RADIAL ARTERY CANNULATION
A prospective study in patients undergoing cardiothoracic surgery

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SUMMARY
Following 333 radial artery cannulations, the frequency of complete occlusion of the vessel on the
day after removal of the cannula was 30%, decreasing to 24% by the 8th day. Arterial occlusion
was assessed using a modified Allen's test and an ultrasonic flow meter. The frequency correlated
with the type and size of cannula used, being least (3%) with 20-gauge Teflon cannulae, with the
degree of bruising, and with the sex of the patient, being significantly greater in women (37.5%)>
than in men (27%). Other variables such as insertion technique, low cardiac output, anticoagulation
after operation and the duration of cannulation were assessed. Using multivariate analysis of 13
variables, it did not appear possible to predict with any certainty the outcome of arterial cannulation.
The frequency of major complications was small and no permanent sequelae were detected.

Percutaneous radial artery cannulation is a well-
established clinical technique. Several large retro-
spective reviews (Mortensen, 1967; Zorab, 1969;
Dalton and Laver, 1971; Gardner et al., 1974) have
suggested that serious complications such as gangrene
of the extremities have been rare, although there is a
definite morbidity, in particular the occurrence of
thrombosis and occlusion. Recently, Bedford (1977)
and Davis (1978) have reported that the type and
size of catheter employed significantly influences the
frequency of subsequent thrombosis. The importance
of possible "risk" factors and their predictive value
in the development of arterial thrombosis is reviewed.

METHODS
Three hundred and thirty-three radial artery cannula-
tions were performed in 330 adult patients over an
8-month period, all except 11 undergoing cardio-
pulmonary bypass surgery with moderate (30–32 °C)
hypothermia (table I).

There are inevitable differences between the
surgical groups. Only 15% of procedures performed
in patients aged less than 40 yr were coronary artery
bypass grafts (CABG), whereas by the sixth decade
CABG accounted for 80% and were more often
performed in men (63%) than in women (30%). On
the other hand, 74% of all mitral valve surgery was
performed in women, whilst aortic valve surgery was
distributed proportionately in the two sexes. These
differences may be relevant to subsequent discussion
regarding the frequency of radial artery thrombosis.

The first phase of the study was an assessment of
current departmental practice. The second phase
was a randomized trial of four cannulae to assess the
influence of catheter size and material on arterial
occlusion (Davis, 1978). For the purposes of this
report the data from these two phases have been
combined, there being no statistically significant
differences in the cannula groups common to both—
18- and 20-gauge polypropylene catheters.

Assessment before operation
Collateral arterial blood supply to the hand was
assessed using the modified Allen's test (Allen, 1929;
Oh and Davis, 1975). This was graded as: grade 1,
0–7 s “flush” time, normal; grade 2, 8–14 s, equivocal; grade 3, longer than 15 s, poor or abnormal. In some patients, arterial dominance was noted (Husum and Palm, 1978).

Cannulation technique

Cannulation was performed using a single-wall puncture or transfixion of the artery either percutaneously (299 patients) or via a surgical cut-down. The cannula was flushed intermittently with a few millilitre of 5% dextrose solution containing heparin 2500 i.u. per 500 ml. A continuous flushing device was not used in this study. Four different cannulae were used: 18- and 20-gauge polypropylene (Argyle Medicut), and 18- and 20-gauge Teflon (Longdwell) catheters.

Post-canmtlation examination

Patients were examined on several occasions by one person (FMD) following removal of the cannulae, the examiner being unaware of the catheter used. Assessment involved inspection of the puncture site and hand, palpation of the distal radial pulse, Allen’s test and the use of an ultrasonic flow probe.

Inspection. The presence of discharge or inflammation was recorded. Haematoma was scored 0 (no bruising) to 4 (severe bruising reaching to the elbow, plus considerable local swelling). Evidence of impaired blood supply, particularly over the radial aspect, and swelling of the hand were noted.

Radial pulse. The strength of the radial pulse distal to the puncture site was recorded as normal, that is equal to the non-cannulated side, reduced or absent.

Allen’s test. This was graded as described above. Whilst the preoperative grade referred to the ulnar release “flush” time, after the catheter’s removal the “flush” time from the radial artery was recorded.

Palmar blood flow. A Doppler flow meter (Sonicaid Foetal Heart Monitor) placed on the thenar eminence of the palm as described by Mozersky and others (1973) was used. Patency of the radial artery was graded in three categories by the combined use of Allen’s test and flow monitoring with the ulnar artery compressed: Normal—grade 1 or 2 Allen’s test plus a “normal” biphasic flow signal. Partial occlusion—grade 2 or 3 Allen’s test plus a reduced uniphasic flow signal which did not completely disappear with ulnar compression. Complete occlusion—grade 3 Allen’s test plus a reduced uniphasic flow signal which disappeared completely with ulnar compression.

Grade 1 Allen’s test was never associated with an impaired flow signal, but a “normal” biphasic signal was occasionally heard in combination with a grade 2 Allen’s test.

Thumb temperature. The skin temperature of both thumbs was measured in 78 patients using a YSI Telethermometer and series 400 skin probe.

Statistics

Data retrieval was over 80% for all variables. Univariate analysis of the raw data utilized routine statistical tests, namely, the χ² test, Fisher’s exact test, Dunn’s test for Multiple Comparisons (Dunn, 1964), Mann–Whitney U Test (Z statistic) and Kruskal–Wallis one-way analysis of variance (H statistic). A 2% level of significance was used throughout.

In an attempt to discover how accurately the recorded variables could predict the likelihood of thrombosis and which variables appeared to be important in doing so, the multivariate successive screening technique was used. The 13 independent variables that it was hoped might be useful in predicting the probability of thrombosis were: age, sex, surgical procedure, cannula type, cannula size, number of attempts at arterial puncture, the actual number of vessel punctures, repeat cannulation, cut-down procedure, time catheter left in situ, low cardiac output state, size of haematoma and use of anticoagulants. The three categories formed from the Allen’s test and Doppler flow monitoring were used as the groups to which it was attempted to allocate the patients using the above variables. Only those patients with all these variables recorded were included.

As the independent variables were mainly categorical in nature, the usual discriminant function techniques could not be used. Therefore, a sequential screening approach (Fieldman, Klein and Honigfeld, 1969, 1972) which makes no distribution assumptions was used. At each step of this technique the item which maximizes the ratio of true to false positives is accepted and the patients satisfying this criteria are classified. Eventually, this results in all patients being classified into the three groups.

RESULTS

Allen’s test before operation

Eighty per cent of patients had good ulnar collateral flow. In 17% collateral flow was present but diminished and it was absent in 3% of patients, bilaterally absent in three. There was no difference
between the sexes. In 26 patients who had undergone cardiac surgery previously, radial blood flow appeared normal before operation. However, in three a stricture of the vessel was apparent during cannulation.

Frequency of thrombosis

Complete occlusion of the radial artery occurred in 30% of patients one day after removal of the cannula, reducing to 24% by the 8th day. A further 12% were partially occluded. The frequency of occlusion using the four different cannulae varied \((H = 19.9; 3\ d.f.)\); the 20-gauge Teflon cannula having a significantly lesser frequency (3%) than the other three used (fig. 1).

![Figure 1](image_url)

To examine related aspects of arterial occlusion the data for all cannula groups were combined, the only significant difference between them being a preponderance of women in the 20-gauge Teflon group \(\left(\chi^2 = 13.3; 3\ d.f.\right)\). Results for the 1st and 8th days following catheter removal were essentially similar unless specifically stated.

Significant associations were found between occlusion and the following variables:

Sex. Occlusion occurred more frequently in women than in men (table II). This is of importance in the analysis of the four types of cannula used, as the group with the lowest rate of occlusion—20-gauge Teflon—contained a significantly higher proportion of women than did the others.

Table II. The frequency of radial artery occlusion was significantly greater in women than in men \((Z\ statistic\ shown)\)

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>Day 1</th>
<th>Day 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Patent</td>
<td>146</td>
<td>38</td>
</tr>
<tr>
<td>Partial occlusion</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Complete occlusion</td>
<td>62</td>
<td>30</td>
</tr>
<tr>
<td>(Z = 2.3)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of arterial punctures. Forty-seven and a half per cent of vessels were occluded following multiple punctures during cannulation, compared with 26% when only a single insertion was made \((H = 9.8; 2\ d.f.)\).

Surgical cut-down. This was performed in 34 patients. The frequency of occlusion on the first day was greater (48%) than for percutaneous cannulation (23%); \(Z = 3.0\). By the end of 1 week there was no longer a significant difference between the two techniques.

Low cardiac output. In 53 patients who had a low cardiac output after surgery, most of whom received positive inotropic agents, the frequency of occlusion was significantly greater (44%) than in those who followed a “normal” course after operation (25%); \(Z = 2.8\). The only two cases of severe hand ischaemia in this series occurred in patients with prolonged low output states over many days.

Surgical procedure. Because of the varied nature of the surgery undertaken it proved difficult to assess this factor and no definite conclusions can be drawn. Certainly, statistical differences in the frequency of occlusion occurred, but these cannot be separated easily from other related factors.

Anticoagulation after operation. Two methods of anticoagulation were used. In patients undergoing CABG, subcutaneous low-dose heparin was commenced 6 h after removal of chest drains, while warfarin sodium was prescribed after prosthetic valve replacements and some mitral valveotomies. Patients receiving an aortic homograft valve were not anticoagulated. The 1st-day examination occurred before anticoagulation in most cases and there were no statistical differences between these three groups of patients. However, by the 8th day there was a greater frequency of occlusion in those patients receiving warfarin (48%) than either those receiving subcutaneous heparin (20%) or those receiving no anticoagulants (22%) (table III).
The frequency of radial artery occlusion was significantly greater in patients anticoagulated with warfarin after operation than in those treated with subcutaneous low-dose heparin or not receiving anticoagulants (H statistic shown).

<table>
<thead>
<tr>
<th></th>
<th>No anticoagulation</th>
<th>Heparin</th>
<th>Warfarin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patent</td>
<td>56</td>
<td>138</td>
<td>19</td>
</tr>
<tr>
<td>Partial occlusion</td>
<td>13</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>Complete occlusion</td>
<td>19</td>
<td>39</td>
<td>20</td>
</tr>
</tbody>
</table>

$H = 12.3$; 2 d.f.

Haematoma formation. Occlusion occurred in 14 of 29 (48%) patients with a large haematoma compared with only 23 in those with minimal or no bruising. Large bruises were more common in women than in men ($Z = 3.0$), after cut-down procedures ($Z = 2.8$), and after anticoagulation with warfarin ($H = 12.6$; 2 d.f.).

Non-significant variables. No statistical association was found between the frequency of arterial occlusion and age, previous cannulation of the same vessel, Allen's test before operation or the technique of cannulation (single-wall or transfixion). The mean duration of cannulation was 27 h with a range of 1-80 h. The frequency of occlusion did not increase with the duration of cannulation. No occlusions were seen following cannulation of less than 4 h. Bacterial cultures were possible from 24 of 59 cannula tips using an enrichment media technique (Davis and Cornere, 1979), but the occurrence of infection was not significantly associated with the occlusion rate ($\chi^2 = 2.099$; 1 d.f.).

**Predictability of thrombosis**

The results for multivariate analysis using the sequential screening method on the 1st day after removal of the catheter are shown in table IV. Only 32% of category 3 patients were correctly classified by this technique, 23% of category 2 and 91% of category 1. The results for the 8th day were similar. The outcome of this analysis would appear to be rather unsatisfactory as a means of predicting the patient likely to develop thrombosis. Thus, although many of the variables investigated correlated with the likelihood of thrombus formation, they do not, on their own, predict the outcome. For both the 1st and 8th days, cannula type and size and the grade of haematoma were the variables which best separated the groups. The sex of the patient was also of importance on the 8th day.

**Features associated with thrombosis**

Cannula management. Pressure waveform damping or difficulty in drawing blood samples soon negate the value of an arterial line. These were encountered in 30% of patients; twice as often in those patients whose arteries subsequently occluded than in those patients with patent vessels (table V).

Distal radial pulse. The radial pulse was palpable distally in 49% of completely occluded vessels, and in 7% was equal in volume to the pulse on the opposite, non-occluded side.

**Clinical sequelae**

Twelve patients (3.6%) developed signs of impaired perfusion of the hand during or following cannula-
required repeated sympathetic blockade (axillary brachial plexus block) to treat gangrene of her hand which eventually recovered.

Transient numbness of the thumb occurred in one case.

Superficial inflammation of the skin entry site was seen after eight percutaneous (2.7%) and eight cut-down (23.5%) cannulations. Bacterial cultures were negative in these, and the inflammation settled rapidly.

Accidental removal of the cannula (two patients) and disconnection of the manometer line (two patients) were the only technical complications encountered.

**DISCUSSION**

There is evidence that both the type and size of cannula used are of importance in reducing the risks of arterial occlusion (Downs et al., 1973; Bedford, 1975, 1977; Kim, Arakawa and Bliss, 1975), but not all studies have supported this (Bedford and Wollman, 1973; Evans and Kerr, 1974). The present study confirms that occlusion is greatly minimized by using 20-gauge Teflon cannulae. Thus, the high frequency of complications, especially hand ischaemia, reported using 15-gauge catheters (Little, Clarke and Shanks, 1975) can be readily avoided.

Our findings substantiate that occlusion occurs more commonly in women than in men (Kim, Arakawa and Bliss, 1975). This is most likely to be related to the ratio of the lumen of the vessel to the external diameter of the catheter as reported by Bedford (1977). One might predict, therefore, a higher frequency of occlusion in children even if 22-gauge Teflon catheters are used.

The dynamics of blood flow have been reported in only 12 patients (Ryan et al., 1973). The effect of pre-existing arterial disease has not been elucidated, although diminished digital pulse volume has been reported by Ryan in five of seven patients with previous brachial artery catheterization. Re-cannulation of 26 previously cannulated vessels in our patients, however, did not appear to result in an increased frequency of occlusion or hand ischaemia.

It was further suggested by Ryan and others (1973) that the non-dominant artery should always be cannulated in preference. This is probably unnecessary, provided the collateral flow from the other vessel is adequate. Indeed, there was evidence from the 46 patients in whom we assessed arterial dominance to suggest that partial or complete occlusion was significantly more likely to occur if the radial artery were the non-dominant vessel ($H = 8.2; 2$ d.f.). This observation, which requires to be confirmed, may be related to the findings of Bedford (1977). Cannulation of 33 radial arteries in the face of a grade 2 Allen’s test was uneventful, and this level of ulnar collateral flow can probably be regarded as acceptable. Bedford (1977) has adopted the more stringent criteria of a thenar eminence “flush” within 5 s of ulnar release.

Increased trauma to the vessel because of multiple needling or surgery does seem to increase the likelihood of subsequent occlusion, although others have not been able to demonstrate this (Kim, Arakawa and Bliss, 1975). It is important to note that not all surgical cut-downs thrombose. Therefore, routine ligation of the vessel distally cannot be condoned, and cannulation is best performed by single-wall puncture using trocar and 20-gauge cannula under direct vision when a cut-down is necessary.

The frequency of thrombosis has been reported to be related to the duration of cannulation (Bedford and Wollman, 1973; Evans and Kerr, 1974), but others have been unable to confirm this (Kim, Arakawa and Bliss, 1975). In the present study, there was no relationship between the duration of cannulation and the frequency of occlusion. However, there were only 12 patients in our series in what appears to be the critical 6–18-h cannulation period (Bedford and Wollman, 1973).

We were able to confirm the observations of Gardner and others (1974) that arterial complications are more common in the presence of hypotension and following the use of inotropic agents. However, the value of an intra-arterial line in such life-threatening circumstances outweighs the risks of local vascular complications. No permanent sequelae were observed in the present series, nor was any surgical intervention required.

Thermographic differences have been reported between the upper limbs of patients with clinically demonstrable arterial occlusion (Evans and Kerr, 1974). However, thumb temperature difference between the two sides did not appear to be a particularly useful screening test for occlusion in the present study. The presence of venous cannulae and subsequent common occurrence of superficial venous thrombosis in the same limb may have contributed to this. We have reported a much greater frequency of damping and sampling problems in vessels which were subsequently shown to be occluded. The occurrence of these difficulties during cannulation
should raise suspicion of the development of an arterial thrombosis.

From our studies, it does not appear possible to state the probability of subsequent radial artery thrombosis with accuracy, although many "risk" factors contribute to the morbidity of the technique. Therefore, guidelines for patient care (Oh and Davis, 1975) should be followed in order to minimize complications. In particular, the duration of cannulation should be the shortest and the Teflon cannula the smallest compatible with clinical needs.

The most important factors related to occlusion following arterial cannulation are the size and material of the catheter. The frequency reported with 20-gauge Teflon cannulae was only 3%. Secondarily, the patient's sex, trauma to the vessel, low cardiac output states and aspects of general patient care and catheter management all play a part. It does not appear possible from our data to predict the outcome of arterial cannulation in any given patient on the basis of these variables. The frequency of major complications was extremely low, and without permanent sequelae. The risks of arterial occlusion must be weighed against the proven value of direct intra-arterial pressure monitoring and serial arterial blood sampling.

ACKNOWLEDGEMENTS

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REFERENCES


POSE D'UNE CANULE DANS L'ARTERE RADIALE

Etude sur des patients subissant une intervention chirurgicale cardiothoracique

RESUME

Après avoir effectué 333 poses de canules dans l'artère radiale, la fréquence d'occlusion complète du vaisseau le lendemain du retrait de la canule a été de 30% ; diminuant à 24% vers le huitième jour. On a évalué l'occlusion artérielle en se servant d'un débitmètre ultrason modifié et en utilisant le test d'Allen. La fréquence a été fonction du type et de la dimension de la canule utilisée, la plus faible (3%) étant constatée avec les canules en Téflon d'un calibre de 20; du degré de contusions et du sexe du patient, celle-ci étant nettement plus élevée chez les femmes (37,5%) que chez les hommes (27%). On a estimé d'autres éléments variables, tels que la technique d'insertion, la faiblesse du débit cardiaque, l'anticoagulation après l'opération et la durée de la pose de la canule. En procédant à des analyses de 13 éléments variables, il n'a pas semblé possible de prédire avec certitude les résultats de la pose....
RADIAL ARTERY CANNULATION

des canules artérielles. La fréquence de complications importantes a été faible et l'on n'a pu détecter aucunes séquelles permanentes.

KANÜLENEINFÜHRUNG IN DIE RADIALARTERIE
Studie von Patienten bei Herz-Brustraumoperationen

ZUSAMMENFASSUNG


CANULACION DE LA ARTERIA RADIAL
Un estudio exploratorio en pacientes sometidos a cirugía cardiotorácica

SUMARIO

A raíz de 333 canulaciones de la arteria radial, se comprobó que la frecuencia de una oclusión completa del vaso al día siguiente de la remoción de la cánula era de 30% y había disminuido hasta un 24% 8 días después. Se evaluó la oclusión arterial mediante una prueba de Allen modificada y un medidor ultrasónico de flujo. Dicha frecuencia en relación con el tipo y tamaño de la cánula usada era menor (3%) con cánulas de Teflón de calibre 20, y con el grado de contusión y el sexo del paciente mucho mayor en mujeres (37,5%) que en los hombres (27%). Se evaluaron también otras variables tales como técnica de inserción, función cardíaca baja, anticoagulación después de la operación y duración de canulación. Al hacer un análisis multivariado de 13 variables, no pareció posible predecir con alguna certeza el resultado de la canulación arterial. Fue baja la frecuencia de complicaciones mayores y no se descubrió ninguna secuela permanente.