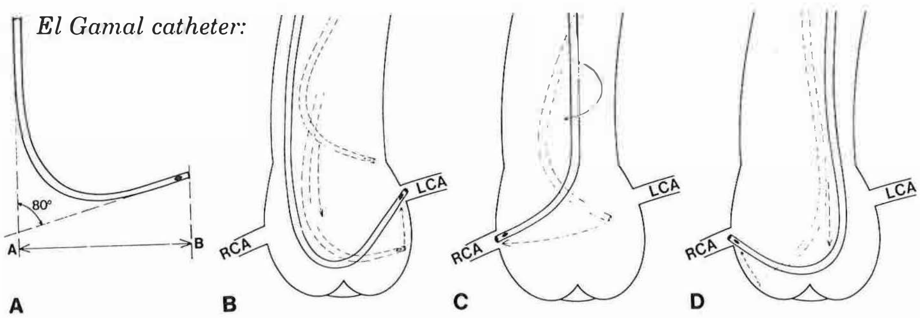


Fig.3.5. Rotations: 15° around longitudinal axis
A to B 40° around transverse axis
(Courtesy of M. El Gamal, Catharina Hospital, Eindhoven, Netherlands)

If the procedure with the Gamal catheter is not immediately successful, the catheter is changed fairly rapidly and the Judkins or Amplatz catheter is then used. These also have a fairly high success percentage.

3.2.3.6. Catheterization of the left ventricle:

The left ventriculogram is made by inserting a pigtail catheter into the LV.
In most cases, the LV is shown in the LAO 60° projection, as well as the RAO 30° projection. Here the LV is divided into five segments in the RAO projection and into two segments in the LAO projection, while in addition the septum is shown here.

3.2.3.7. Results and complications

Two tables are reprinted below, in which respect it must be remembered that these results date from 1980 when experience was not yet optimum.

Table 1. Results in 1100 Cases of Coronary Angiography

	Number	Percentage
Successful intubation of both coronary arteries	945	85.9
Failure to intubate the right coronary artery	54	5.0
Failure to intubate the left coronary artery	80	7.0
Successful intubation of coronary artery bypass grafts (129 attempts)	118	91.4

Table 2. Complications in 1100 Cases of Coronary Angiography

	Number	Percentage
Ventricular fibrillation	8	0.7
Ventricular tachycardia	1	0.1
Myocardial infarction	1	0.1
Minor cerebrovascular accident	1	0.1
Minor subintimal dissection of abdominal aorta*	3	0.3
Dissection of an occluded right coronary artery	1	0.1
Femoral artery occlusion	-	
Mortality	-	

* Catheter was introduced through an arterial sheath.

3.2.4. CONTRAST MEDIA USED IN CORONARY ANGIOGRAPHIC EXAMINATION

In order to obtain a good result in coronary angiography by injecting contrast media both into the coronary arteries as well as into the left ventricle, the contrast medium used must meet the following requirements: toxicity must be very low to avoid little or no side effects on the myocardium or coronary vessels; it must contain enough iodine atoms in order to obtain a coronary angiogram that can be readily evaluated; the osmolality of the contrast medium must be as low as possible and have a low viscosity for in selective catheterization of a coronary vessel it is often injected by hand.
In our clinic, this selective injection of contrast media into the coronary vessel is carried out with a pressure pump.

At present there are various contrast media available, both non-ionized and ionized.
Generally speaking, the ionized contrast media have a high osmolality and consist of a benzene ring to which three iodine atoms are linked; in addition sodium is linked as the anion and methylglucamine as the cation.
As a result, a dissociation of Na^+ and MEG^- can occur.
The non-ionized contrast media belong to the new generation whose common feature is a low osmolality.
The ionized contrast media include: diatrizoate (Urografin[r]), iothalamate (Conray[r]), metrizoate (Isopaque[r]).
Ioxaglate (Hexabrix[r]) is a dimeric ionized contrast medium, that, in contrary to the classic ionized media, has a very low osmolality.
The non-ionized contrast media include: iopromide (Ultravist[r]), iohexol (Omnipaque[r]), iopamidol (Iopamiro[r]).

The intravenous or intra-arterial injection of these contrast media can result in a number of side effects. (systemic-cardiac-electrical and vascular). These side effects will not be discussed in detail.

One of the contrast media used in our department is Urografin[r] 76% (Schering) which is generally well tolerated by the patients. When studying the coronary films dyskinesia is occasionally seen during the LV injection of contrast medium and this can result in a false mitral insufficiency. A few seconds after the injection normal contractions return, so that the LV function can be readily evaluated.

The same phenomenon occurs to a lesser extent when injecting contrast medium into the coronary arteries.
In patients with an increased risk such as decompensation, recent myocardial infarction and patients who have to undergo a streptokinase infusion therapy (SIT procedure) or a PTCA procedure, use has been made of ioxaglate (Hexabrix[r]) which has a very low osmo-

lality. Nowadays we use iopamiro in high risk patients. Unfortunately, in view of the cost aspect, it appears that general use of these non-ionized contrast media is not feasible at present and in our opinion they should therefore be reserved for high-risk patients as described above.

Contrast quantities

Generally, 9 ml of contrast medium are injected into the LCA with a flow of 3 ml per second. The RCA generally receives 7 ml contrast medium, with a flow of 2 ml per second, depending on the anatomical picture obtained by the test injection. On average, 7 ml is injected into the graft, also with a flow of 2 ml per second, while here again each individual case is looked at to see to what extent a gracile graft and/or fairly wide graft is involved.
The amount of contrast medium injection to visualize the left ventricle in both the RAO and the LAO projection mostly is 35 ml per injection, so the total quantity of contrast medium, used in coronary angiography as well as in ventriculography hardly exceeds the usual limits (2-3 ml/kg body weight).

In all cases use is made of a pressure syringe (Medrad[r]). This pressure syringe is operated by a foot switch and can be controlled by a circuit from behind the lead glass screen, where the various pressure and ECG computer equipment has been set up.

3.2.5. THE MOST COMMON PROJECTIONS IN CORONARY ANGIOGRAPHY

The most frequently used projections in our catheterization department to visualize both the LCA, the RCA and the LV are presented here.
Different projections are of great importance in order to obtain a clear picture of the anatomical subdivision of both the LCA and the RCA. The schematic representation will be found in the anatomic form as well as in the computer form (Chapter 4).

3.2.5.1. Left coronary artery (LCA)

In this study the RAO, the LAO, the purely lateral (90°) projections are used, together with the RAO and LAO craniocaudal projections.
Depending on the path of the system, supplementary exposures can be made "in which" the Poly-C can easily be angulated.

3.2.5.2. Right coronary artery (RCA)

In this study the projections RAO 35°, LAO 45° and LAO 30° craniocaudal are used. Angulation can be adapted to the course of the coronary system and any superimposed projection of the various branches.

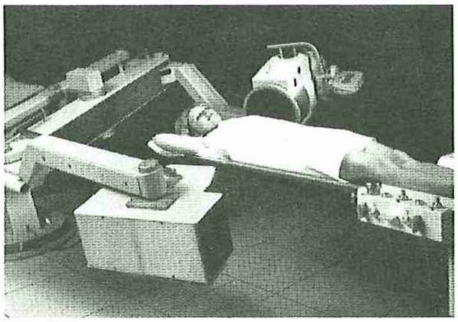


Fig.3.6.
Position A: 75° LAO
20° cranial caudal

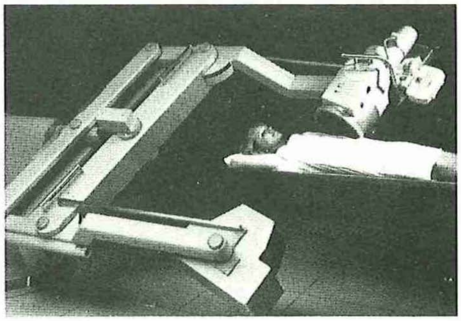


Fig.3.7.
Position B: 60° LAO
20° caudal

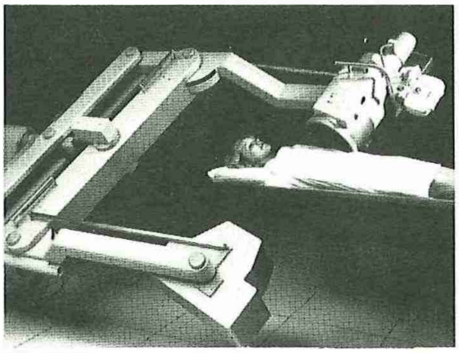


Fig.3.8.
Rotations: 75° around longitudinal axis
A to B 0° around transverse axis
Position A: 45° LAO
20° caudal

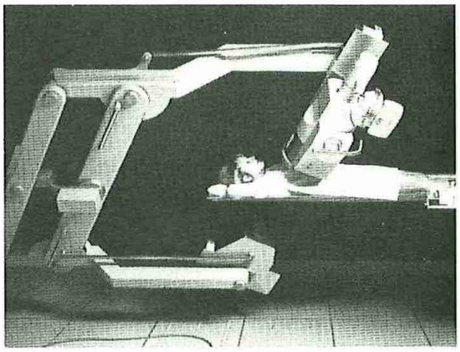


Fig.3.9.
Position B: 30° RAO
20° caudal cranial
(Courtesy of Philips Medical Systems)

3.2.5.3. Left ventricle (LV)

In most cases, the LV is shown in the LAO 60° projection, as well as in the RAO 30° projection.

3.2.6. RADIATION PROTECTION

During coronary angiographic procedures special care in relation to radiation* protection, both to the patient and the angiographer, should be taken.

3.2.6.1. Radiation protection of the patient

The patient is only protected by the general rule and it should be the radiologist's duty to protect the patient by the following two rules (Puylaert, 1981):

a. No unnecessary X-ray procedure.
b. No unnecessary radiation for any X-ray procedure.

In our department (1979) the average radiation exposure, in a coronary angiographic procedure, to the patient was:

	fluoroscopy	cinefluoroscopy	total
Eye	0.63 mrem	4.65 mrem	5.28 mrem
Gonads	1.49 mrem	10.95 mrem	12.44 mrem

Most radiation exposure is due to the cine dose, which takes about 1-1.5 min.

In their department Noel et al. (1980) found an average heart exposure rate of 70 mrem/min. and a total dose of 3600 mrad, during a mean fluoroscopy time of 31 min. and a cine time of nearly 1 min. The maximum eye dose was 200 mrad, the gonad dose was 350 mrad.
According to Levin (1980) radiation exposure on an average sized patient gives a skin dose of approximately 0.5 to 1.0 rem/mA/min.

3.2.6.2 Radiation protection of the angiographer

The personnel performing radiological examinations are, of course, protected by the law. For the Netherlands the limits are 5 rem/year. Levin (1982) found that the approximate dose rate per frame for 35 mm cine film, was 20uR. This value may vary with the film and technique used. We found a mean dose rate of 10uR on the 9" and 15uR on the 6.5" image intensifier. Data from his laboratory indicate that during an average cardiac catheterization, with left

* The introduction of the Système Internationale d'Unités (SI) has changed these units of measurement: e.g., the ion dose (R) is now expressed as coulomb/kg and the energy and equivalent dose (rad and rem) are expressed in joule/kg, or gray units (Gy). 1 Gy=1 J/k =100 rad. The SI unit of radionuclide activity is the Becquerel (former Curie) and the dose equivalent is now called sievert (1 Sv=100 rem).

ventriculography and coronary angiography entailing 60 to 90 seconds of cine time, the mean radiation dose to the angiographer is 15mR to the hand, 10 to 15 mR to the eye and 2 mR to the abdomen and chest areas beneath the protective lead apron.

In our Department, Den Boer and Mohr (1976) found the following values for radiation exposure to the angiographer (without radiation protection):

Eye	:	8.5 mR/h.
Thyroid	:	12.0 mR/h.
Gonads	:	20.0 mR/h.

The highest exposure rate of up to 3 mR/h close to the patient, was measured at the height of 1.5 m in the LAO projection. In this projection the angiographer stands on the right side of the patient. In the RAO projection the distribution of scattered radiation is influenced by the image intensifier housing.

In this way, some 60 examinations per week per angiographer can be carried out without exceeding the maximum permitted dose to the eyes. (dose to the head: 0.3 R/week). It should be noted that some countries quote a yearly maximum permissible dose for the eyes of 5 rem.

Gustafsson and Lunderquist (1981) found an average absorbed dose to the forehead and neck of 0.07 mrad per minute in fluoroscopy. Radiation exposure of the head and neck regions gives the highest contribution to the effective dose equivalent.

Using protective clothes, a lead equivalent of 0.25 mm Pb will reduce the scattered radiation of a factor 10 (at 110 kV) to a factor 90 (at 60 kV).

Furthermore, the LAO projection is not used continuously, so that the actual exposure to the eye lenses is far less.
It is obvious that personnel should wear a film badge or thermoluminescent dosimeter (TLD) which should be located at the head or neck level. Lead aprons of at least 0.25 mm lead equivalence are necessary. During these procedures it is not possible to retire behind a protective barrier. In our department a ceiling-suspended glass-lead shield can be placed between the patient and the angiographer, which reduces the exposure to the angiographer significantly. Some angiographers use lead-glass glasses or even a mask with a lead-glass window to protect the lens of the eye. There is no excuse for the angiographer's hand entering the ray beam at any time.

During fluoroscopy and cine filming, our radiological technician makes notes in a special logbook, which includes kV, mA fluoroscopy time, cine time and the position of the X-ray tube with respect to the patient. These notes give us a good impression of the total patient exposure.

Especially the new intervention techniques, such as percutaneous transluminal coronary angioplasty (PTCA) or streptokinase infusion therapy (SIT), take more time and consequently involve more radiation exposure.
Even if the radiologist is not directly involved in the coronary angiographic procedure, he has to check these figures and should take measures, if necessary, to prevent faulty practices and unnecessary exposures in order to protect both patients and personnel.

3.3. INTERPRETATION AND METHOD OF ASSESSING STENOSIS

In assessing the accuracy of the coronary angiogram the exact quantitation of a stenosis is of great importance. In the international literature disagreement between cine-angiographic and pathologic findings has frequently been mentioned. Underestimation, especially of focal lesions, together with lesions greater than 50%, (De Rouen et al. 1977) is often mentioned.

A cine-analyser is necessary for studying the coronary angiogram. For this purpose we use a Tagarno 35 CX, which gives us a very good image.
The Tagarno 35 CX-B1 Biplane-Cine-Analyser has the advantage that it can be used as two standard 35 mm projectors, with simultaneous projection of two 35 mm films. (Especially during PTCA; comparing pre- and post-operative coronary angiograms).

In this study we frequently used a clock meter, in which the points of the measuring instrument indicated with an arrow are placed on the edges of the vessel or the stenosis. The diameter can then be read off from the movable clock. Though this method is rather accurate it is a time consuming procedure. In a number of cases an estimation of the stenosis has been made. If a stenosis is found to be present when assessing the coronary angiogram the percentage stenosis is taken that represents itself as being more serious. In other words, if a stenosis in LAD-mid is 50% in the RAO position but is 75% in the cranio-caudal LAO position, we take the stenosis to be entered as 75%.
Assessment of a vascular stenosis is more accurate if we can investigate the stenosis in two different, if possible, perpendicular positions.

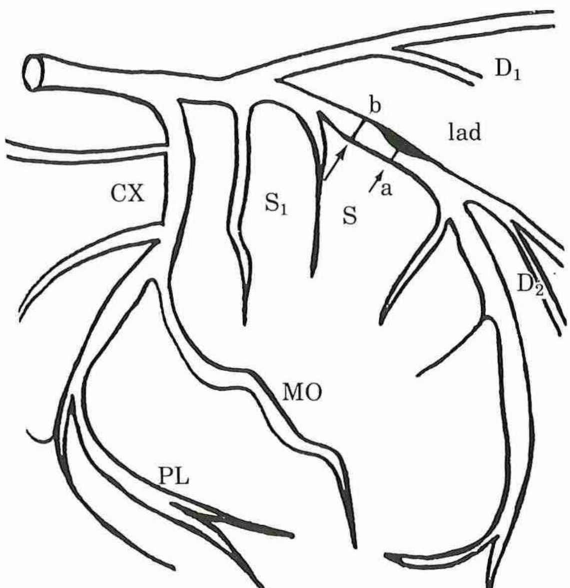


Fig.3.10. $a/b \times 100\% = \quad \%$

The pre- and post-operative angiograms were seen by several colleagues, while all the c.a.g.'s were discussed in the cardio-surgical team. The author was either present at these meetings or received a report on them. The findings of this 'intake' team are recorded on a separate form and were compared in this way with our own data.

In the event of any discrepancy, the relevant c.a.g. was also judged by a second radiologist.

Various methods are used by others for image border information, such as caliper measurements, magnified vernier measurement, computer-assisted image reconstruction, photodensitometry of the image of combinations of these methods. All these methods have their variability of percentage stenosis measuring though the computer-assisted method seems to be the most reliable method. The method of visual interpretation has intra-and inter-observer variability. In addition, angiographers have, as already mentioned, a tendency to underestimate the severity of lesions, especially in the 60-80% stenosis range.
(McMahon et al., 1979; De Rouen et al., 1977; Zir et al., 1975). De Rouen et al. (1977) found a mean variability of visual estimation of 30%, while for the computer-assisted method it is 3%.

Several factors related to this variability have been mentioned. First, the technical quality of the final product, the coronary angiogram, is important. Differences in reader perception undoubtedly contribute to interobserver variability. The type of training of the angiographer, whether radiologist or cardiologist, and the level of experience and ability are both important factors in interobserver variability. Reader fatique and "reader set" (prior knowledge of a patient's clinical history) all may be important contributing factors.
On the other hand stenosis can be underestimated because a stream of contrast medium is locally thinned by arterial narrowing, caused by stratification (Puylaert, 1961).

The stenosis itself is measured at the vascular section located proximally immediately above it; see figure 3.10.

In addition to the anatomical abnormalities described and their recognition, it is very important for the researcher to be familiar with the reactions which occur during the injection of the contrast medium. When administering ionic contrast media, arrhythmia, bradycardia or dyskinesia are not infrequently seen. In injections into the right coronary artery a slowing of the heart action is often observed between two and five seconds after the injection, which persists for between three and five seconds.

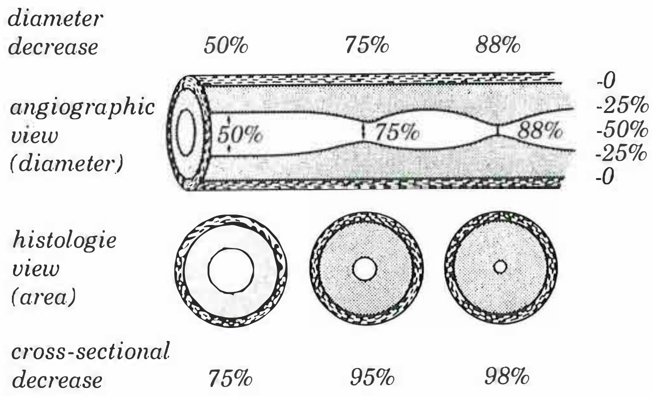


Fig.3.11.
Representation of angiographic view and analysis of coronary artery stenosis

Most disagreements were observed in assessments of distal arterial segments, nonopacified segments and cine-angiograms taken in severe disease or those that were technically inadequate.

It is known that there may be an angiographic-pathologic discrepancy of the stenosis. One problem that must be dealt with is the method of assessing the stenosis of a coronary artery in arteriography. For the most part, this is based on a decrease in luminal diameter as compared with what is assumed to be the normal calibre. Since atherosclerosis is a diffuse disease, however, what appears to be normal may actually be a narrowed segment.

Furthermore, the pathologist is analysing a bloodvessel in cross-section while the coronary angiogram provides a two-dimensional view of the altered diameter.
On the other hand, in vivo-angiographic examinations differ from post mortem examination because of the total change in physiological point of view e.g. the loss of elasticity of the vascular wall and the fact that post-mortem examination is sometimes performed months to years after the angiographic studies.

Chapter 4

Material and Methods

4.1. Material

This study relates to a group of 303 patients who underwent a post-CABG coronary angiographic examination in the Catharina Hospital at Eindhoven in connection with the pattern of complaints which these patients demonstrated after undergoing operation. It is a retrospective study in which the pattern of complaints followed the NYHA classification. This study took place between January 1981 and January 1983.

NYHA classification:

I : no symptoms
II : symptoms during stenuous exertion
III : symptoms during light exertion
IV : symptoms during rest

In this study it was found that some patients reported complaints which could not be exactly placed in one of the NYHA groups but more in a transition between these groups. The group of 303 patients showed the following NYHA sub-division:

II : 44%
II-III: 10%
III : 34%
IV : 12%

In order to evaluate these complaints in more detail a repeat c.a.g. was carried out which, within the context of this study, was compared with the last pre-CABG c.a.g.

Open heart surgery was started in the Catharina Hospital on 27 February 1978 and up to 31-12-1982 - the final date of this study - 1347 CAGB operations had been performed.

The total number of CABG operations relating to this study was 1347, subdivided as follows:

1978: 58 = 4.3%
1979: 144 = 10.7%
1980: 265 = 19.6%
1981: 335 = 24.9%
1982: 545 = 40.5%

Table 3. Patient data compared.

	male %	female %	average age year	operation mortality % within 30 days	
Lawrie et al.	89.2	10.8	50.1	4.6	(1982)
Cosgrove et al.	88.0	12.0	57.0	1.5	(1982)
Kennedy et al.	75.7	24.3	54.0	2.3	(1982)
Laird-Meeter	87.9	12.1	54.0	1.2	(1983)
Bijlsma	84.5	15.5	56.2	3.0	(1983)
Takaro et al.	-	-	-	5.8	(1982)
European Study	-	-	-	3.3	(1980)

The cardiac surgeons in the hospital have changed on various occasions in recent years. The question of whether certain operation results should be superimposed on a difference in surgical treatment has been disregarded.

Of the total number of patients who underwent operations in Eindhoven (1347), 254 patients returned for a repeat angiogram, a percentage of 19.0%. Frye (1980) describes a new occurrence of complaints post-operatively in 5% of the patients per year, which in our case would, roughly calculated, amount to a total of 22.5%.

Of the group of patients involved in the study, 49 (=16%) had been operated upon elsewhere; 16 (=5%) of them in Houston and 33 (=11%) in other clinics (Amsterdam, Rotterdam, Nijmegen, Genolier, Londen and Utrecht).

Re-operations were performed on 15 of the 303 patients, a percentage of 5.0%. Lawrie et al. (1982) report 9.0% re-operations, Laird-Meeter et al. (1982) 5.2% and Loop (1981) reports 4.5%.

4.2. Methods

A total of 864 coronary angiograms were studied for this research, of which 512 were pre-CABG angiograms and 352 post-angiograms (303 + 49, in connection with a PTCA procedure or streptokinase infusion therapy).

In order to classify these data adequately, a double-coronary angiography form was designed first (Fig.4.3.). In addition to the personal data and the data of the operation, etc., the abnormality found on the pre-CABG coronary film was entered in the top half, while the bottom half related to the abnormalities found in the coronary angiogram just after the CABG operation. Some items were added to this, of which only 'a' and 'b' were actually filled in during the examination, the item 'e' being added at a later stage after streptokinasis infusion therapy was introduced into our clinic.

To enable the date to be recorded in an orderly and convenient way a computer form (fig.4.4.) was designed to link up with the coronary angiogram form (fig.4.3.).

A diameter stenosis coding was also entered, divided into six classes:

Class A-1 : 0-24% stenosis
Class A-2 : 25-49% stenosis
Class A-3 : 50-74% stenosis
Class A-4 : 75-90% stenosis
Class A-5 : 91-99% stenosis
Class A-6 : 100% stenosis

These stenosis classifications, in turn, were again subdivided into b (=before CABG) and a (=after CABG). The coronary arteries were subdivided into 18 segments.

In addition, a graft typing classification was made in order to permit these to be classified in such a way that the vascular segments to which the graft was stitched could be noted immediately regarding the grafts - which were, of course, only classified in a column if abnormalities were found - a sub-division was also made into proximal (=p), mid (=m) and distal (=d) in order to be able to indicate where a stenosis or occlusion was present in the graft. Hence proximal in the graft means from the origin of the graft to -2 cm below it, distal means attachment to the relevant coronary artery segment up to 2 cm before it and mid relates to the section between proximal and distal.

The left ventricle has been divided into seven segments as shown in figure 4.1. and 4.2.

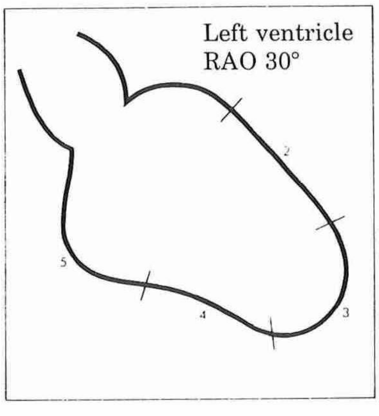


Fig. 4.1. Left ventricle RAO 30°
1. *Anterobasal segment*
2. *Anterolateral segment*
3. *Apical segment*
4. *Diaphragmatic segment*
5. *Posterobasal segment*

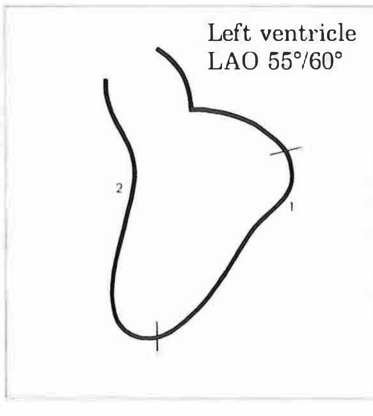


Fig. 4.2. Left ventricle LAO 55°/60°
1. *Posterolateral segment*
2. *Septum*

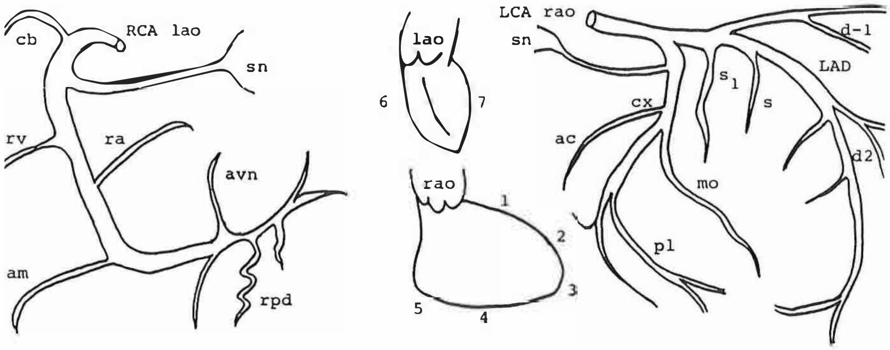
No: ______

Coronary angiographio findings in post CABG patients

Name: ________________________ Date of birth: ______ m/f   Film no.: ______

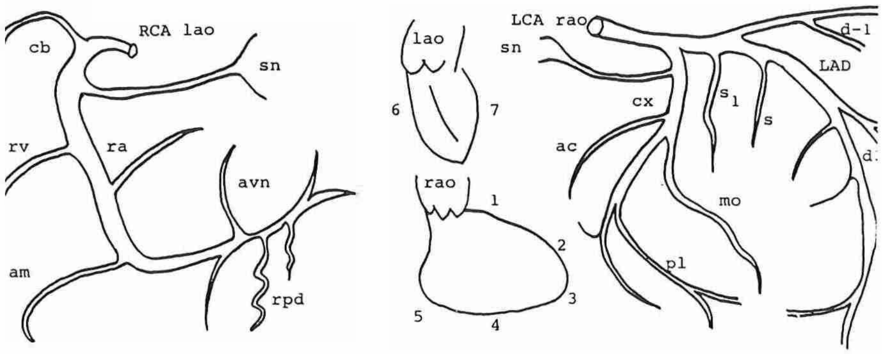
Date of c.a.g. pre-CABG: _______ Pat. no.: ___________

c.a.g pre-CABG:



Date of CABG: No. of graft(s): ____ Type of graft(s): ____________

c.a.g post-CABG: Date of c.a.g. post-CABG: ___________ Film no.: ______



Further aotion: a) 2nd CABG. Date: ______
b) PTCA. Yes/no.   Film no.: _____ Date: _______
c) medioamentous.
d) no therapy.
e) misoellaneous _________

NYHA olassifioation: ________

Fig. 4.3. Anatomical form (coronary arteries and left ventricle)

Coronary angiographio findings in post-CABG patients

Name: ______ M/F Pat. no.: ______ Film no.: ______ Date: ____
Date of birth: ______ Film no.: ______ Date: ____
Plaoe of operation: ______ Film no.: ______ Date: ____
Date of CABG: ______ Film no.: ______ Date: ____
Plaoe of operation: ______ Film no.: ______ Date: ____
Date of CABG: ______ Film no.: ______ Date: ____

stenosis code		1		2		3		4		5		6	
stenosis %		0 - 24		25 - 49		50 - 74		75 -90		91 -99		100	
LAC		B	A	B	A	B	A	B	A	B	A	B	A
1) Left main	1												
2)LAD-prox.	2												
3)LAD-mid.	3												
4)LAD-dist.	4												
5)D-1	5												
6)D-2	6												
7)D-3	7												
8)I.M	8												
9)CX-prox.	9												
10)CX-dist.	10												
11)CX-PL	11												
12)MO-1	12												
13)MO-2	13												
14)L.D.P	14												
15)Collat.	15												
RAC		B	A	B	A	B	A	B	A	B	A	B	A
16)RAC-prox.	16												
17)RAC-mid.	17												
18)RAC-dist.	18												
19)RPD	19												
20)Collat.	20												
Graft code(S-Y- I-Sn)		B	A	B	A	B	A	B	A	B	A	B	A
21).....graft to....	21												
22).....graft to....	22												
23).....graft to....	23												
24).....graft to....	24												
25).....graft to....	25												
26).....graft to....	26												
LV		normal		hypokin		dyskin		akin		aneurysm		p=prox. m=mid. d=dist.	
27)segment 1	27												
28)segment 2	28												
29)segment 3	29												
30)segment 4	30												
31)segment 5	31												
32)segment 6	32												
33)segment 7	33												
		B	A	B	A	B	A	B	A	B	A		

34)Congenital variant: yes/no.
35)PTCA: yes/no. Date: ______
36)Time interval pre-post CABG angiogram: ______wks.
37)Time interval pre-CABG angiogram: CABG: ______wks.
38)Time interval post-CABG angiogram: CABG: ______wks.

By

Fig. 4.4. Computer form

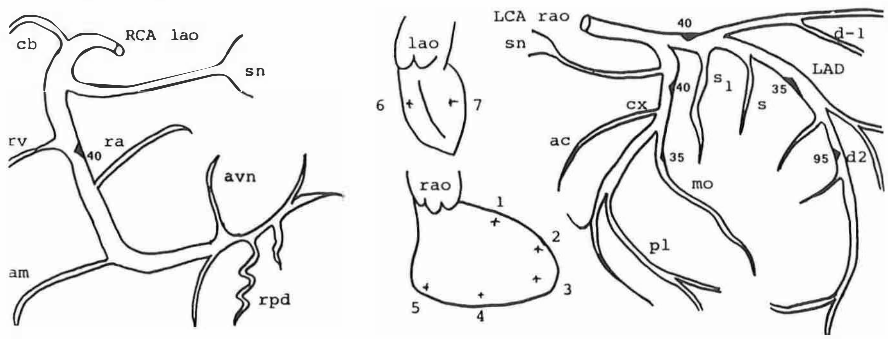
No: ______

Coronary angiographic findings in post CABG patients

Name: Example ______ Date of birth: 25-10-32 m/f ______ Film no.: 8000

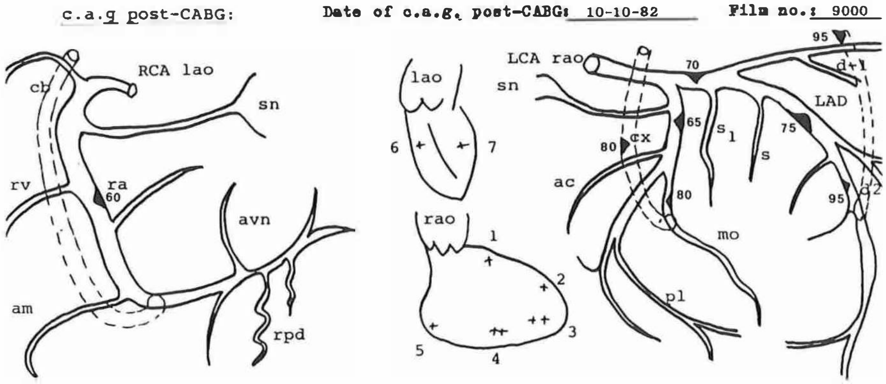
Date of c.a.g. pre-CABG: 10-10-81 Pat. no.: 25103260051

c.a.g pre-CABG:



Date of CABG: 10-12-81 No. of graft(s): 3 Type of graft(s): S

c.a.g post-CABG: Date of c.a.g. post-CABG: 10-10-82 Film no.: 9000



Further action: a) 2nd CABG. Date: ______
b) PTCA. Yes/no. Film no.: ______ Date: ______
c) medicamentous.
d) no therapy.
e) miscellaneous ______

NYHA classification: ______.

 Fig. 4.5. Anatomical form (coronary arteries and left ventricle)

Coronary angiographic findings in post-CABG patients

Name: EXAMPLE M/F Pat. no.: 25103260051 Film no.: 8000 Date: 101081

Date of birth: 25 10 32 Film no.: 9000 Date: 101082

Place of operation: EIND Film no.: ____ Date: ____

Date of CABG: 10 12 81 Film no.: ____ Date: ____

Place of operation: ____ Film no.: ____ Date: ____

Date of CABG: ____ Film no.: ____ Date: ____

stenosis code		1		2		3		4		5		6	
stenosis %		0 - 24		25 - 49		50 - 74		75 - 90		91 - 99		100	
LAC		B	A	B	A	B	A	B	A	B	A	B	A
1) Left main	1												
2) LAO-prox.	2			2			3						
3) LAO-mid.	3			2					4				
4) LAO-dist.	4									5	5		
5) O-1	5												
6) O-2	6												
7) O-3	7												
8) I.M	8												
9) CX-prox.	9			2			3						
10) CX-dist.	10												
11) CX-PL	11												
12) MO-1	12			2					4				
13) MO-2	13												
14) L.O.P	14												
15) Collat.	15												
RAC		B	A	B	A	B	A	B	A	B	A	B	A
16) RAC-prox.	16												
17) RAC-mid.	17			2			3						
18) RAC-dist.	18												
19) RPO	19												
20) Collat.	20												
Graft code (S-Y- I-Sn)		B	A	B	A	B	A	B	A	B	A	B	A
21) ..S.. graft to ..4..	21										5m		
22) ..S.. graft to .12..	22								4p				
23) ..S.. graft to .18..	23												
24) ..... graft to	24												
25) ..... graft to	25												
26) ..... graft to	26												

LV		normal		hypokin		dyskin		akin		aneurysm	
27) segment 1	27			2	2						
28) segment 2	28			2	2						
29) segment 3	29			2		4	4				
30) segment 4	30			2			4				
31) segment 5	31			2	2						
32) segment 6	32			2	2						
33) segment 7	33			2	2						
		B	A	B	A	B	A	B	A	B	A

p=prox.
m=mid.
d=dist.

34) Congenital variant: ~~yes~~/no.

35) PTCA: ~~yes~~/no. Date: ____

36) Time interval pre-post CABG angiogram: 52 wks.

37) Time interval pre-CABG angiogram: CABG: 9 wks.

38) Time interval post-CABG angiogram: CABG: 43 wks.

By

Fig. 4.6. Computer form

```
**************************************************************************
*  000 0000 ONE        [ ][ TWO ]                                        *
*                                                                        *
*                                                                        *
*          CORONARY    ANGIOGRAPHIC    FINDINGS IN CABG@PATIENTS         *
*                                                                        *
*                                                                        *
*                                                                        *
* PATIENT NUMBER: 25103260051              NAME: TEST PERSON             *
*                                                                        *
*                             DATE OF BIRTH: 251032           M/F: M     *
*                              CITY (@CABG): EINDHOVEN                   *
*                                CABG_DATE: 101281                       *
*                              CITY (@CABG):                             *
*                                CABG DATE:                              *
*                                                                        *
*                                                                        *
*                                                                        *
*                                                                        *
*                     FILMNR: 8000          DATE: 101081                 *
*                     FILMNR: 9000          DATE: 101082                 *
*                     FILMNR:               DATE:                        *
*                     FILMNR:               DATE:                        *
*                     FILMNR:               DATE:                        *
*                                                                        *
**************************************************************************
```

```
**************************************************************************
*  000 0000 TWO          [ ][THREE]                                      *
*                                                                        *
*                                          STENOSIS CODE    STENOSIS %   *
*                                                                        *
*        LCA DATA                                1           0 - 24 %    *
*                                                2          25 - 49 %    *
*                         BEFORE      AFTER      3          50 - 74 %    *
*  LEFT MAIN                                     4          75 - 90 %    *
*  LAD-PROX                  2          3        5          91 - 99 %    *
*  LAD-MID                   2          4        6             100 %     *
*  LAD-DIST                  5          5                                *
*  D-1                                                                   *
*  D-2                                                                   *
*  D-3                                                                   *
*  I.M                                                                   *
*  CX-PROX                   2          3                                *
*  CX-DIST                                                               *
*  CX-PL                                                                 *
*  MO-1                      2          4                                *
*  MO-2                                                                  *
*  L.D.P.                                                                *
*  COLLAT                                                                *
*                                                                        *
*                                                                        *
**************************************************************************
```

 Fig. 4.7.-4.8. Computer screen examples

```
  000 0000 THREE        [ ][FOUR]

                                                          STENOSIS CODE    STENOSIS %

          RCA DATA                                             1            0 - 24 %
                                                               2           25 - 49 %
                        BEFORE      AFTER                      3           50 - 74 %
  RAC-PROX                                                     4           75 - 90 %
  RAC-MID                    2          3                      5           91 - 99 %
  RAC-DIST                                                     6              100 %
  RPD
  COLLAT

                                                                  P = PROX
                                                                  M = MID
                                                                  D = DIST
  S    GRAFT OP   4    5    P
  S    GRAFT OP  12    4    M
  S    GRAFT OP  18         P
       GRAFT OP
       GRAFT OP
       GRAFT OP
```

```
  000 0000 FOUR        [ ][ ONE ]
                                                                  CODE


          LV DATA                                                  1          NORMAL
                                                                   2          HYPOKIN
                      BEFORE      AFTER                            3          DYSKIN
  SEGMENT1                 2          2                            4          AKIN
  SEGMENT2                 2          2                            5          ANEURYSM
  SEGMENT3                 2          3
  SEGMENT4                 2          3
  SEGMENT5                 2          2
  SEGMENT6                 2          2
  SEGMENT7                 2          2



               CONGENITALE VARIANT?       NO<
               PTCA?                      YES        DATE:

               TIME INTERVAL PRE-POST OHO ANGIOGRAM  52 WEEKS
                             PRE-OHO ANGIOGRAM-OHO    9 WEEKS
                             POST-OHO ANGIOGRAM      45 WEEKS
```

Fig. 4.9.-4.10. Computer screen examples

4.3. Computer data analysis

In order to enable all these data to be entered in a computer made available for this purpose, in consultation with and with the aid of the Automation Department (Head: Mr. J. Berghuis), a search was made for a suitable computer program to enable this multitude of information to be stored as computer data and then, on the basis of specific questions formulated in consultation with and by the programmer, to have these questions answered by the computer. In cooperation with Burroughs a special computer form was developed. This program ODESY (on-line data entry system) can be used as:

a. a 'front-end' to existing application systems;
b. an integrated data entry system for new applications requiring existence checks at the time of entry;
c. a method of providing simple inquiry facilities.

ODESY is primairly designed for the entry of batches of data which will later be processed by other application systems. Its auditing facilities enable the data to be checked for errors during entry and verifications, so that the application systems may process error-free data. Data entry is the transcription of information from original documents which will normally be some type of preprinted form, to a medium suitable for input to a computer.

The format of the preprinted stationary will have been defined over a period of time by the user's requirements and is not easy to change. Similarly, the format of the data supplied to the computer, which is determined by the program which processes the information, is very difficult to change without lengthy consultations.

During the entry phase the data are keyed in and ODESY applied the audit checks. If the data are correct, they are stored away in a batch, but if errors are found the field in error is marked and the data are returned to the operator for correction. (This procedure proved very helpful in avoiding false data entry). When the complete batch has been entered and verified, the operator schedules it for extraction (extraction is the process of creating the file required by the explanation system). It is an independent process, performed by a separate program and may take place while date entry is continuing. During extraction, the data may be completely reorganized.

4.3.1. INQUIRY FACILITIES

A user program interface is provided which serves two main purposes:

a. It helps the user to retrieve data from a master file and display it on the screen.
b. It allows checks against a master file to be performed upon the data entered.

In order to take advantage of these facilities a small program must be written by the user. This user programm will access the master files in response to messages from ODESY.

4.3.2. SECURITY

The security features have been designed to prevent unauthorized access to the system without being unduly obstructive to authorized users. There is an operator password system for logging in and a security level system to restrict the use of formats to qualified operators. In addition, certain commands may be restricted to supervisors. The security of a computer data entry is particularly important in the case of medical data. During this study, it became obviously impossible to open the system without using the new password system. This, in particular, makes computer entry of medical data very attractive.

4.3.3. STATISTICS

During data entry, ODESY is able to gather a wide range of statistical information. If the user wishes to analyse the throughput of this data entry operation, these statistics may be printed separately.

4.3.4. HARDWARE AND SOFTWARE REQUIREMENTS

The hardware requirements for B1000 ODESY are:

1. The use of a central processor memory. Minimum 36kB exclusive of system software (the main memory requirements are based upon the system parameters specification).
2. A disc subsystem.
3. A data communications subsystem.
4. A line printer.
5. A minimum of one terminal.

The only system software required is MCP (with the Stoque module) and NDL (Network Definition Language).

According to the figures 4.3 to 4.6 input of the patient data can start at once. First patient number, date of birth, date of operation(s), male/female, are introduced (fig. 4.3). On computerscreen 4.8 the data input of the coronary angiographic findings can be seen, starting with the LCA data. In the same way the RCA data, together with the graft(s) data are visible on screen example 4.9. On screen 4.10 the left ventricle data, together with some additional data have been introduced.

All data are stored and by using the data computer analysis program the immediate input of the coronary angiographic findings offers the opportunity to get a clear overview of the data at any moment you want.

4.3.5. TIME RELATION BETWEEN pre-CABG c.a.g./ CABG date/ post-CABG c.a.g.

In order to include the time relation between the pre- and post-c.a.g. and the CABG date in the study the data were entered into the computer via the computer form. An analysis yielded the results reported in table 4a.

Table 4a. Time between data of CABG and post-CABG c.a.g.

week(s)	year(s)	n	%
< 1		3	1
1		6	2
2		21	7
3		3	1
4		15	5
5-12		12	4
13-16		9	3
17-20		6	2
21-28		15	5
29-40		21	7
41-48		18	6
49-52		25	8
	1-2	73	24
	2-3	34	11
	3-4	15	5
	4-5	15	5
	5-6	6	2
	6-7	3	1
	>7	3	1

This shows that within one year after undergoing a CABG operation 154 patients were seen for a repeat c.a.g.,i.e. 51% (n=303).

With respect to the 1347 CABG operations this represents a percentage of 11.4%; almost 10% of these patients came back with complaints within 14 days after the CABG operations (=2.2% of the total number of CABG operations). Within one month after the operation this figure rose to 12.5%, with a peak during the second week post-operatively (6.9%). The greatest difference in time between the operation and repeat c.a.g. was 464 weeks (9 years). From the third year onwards 44 patients were seen, i.e. 14.5% of the group investigated and 3.2% of the total operation group. Some 25% of the patients were seen again post-operatively between the first and second years. The average duration between the pre-CABG angiogram and the post-CABG angiogram is 20 months (table 4b). The study also clearly showed that a number of patients came back between the second and sixth years, namely 22.7%, which must be ascribed to late reactions. In other words, atheromatous abnormalities in the grafts take place between two and three years post-operatively, which can influence the renewed occurrence of complaints. All this is described by, among others, Campeau - Lesperance - Bourassa (1979) and Pintar (1977). From the above figures it can be seen that in 25.5% of the CABG patients a post-CABG c.a.g. was made two years or more after the CABG operation.

Table 4b. Time interval pre-CABG c.a.g./post-CABG c.a.g.

week(s)	year(s)	n	%
<2		-	-
2		6	2
3-13		21	7
13-29		36	12
29-49		34	11
49-52		19	6
	1-2	95	31
	2-3	36	12
	3-4	18	6
	4-5	14	5
	5-6	9	3
	6-7	6	2
	>7	9	3

This shows that 116 patients, i.e. 38% of the group investigated, returned within a time interval of less than one year between the pre- and post-CABG angiograms. In 95 patients, i.e. 31% the interval is between 1 and 2 years, with a peak between the 53rd and 65th weeks (40 patients=13%). Between the 2nd and 3rd years 36 patients, i.e. 12% were seen. A total of 56 patients were seen from the third years onwards, i.e. 19%.

It is also important to investigate how much time elapses between the pre-CABG c.a.g. and the CABG date. (table 4c).

Table 4c. Time between CABG date and pre-CABG c.a.g.

week(s)	year(s)	n	%
less than 1		37	12
1		37	12
2		30	10
3		21	7
4		18	6
6- 9		39	13
9-13		21	7
13-28		54	19
28-49		24	8
49-52		13	3

Within one year after undergoing a pre-CABG angiogram 294 patients, i.e. 97% (n=303), underwent an operation. Of these, 46.5% were operated within one month and 85.5% within half a year. The remaining group was divided as follows:

1-2 years : 6 = 2.0%
2-3 years : 3 = 1.0%

The nine remaining patients who underwent an operation after one year, were operated according to the findings on their coronary angiogram made more than a year previously.

Chapter 5

Progression of the coronary arterial abnormalities

5.1. Distribution of coronary artery abnormalities

In this study, the division of the different diseased vessels was observed and compared with the figures in the international literature. Though a similar division into pre- and post-operative has not been found, pre-operative figures were available.

Own observation:	pre-operative n %	post-operative n %
1. Left main disease:	6= 2.0%	5= 1.7%
2. One-vessel disease:	21= 7.0%	16= 5.3%
RCA	6	3
LAD	14	12
CX	1	1
3. Two-vessel disease:	70=23.0%	62=20.5%
RCA + CX	10	8
RCA + LAD	38	8
LAD + CX	22	13
4. Three-vessel disease:	206=68.0%	220=72.5%

Pre-operatively, one-vessel disease and left main disease constitute a percentage of 9.0%, while multi-vessel disease represents 91.0%.

Post-operatively, some increase in three-vessel disease has been found, due to the progression of coronary artery sclerosis.

Lawrie et al. (1982) found a multi-vessel disease in 89.2%. Cosgrove et al. (1982) arrive at 90%. The European Coronary Surgery Study Group (1982) reports 93% and a left main of 7%, while Lawrie arrives at 11% left main disease. A comparison with the international literature is slightly more difficult since most studies are based on stenoses greater than or equal to 50%-e.g. Cosgrove et al. (1982), The European Coronary Surgery Study Group (1982) - while Lawrie et al. (1982), Hammermeister et al. (1982), Whalen et al. (1982) based their findings on significance stenosing if the stenosis was greater than or equal to 70%.

In spite of the fact that we named all the stenoses according to our stenosis code, our figures fit in well with the above mentioned figures.

Left main disease was found much less frequently than in most studies. One reason for this difference seems to be the fact that one vessel and left main vessel disease sometimes are additioned. To get a clear impression of coronary artery abnormalities, it is recommendable to use a uniform distribution and in our opinion left main disease should be separated from one-vessel disease.

5.2. Coronary artery abnormalities

In evaluating the coronary artery abnormalities, a survey of both the abnormalities in the LCA and in the RCA will be given.

5.2.1. ABNORMALITIES IN THE LCA:

Total abnormalities found: 960.
These can be subdivided as follows:

Abnormalities code	stenosis	pre-CABG	post-CABG
A-1 :	0 - 24%	116	8
A-2 :	25 - 49%	240	100
A-3 :	50 - 74%	307	233
A-4 :	75 - 90%	152	181
A-5 :	91 - 99%	76	118
A-6 :	100%	69	320
		960	960

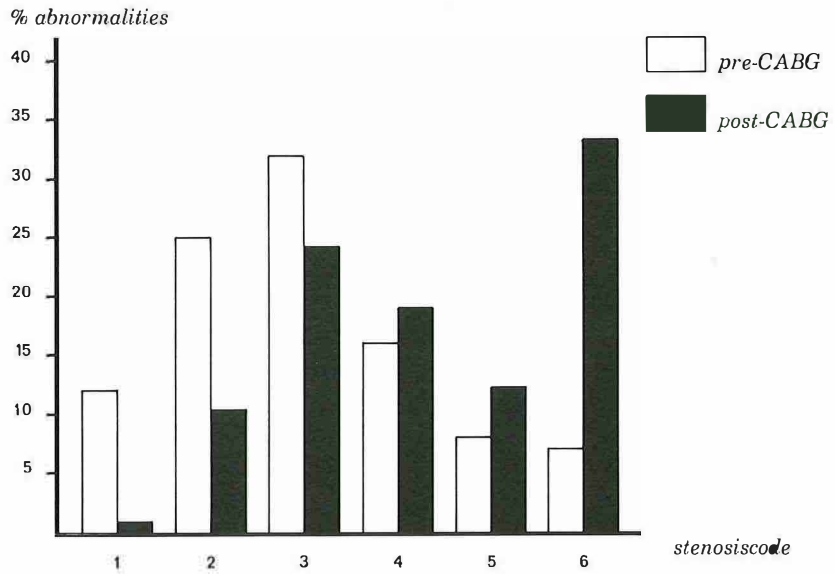


Fig. 5.1. Graph: Total number of abnormalities found in the left coronary artery, both pre- and post-operative.

Pre-operative 356 abnormalities, or <50% stenosis, were seen, i.e. 37%. The post-operative figure was 11.2%. The significant stenoses greater than 50%, amounted to 63% before operation, while post-operatively a percentage of 88.8% was found for stenoses greater than 50%, representing a total increase of 41%. Bourassa et al. (1982) arrive at 57%. If we look at the A-6 (=100%) stenoses we see pre-operatively 69 total stenoses, i.e. 7.2%; post-operatively 320 total stenoses, or 33.3%, an increase by a factor of almost 5 (fig.5.1.)

5.2.2. ABNORMALITIES IN THE RCA:

Total abnormalities found: 437
These can be subdivided as follows:

Abnormalities code	stenosis	pre-CABG	post-CABG
A-1 :	0 - 24%	101	4
A-2 :	25 - 49%	104	83
A-3 :	50 - 74%	96	81
A-4 :	75 - 90%	47	56
A-5 :	91 - 99%	30	66
A-6 :	100%	59	147
		437	437

Pre-operatively, the number of stenoses <50% was 205, i.e. 47%. Post-operatively, the number of stenoses was 20%.

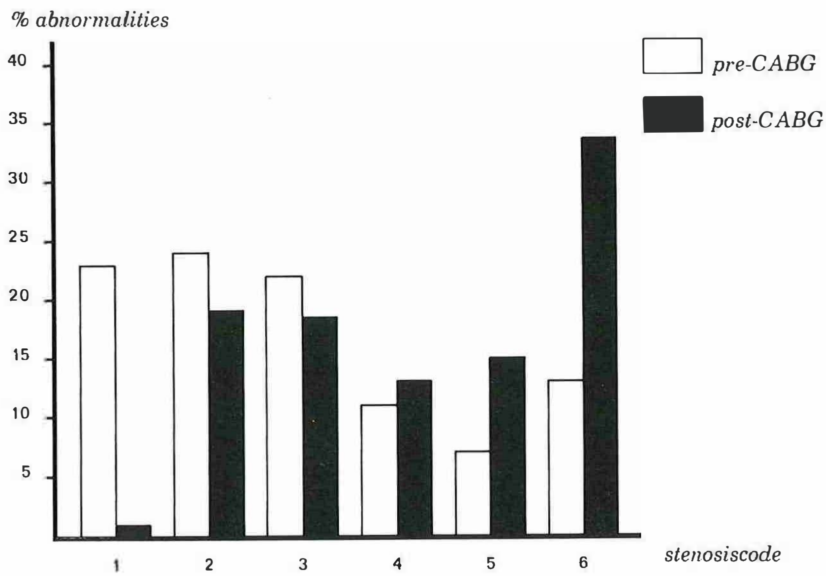


Fig. 5.2. Graph: Total number of abnormalities found in the right coronary artery, both pre- and post-operative.

The significant stenoses greater than 50% were therefore 53% pre-operatively and 80% post-operatively, an increase of no less than 51% which is mainly attributable to the increase in A-6 stenoses from 13.5% pre-operatively to 33.6% post-operatively. This is a percentage increase of 20% and a quantitative increase by a factor of almost 3. (Fig.5.2.).

Figure (5.3.) shows the abnormalities found in the left coronary artery, the right coronary artery and the left ventricle. The abnormalities are given for the different age groups into which the patients were divided.

The greatest number of LCA abnormalities is found in the group of patients born between 1919 and 1923, while the peak of the RCA and LV abnormalities coincides in the group of patients born between 1924 and 1928. A sharp decrease of abnormalities is seen in the group of patients born between 1929 and 1933. This also holds good regard to all of the abnormalities in LCA, RCA and LV.

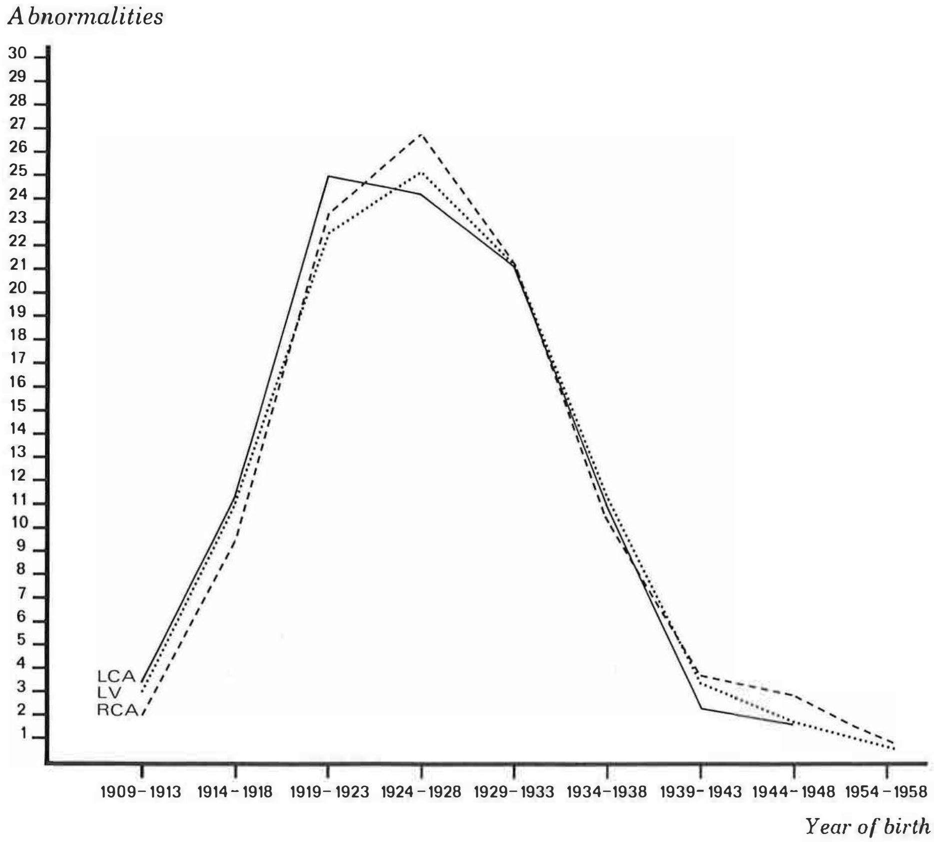


 Fig.5.3. Amount of abnormalities in the LCA, RCA and LV related to the year of birth

Computer data analysis makes it possible to investigate to what extent stenoses have occurred in vascular segments where no, or only very slight, stenoses were seen in the pre-CABG coronary angiogram. This relates to the group which comes under stenosis coding A-1 (0-24%). Although all the vascular segments were looked at and entered into the computer, some important vascular segments are selected for further examination.

5.3. Progression rate of the coronary artery stenoses

5.3.1. PROGRESSION RATE OF THE A-1 (0-24%) AND THE A-2 (25-49%) STENOSES

Table 5a.

Progression rate of the A-1 (0-24%) and the A-2 (25-49%) stenoses

	A-1			A-2		
	n(pre-CABG)	n(post-CABG)	progression rate	n(pre-CABG)	n(post-CABG)	progression rate
LAD prox.	10	3	30%	33	22	68%
mid.	18	6	33%	42	25	60%
dist.	16	14	87%	16	11	69%
D-1	12	6	50%	38	23	60%
MOCX	18	12	67%	24	18	75%
RCA prox.	19	6	32%	27	14	51%
mid.	36	20	56%	45	26	57%
dist.	38	24	63%	32	23	72%

Table 5a represents the progression rate of the A-1 stenoses, found pre-operatively, which became greater than 50%, post-operatively. According to international figures (Cosgrove-1982, Whalen-1982, Veterans Administration-1982, European Coronary Surgery Study Group-1982) the 50% reduction in luminal diameter is haemodynamically significant.

Discussion

In the international literature very little has been published about progression of stenoses in coronary arteries to which a graft has been stitched. Bourassa (1982) reports a percentage of 66% after 6 years of small lesions which became greater than 50%, which coincides with this study.
The highest progression rate has been found in the LAD dist., the vascular segment to which most grafts are stitched. The lowest rate was found in the RCA prox., the segment where never a graft is stitched (32%). Bourassa (1982) found a progression rate of 40% of the vascular segments to which no graft was stitched. The fact that a graft is stitched to a vascular segment seems to increase the probability of a rapid progression of stenosis, with a clear preference for the LAD.

In an identical manner the A-2 stenoses, pre-operatively, showed an increase into stenoses, greater than 50%, as can be seen in table 5a.

Once again, the progression rate is higher in the vascular segments to which a graft is stitched, especially in the MOCX and the RCA dist., equal to the progression rate found in the A-1 stenoses.

If we look at the figures for the stenoses smaller than 50%, pre-operatively (A-1 + A-2), a subdivision can be made (table 5b).

Table 5b

stenoses < 50%	pre-CABG	post-CABG	progression rate
LAD total	30%	11%	42%
RCA total	47%	20%	51%
MOCX	39%	11%	48%
CX	44%	12%	57%

According to the figures of Bourassa et al. (1982) and Lawrie et al. (1982) who reported progression of lesions greater than 50%, in 50% and nearly 60% respectively, the figures found in this study fit in well with these reports.

5.3.2. PROGRESSION RATE OF THE A-3 (50-74%) STENOSES

As mentioned before many investigators internationally regard a stenosis attempting to greater than 50% as haemodynamically significant.
The progression rate of the A-3 stenoses have been deliberately investigated with respect to the most important vascular segments identical to the figures found with respect to the A-1 and A-2 stenoses. (table 5c).

Table 5c.

	nb**	na*	progession rate (stenoses > than A-3)	total occlusion
LAD prox.	51	29	57%	18% (n= 9)
mid.	69	55	80%	35% (n=24)
dist.	23	14	61%	26% (n= 6)
D-1	42	32	75%	32% (n=13)
MOCX	30	24	83%	50% (n=15)
RCA prox.	29	20	69%	13% (n= 8)
mid.	45	32	71%	25% (n=11)
dist.	21	14	67%	19% (n= 4)

In this table the progression rate of A-3 stenoses, post-CABG, into stenoses greater than 50%, is high and once again those segments closely related to a graft in that particular area show a higher percentage of progression.

** number of A-3 stenoses, pre-CABG.
* number of stenoses, > A-3, post-CABG.

5.3.3. PROGRESSION RATE OF A-4 (75-90%) STENOSES

Stenoses greater than 75% are very important from a haemodynamical point of view. A 75% diameter decrease gives a cross-sectional decrease of 95% (van der Werf-1974; Lawrie-1982).

Table 5d

	nb**	na*	progression rate (stenoses > than A-4)	total occlusion
LAD prox.	23	15	65%	39% (n= 9)
mid.	47	41	87%	77% (n=36)
dist.	6	5	83%	50% (n= 3)
MOCX	17	10	59%	53% (n= 9)
RCA prox.	17	14	82%	53% (n= 9)
mid.	17	15	88%	71% (n=12)
dist.	13	10	77%	46% (n= 6)
D-1	18	12	67%	61% (n=11)

** number of A-4 stenoses, pre-CABG.
* number of stenoses, > A-4, post-CABG.

5.3.4. PROGRESSION RATE OF A-5 (90-99%) STENOSES

This results in a total occlusion of that particular segment. The next table shows this in more detail.

Table 5e

	nb	progression rate (=total occlusion)
LAD prox.	14	57% (n= 8)
mid.	28	64% (n=18)
dist.	7	88% (n= 6)
MOCX	10	40% (n= 4)
RCA prox.	7	29% (n= 2)
mid.	16	69% (n=11)
dist.	5	20% (n= 1)

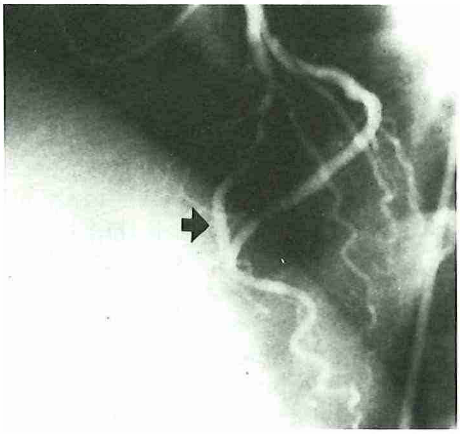


Fig.5.4. Same LAD, occluded after CABG

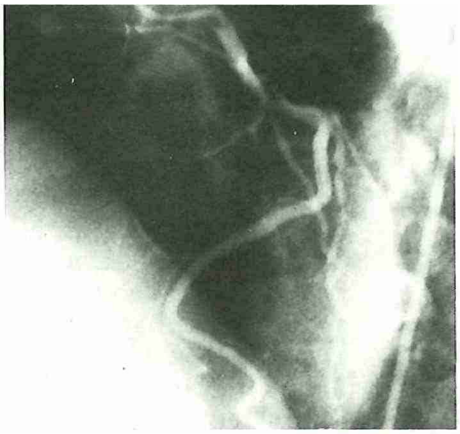


Fig.5.5. LAD pre-CABG patent

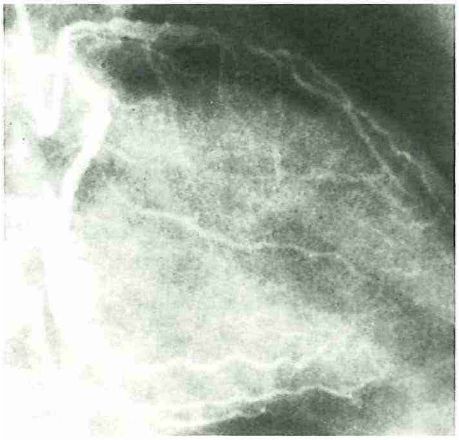


Fig.5.6. Pre-CABG. LAD and and CX patent

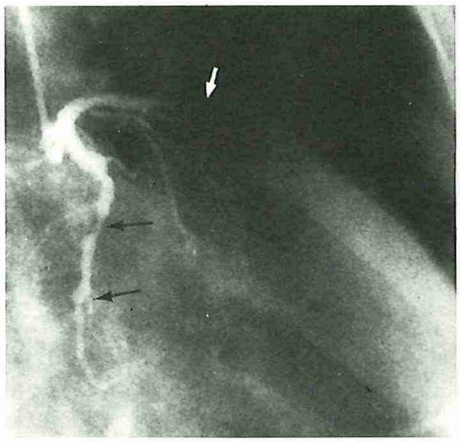


Fig.5.7. Post-cabg. LAD and CXPL occluded. Severe stenosis in CX

The RCA mid. shows the highest increase in occlusion with respect to the RCA as a whole. This segment is closely related to the graft stitched to the RCA and is more frequently involved in the tide phenomenon, which seems to be an important factor in the rapid progression of arteriosclerotic lesions.

5.3.5. From a haemodynamic point of view the total occlusions (A-6) stenoses are the most important stenoses (fig. 5.4-5.7), while distal run-off in the coronary artery now depends on the blood supply from the bypassed graft.
Pre-operatively 69 A-6 stenoses were found, while this number increased to 320 A-6 stenoses. Approximately 46% of these stenoses were found to be present in the LAD. In the LAD mid, the vascular

segment just situated proximally from the graft anastomosis, the most LAD total occlusions were seen, namely 76%.

The LAD counts for 51% if we look at the total number of A-6 stenoses in the LCA. Bourassa et al. (1982) arrived at a figure of 57%.
The increase in A-6 stenoses in the LAD dist., where virtually all the grafts are stitched, is much less pronounced than that in the LAD prox. and LAD mid. In terms of percentage, in the LAD dist. there was even an decrease from 7% to 6%. This figure is closely related to the figure of 8% found by Bourassa et al. (1982).
A striking feature is the virtually equal number of A-6 abnormalities in the D-1, compared with the LAD prox., both pre- and post-operatively. The progression of arteriosclerotic lesions seems to be closely related to those in the LAD prox., where the segment D-1 arises from.
In quantative terms there is an increase of A-6 stenoses by a factor of 5 if we look at the MOCX, post-operatively.

In the RCA the most A-6 stenoses are present in the RCA mid., 50%. The number of total occlusions in the RCA increases post-operatively by a factor of 3. The high amount of A-6 stenoses in the RCA mid. can be explained in the way as the high percentage of A-6 stenoses in LAD mid. Both segments are situated proximal to the graft anastomosis, in which the tide phenomenon seems to be of great importance.

The arteriosclerotic progression in the coronary artery segments distal to the graft anastomosis is nearly the same as the figures found in the proximal segments as regards stenoses smaller than 50%. Stenoses greater than 50% show a progression which is less high than the figures found in the proximal segments. Distal to the grafts nearly 2.0% new lesions were found, while Bourassa et al. (1982) reports 2.4% new lesions distally.
Once again it must be remembered that the figures found in this study relate to CABG patients who had a recurrence of angina.

5.4. Progression of coronary artery abnormalities related to the NYHA classification

In order to investigate a possible relation between the seriousness of the complaints, divided into the NYHA classification, and the increase of luminal narrowing of the native coronary arteries, post-operatively, they were compared with one another. Both the LCA and the RCA were investigated. The haemodynamically most important stenoses were observed, 50% and 100%, respectively.

Table 5f.

NYHA classification	II		III		IV	
LCA lesions in %:	pre	post	pre	post	pre	post
lesions > 50% :	59	90	64	84	78	98
A-6 = 100% :	8	33	5	27	8	52
RCA lesions in %:						
lesions > 50% :	46	71	73	85	39	93
A-6 = 100% :	12	30	16	42	14	31

Discussion

As would be expected the stenoses, greater than 50%, were found to be present in a higher percentage in NYHA IV patients, both pre- and post-operatively. However, the progression rate showed a higher percentage in NYHA II patients.

In the RCA most lesions, greater than 50%, were found to be present in NYHA III patients, pre-operatively, while post-operatively most of these lesions were found in NYHA IV patients.
A nearly identical division of the total obstructions (A-6) in the NYHA groups was found to be present, pre-operatively, while post-operatively most of the A-6 lesions were present in the NYHA III patients.
This is probably due to the fact that most lesions, greater than 50%, pre-operatively, were present in the NYHA III group.
Summarizing it has been made clear that the progression of stenotic lesions is closely related to the severity of the complaints, subdivided into the NYHA classification.

5.5. Left ventricular function

At present, the contrast ventriculography is still the standard investigation technique and the best method for observing the function of the left ventricular (LV) wall.
Though computer systems are available for quantitative analysis of the X-ray image they were not used in this study.
A good knowledge of the ventriculogram, shown on the cine-analyser, gives the observer a fairly good impression of the LV function (Kennedy-1970; Levin et al.-1982).

A subdivision is made into:

1. normal.
2. hypokinesia : generalized or local reduction in ventricular contraction.
3. dyskinesia : paradoxal systolic expansion.
4. akinesia : a total lack of motion of a part of the ventricular wall.
5. aneurysm : dilatation and non-movement of a myocardial segment.

Within the context of this study it seemed interesting to investigate how the various LV segments behaved after the CABG operations. For this purpose a computer data analysis was drawn up which enabled answers to the following questions:

Which LV segments show an akinesia pre-operatively; what abnormalities do the vascular segments and the related grafts show in this respect?

Which LV segments show an akinesia post-operatively, while there was a normal LV function pre-operatively and could this be related to the vascular segments and grafts related to these segments?

Which LV segments show an aneurysm post-operatively and what abnormalities do the vascular segments and the related grafts show in this respect?

The total amount of information is too much to analyse in detail in this study. Nearly a complete new study can be performed with these data and therefore we will give some examples of LV data analysis in order to give an impression of what kind of information one can gather by using an up to date computer data analysis program as we have been using.

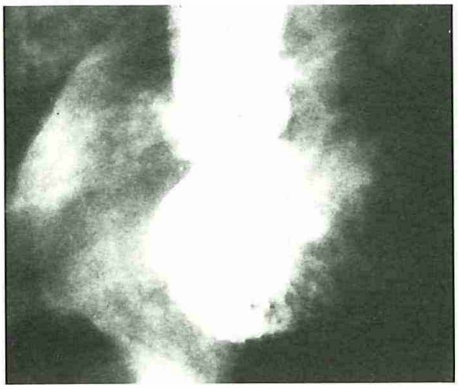


Fig. 5.8. Normal LV in LAO position

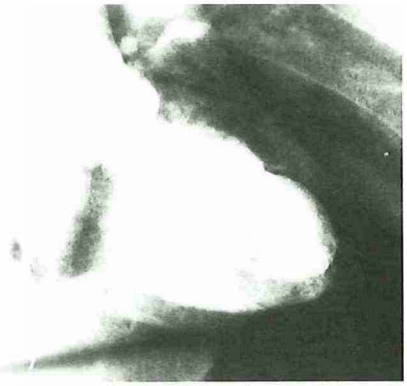


Fig. 5.9. Normal LV in RAO position

5.5.1. MATERIAL

In this study 2089 ventricular segments were investigated. The following distribution was found:

	pre-CABG	post-CABG
normal	66.4%	48.0%
hypokinesia	29.4%	37.1%
dyskinesia	0.1%	0.1%
akinesia	4.0%	12.8%
aneurysm	0.1%	2.0%

We compared these figures with international data and concluded that in the present study 67% of the patients presented a normal LV function pre-CABG.

	normal function pre-CABG
Lawrie et al. (1979)	66%
Cosgrove et al. (1979)	46%
Kennedy et al. (1982)	47%
European Coronary Study Group (1980)	42%

A study by Buis (1974) showed no change in LV function, post-operatively in 50-60%, while some 30% showed a detoriation. Kolsters (1977) reports a detoriation in 27%, while in this study this percentage was 26%.

In particular, akinesia of the LV segments and aneurysms increased by a factor of 3 and a factor of 20, respectively.
We found no improvement in LV function but this is not surprising because in the patient group we studied all returned because of a recurrence of angina and therefore belonged to a selective population.

As mentioned before some examples of data analysis with respect to the LV function changes, both pre- and post-operatively, will be given.

An interesting and often affected segment is segment 3 (apex cordis).
A total of 299 segments 3 were investigated.

Segment 3 (apex cordis);

		pre-operative	post-operative
normal	:	156	86
hypokinesia	:	131	157
akinesia	:	12	34
aneurysm	:	-	22

Reviewing these data we found out that the normal segments 3 changed, post-operatively into:

normal	55%	akinesia	4%
hypokinesia	38%	aneurysm	3%

The same division can be made for the segments 3 which were hypokinetic, pre-operatively, and changed post-operatively into:

hypokinesia	74%	akinesia	13%	aneurysm	13%

Pre-operative normal wall motion of the anterior wall and apex shows a change in function in about 40% (hypokinesia 35% - 2.5% akinesia - 2.5% aneurysm). Basal wall motion changed from normal to hypokinesia in 24%; 6% became akinetic.

Pre-operative hypokinesia of segment 2 changed post-operatively into 17% (akinesia in 11%; 6% aneurysm).

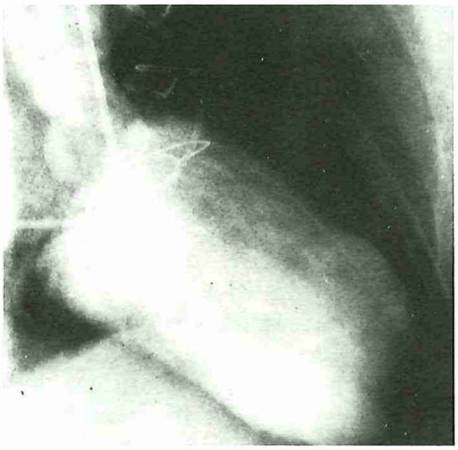


Fig. 5.10. Akinesia segments 2-3-4 diastolic phase, pre-CBAG

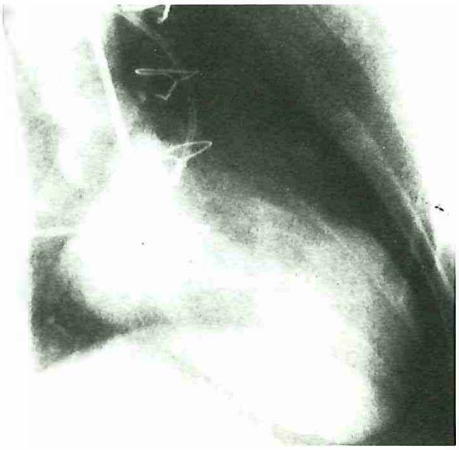


Fig. 5.11. Same LV, systolic phase

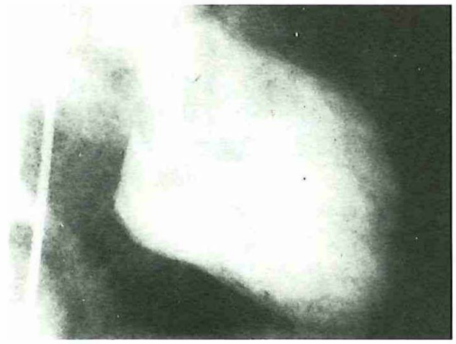


Fig. 5.12. Severe akinesia segments 4-5 with only a 35% stenosis in the LAD. Systolic phase

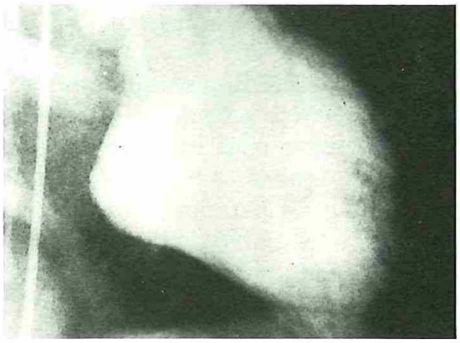


Fig. 5.13. Same LV, diastolic phase

The apical segment shows a change in 26% (akinesia and aneurysm in both 13%. Segments 4 and 5 changed in about 52% of the cases into akinesia (51%) and aneurysm (1%).

To sum up, akinesia has been found more frequently in segments 4 and 5 when these segments were normal pre-operatively. Hypokinesia was seen more at the anterior wall and apex. These figures were even more striking if hypokinesia was found pre-operatively. Akinesia was seen significantly more in segments 4 and 5 than in segments 2 and 3. The apical segment showed more aneurysm than the other segments.

In order to obtain some idea of the change in left ventricular function post-operatively, a program was compiled in which each segment could be examined separately, coupled to both the vascular abnormalities and the grafts which were sutured to the relevant vascular segments. This permitted the change in the relevant ventricular segment, the abnormality in the vascular segment and any stenosis in the graft or grafts to be read off.

Akinesia (fig. 5.10-5.13) of segment 3, pre-operatively, was related to 173 abnormalities in the coronary arteries, divided in the LCA and the RCA, 71% and 29%, respectively. The significant stenoses (A3-A6) represent 62% of the total in the pre-CABG period, while post-CABG this percentage increased to 89%.
In the pre-CABG period no MOCX abnormalities, with respect to akinesia of segment 3 was present, but post-CABG 15% of the abnormalities were found to be MOCX lesions. The lesions in the LAD and D-1 were, percentage-wise, nearly equal, both pre- and post-CABG, namely 43% and 59% respectively. In quantitative terms the number of MOCX lesions showed a rapid increase, followed by the LAD prox. With respect to the RCA it was pointed out that 2.5 times more total RCA occlusions, especially in the RCA mid., were present.

Proceeding we can analyse the patency (patency is the condition in which a venous graft remains open, Chapter 6) of the grafts which were used in those patients who showed an akinetic segment 3. A total of 73 S grafts were used, having a graft patency of 58%. The graft patency of the 11 Sn grafts used was 100%.
Compared with the overall patency of the S grafts the patency found here was 15% lower. If we also include the significant stenoses in this way, we see that 58% of the S grafts show definite changes in flow.
It is possible to analyse where these grafts stenoses can be found, i.e. prox., dist. or mid.

By studying the apex cordis it seems interesting to know what happened to the akinetic segments 3, found pre-CABG and stayed akinetic, post-CABG, regarding the grafts used. The graft patency was found to be 45% and if we include the haemodynamically significant stenosis in this, i.e. from A-3 onwards, it proves that a very marked limitation of the graft flow is present in 69% of the grafts used. This knowledge can influence the answer to the question of wether the relevant patient should or should not have a coronary artery bypass operation.

According to the grafts, the next step in the graft patency evaluation is to analyse the flow rate in the grafts, which, again by computer data analysis was possible.
Taking again the akinetic segments 3, we found out that in patent grafts, the ratio of the flow rate lower than 40 cc/min. to the flow rate greater than 40 cc/min. is the same as this ratio in the occluded grafts (flow measurement per-operatively).

We can therefore conclude that the flow rate is not the main factor in low graft patency in this particular situation. The progression in arteriosclerosis is probably the main cause in this patency rate.

In akinesia of segment 5 (posterobasal), pre-operatively, 50 S grafts were used and during this study a graft patency of 68% was found. Flow rate study here showed that in patent grafts, the ratio of grafts with a flow rate lower than 40 cc/min. to grafts with a flow rate greater than 40 cc/min. is 1:3.5. This ratio in later occluded grafts was found to be 1:1 so in patent grafts the flow rate is an important factor in patency, while in the occluded grafts another factor or factors influenced their occlusion in which the progression of arteriosclerosis of the native coronary artery is an important factor.

As an example figure 5.14 has been produced. The graft patency has been plotted out against the akinetic LV segments, investigated in this study.
Both the akinetic segments, pre-CABG, and the akinetic segments, post-CABG were analyzed in order to find out how many grafts and what types of grafts were used. In this way it became possible to say something about the patency rate of grafts in a prospective way. It already has been pointed out that an abnormal LV funktion, found pre-operatively, tends to a less positive operation result.

The graft patency figures in akinesia both pre- and post-operatively can be plotted in a graph:

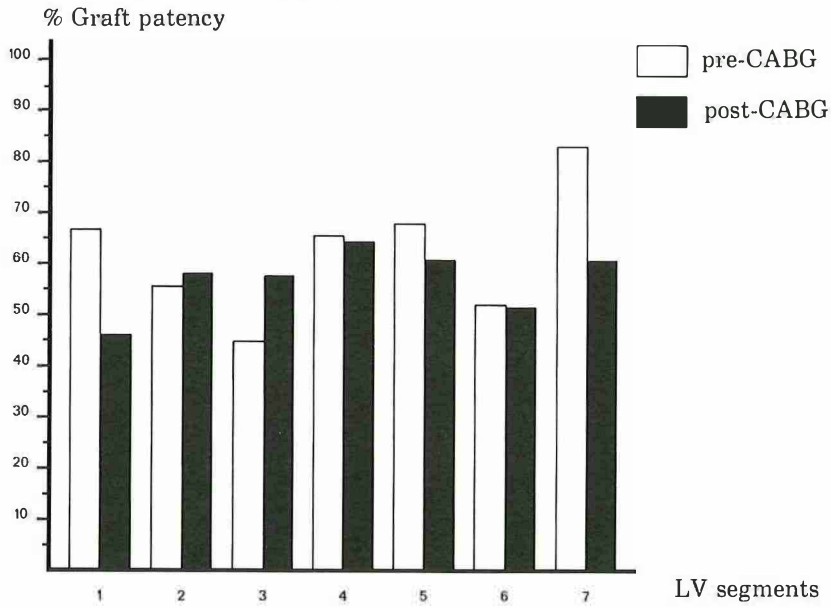


Fig. 5.14. Graft patency, post-operative, when pre-operative akinesia of LV segment(s) was present, versus graft patency, when post-operative, akinesia of LV(s) was present

In regard to some segments a discrepancy in graft patency is seen both pre- and post-operatively, while some other segments show virtually the same graft patency (segments 2, 4 and 6).

Chapter 6

Graft patency evaluation

Graft patency, i.e. the condition in which a graft remains open after it has been made, has been the subject of countless studies, many of which are quoted in the present study. A closer study of graft patency was made in our research, too, since it constitutes feedback for both the surgical action and for pathological processes which can influence this patency.

Surgical procedures

The first attempt at surgical therapy on the coronary arteries was introduced by Vineberg and Miller (1948), who implanted the left internal mammary artery into the myocardium. Because of the apparently small increment of blood flow to the ischaemic heart and its dubious long-term effect upon the relief of angina other procedures were sought. In 1964 Garret carried out the first successful venous aorto-coronary bypass grafting, popularized by Favaloro and Effler after 1967. Kolessov et al. (1967) performed the first anastomosis from the internal mammary artery to the coronary artery, followed by Bailey in 1968.

The most common procedure nowadays is to use a segment of the saphenous vein from the patient's lower leg for making an aorto-coronary bypass. The saphenous vein is reversed so that the valves become incompetent and it is then placed between the aorta and the distal segment of a coronary artery, thus bypassing the obstruction.
The anastomoses to the coronary artery are performed under extracorporal circulation and hypothermia. Usually, several grafts are needed to obtain complete or optimum correction, i.e. by bypassing the obstructed major arteries and their primary branches. A single bypass on a coronary artery is attached by an end-to side anastomoses. Grafts with multiple sequential coronary anastomoses are also frequently used and are attached by a side-to-side anastomosis.
The venous graft should not be too short, while retraction produces tenting or kinking of the recipient coronary artery segment. After the bypass is completed, the flow rate through the graft is measured, peroperatively, with an electromagnetic flow indicator.

Factors which play a role in graft patency are:

1. Biological factors: fibroplasia/thrombosis.
2. Physiological factors: distal run-off; progression of arteriosclerosis of the coronary vessels.

3. Operation trauma on the vessels: technical problems/inadequate operation experience.

The flow rate plays an important part in graft patency and is described by various researches (Buis-1974, Campeau-1982). It is stated that a flow rate higher than 40 cc per minute through a graft causes an increase in graft patency.
All this corresponds with the results in the present study. The changed flow situation is also important. The flow in the graft reacts with the one in the relevant coronary vessel and thus brings about interactions. These interactions have already been described as the 'tide phenomenon' in chapter 2.
The findings reported on the following pages relate to graft patency and changes in grafts, the distribution of the grafts by point of attachment, and stenoses.

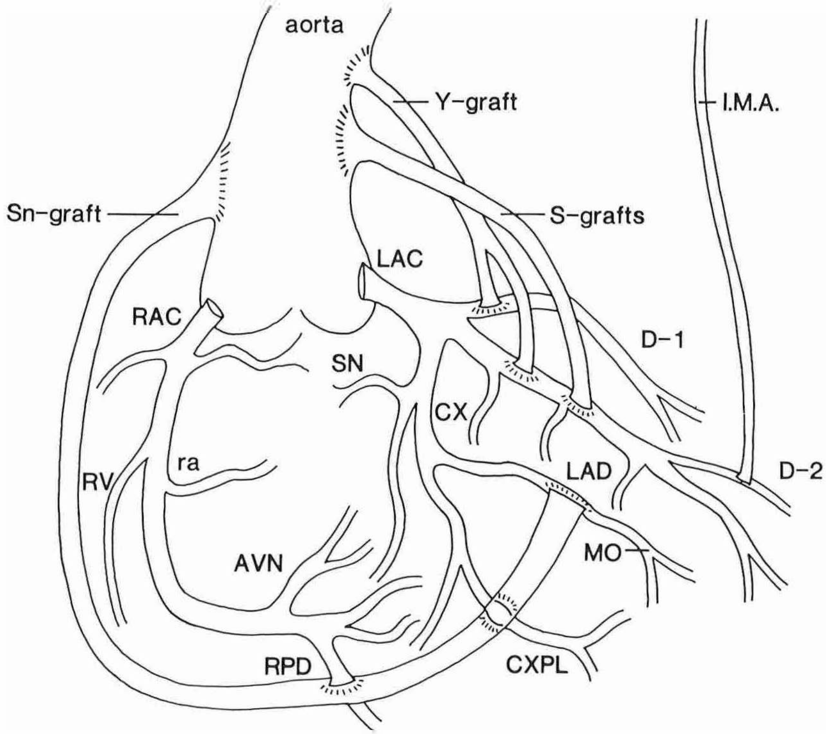


Fig. 6.1. schematic drawing of the different type of grafts

6.1. Types of grafts

In this study, the various grafts were named as follows, see also figure 6.1.

a. S = single graft (fig. 6.2-6.3)
This relates to a graft in which an end-to-side anastomosis is made with the coronary artery.

b. Sn = snake graft (fig. 6.4)
In which a side-to-side anastomosis is made with the various coronary artery branches. This type of graft is also termed a sequential graft.

c. Y graft (fig. 6.6)
Y is a graft in which the division of the graft from the aorta occurs in two side branches, with these branches being stitched to various coronary artery branches.

d. IMA (= Internal Mammary Artery) (fig. 6.5)
Since this branch is used almost exclusively from the left, the term LIMA graft is also used sometimes . The distal end of the Internal Mammary Artery (IMA) is stitched to a coronary artery, bypassing the obstruction. Because the anastomosis from the IMA to coronary artery is technically more difficult and provides smaller flows, this procedure is restricted in most centres to small anterior descending arteries (LAD) or to patients in whom suitable veins are not available. The advantage of the IMA is that its patency rate is very high and only one anastomosis is needed.

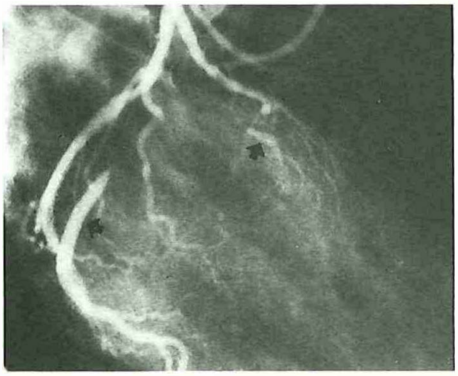


Fig.6.2. visualization of two S grafts stitched to the CX and to the LAD

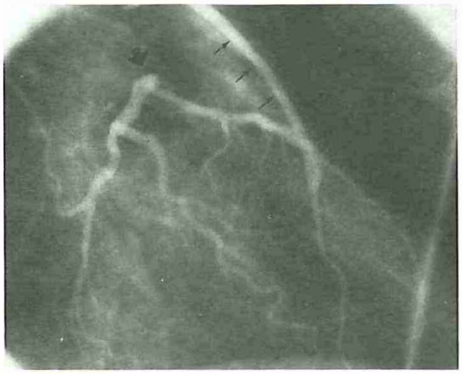


Fig.6.3. S graft stitched to the LAD distal. Left main occlusion

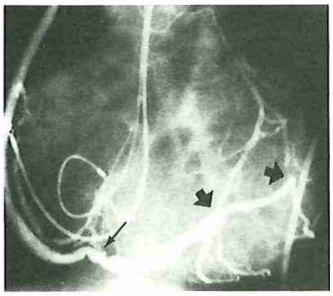


Fig. 6.4. Sn graft, stitched to RPD-CXPL-MO

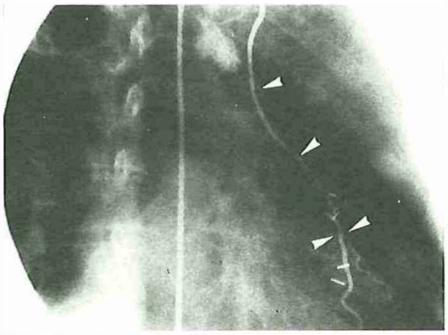


Fig.6.5. I.M.A., stitched to LAD distal

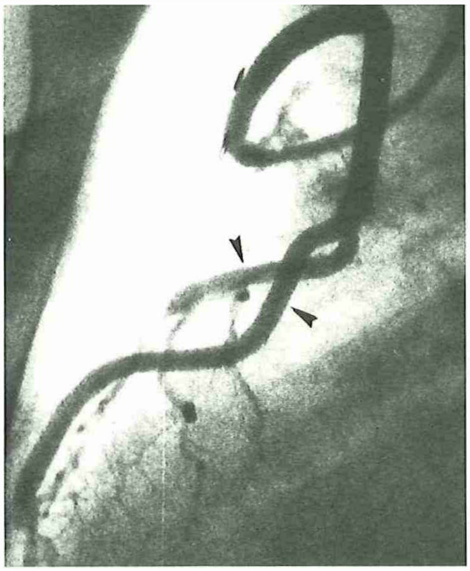


Fig.6.6. Y-graft, stitched to the LAD and D-1

6.2. Graft patency

In this study the various types of grafts, -Single, Snake, Y and IMA- are the subject of graft patency evaluation.

The figures found are related to the international figures. Once again it must be pointed out that the patients in this study are suffering from renewed heart complaints.

In this study 693 grafts were used in 303 operations. Compared with the international literature we came to the following figures (table 6a).

Table 6a

		number of grafts per patient
Lawrie et al.	(1982)	1.7
Takaro et al.	(1982)	2.0
Laird-Meeter.	(1980)	3.0
Bourassa et al.	(1982)	2.1
Cosgrove et al.	(1979)	2.7
European Group	(1982)	2.4
Bijlsma	(1986)	2.3

Classification of the grafts used.

S grafts	: 612
Sn grafts	: 62
Y grafts	: 10
IMA	: 9

The total number of occluded grafts was: 186. The following distribution was found in this respect:

Number of occluded S grafts	: 179.	Graft patency:	70.8%	(n=612);
Number of occluded Sn grafts	: 6.	Graft patency:	90.0%	(n= 62);
Number of occluded Y grafts	: 0.	Graft patency:	100.0%	(n= 10);
Number of occluded IMA grafts	: 1.	Graft patency:	89.0%	(n= 9).

Calculating the overall graft patency we arrive at: 73.2%. In order to interpret this graft patency in more detail it is necessary to involve the time which elapsed post-operatively. The figures then give a somewhat different picture.

If we now include these figures in the graft patency described above we arrive at (table 6b).

Table 6b.
Graft occlusion related to the number of years, post-CABG

year	occlusion rate	patency rate
1	12.5%	87.5%
1-2	7.5%	80.0%
2-3	2.0%	78.0%
3-4	1.2%	76.8%
4-5	3.6%	73.2%

Walker (1971) found a direct occlusion post-operatively in 12% of the grafts and ascribes this to faulty operation technique; the percentage of late occlusions of grafts in his study was 13%, so that a total graft patency of 75% was found. Sheldon et al.(1972) found a patency of 83.7% after 25 months. Buis (1984) found a direct patency of 83% and a late patency of 74% (52 months). In an 11-year evaluation Loop et al. (1979) found a graft occlusion of 20% in the first year post-operatively, while Guthaner et al. (1978) and Epstein (1978) also arrived at identical figures. Bourassa et al. (1982) found a patency of 74-85% at 52 weeks post-operatively and between one and six years post-operatively a decline of 2.2% in patency per year.

The European Coronary Surgery Group (1982) reports 10% occlusion during the first nine months and 23% between nine and 18 months. A further graft occlusion of 2.5% per year was also found. Loop et al. (1982) found a graft patency of 87.0% during the first year (CASS report). Lawrie and Morris (1982) conclude that there is a decline in graft patency of 1.0% per year and record a first-year patency of 86.4%. Sheldon et al. (1980) found a patency of 71.7% in patients who had been operated on between 1967 and 1970, while a repeat of this study in 1980 showed an overall patency of 84% in the first year and 77% after four years. This is attributed to the increased experience of the operating surgeons.
Our figures fit in well with these international data.

6.3. Changes in grafts

The consecutive angiographic evaluation of grafts can be described as follows.

6.3.1. CLASSIFICATION IN STENOSIS CODING

Since the occluded grafts are not the only important ones, we also looked at the other stenoses which occurred in the grafts.
For example, the stenoses both in the S en Sn grafts (fig. 6.7-6.10) were studied. (table 6c).

Table 6c		S grafts		Sn-grafts
stenosis code	n	%	n	%
A-6	179	29%	6	10%
A-5	18	3%	4	6%
A-4	26	4%	5	8%
A-3	34	6%	8	13%
A-2	3	0.5%	3	5%
A-1	352	57.5%	36	58%
Total	612		62	

If we start the assumption. which is most commonly used internationally, that a stenosis of 75% or more results in marked changes in flow, we see that in this study 36% of the S grafts show such changes. Graft stenoses, occlusion excluded, show changes in luminal diameter greater than 50% in 13% of the grafts.
Bourassa reports segmental stenosis greater than 50% in 15% of the patent grafts.

Graft stenoses in patent grafts greater than 50% occurred in 27% of the patent Sn grafts, which is proportionally nearly twice as many as in the S grafts.
Multiple anastomoses are probably responsible for the higher stenosis percentage.

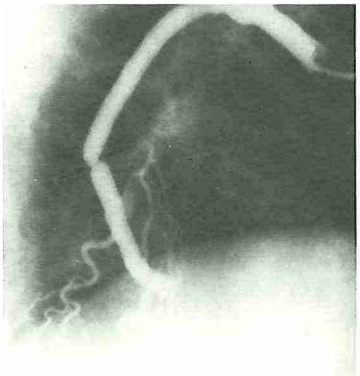


Fig. 6.7. Stenosis in Sn graft stitched to CX distal - CXPL-MOCX

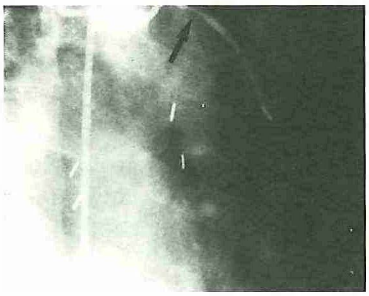


Fig. 6.8. Stenosis proximal in S graft on LAD distal

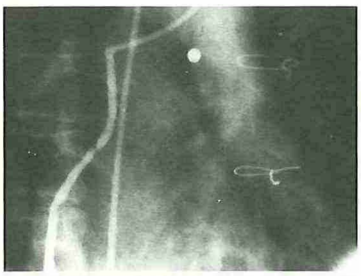


Fig. 6.9. Subtotal stenosis in S graft on the RCA

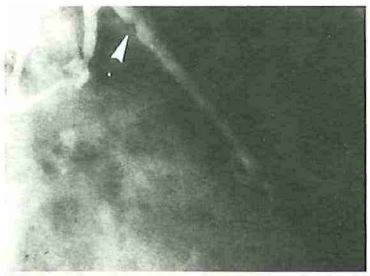


Fig. 6.10. Stenosis proximal in S graft on the LAD

In order to compare changes in grafts within one year after surgery, these changes were classified (table 6d).

Graft changes within one year after CABG:

Table 6d	A-1	A-2	A-3	A-4	A-5	A-6
0- 4 weeks:	1	11	5	3	2	23
5-12 weeks:	-	3	1	1	-	10
13-26 weeks:	-	4	13	6	6	23
27-42 weeks:	-	3	3	2	1	19
43-52 weeks:	-	5	4	4	2	12
Total	1	26	26	16	11	87

Bourassa et al. (1982) found graft changes greater than 50% within one month after surgery in 5% of the patent grafts. In this study 2.0% was found. One year after surgery 10% of the patent grafts showed a stenosis greater than 50%, while Bourassa found 9%. Early patency in our study was 96%, while Catinella (1982) found 89%. He found a patency difference between graft preparation with heparinized blood and with electrolyte solution with added paverine, in which respect the latter gave better results.

Early occlusion and stenoses in grafts are due to thrombosis and surgical technique. During the first year after surgery total occlusion in grafts was found to be 12.5%. Together with the 10% of the patent grafts with a stenosis greater than 50%, 22.5% of the grafts show significant flow reduction, which seems to be responsible for the (re-)occurence of complaints.

In order to obtain a better overview, a classification was made according to the number of grafts per patient, as well as by the type of grafts and the coronary artery segments to which the graft(s) were stitched.

6.3.3. RESULTS

After surgery 156 patients (=51.5%) showed at least one graft occluded. Of the total number of occluded grafts, some 70% were stitched to vascular segments of the LCA, the LAD accounting for over 26%, followed by the MOCX with 21.5%, while over 30% of the occluded grafts were stitched to the RCA. If we look at the LAD as a whole, we find that 236 grafts were stitched to the LAD, 58 of which were completely occluded, representing a graft patency of 75.5%.

receiving vascular segment	patency rate
LAD mid:	63%
LAD dist:	77%
RCA:	68%
MOCX:	62%
D-1:	75%
D-2:	67%
IM:	67%
CXPL:	58%

6.3.4. DISCUSSION

To compare the figures found in the international literature it is important to know what description the author uses when he speaks about graft patency.
Is it the early patency or the patency rate after a defined period of time and to what kind of grafts is the specific patency rate related?
In studying the literature it became obvious that one should use the same definitions.
In our opinion this can be achieved by using both time and type of graft in relation to the mentioned graft patency.

According to research done by Cosgrove, Loop and Sheldon (1982) the patency rate in 1970 was 74.9% and in 1974 it worked out at 83.7% In conformity with their findings, it turns out here too that the patency rate for grafts to the LAD is higher than that for grafts to the RCA and the MOCX. As already mentioned, Guthaner et al. (1979) came to the same conclusion.

Walker (1972), Effler (1971) and Favaloro (1971) attribute the direct occlusion of a graft to faulty operation technique, while Bourassa and Campeau (1982) mainly ascribe very early occlusion to thrombosing in the graft. Late occlusion is regarded by many (Sheldon, Edwards, Vlodaver, Campeau, Bourassa) as a consequence of an intimal proliferation.

It has also been found that S grafts, i.e. end-to-side anastomoses, have a higher occlusion percentage than side-to-side anastomoses of the Sn-grafts. (Guthaner et al. 1979). This experience is shared by us. The St. Antonius Hospital in Utrecht (ANU) found a Sn-graft patency of 93% during the period 1977-1979 (Bruschke et al. 1980). In addition, the localisation of the graft at a particular vascular segment is said to be important.
Guthaner et al. (1979) found that grafts to the LAD stay open longer than grafts stitched to the CX or MOCX. Campeau (1979) and Pintar (1979), among others, have described atheromatous abnormalities in grafts which are regarded as a late reaction. Kouchoukos (1978) has also described this a late reaction. Kouchoukos

(1978) has also described this late occlusion after three years, for which he found a percentage of 5% per year.

6.4. Graft patency evaluation and NYHA classification

In order to investigate the relation between the seriousness of the complaints of our patient population and the abnormalities found on the coronary angiogram, pre- and post-operatively, a subdivision according to the NYHA classification was made.

NYHA	% of the patients
II	44%
III	44%
IV	12%

In relation with the total amount of grafts, used in these patients, the following division was made. (table 6e)

Table 6e

NYHA	total grafts	S-grafts	S-grafts (occluded)	Șn	Sn (occluded)	Y	IMA
II	304	267	60	31	2	2	4
III	285	250	61	27	4	6	2
IV	104	95	58	4	-	2	2(1)
Total	693	612	179	62	6	10	8(1)

For the different NYHA classifications the graft patency rate can be calculated.

NYHA	graft patency rate
II	80%
III	77%
IV	42%

Discussion

In this study an overall patency rate of 73.2% was found. There is a marked difference between the patency rate found in the NYHA II and III patients on one hand and the graft patency rate in patients belonging to the NYHA IV class on the other hand, which was significantly lower.

The patency rate in the IMA grafts in our study has found to be 89%, while Cosgroove et al. (1982) recorded a percentage of 94.5% and Loop (1981) reports 97% with regard to the IMA grafts. In IMA grafts, hyperplasia or accelerated atheromatous changes have not been found after a period of three years.

6.5. Graft patency evaluation in coronary artery bypass grafting: clips versus no-clips

In studying the computer data it was found that, particulary in 1980, a sudden rapid increase in the number of repeat c.a.g.'s took place.

Breakdown of post-operative c.a.g.'s:	CABG-operations:
1977 : 2 %	
1978 : 7 %	1978 : 58
1979 : 14 %	1979 : 144
1980 : 44 %	1980 : 265
1981 : 23 %	1981 : 335
1982 : 10 %	1982 : 545

Comparison with the progression of the CABG operations, shows that this progression does not correlate with this increase of repeated c.a.g.'s. In order to explain these findings, we investigated the way in which the patients had been operated upon in the various years.
What changes had taken place? (Technique, methods, patient selection, cardiac surgeon, increased number of CABG operations?).

It was found that these results could be attributed to the use of metallic clips which are used for clamping off the side branches of the venous graft, after which the graft was made in accordance with the normal procedure.

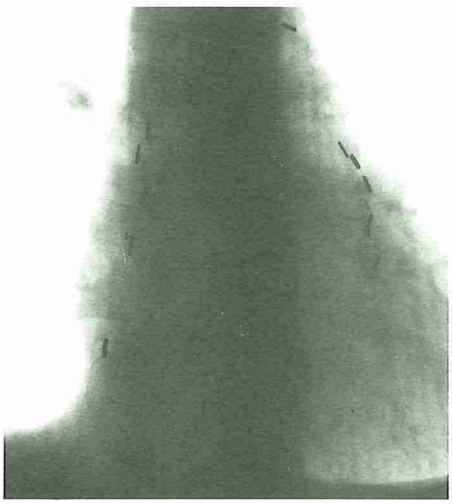


Fig. 6.11. Chest X-ray P.A. view. Metallic clips used in CABG

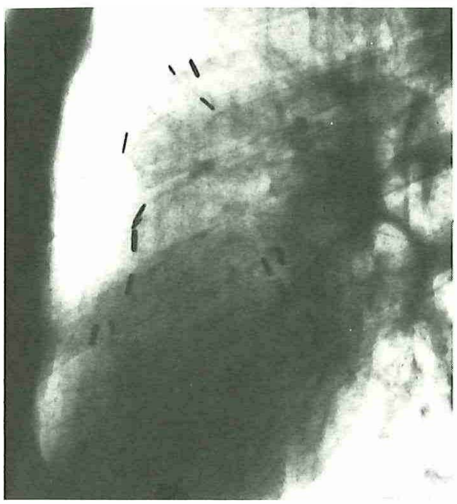


Fig. 6.12. Same patient. Transverse view

These clips were used from September 1979 to April 1981, after which the procedure was changed to tying off the side branches. At that time there were no definite suspicions about the use of clips as a cause of the reduced graft patency. We have not been able to find any mention of the use of clips as a cause of a reduced operation result so far in the international literature (Bijlsma, 1986).

6.5.1. RESULTS:

A study was made of 109 patients who had been operated on, using these clips. These patients received 234 grafts, namely:

S grafts	:	208
Sn grafts	:	14
Y grafts	:	8
IMA	:	4
		234

It was found that 91 of these grafts were occluded, i.e. 39%, representing a graft patency of 61%. The following distribution was seen in this respect:

S grafts : 88 = 42% (n=208): patency = 58%.
Sn grafts: 3 = 21% (n= 14): patency = 79%.

If we compare the graft patency of 73.2% found earlier with the graft patency in 'clips CABG', we then see a clear decline of 12% in the operation result. It should be remembered that the total graft patency of 73.2% also includes the graft patency 'clips' patients.

The graft patency of the Sn grafts, however, is clearly different. While the number of totally occluded Sn grafts was 6, in 'clips' patients 3 Sn grafts were found to be occluded. These figures are too small to enable us to draw any conlusions, but if we plotted them against the total number of Sn grafts (n=62) we would find the following graft patency for Sn grafts:

Occluded Sn grafts without clips: (n=48): 3=6%, graft patency = 94%.
Occluded Sn grafts with clips: (n=14): 3=21%, graft patency = 79%.

It is interesting to investigate what stenoses, e.g. in the non-occluded S grafts, were found in these 'clips' patients:

A-3 stenosis: 14 = 6%
A-4 stenosis: 8 = 3%
A-5 stenosis: 8 = 3%

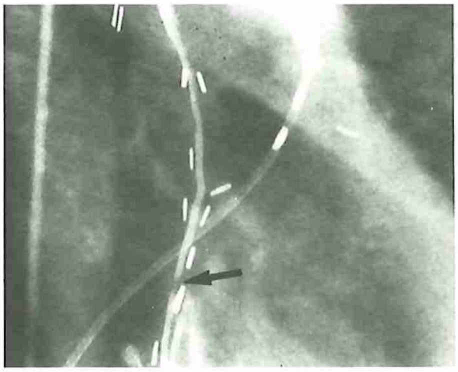


Fig. 6.13. Subtotal stenosis in S graft on RCA

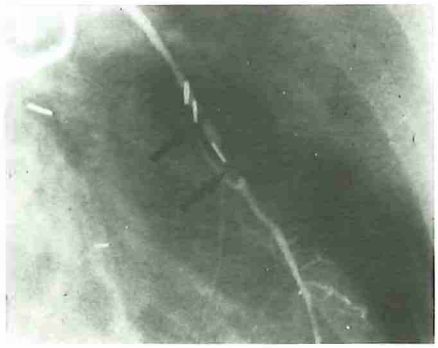


Fig. 6.14. Subtotal stenosis in S graft on LAD

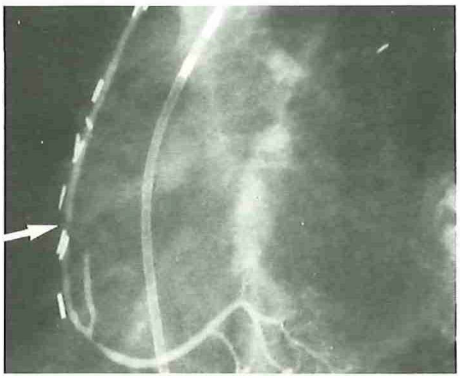


Fig. 6.15. Subtotal stenosis in S graft on RCA

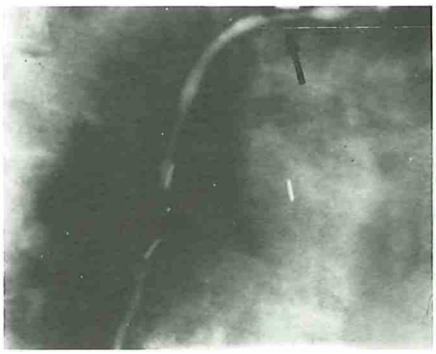


Fig. 6.16. Subtotal stenosis in S graft on LAD

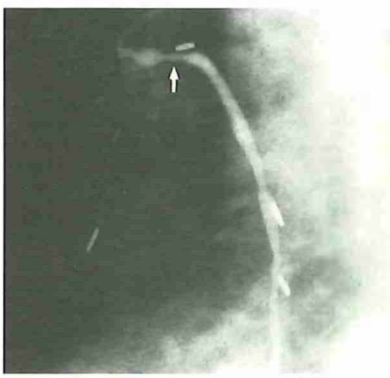


Fig. 6.17. 70% stenosis in S graft on CX distal

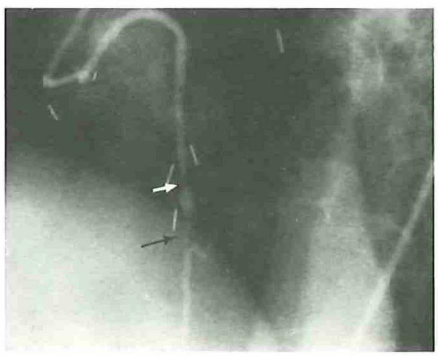


Fig. 6.18. Subtotal stenoses in S graft on LAD

Examples of stenotic lesions in grafts in which metallic clips were used.

6.5.2. FLOW RATE STUDY

In several studies (Walker-1971; Buis-1974) it was reported that a flow rate of 40 cc/min. in grafts can be taken as a borderline between a better or a poorer graft patency.
According to these studies we investigated a random sample of both 68 'clips' and 68 'no-clips' patients and examined the flow rate, measured peroperatively (table I).
In the occluded grafts 33% showed a flow rate of less than 40 cc/min, while in the patent grafts this percentage was 31%. These figures indicate that no significant difference is seen in the degree of total occlusion of a graft in a 'clips' patient if we take the flow rate as a criterion.
In an identical manner a random sample of no-clips patients were examined (table II).

Table I

Clips	Grafts (n = 159)	Flow rate	Patent (n = 98)	Occluded (n = 61)
		less than 40 cc/min.	30	20
		40-49 cc/min.	17	14
		50-70 cc/min.	18	11
		more than 70 cc/min.	33	16

Table II

No-clips 137)	Grafts (n = 179)	Flow rate	Patent (n = 137)	Occluded (n = 42)
		less than 40 cc/min.	27	16
		40-49 cc/min.	18	6
		50-70 cc/min.	57	11
		more than 70 cc/min.	35	9

Here, the flow rate, less than 40 cc/min. was found in 38% of the occluded grafts while in patent grafts this percentage was 20%. A marked difference is now seen with regard to the occluded grafts and their flow rate, with the occluded grafts showing twice as high a number of grafts with a flow rate of less than 40 cc/min.
In studying these figures we find that the use of metallic clips in clamping off the brances of the venous graft entails an extra risk overshadowing the flow race while this has not been found in no-clips patients.
Postmortem examinations of grafts (Tjan Go) in which clips were used showed the occurrence of fibrous tissue near the clips, which

caused contraction of the surrounding followed by luminal narrowing of the graft. It seems very likely that the metallic clips create a tissue reaction.

6.5.3. CONCLUSIONS:

- A significantly lower graft patency was found in CABG patients in whom clips had been using during the operation with those CABG patients in whom no clips were used, namely 61% and 79% respectively. ($P << 0.001$, Chi square test).

- In CABG patients in whom clips were used the flow rate, both in later occluded grafts and in still open grafts, showed no difference and therefore did not have a direct influence on the occlusion process in the grafts.

In CABG patients in whom no clips were used a very marked difference was found with regard to the flow rate in the later occluded grafts and the still open grafts. In occluded grafts twice as high a flow rate of less than 40 cc/min. was measured beforehand. In this group of patients, the flow rate therefore has a definite influence on graft patency ($P = \pm 0.05$, Chi square test).

The findings of this study therefore show that the use of metallic clips in CABG operations leads to a substantial poorer operation result and they should therefore not be used.

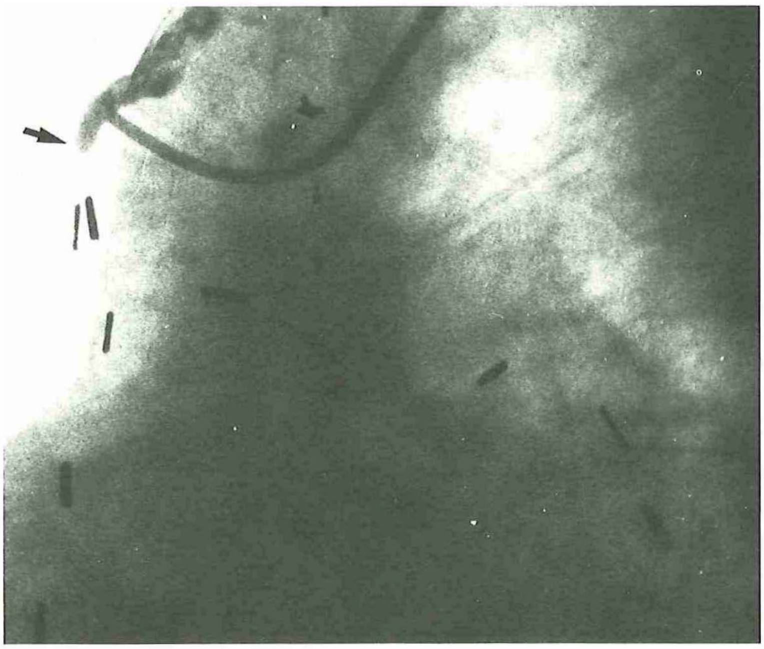


Fig. 6.19. Occluded S graft (clips operation)

SAMENVATTING

Hoofdstuk 1

Coronairangiografie is tot op heden de "gouden standaard" voor het pre- en post-operatieve onderzoek der coronair arterien. Na coronairchirurgie worden door een aantal patienten opnieuw klachten aangegeven. Door ons werden 303 van dergelijke patienten onderzocht waarbij een viertal vraagstellingen voor het onderzoek werden geformuleerd. Allereerst was het doel van deze studie na te gaan, welke veranderingen in de coronairarterien optraden, nadat een bypass was aangebracht. Tevens werd gekeken naar de graft patency, gerelateerd aan diverse faktoren. De verschillen in graft patency die optraden bij het gebruik van verschillende bypass technieken, werden nader bestudeerd. Daarnaast werd nagegaan in hoeverre de ontwikkelde computer data analyse voldeed. In het kort werd ingegaan op de linker ventrikelfunktie.

Hoofdstuk 2 beschrijft de anatomie en de pathologie der coronairvaten, de diverse anatomische variaties, zowel de congenitale als de verkregen variaties. Enkele bladzijden zijn gewijd aan het coronairlijden en de verschillende theoriëen over het ontstaan van arterioslecorse.
Tevens wordt kort ingegaan op enkele haemodynamische aspecten van de coronaire circulatie.

In **hoofdstuk** 3 wordt een kort historisch overzicht der coronairangiografie gegeven. De technische aspecten der coronairangiografie worden behandeld, zoals de apparatuur, coronairangiografie procedure, contrast middelen, projectie-richtingen, cinematografische achtergronden, stralenbescherming en de wijze van interpretatie van het coronairangiogram.

In **hoofdstuk** 4 wordt een beschrijving gegeven van de patiëntenpopulatie, terwijl verder wordt ingegaan op de gebruikte onderzoekmethode. Uiteenzetting en over computerspecificaties, een beschrijving van het anatomische formulier, het computerformulier, alsmede voorbeelden van beeldschermformulieren vindt men eveneens in dit hoofdstuk.
Gegevens verkregen uit het routine klinisch onderzoek worden vermeld en vergeleken met de internationale literatuur. Indeling volgens de NYHA classificatie toonde, dat 44% der patiënten uit deze studie in klasse II kan worden ondergebracht, 10% in klasse II-III, 34% in klasse III en 12% in klasse IV. De gemiddelde leeftijd bedroeg 56.2 jaar, de man/vrouw verhouding 6:1. De operatie mortaliteit (overlijden binnen 30 dagen na de operatie) bedroeg 3.0%. Binnen 1 jaar na de operatie had 51% van de patiënten een hernieuwd angiogram ondergaan, ter beoordeling van het klachtenpatroon. 10% van de patiënten onderging een hernieuwd angiogram wegens klachten binnen 14 dagen na de operatie. Op het totaal aantal bypass operaties was dit 2.2%.

In **hoofdstuk 5** wordt uitvoerig ingegaan op de progressie der stenosen in het coronair vaatstelsel, zoals die pre-operatief werden gevonden. Linker hoofdstam afwijkingen werden in 2% gevonden, een-taks afwijkingen in 7%, twee-taks afwijkingen in 23% en in 68% werden drie-taks afwijkingen gevonden. Een verdeling in afwijkingen in de linker en rechter coronair arterie, zowel pre- als post-operatief wordt gegeven. Pre-operatief bleek in de linker coronair arterie 37% der stenosen kleiner dan 50% te zijn, terwijl dit post-operatief 11% was: in de rechter coronair arterie was dit pre-operatief 47%, post-operatief 20%. Het aantal totale afsluitingen van een coronairvat segment was pre-operatief 13%, post-operatief 34%.
Uitvoerig wordt ingegaan op de progressie der stenose groepen. De progressie is vooral hoog in die segmenten waar een bypass is aangebracht of proximaal van dit niveau. (LAD mid/RCA mid, MOCX). Zo blijkt in de A-3 (50-74%) groep, dat 35% van deze stenosen in de LAD mid., post-operatief, een volledige afsluiting vertoont, in de MOCX is dit 50% en in de RCA mid. 25%.
In de A-4 (75-90%) is 77% der LAD mid.stenosen, post-operatief, afgesloten, in de MOCX 53% en in de RCA mid. 71%. Het **getij-fenomeen**, zoals dat in het anastomose gebied wordt waargenomen, lijkt van grote invloed op de progressie van de stenose.

Ten aanzien van de NYHA classificatie blijkt het aantal stenosen, groter dan 50%, vooral in de NYHA IV voor te komen, terwijl de stenose progressie vooral in de NYHA II groep toenam. Het aantal pre-operatieve afsluitingen was het grootst in NYHA IV, post-operatief echter in de NYHA III groep. De progressie der stenosen blijkt nauw gerelateerd te zijn aan de ernst der klachten, onderverdeeld in de NYHA classificatie.

De linker ventrikel funktie wordt geanalyseerd en enkele voorbeelden, als illustratie van computer analyse, worden gegeven. Totaal werden 2089 linker ventrikel segmenten bekeken. Pre-operatief was 66.5% normaal, post-operatief was dit 48%. Hypokinesie werd pre-operatief gezien in 29%, post-operatief in 37%. Akinesie nam toe van 4% tot 13%. Geen der afwijkende segmenten bleek post-operatief normaal te zijn geworden.

Ieder segment kon worden gerelateerd aan zowel de coronair afwijkingen, als aan de graft doorgankelijkheid. Zo werd bij, pre-operatief gevonden, akinesie van segment 3 (apex), duidelijk dat de graft patency later beduidend lager was dan de gevonden overall patency (45% tegen 73.2%).
Ten aanzien van de coronair vaten was, bij deze apex akinesie, post-operatief, de stenose progressie vooral in de MOCX, gevolgd door de LAD prox., toegenomen. Deze gegevens lijken van invloed op de beslissing of een patiënt met deze afwijkingen wel of niet dient te worden geopereerd. Indien operatie toch is geindiceerd is toepassing van een S-graft minder gewenst:een Sn-graft of een IMA-graft bleek in deze studie, bij deze patiënten, een graft patency van 90% te hebben, zodat hier de voorkeur naar uit zou dienen te gaan.
 De flow in de gebruikte grafts werd gemeten en gebleken is dat, in deze

patiëntengroep, de flow niet de belangrijkste factor was ten aanzien van de graft doorgankelijkheid. De stenose progressie speelt hier een grotere rol.

Hoofdstuk 6 gaat nader in op de graft doorgankelijkheid (graft patency), zowel qua type en qua tijdstip, post-operatief. De overall-patency bedroeg 73.2%, bij S(single) grafts 70.8%, Sn grafts 90%, Y-grafts 100% en de IMA grafts 89%.
De verschillende patency gegevens werden vergeleken met de internationale gegevens en ingedeeld in patency per jaar, post-operatief. In het eerste jaar na de operatie werd een patency van 87.5% gevonden, afnemend tot 77.3% in het vierde jaar.
Het optreden van stenosen in de grafts werd nagegaan, per type graft en per stenose codering. In de S-grafts bleek 13% stenosen te vertonen, groter dan 50%. In de Sn-grafts was dit percentage 27%. In de IMA grafts werden geen stenosen, behoudens een occlusie, gevonden. Ook bleek de graft patency groter in die grafts, die aan de LAD waren gehecht.
De graft patency werd ook gerelateerd aan de NYHA classificatie, post-operatief en hierbij bleek de graft patency significant lager bij patiënten uit de NYHA IV groep (42%), in vergelijking met de NYHA II en III, respectievelijk 80% en 77%.

Tijdens deze studie kwam duidelijk naar voren dat het gebruik van clips bij grafts, ter afsluiting van zijtakjes, van invloed is op de graft patency. Bij gebruik van clips werd een patency van 61% gevonden. Werden de zijtakjes afgebonden, dan bleek de patency 79% te bedragen. De gemeten flow had hier geen invloed op. Geconcludeerd kan worden dat het gebruik van clips dient te worden afgeraden.

SUMMARY

Up to the present, coronary angiography is still the gold standard in the field of pre-operative cardiac examination.
In this study, 303 patients with renewed complaints after undergoing coronary artery bypass grafting (CBAG) were examined in order to establish what abnormalities existed in the coronary arteries, as well as in the venous and arterial bypasses and in de left ventricle function.

With the aid of forms developed for this purpose these data were made suitable for computer data analyse. The numerous data obtained in this way were assessed with reference to the international literature.

Chapter 1 contains the introduction. The first objective was to investigate whether changes have occurred in the native coronary arteries which have been bypassed. The graft patency related to several factors was also evaluated.
The second objective was to investigate what factors are of influence in relation to the difference in graft patency, found in two groups of patients operated upon whereby for each group of patients a different operation technique has been used.
To investigate the availability of the computer data analysis, designed for this study, was the third objective.
Left ventricle evaluation, post-operatively, has been carried out.
Several chapters are devoted to the anatomy, haemodynamics, coronary angiography and radiological aspects, in order to create a short manual for the radiologist, interested in cardiology.

Chapter 2 deals with the anatomy and pathology of the coronary arteries together with the various anatomical variations, both congenital and obtained. A few pages are devoted to coronary artery disease and the different theories dealing with the development of arteriosclerosis.
Some haemodynamically aspects of the coronary arterial circulation are mentioned.

In **chapter 3** a short historical review of coronary angiography has been given. It also deals with the technical aspects of coronary angiography such as the equipment, the procedure of coronary angiography, used contrast media, the various exposure techniques, cinematographic backgrounds, radiation protection and interpretation of the coronary angiogram.

Chapter 4 deals with material and methods. Computer specifications are described, together with the anatomical and computer form, while examples of monitor-screen forms are given.
Data from routine clinical investigation are mentioned and compared with data from the international literature. According to the NYHA classification 44% of our patients belong to NYHA II, 10% to NYHA II-III, 34% to NYHA III and 12 % to NYHA IV.

The average age was 56.2 years, a male/female ratio of 6:1. Operation mortality (i.e. mortality within 30 days after the operation) was 3.0%. Within 1 year after the CABG 51% of our patients underwent a renewed coronary angiogram in order to explain the recurrence of angina and in 10% of our group this was carried out within 2 weeks, post-operatively, which was 2.2% of the total CABG patients at the time of this study.

In **chapter 5** the progression of the stenoses found pre-operatively is studied. Left main abnormalities were found in 2%, one-vessel disease in 7%, two-vessel disease in 23% and 68% showed three-vessel abnormalities. A pre- and post-operative division of the abnormalities both in the left and right coronary artery has been given. Pre-operatively, 37% of the LCA stenoses was smaller than 50%, while this percentage was 11%, post-operatively. In the RCA pre-operatively, this number was 47% while this was 20%, post-operatively. Pre-operatively, the number of occlusions was 13%, while this percentage has been increased to 34%, post-operatively.
In detail, the progression of the stenoses groups were studied. In those segments to which a bypass had been stitched the progression is high. This is also the case in the segments, just proximal to the anastomosis. (LAD mid./RCA mid., MOCX).
In the A-3 (50-74%) group, 35% of the stenoses in LAD mid. changed into complete obstructions, post-operatively, while these figures were 50% and 25% in the MOCX and RCA mid., respectively.
In the A-4 (75-90%) group, post-operatively, the LAD mid., RCA mid. and MOCX were occluded in 77%, 71% and 53%, respectively.
The **tide-phenomenon** appears to play an important part in the progression of stenoses.

With regard to the NYHA classification the total number of stenoses, greater than 50%, appears to be present especially in the NYHA IV, while the progression of stenoses increased most in NYHA II. Pre-operatively, most of the occlusions were found to be present in NYHA IV, post-operatively however in NYHA III.
The progression of the stenoses is closely related to the severity of complaints, as subdivided into the NYHA classification.

The left ventricular function was also investigated and some examples, to illustrate the possibilities of computer data analysis, are given. A total of 2089 left ventricular segments were studied. Pre-operatively, 66.5% of these segments were normal, while this percentage was 48%, post-operatively. Hypokinesia was found to be present in 29%, pre-operatively, and increased to 37%, post-operatively. Akinesia increased from 4% to 13%. None of the abnormal segments became normal, post-operatively.
Each segment could be related to the coronary abnormalities as well as to the graft patency. For example, in akinesia of segment 3 (apex cordis), found per-operatively, it became obvious that the graft patency later on was much lower than the overall graft patency, 45% and 73.2% respectively.
 In akinesia of the apex, post-operatively, the coronary arteries showed a

progression of the stenoses especially in the MOCX, followed by the LAD prox. These data can be of help in making a decision whether to operate on such a patient or not.
In this study it became obvious that the use of Sn-grafts and IMA grafts has the preference to the use of S-grafts because of the higher patency rate of both Sn and IMA grafts.
The flow rate of the blood in the grafts measured per-operatively was also investigated and in our material it became obvious that flow rate was not the most important factor in graft patency. The severity and progression of arteriosclerosis in the coronary vascular segments to which these grafts were stitched was of more importance.

Chapter 6 describes in greater detail the graft patency, both typing of graft and time relation. An overall-patency of 73.2% was found. This was found to be 70.8% for the S (S=single) grafts, 90% for Sn (Sn=Snake), 100% for the Y-grafts and 89% for the IMA (internal mammary artery).
The graft patency data, found in this study, were compared with the data in the international literature. Graft patency was also subdivided into patency rate per year, post-operatively. One year after the CABG a patency rate of 87.5% was found, decreasing to 77.3% at the end of the fourth year, post-operatively. The presence of stenoses in the grafts itself was studied, both for graft type and stenosis code. In the S grafts 13% showed a stenosis, greater than 50%, while in the Sn graft this percentage was 27%. In the IMA graft no stenoses were found, except for one occlusion. The graft patency rate appeared to be higher in those grafts, stitched to the LAD.

The graft patency was also related to the NYHA classification, post-operatively and graft patency was significant lower in NYHA IV patients, compared with NYHA II and III patients. The figures were found to be 42%, 80% and 77%, respectively.

During this study it became obvious that the use of metallic clips, to tie off the side branches of the venous graft, influenced the graft patency. By using these clips the graft patency was found to be 61%, while using suture material for closing the side branches, this percentage was 79%, which is significantly higher. The flow rate measured in these grafts was of no direct influence. It is recommended that the clips technique should not be used.

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