A Prospective Comparison of Lower Limb Colour-coded Duplex Scanning with Arteriography


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Objective: To compare the diagnostic value of colour Duplex scanning with arteriography for the detection of arterial disease of the aortoiliac arteries, femoropopliteal arteries and the origins of the tibial vessels.

Design: Prospective, semi-blind study.

Setting: Vascular laboratory and radiology department, University Hospital.

Methods: A total of 1658 arterial segments in 148 limbs were studied both by colour Duplex scanning and digital subtraction arteriography. Individual arterial segments were classified on the basis of peak systolic velocity ratios < 2.0, ≥ 2.0 or an absent doppler signal, as 0–49%, 50–99% diameter reduced, or occluded. The same arterial segments were similarly classified on the basis of arteriography and the two modalities were compared using a Kappa (k) analysis.

Results: The overall agreement between arteriography and colour-coded Duplex was k = 0.74 (95% CI, 0.70–0.78), this indicates substantial agreement. Kappa values (95% CI) from the aortoiliac, femoropopliteal and the origins of the infrapopliteal arteries were k = 0.59 (0.49–0.73; moderate agreement), k = 0.80 (0.76–0.84; substantial agreement) and k = 0.48 (0.35–0.61; moderate agreement) respectively.

Conclusion: We conclude that there is substantial agreement between colour-coded Duplex and arteriography of the lower limbs, and that the ability of colour-coded duplex to plan and guide lower limb vascular interventions requires investigation.

Key Words: Duplex scanning; Doppler; Arterial disease; Angiography.

Introduction

Although intra-arterial angiography of the lower limbs is associated with minimal morbidity, it is expensive, invasive, requires at least day case hospital admission and provides only anatomical information. Conversely, Duplex ultrasound is relatively inexpensive, non-invasive, can be performed on an outpatient basis and provides both haemodynamic and anatomical information. Whilst conventional Duplex scanning of the lower limbs is time consuming, the introduction of colour-coded Doppler ultrasound has enabled real-time Doppler information to be displayed, allowing the rapid identification of haemodynamic abnormalities. In view of the potential advantages of colour-coded Doppler ultrasound over arteriography, the purpose of this study was to prospectively compare the two techniques in a consecutive series of patients with lower limb arterial disease.

Material and Methods

Patients, study design and data analysis

Patients awaiting diagnostic arteriography underwent colour-coded Duplex examinations of the distal infrarenal aorta, the iliac arteries and the arteries of the lower limbs. The arterial system was classified into the following 13 segments: distal aorta, common iliac, external iliac, common femoral, profunda, proximal, mid and distal superficial femoral, popliteal, anterior tibial origin, tibioperoneal trunk, posterior tibial and peroneal artery origins. For Duplex and arteriography each arterial segment was categorised as < 50% stenosed, ≥ 50% stenosed or occluded. In the case of Duplex this classification was based on the result of peak systolic velocity ratios whilst in the case of
arteriography it was based on diameter reduction. A value of 50% diameter reduction was chosen on the basis of experimental work showing that such lesions cause a significant reduction in flow and distal pressure.1,2

For the purposes of the comparative analysis, arteriography was assumed to be the "gold standard". This approach does of course have its limitations, particularly in view of recent magnetic resonance (MR) angiography studies showing that MR angiography can demonstrate patent vessels not seen on conventional arteriography.3,4 Colour-coded Duplex was compared with arteriography using the Kappa (k) statistic.5,6 This is a chance corrected proportion of agreement for categorical data. Kappa values range from < 0, indicating agreement less than that given by chance, to 1, indicating perfect agreement. In order to increase the power of the analysis, the 13 arterial segments were grouped into aortoiliac (distal aorta, common and external iliac), femoropopliteal (common femoral, profunda, proximal, mid and distal superficial artery and popliteal artery), and infrapopliteal (anterior tibial origin, tibioperoneal trunk, posterior tibial and peroneal artery origins). Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and the accuracy of colour-coded Duplex were calculated using standard definitions.5

The analysis firstly investigated the duplex PSV ratio that best predicted the arteriographic classification of a 50% diameter-reducing stenosis (receiver operator characteristics) and this ratio was then used to compare the results of arteriography with the results of colour-coded Duplex.

The effect of adjacent segment disease on the accuracy of ultrasound classification was examined by comparing the results from those segments with at least one ≥50% diameter-reducing lesion (detected by Duplex) in an adjacent proximal or distal segment with the results from segments without adjacent segment disease. The definition of an adjacent segment for the purposes of this analysis is summarised as follows with the adjacent segments given in parentheses: common iliac (distal aorta/external iliac); external iliac (common iliac/common femoral); common femoral (external iliac/proximal superficial femoral); profunda (common femoral); proximal superficial femoral (common femoral/mid-superficial femoral); mid-superficial femoral (proximal superficial femoral/distal superficial femoral); distal superficial femoral (mid-superficial femoral/popliteal); popliteal (distal superficial femoral/anterior tibial/tibioperoneal trunk.)

Ultrasonography

Ultrasound scans were performed by one of two vascular technicians (Y.S. or T.H.) using a Diasonics Spectra (Diasonics, Bedford, U.K.) machine a median (range) of 2 (0–19) days prior to arteriography. For optimal ultrasonic visualisation of the aortoiliac segments, patients were starved overnight and, examined supine with a 3.5MHz probe. A 5MHz probe was reserved for the more superficial femoropopliteal and infrapopliteal arteries which were scanned with the upper body elevated and both legs relaxed in slight external rotation. Insonation of the popliteal artery was performed in a lateral position with the knee gently flexed. The origins to the tibial vessels were similarly insonated. Arterial lesions were located by changes in colour flow patterns and then further studied for changes in vessel diameter (seen from the image) and broadening of the Doppler spectrum. The degree of stenosis was quantified by measuring the peak systolic velocity (PSV) across the lesion. By comparing the PSV within a stenosis to that in the nearest disease free segment, a ratio is created independent of individual variations in blood pressure, vascular compliance and cardiac function.7 Whenever possible, the velocity within a stenosis was compared to the velocity just proximal to the stenosis. This is because the distal velocity is distorted particularly when stenoses are severe.7,8 Vessels were considered occluded if no colour flow could be detected and no pulsatile flow was present with the pulsed Doppler.

Arteriography

Diagnostic arteriography was performed by a single consultant radiologist (A.B.) using a Seldinger technique. The majority of pictures were uniplanar, though in some instances the aortoiliac arteries were captured in two planes. Digital subtraction was used routinely. The results of the Duplex examination were not available to the radiologist who recorded on a proforma sites of arterial occlusion or stenosis greater than 50%.

Results

Patients and limb segments examined

The study population consisted of 76 consecutive patients who underwent both arteriographic and
colour-coded Duplex examinations. There were 44 males and 32 females, with a median (range) age of 71 (46-84) years. Nine patients had critical ischaemia (all rest pain), 67 were claudicants and 15 were diabetic. Seventy-two patients underwent bilateral examinations, two had unilateral examinations and two were amputees. Therefore, a total of 148 limbs were studied and in theory, 1850 individual arterial segments were available for comparison. However, in some cases, particularly in the earlier part of the study, Duplex examinations were incomplete due to time constraints (182 segments) and 14 segments were not visualised, six attributable to ultrasound and eight to angiography. Of the six unseen by ultrasound, five were the aortoiliac segments in a patient suffering bilateral herniae, and one was a non-visualised peroneal artery. Six of the eight arteries not visualised by angiography were tibial arteries and two were profunda artery origins. Hence, from a potential total of 1850, 1658 (90% of the total) segments could be compared. During the first 3 months of the study a Duplex examination of both lower limbs took 2 h, by the final 3 months of the study this time had reduced to 1.5 h.

Receiver operating characteristic analysis

Table 1 gives the sensitivities, specificities, PPV, NPV and accuracies of PSV ratios between 1.5 and 3.0 for the prediction of a stenosis of ≥50% on arteriography for all 1658 arterial segments compared. It can be seen from that the best combination of sensitivity, specificity, prediction and accuracy is provided by a PSV ratio of ≥ 2.0. The positive predictive value of a PSV of ≥1.5 is too low (44%) and although PSV ratios of ≥2.5 and ≥3.0 yield high positive predictive values, their sensitivities are too low (50% and 40% respectively). The k values for PSV ratios of ≥1.5, ≥2.0, ≥2.5 and ≥3.0 were 0.68, 0.74, 0.71 and 0.71 respectively (Table 3). This holds true both for individual segments and grouped segments and for this reason a PSV ratio of ≥ 2.0 was chosen for all the subsequent analyses.

Ability of a PSV ratio of ≥2.0 to predict a significant arteriographic lesion

The concordance between Duplex scanning and arteriography for all 1658 arterial segments is shown as a two-way contingency in Table 2. The overall k value of 0.74 shows substantial agreement between the two modalities. If arteriography is considered the “gold standard” then the false-positives (80; 4.8%) and false-negatives (89; 5.4%) of Duplex are equally distributed.

Table 3 shows the results of a k analysis for the grouped segments and Table 4 gives the sensitivities, specificities, PPV, NPV and accuracies of PSV ratios between 1.5 and 3.0 for the prediction of a stenosis of ≥50% on arteriography for all 1658 arterial segments compared.
specificities, PPV, NPV and accuracy for stenoses and occlusions of the three grouped segments. It can be seen that the best results lie within the femoropopliteal segment (k = 0.80). Duplex appeared particularly accurate in the three superficial femoral artery segments (proximal, mid and distal) where an overall accuracy of 91% was achieved for stenoses and 96% for occlusions. The k value for the aortoiliac segment revealed moderate agreement (k = 0.59). We experienced few problems (one patient with bilateral inguinal herniae) with overlying bowel gas, probably because patients had been starved overnight prior to the scan. Moderate agreement was achieved in the infrapopliteal region (k = 0.48).

Influence of adjacent disease

The k (95% CI) values for the comparison of colour-coded Duplex with arteriography in arterial segments in the presence of at least one adjacent ≥ 50% lesion were 0.77 (0.68–0.86) for proximal lesions, 0.70 (0.61–0.79) for distal disease and 0.75 (0.61–0.89) for combined proximal and distal lesions. The k value for arterial segments free of adjacent disease was 0.63 (0.53–0.73), a value not significantly different from those of segments with adjacent arterial disease.

Discussion

Although arterial Duplex scanning has proven a valuable diagnostic tool and many centres use it as the sole investigation for the delineation of carotid artery disease, there are only a few publications that have systematically compared Duplex scanning of the lower limb with arteriography. There have been four studies that have compared black and white Duplex ultrasound with arteriography of aortoiliac and femoropopliteal arteries. Jager et al. using doppler waveform and velocity analysis found that the agreement achieved by two radiologists grading the same angiograms was little different to that obtained when comparing Duplex with angiography. Demes et al. concluded that Duplex ultrasound was a useful adjunct to arteriography whilst Legemate et al. using PSV ratio analysis, concluded that Duplex scanning had the potential to replace aortoiliac and femoropopliteal arteriography.

Three authors have compared colour-coded Duplex scanning with lower limb arteriography. Cosman et al. mapped the iliofemoral and femoropopliteal segments with colour Duplex and found that Duplex had an accuracy of 95% for ≥ 50% stenoses and 95% for occlusions. Moneta et al. compared colour-coded duplex scanning of the aortoiliac, femoropopliteal and infrapopliteal vessels with arteriography and although their method of data analysis was slightly different to the present study, their overall results for the aortoiliac and femoropopliteal segments were similar to ours (see Table 4). It is not possible to draw meaningful conclusions from the study by Mulligan et al. because only 12 patients were included.

Retrospective receiver operator characteristic (ROC) analysis of our data (Table 1) showed that a PSV ratio of ≥ 2.0 best predicted the presence of a ≥ 50% stenosis on arteriography. Although previous studies have used a PSV ratio of either ≥ 2.0, > 2.5, or ≥ 3.0, very few investigators have used ROC analysis to determine the optimum PSV ratio. Ranke et al. have all shown a good correlation between PSV ratio and arteriographic diameter reduction up to 75% reduction and concluded by ROC analysis that the optimum PSV ratio cut off was 2.4, 2.5 and 3.0 respectively. There are a number of possible reasons for these disparate results, including differences in measurement techniques, differences in interpretation of arteriograms and differing interpretations of ROC analysis. At a practical level however the differences in the PSV ratio selected by various authors are probably not of great importance. Thus although we selected a PSV ratio of ≥ 2.0, it can be seen (Table 1) from the ROC analysis that the results of using a ratio of ≥ 2.5 are not greatly different. Interestingly, our sensitivity, specificity, PPV, NPV and k values using a PSV ratio of ≥ 2.0 are remarkably similar to those of Leng et al. who used a ratio of ≥ 3.0.

Although we have found that multilevel disease did not effect the accuracy of ultrasound mapping, Allard et al. have recently reported that adjacent arterial disease does reduce the accuracy of ultrasound scanning. The major difference between the two studies is that we have used only PSV ratios to classify the degree of stenosis whereas Allard et al. have used in addition spectral analysis criteria such as waveform phase and spectral broadening. The latter parameters are influenced by neighbouring disease, whereas velocity ratios (as opposed to actual velocities) compensate for blood flow distortions created by multiple stenoses. Indeed, we conclude from our data that providing that only the PSV ratio is used to classify the degree of stenosis that multilevel disease does not adversely effect the accuracy of Duplex arterial mapping.

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The major limitation of a comparative study of this nature is the need to define one of the parameters, in this case arteriography, as the "gold standard". Inevitably, the other parameter, in this case Duplex, is going to appear second rate. It is important to note that arteriography is essentially a morphological study and depicts arterial lumen, whereas colour Duplex ultrasound is a functional study and lays emphasis on haemodynamic information. Arteriography is well known to have constraints and in the present study, apart from the aortoiliac arteries, all angiographic pictures were captured in one plane. Given that, particularly in the aortoiliac and profunda arteries, atheroma has a tendency to develop on the posterior arterial wall, the use of uniplanar arteriography is not ideal. Interestingly, when we reviewed the arteriograms of two patients who had significant iliaca stenoses on Duplex but not on arteriography, it became apparent that stenoses were indeed apparent on the arteriograms. The difficulties of interpreting aortoiliac arteriograms have been highlighted by Thiele et al., who using intra-arterial Papaverine tests as the "gold standard", reported that arteriography had only a 69% sensitivity and 75% specificity for the identification of haemodynamically significant aortoiliac stenoses.

Although oblique views may aid interpretation of the aortoiliac arteries, they do little to address the problems posed by the profunda vessel. In the present study, Duplex appeared to report eight falsely-positive stenotic findings in the profunda vessels, however, review of the angiograms revealed two cases where superimposition of the proximal superficial femoral artery obscured the origin of the profunda, but no further oblique views had been taken. Indeed, a number of studies have reported angiographic interpretation of the profunda artery as highly inaccurate and Beales et al. found that multiplanar arteriography identified only 41% of profunda origin stenoses that were subsequently found at surgery.

One of the other major areas of disagreement between Duplex and arteriography was the question of whether or not an arterial segment contained an occlusion or not. Thus of a total of 259 arteriographically occluded segments (Table 2), 52 were said to be patent on Duplex. This disparity has arisen because of disagreement as to whether or not an occlusion runs into an adjacent segment. For the superficial femoral artery in particular, colour Duplex measured occlusions shorter than arteriography and thus three-quarters of the disparities regarding superficial femoral patency were due to falsely negative rather than to falsely positive results. This is a trend other studies have identified and is considered more a limitation of arteriography than of ultrasound.

The agreement between arteriography and Duplex was poorest in the infrapopliteal segment (Table 3). However, only the origins to the tibial vessel were examined and therefore there is the potential for discrepancies regarding whether or not lesions found angiographically actually lay within the region examined by the preceding colour Duplex scan. In addition, the inaccuracies of arteriography in the infrapopliteal vessels are well described. We now routinely scan the entire length of the infrapopliteal vessels and have started a further study comparing infrapopliteal colour-coded Doppler scanning with intraoperative arteriography in patients undergoing femorodistal bypass. Only one other study has examined the infrapopliteal arteries, however it is difficult to make meaningful comparisons between our infrapopliteal results and those of Moneta et al. because the latter study did not attempt to differentiate between infrapopliteal stenoses and occlusion.

During the latter stages of this study, the scanning time for a bilateral leg scan was reduced to 1.5 h. This is in agreement with the times reported by other studies and confirms that a complete examination can be performed relatively quickly. In conclusion, this study has shown substantial overall agreement between lower limb arteriography and colour-coded Doppler and has also highlighted some of the pitfalls of conventional arteriography. Indeed, we suggest that arteriography should no longer be regarded as the diagnostic "gold standard" and that future studies of lower limb colour-coded Duplex should not compare it with arteriography, but should examine its ability to safely and accurately guide therapeutic vascular interventions.

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