Quantitative Endoluminal Measurements During Angioscopy: An Innovative Technique

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Aim: To evaluate angioscopy in this Unit with respect to its application in lower limb vascular reconstructions. By providing magnified, colour images of the luminal surfaces of vein grafts, anastomoses and native arteries, angioscopy allows direct visualisation of imperfections and is sensitive in diagnosing technical problems. However, assessment is qualitative and magnification of the image can distort the operator's impression of true size. Angioscopy would be more versatile if it were possible to quantify the observed images.

Method: A new technique has been developed to measure intra-luminal diameter from the angioscopic images. A linear displacement transducer is attached to the angioscope and accurately monitors its axial shift. Signals from the transducer are received by a personal computer equipped with a video frame grabber and analogue digital converter, together with appropriate software. The computer generates calculated dimensions based on geometrical principles, once each angioscope has been appropriately calibrated at the outset.

Results: Laboratory studies examining tubes of known dimensions have confirmed the reproducibility and accuracy of the technique. Simultaneous angioscopic and Duplex ultrasound measurements of the internal diameters of segments of vein suspended in a water bath were then carried out. Using the Duplex results as the 'gold standard', there was a strong correlation between the measurements obtained with the two techniques (R² = 0.92).

Conclusions: In the clinical context, this system has the capability to generate accurate endoluminal measurements during angioscopy. This has application for quality control in the selection of veins and inspection of run-off vessels during bypass grafting and in completion studies, following both operative and percutaneous procedures.

Key Words: Angioscopy; Endoluminal measurement; Duplex ultrasound.

Introduction

In the context of lower limb revascularisation, intraoperative angioscopy has therapeutic application in vein graft preparation, but probably more important is its role in quality control as a diagnostic tool for inspecting the vein and for completion studies.¹,² Some degree of vein quality assessment is possible through preoperative Duplex ultrasound scanning³,⁴ and traditionally, arteriography has been the 'gold standard' for intraoperative surveillance.³ However, this latter method is anything but precise, the two-dimensional image of the vessel lumen giving little information on intimal detail. Angioscopy complements the existing modalities and provides a direct, magnified, colour image of the luminal surface of the graft, anastomoses and native vessels. It has been shown to be more sensitive than completion arteriography in characterising plaque morphology and detecting technical errors.⁶-⁸

However, as with any imaging technique, the assessment is qualitative and interpretation of the observed endoscopic findings is subjective and highly dependent on the experience of the angioscopist. Moreover, the image projected onto the monitor is a relative field with size changes being dependent on the distance between the lens and the object being observed. The operator’s appreciation of size may be distorted by the magnification and this, together with the sensitivity of the instrument can lead to an over-reporting of insignificant pathologies in inexperienced hands.⁹ At present, during inspection of a potential vein graft or run-off vessel, patency and luminal features are immediately apparent, but it is not possible to accurately assess calibre. If it were possible...

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to measure intraluminal diameter from the angioscopic images, then the versatility of angioscopy would be greatly enhanced. In the context of bypass grafting, where vein size is one critical factor,10 such measurements would complement those provided by preoperative Duplex ultrasound and enable meaningful selection of adequate calibre vein when using “minimally invasive” angioscopic vein preparation techniques, where the external surface is not freely available for inspection. In the context of interventional radiology, a “quantitative” angioscope would allow intraluminal arterial measurement before and after treatment such as angioplasty or atherectomy and in planning for stent placement.

An innovative method to enable quantitative measurements during angioscopy, using a technique based on computer processing of captured video images is presented.

Materials and Methods

Principle of Method and Calibration

Objects with different dimensions all appear the same size when observed angioscopically if light reflected from them subtends the same angle at the angioscope lens. In order to quantify objects, additional information is required. The principle of the method is that an object ‘X’ (Fig. 1) can be quantified with the angioscope if axial projection is assumed and if two other variables are known. These are the linear distance between X and the lens (OB in Fig. 1) and the half-angle α subtended by light reflected from X onto the angioscope. Neither of these variables are known, but with the angioscope in a new position, X can be derived if the new half-angle (β) and the linear displacement 'D' of the angioscope are available. D can easily be measured, but the angles are still needed and are obtained by carrying out a calibration procedure on each individual angioscope before use.

The calibration sequence is stored on the computer’s hard disc. The manoeuvre need only be carried out once for each angioscope as the data obtained is also stored and is called up each time the programme is run, once the operator has specified the angioscope in use at the commencement of that run. To carry out the calibration, each angioscope is fixed into a jig at a known distance ‘d’ from a linear scale with 1mm graduations (Fig. 2). In this set-up, the dimension X to be measured is known by pre-selection from the scale and d is fixed. As X varies, so do the values for α and the relationship between these two variables is described by the equation: 

$$\alpha = \tan^{-1} \frac{X}{2d}$$

Using this equation, the computer plots a calibration curve of image size and angle for each scope and stores the data. This is a slight over-simplification, because it is assumed that the angioscope lens is set at the tip of the instrument and, in fact, the lens is set back a short way. This has been accounted for by introducing a correction factor into the programme, derived by calibrating at two fixed distances from the angioscope tip.

Referring to Fig. 1 again, X (the unknown dimension) can be measured using the geometrical principles which relate α and D, both of which are now available.

$$D = OB-AB$$

$$D = 0.5X \left( \tan \alpha \right)^{-1} - \left( \tan \beta \right)^{-1}$$

$$0.5X = D \left( \tan \alpha \right)^{-1} - \left( \tan \beta \right)^{-1}$$

$$X = 2D \left( \tan \alpha \right)^{-1} - \left( \tan \beta \right)^{-1}$$

Fig. 1. Diagram to illustrate the geometrical principles underlying the method for quantitative angioscopic measurement. [α and β represent the half-angles of light subtended from the object X at the lens with the angioscope in two different positions; D represents the displacement between the two angioscope positions; X represents an object of unknown dimension to be measured.]
Quantitative Measurements During Angioscopy

Fig. 2. Diagram to illustrate the principle of the calibration sequence. [x represents a known interval on the 1mm scale; d represents the fixed distance between the scale and the angioscope tip.]

The set-up

To measure the displacement of the angioscope, a linear transducer (Linear Potentiometer HLP095 - Penny and Giles Position Sensors, Christchurch, U.K.) is used. This device converts linear movement into an electrical signal (Fig. 3). The angioscope is inserted through the perspex arm of the transducer and can be gripped by it so that any linear movement of the angioscope is mirrored by identical movement of the transducer arm which generates the appropriate signal. The transducer is connected to a personal computer via an analogue digital converter (Pico Technology Ltd., Cambridge, U.K.) which, with appropriate software interprets the electrical signals from the transducer (Fig. 3). For clinical use, the transducer and its cable can be sterilised by ethylene oxide gas sterilisation.

For initial studies, we used a Compuadd 212 personal computer (286 chip with maths co-processor). The computer was fitted with a frame grabber board and supporting software (ELVIS - Vision Dynamics Ltd., Hemel Hempstead, U.K.) which enabled appropriate video images to be captured. It was connected to the video recorder on the angioscopy stack system. The stack system itself was obviously a vital component and was connected via the angioscope to the linear transducer to complete the circuit (Fig. 3).

The appropriate software was installed and programming carried out using the language, Borland Turbo C to produce a menu-driven programme with optional keyboard or mouse control. According to the various screen prompts, two angioscopic images of the same object were captured using the frame grabber and cursors placed at the appropriate points on the screen to enable the computer to calculate the dimension. The movement of the angioscope between the two image positions must be performed smoothly in order for the linear transducer to accurately monitor the displacement. It was easier to obtain the second image on withdrawal of the angioscope from the object, as advancement could be jerky and part of the object could come to lie outside the field of view. Once programming was completed, bench trials were carried out.

Laboratory trials

To test the feasibility of the system, angioscopic measurements on tubes of known diameter were performed. Drill holes of known dimensions were drilled into a perspex block and some of the drill holes were continued to the free edge of the block where a
linear scale was fixed and could be viewed by the angioscope in different positions. By taking repeated measurements in the tubes, the accuracy and reproducibility of the system were assessed.

In the next phase, the system was tested on “tubes” of unknown diameter. For this purpose, segments of human saphenous vein were used. The veins were harvested from patients undergoing stripping at varicose vein surgery. The stripped veins were repaired and tributaries ligated to produce a blind-ended tube, open at one end only.

The veins were cannulated using a valved introduction catheter with irrigating side arm (6 or 8 Fr for the 1.4mm angioscope and 10 Fr for the 2.8mm scope) and suspended in a saline bath. With the catheter connected to the angioscopy irrigation pump (Olympus Angiopump - Keymed Ltd., Essex, U.K.), the vein could be distended with saline. The angioscopes (Olympus AF 1.4mm and 2.8mm - Keymed Ltd.) were inserted, in turn, into the vein via the catheters. The Duplex ultrasound scanner (Ultramark 9 HDI - Advanced Technology Laboratories, Letchworth, U.K.) was used to provide a comparative “gold standard” estimate of the vein’s internal diameter, taking into account the correction factor required for scanning in saline as opposed to tissue for which the machine was set up.

A series of paired readings were taken (angiographic and Duplex) at different points along various veins. To be certain that the angioscope and Duplex scanner were measuring exactly the same dimension, silk sutures were passed across the lumen of the vein. The suture could easily be visualised by Duplex and provided a useful landmark for the angioscope in veins which had few endoluminal features remaining after stripping. The two methods of measuring were carried out simultaneously to ensure identical distension of the vein by the irrigation.

Fig. 3. Diagrammatic representation of equipment required for quantitative angioscopic measurement.
Results

The laboratory trials on tubes of known dimensions produced a series of angioscopic readings which could be plotted against the true values. In Fig. 4, the mean values for a series of angioscopic measurements are plotted (bold line). The standard deviations about the mean values are remarkably uniform across the range, showing this to be a reproducible technique. In terms of the accuracy, however, there is some deviation from the true value (dotted line), when measuring larger dimensions. Table 1 shows the standard deviations of the angioscopic readings taken around the true value (accuracy), as opposed to the mean value of the measurements (reproducibility).

The laboratory trials on vein segments, demonstrated a high level of agreement between Duplex and angioscopic measurements (Fig. 5). In Fig. 5a, angioscopic and Duplex measurements are plotted. The correlation coefficient ($R_s$) is 0.92 and the Bland Altman plot in Fig. 5b confirms the close agreement between the two methods.

Fig. 4. (a) Photograph illustrating the linear transducer which enables accurate measurements of axial shift of the angioscope. (b) Schematic diagram of linear transducer, showing details of component parts.
Table 1. Data obtained from laboratory angioscopic measurements of known dimensions

<table>
<thead>
<tr>
<th>Known dimension (mm)</th>
<th>Measured mean dimension (mm)</th>
<th>[range]</th>
<th>S.D.</th>
<th>S.D. about known dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>0.57</td>
<td>[0.42-0.74]</td>
<td>0.085</td>
<td>0.115</td>
</tr>
<tr>
<td>1.00</td>
<td>1.07</td>
<td>[0.99-1.13]</td>
<td>0.043</td>
<td>0.089</td>
</tr>
<tr>
<td>1.50</td>
<td>1.55</td>
<td>[1.51-1.6]</td>
<td>0.066</td>
<td>0.108</td>
</tr>
<tr>
<td>2.00</td>
<td>2.11</td>
<td>[1.98-2.22]</td>
<td>0.078</td>
<td>0.147</td>
</tr>
<tr>
<td>2.50</td>
<td>2.69</td>
<td>[2.54-2.79]</td>
<td>0.096</td>
<td>0.230</td>
</tr>
<tr>
<td>3.00</td>
<td>3.18</td>
<td>[3.12-3.27]</td>
<td>0.069</td>
<td>0.216</td>
</tr>
</tbody>
</table>

(S.D. = standard deviation)

Discussion

Modern angioscopy, such as the system used in this study, yields high resolution images, often allowing visualisation of the luminal features in exquisite detail. However, its sensitivity can be its undoing as there is a long learning curve in the interpretation of some appearances (quite apart from the handling of the instruments themselves in the clinical setting). This point was recently illustrated in the report by Gaunt et al., on angioscopic completion studies following carotid endarterectomy, where a 30% detection rate of carotid abnormality far exceeded the accepted stroke rate of 3–4%, suggesting that the majority of abnormalities were insignificant.

At Bristol Royal Infirmary, the role of angioscopy in lower limb revascularisation is being evaluated. The technique is regularly used for vein inspection and preparation (valve lysis and identification of tributaries for ligation via “minimally invasive” stab incisions) in patients undergoing femoropopliteal and femorodistal bypass. Recently, there has been some doubt cast on the practicality of routine angioscopy, but in our experience, angioscopy has positive application in quality control (complemented by preoperative Duplex vein mapping), and obviously, in this context, versatility would be greatly enhanced if it were possible to make quantitative endoluminal measurements. Anecdotally, our interest in this development was stimulated by experiences with patients undergoing full angioscopically-assisted bypass who had vein of adequate calibre, on the basis of magnified angioscopic images, although completion studies revealed problems and subsequent external assessment confirmed that the vein was sub-optimal. In all cases, the angioscopic view distorted the true impression of size and preoperative vein mapping had failed to warn of possible dysplastic segments.

In the process of developing the method described above, other possible techniques were considered. An object of known size could be used as a reference and could either be passed down the irrigation channel of the larger angioscope or alongside the angioscope to provide a comparative dimension for estimating luminal diameter. It would however, be very much an estimate and involves additional endoluminal manipulation, with potentially increased endothelial injury.

Optical projection of a calibration scale, superimposed on the field of view was also considered.
However, this method was dismissed on the basis that it would assign the same measurement value to objects of different dimensions subtending the same reflective angle at the lens of the angioscope. Moreover, the measured dimensions of the same object would vary according to the distance between the angioscope and the object.

A third possibility, as a future development, may be the use of laser beams projected down individual optical fibres and made to converge at the appropriate place where a measurement is required.

There are certain limitations with the chosen angioscope displacement/video processing method, but refinements continue as experience grows. The limited accuracy with measuring larger dimensions (Fig. 4) occurs because of optical distortion towards the periphery of the field of view. A further correction factor has since been introduced into the programme to take account of the altered geometry at the edge of the field.

It is also appreciated that the system in its current format, is dependent on the presence of some endoluminal feature to provide the basis of the two captured images. In the clinical setting, we would anticipate using a valve, open tributary orifice or other endoluminal feature to provide a landmark for measurement. Any unsuspected pathology, such as webs/bands or thrombus would serve just as well. In a clear vessel, with no distinguishing features, accuracy could be compromised as it would be difficult to ensure capture

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![Graphs](image-url)

**Fig. 6.** (a) Plot of angioscopic and "gold standard" Duplex measurements of internal diameters of a series of human saphenous veins. (The two methods of measurement were done simultaneously to ensure that the vein was identically distended by the angioscopic irrigation). \( R_s = 0.92 \)

(b) Bland Altman plot for the same series of measurements as in Fig. 5a, showing a high level of agreement between the two methods.
of precisely the same point on the wall in both images. Placement of cursors would also be very subjective in this scenario.

The manufacturers of the Duplex scanner used in this study claim a 0.5% accuracy when measuring linear dimensions and for the purposes of this study, Duplex measurements provided the most convenient "gold standard" comparison. Ideally, endoluminal ultrasound would be the "gold standard" technique of choice for comparison. However, intravascular ultrasound systems are costly and not widely used, as yet, in routine practice. The quantitative system described here, could be installed to complement existing angiography systems for around £1400 for the video frame grabber, linear transducer and appropriate software, if an existing computer could be spared for use in theatre. Otherwise, the cost of a computer (286 and 386 chip processors are adequate to run the software) would have to be added to estimates for installation (around £2500 in total).

The next step is to test the system in the clinical setting, during angioscopic vein inspection/preparation in patients undergoing bypass grafting. These laboratory trials show the system to be accurate and reproducible, with the potential to enhance what is already a useful tool. As yet, no claims can be made as to the precise practical applications in either the operating theatre or the radiology suite.

The justification for this work originates from a striving to improve methods for quality control in a centre which operates a preferential vein policy for infrainguinal reconstruction, including at the above-knee level, but also recognises that poor vein can be inferior to prosthetic material. Angioscopy has potential application in this area. We await the results of the clinical trials.

Acknowledgements

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References


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