Pre-procedure ultrasound increases the success and safety of central venous catheterization†

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Editor’s key points

- It is recommended that ultrasound (US) is used to facilitate cannulation of the internal jugular vein (IJV).
- This observational cohort study compared pre-procedural US with landmark techniques for IJV cannulation under general anaesthesia.
- Pre-procedural US was associated with higher success rates, shorter cannulation times, and fewer complications.
- These differences occurred with both experienced and inexperienced operators.

Background. Real-time ultrasound (US) in central venous catheterization is superior to pre-procedure US. However, moving real-time US into routine practice is impeded by its perceived expense and difficulty. Currently, pre-procedure US and landmark (LM) methods are most widely used. We investigated these techniques in internal jugular vein (IJV) catheterization in respect of operator experience, complications, and risk factors.

Methods. In an observational non-randomized study, we investigated 606 of ~1300 procedures, that is, 200 patients were treated under pre-procedure US and 406 under LM [pathfinder (PF) n=202, direct cannulation (DC) n=204]. We recorded first needle pass success rate, success rate after the third attempt, and the cannulation time. Procedures were performed by inexperienced (<100) or experienced (>100 catheterizations) operators.

Results. Pre-procedure US was associated with more successful attempts and shorter cannulation times. Under pre-procedure US, 88% of first attempts were successful and 100% of third attempts. The median (range) cannulation time was 39 (10–330) s. Under PF, only 56% of first, and 87% of third, attempts were successful with a median (range) cannulation time of 100 (25–3600) s. Under DC, 61% of first and 89% of third attempts were successful; the median (range) cannulation time was 70 (10–3600) s. Remarkably, inexperienced operators using pre-procedure US (n=38) were significantly faster than experienced operators using PF or DC (n=343) (cannulation time: median 60 s, range 12–330, for inexperienced; 60 s, range 10–3600, for experienced). First puncture success rates were higher (pre-procedure US, inexperienced 84%, PF or DC, experienced 57%).

Conclusions. Pre-procedure US for IJV catheterization is safe, quick, and superior to LM.

Keywords: cannulation time; central venous catheterization; complications; internal jugular vein; success rate; ultrasound

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Anaesthesia-related complications are still a major concern, with central venous (CV) cannulation complications being the leading cause of anaesthesia-related deaths according to one Danish closed claim study.1 Two-dimensional imaging with real-time ultrasound (US) is superior to external landmark (LM)-guided CV catheterization (CVC) with respect to cannulation success and avoidance of early mechanical complications.2–4 Real-time US, a technique proved to prevent those complications, is now the recommended method of inserting CV catheters into the internal jugular vein (IJV).5 Unfortunately, there is a delay between recognizing the benefits and actually implementing real-time US in the clinical environment. This delay arises through concern that real-time US is unsuitable for everyday use, fear of large investments in hardware and training, and the under-estimation of the complications arising under current techniques.6 Regardless of the reasons, the end result is that most practitioners do not have real-time US as an option. They

†This report describes research on humans. IRB contact information: Ethik-Kommission der Friedrich Schiller Universität Jena an der Medizinischen Fakultät. Professor Dr. med. d. Bartz, approved under No.: 1694-01/06. Tel: +49 3641 933770; fax: +49 3641 933771; E-mail: ulrike.skorsetz@med.uni-jena.de. This study was conducted with written informed consent from the study subjects.
must use either pre-procedure US or LM, with LM being their first choice.\textsuperscript{7}

In surveys from 2003 and 2007 of German anaesthesiologists, respondents, particularly the longest practicing, overwhelmingly indicated a preference for LM over pre-procedure US.\textsuperscript{6,8} We believe that this preference is not unique to German anaesthesiologists, but a global phenomenon. This preference exists despite a mechanical failure rate with LM of 5–19\%, and up to 6\% even for highly experienced operators.\textsuperscript{9,10} The aim of our study was to determine, whether pre-procedure US or LM techniques was the safest and the most successful in a real life clinical environment. We intentionally included the real-life features of differences in operator experience and risk factors (BMI $<$21 or $>$32 kg m\(^{-2}\), previous CVC, goitre, left IJV). We recorded success rates, cannulation times, and the occurrence of complications.

**Methods**

After approval from the local Ethical Committee, we conducted a non-randomized clinical trial of IJV catheterization in an operating theatre of Jena University Hospital. Patients were included if there were indications for CVC as determined by the attending physician and the type of surgery. We included patients more than 12 yr old. Adult patients gave written consent. For non-adult patients (those $<$18 yr old), parents gave written consent. The exclusion criteria were any contraindications for IJV placement or not being able to obtain written consent (which automatically excluded emergencies).

We compared pre-procedure US with two LM techniques (pathfinder (PF) and direct cannulation (DC)). We performed pre-procedure US first for 4 months because we were lent a portable Esaote\textsuperscript{®} (MyLab\textsuperscript{TM}30CV) US machine for this period by the manufacturer (Esaote Biomedica Deutschland GmbH, Cologne, Germany). Data were recorded from 200 patients. We then performed PF and DC until similar sample sizes had been obtained for each technique (PF $=$202, DC $=$204). This took a further 6 months, so the study totalled 10 months in all. Whether PF or DC was used by an operator was determined at random by the supervising investigator tossing a coin. However, DC was never assigned to novices (operators with $<$50 catheterizations).

We recorded data from 606 IJV catheterizations, all those that took place in the presence of the investigator. Data were not recorded from any others in order to avoid the possibility of inaccurate self-reporting. However, $\sim$1300 IJV catheterizations were performed during the 10 months of the study.

The CVCs were carried out by physicians from Jena University Hospital, Department of Anaesthesiology. Thirteen of these were trainees and 50 postgraduates of year 3 or above and thus of differing degrees of skill and amounts of experience. We divided the 63 operators into experienced ($>$100 successful unsupervised catheterizations) and inexperienced (with fewer).

All catheterizations were supervised by a single investigator who also recorded the results, so avoiding inter-investigator differences. The investigator also documented the characteristics of the patients and operators and also any complications that occurred. The data recorded were the number of cannulation attempts, the first needle pass success rate, third attempt success rate, cannulation time, and early mechanical complications. The first needle pass success rate was defined as successful IJV cannulation with a wide-bore needle. A cannulation attempt was defined as a single skin puncture. Any attempt with a seeker needle was documented separately. Cannulation time was measured from ‘needle to skin to J-wire in’.

Because previous CVC, BMI $<$21 or $>$32 kg m\(^{-2}\), goitre, and CVC via the left IJV are associated with more complications under LM,\textsuperscript{10–14} we recorded these details. We defined goitre as a visibly enlarged thyroid gland (WHO grade III). Complications recorded included haematoma and pneumothorax. Severe haematoma was defined as a visible haematoma large enough to compromise the airway (without any particular technical assessment).

All CV catheters were inserted with the Seldinger technique using a Certofix\textsuperscript{®} Trio (B. Braun Melsungen AG, Germany). Most CVCs were performed in patients under general anaesthesia and mechanical ventilation (tidal volume 6–8 ml kg\(^{-1}\), PEEP 5 cm H\(_{2}\)O). Otherwise ($n$=84), CVC was performed under local anaesthesia using 1% lidocaine at the cannulation site. All patients were placed in a 30° Trendelenburg supine position with the head in a neutral position.

**Pre-procedure US**

This involved scanning the neck and antero-lateral vessel area with two-dimensional US before cannulation. Scans were made using a portable Esaote\textsuperscript{®} machine (MyLab\textsuperscript{TM}30CV, Esaote Biomedica Deutschland GmbH) with an 18–6 MHz linear-array probe. Both left and right IJVs were evaluated in terms of their course, calibre, patency, and relationship to the carotid artery. No skin markings were applied. The cannulation site was subsequently prepared and draped under sterile precautions. The vein was punctured with an 18 G needle without the use of a seeker needle, palpation of external LMs, or of the carotid artery.

**LM techniques**

After sterile preparation of the cannulation site, the anticipated position of the IJV was identified by external LMs. The approach used (central, anterior, or posterior) depended on operator preference. PF used a 21 G seeker needle to identify the IJV. The vein was then punctured with a wide-bore needle, while the fine gauge needle remained in place. DC was carried out using an 18 G needle for direct IJV puncture.

**Rescue US**

Catheterization failure was defined as no success after three attempts, no success within 10 min, or if there were complications. Under any of these three circumstances, operators were able to request rescue US, but it was not mandatory to do so. CVCs requiring rescue US were excluded from the study as they were then no longer true LM.
Statistical analysis

Nominal data such as success or complication rates are presented as numbers and percentages. Count data for cannulation attempts and cannulation time are presented as the median and range. Statistical analysis was performed with SPSS® version 13.0 (SPSS Inc., Chicago, IL, USA). Nominal data, such as success and complication rates, were analysed using the χ² test. The Mann–Whitney tests were used for comparing cannulation time and number of attempts. A P-value of <0.05 was considered as statistically significant.

Results

Patient characteristics were similar from group to group (Table 1) and only the techniques and operators differed. Overall, all operators using pre-procedure US compared with all using LM, pre-procedure US was associated with a significantly higher first needle pass success rate (88% rather than 58%), shorter cannulation time (median 39 s, range 10–330, rather than median 80 s, range 10–3600), fewer cannulation attempts (median 1, range 1–3, compared with median 1, range 1–20), and fewer arterial punctures (n=1; 0.5% of all patients compared with n=40; 9.9%) (Figs 1–3, Table 2). In particular, even for experienced users, cannulation times were lower under pre-procedure US than under LM (median 30 s, 10–210, rather than 60 s, 10–3600 (Mann–Whitney U-test; P<0.001)). The range under LM shows that many experienced operators took longer to cannulate than the maximum time under pre-procedure US.

Under pre-procedure US, there was one arterial puncture (0.5%) and no failures. In LM groups, there were 40 (9.9%) arterial punctures and 66 (16.3%) failures. There were more attempts (median 1, range 1–6) with the fine-bore seeker needle under PF than under DC, more arterial punctures (12% vs 7%; χ² test; P=0.09) but fewer haematomas (n=2 vs n=5; χ² test; NS). In no case did surgery have to be cancelled due to haematoma. Under LM, the first needle pass rate for patients with low BMI (<21 kg m⁻²) was only 46% compared with 59% for patients with normal BMI (Mann–Whitney U-test; NS). The third attempt success rate was also lower, 77% compared with 89%, and significantly so (Mann–Whitney U-test; P=0.037). The arterial puncture rate was 13% compared with 9.5%. The results under LM for patients with high BMI (>32 kg m⁻²) were similar to those of the normal population and all were cannulated within three attempts.

Under LM, operator experience did not cause significant differences in cannulation time or success rates. Remarkably, however, arterial puncture rates were 11% for experienced but only 5% for inexperienced operators, even though the difference was not significant (χ² test; P=0.17). Inexperienced operators caused three of 41 arterial punctures, all of which occurred under PF. Experienced operators caused 37 arterial punctures under LM and the only arterial puncture that occurred under pre-procedure US.

Under LM, the number of attempts with the wide-bore needle was similar in PF and DC (median 1, range 1–10, for PF vs median 1, range 1–20, for DC). However, cannulation

Table 1 Patient characteristics. Data are given as number n and (%) and median (range). CVC, central venous catheterization; IJV, internal jugular vein

<table>
<thead>
<tr>
<th></th>
<th>Ultrasound (US)</th>
<th>Pathfinder (PF)</th>
<th>Direct cannulation (DC)</th>
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</thead>
<tbody>
<tr>
<td>CVC [n (%)]</td>
<td>200 (33.0)</td>
<td>202 (33.3)</td>
<td>204 (33.7)</td>
</tr>
<tr>
<td>Experienced operator [n (%)]</td>
<td>162 (81.0)</td>
<td>153 (75.7)</td>
<td>190 (93.1)</td>
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<tr>
<td>Patients</td>
<td></td>
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<tr>
<td>Females [n (%)]</td>
<td>91 (45.5)</td>
<td>76 (37.6)</td>
<td>108 (52.9)</td>
</tr>
<tr>
<td>Age (yr) [median (range)]</td>
<td>65 (15–86)</td>
<td>63 (13–85)</td>
<td>65 (21–83)</td>
</tr>
<tr>
<td>Height (cm) [median (range)]</td>
<td>170 (148–191)</td>
<td>171 (148–196)</td>
<td>169 (149–189)</td>
</tr>
<tr>
<td>Body weight (kg) [median (range)]</td>
<td>75 (37–130)</td>
<td>76 (38–180)</td>
<td>75 (44–128)</td>
</tr>
<tr>
<td>BMI (kg m⁻²) [median (range)]</td>
<td>25.7 (15.4–52)</td>
<td>25.7 (15.8–62)</td>
<td>26.3 (17.5–58)</td>
</tr>
<tr>
<td>Cardiac surgery [n (%)]</td>
<td>74 (37.0)</td>
<td>41 (20.3)</td>
<td>89 (43.6)</td>
</tr>
<tr>
<td>General surgery [n (%)]</td>
<td>73 (36.5)</td>
<td>63 (31.2)</td>
<td>44 (21.6)</td>
</tr>
<tr>
<td>Neurosurgery [n (%)]</td>
<td>17 (8.5)</td>
<td>21 (10.4)</td>
<td>12 (5.9)</td>
</tr>
<tr>
<td>Others [n (%)]</td>
<td>36 (18.0)</td>
<td>77 (38.1)</td>
<td>59 (28.9)</td>
</tr>
<tr>
<td>Goitre [n (%)]</td>
<td>23 (11.5)</td>
<td>20 (9.9)</td>
<td>22 (10.8)</td>
</tr>
<tr>
<td>Previous CVC [n (%)]</td>
<td>60 (32.3)</td>
<td>83 (44.6)</td>
<td>43 (23.1)</td>
</tr>
<tr>
<td>BMI &lt; 21 kg m⁻² [n (%)]</td>
<td>18 (9.2)</td>
<td>20 (9.9)</td>
<td>19 (9.5)</td>
</tr>
<tr>
<td>BMI &gt; 32 kg m⁻² [n (%)]</td>
<td>21 (10.7)</td>
<td>26 (12.9)</td>
<td>33 (16.4)</td>
</tr>
<tr>
<td>Puncture of the left IJV [n (%)]</td>
<td>35 (17.5)</td>
<td>47 (23.3)</td>
<td>34 (16.7)</td>
</tr>
<tr>
<td>Mechanical complications</td>
<td></td>
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<tr>
<td>Arterial puncture [n (%)]</td>
<td>1 (0.5)</td>
<td>25 (12.4)</td>
<td>15 (7.4)</td>
</tr>
<tr>
<td>Severe haematoma [n (%)]</td>
<td>1 (0.5)</td>
<td>2 (1)</td>
<td>5 (2.5)</td>
</tr>
<tr>
<td>Pneumo-/haemothorax [n (%)]</td>
<td>1 (0.5)</td>
<td>1 (0.5)</td>
<td>2 (1)</td>
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</table>
time was significantly shorter (Mann–Whitney $U$-test; $P<0.013$) under PF (median 100 s, range 25–3600) than under DC (median 70 s, range 10–3600).

The only statistically significant difference (Mann–Whitney $U$-test; $P=0.004$) under LM between patients with and without previous CVC was for the third attempt success rate. This was 81% for patients with previous CVC and 91% for those without. There was no significant difference in the number of cannulation attempts or in cannulation time. The arterial puncture rate was 10% in patients with previous CVC.

**Fig 1** Success rates (in per cent) with first puncture attempt and wire. (a) All operators. (a) Differentiation according to operator experience. US, ultrasound; PF, pathfinder; DC, direct cannulation. $\chi^2$ test; *$P<0.05$ vs US (A), respectively, vs US within each category of operator (a).

**Fig 2** Cannulation time with one wire (in seconds). (A) All operators. (a) Differentiation according to operator experience. Analyses are without rescue cases. US, ultrasound; PF, pathfinder; DC, direct cannulation. Box whisker diagram present the median (bold line), 25–75% quartile (box), and 1.5 inter-quartile range (whiskers). Squares indicate mild outliers and triangles extreme outliers. Mann–Whitney $U$-test; *$P<0.05$ vs US (A), respectively, vs US within each category of operator (a).
Table 2 Comparison of pre-procedure US and the LM guidance techniques PF and DC. Successful punctures for all operators, in inexperienced and in experienced operators. Results as absolute numbers (n) and percentages, χ² test; *P < 0.05 for LM against pre-procedure US

<table>
<thead>
<tr>
<th>Success with</th>
<th>Ultrasound</th>
<th></th>
<th>Pathfinder</th>
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<th>Direct cannulation</th>
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<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
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<td>All operators</td>
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<tr>
<td>Pre-puncture in first attempt</td>
<td>130</td>
<td>64.4</td>
<td></td>
<td></td>
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<tr>
<td>First wire in first attempt</td>
<td>175</td>
<td>87.5</td>
<td>113</td>
<td>55.9*</td>
<td>124</td>
<td>60.8*</td>
</tr>
<tr>
<td>First wire after third attempt</td>
<td>200</td>
<td>100.0</td>
<td>176</td>
<td>87.1*</td>
<td>181</td>
<td>88.7*</td>
</tr>
<tr>
<td>Second wire in first attempt</td>
<td>64</td>
<td>86.5</td>
<td>29</td>
<td>76.3</td>
<td>83</td>
<td>77.6</td>
</tr>
<tr>
<td>Arterial puncture</td>
<td>1</td>
<td>0.5</td>
<td>25</td>
<td>12.4</td>
<td>15</td>
<td>7.4*</td>
</tr>
<tr>
<td>Inexperienced operators</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Pre-puncture in first attempt</td>
<td>27</td>
<td>55.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First wire in first attempt</td>
<td>32</td>
<td>84.2</td>
<td>35</td>
<td>71.4</td>
<td>7</td>
<td>50.0</td>
</tr>
<tr>
<td>First wire after third attempt</td>
<td>38</td>
<td>100.0</td>
<td>44</td>
<td>89.8</td>
<td>13</td>
<td>92.9</td>
</tr>
<tr>
<td>Second wire in first attempt</td>
<td>1</td>
<td>100.0</td>
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<tr>
<td>Arterial puncture</td>
<td>3</td>
<td>6.1</td>
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<tr>
<td>Experienced operators</td>
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<tr>
<td>Pre-puncture in first attempt</td>
<td>103</td>
<td>67.3</td>
<td></td>
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<td></td>
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<tr>
<td>First wire in first attempt</td>
<td>143</td>
<td>88.3</td>
<td>78</td>
<td>51.0*</td>
<td>117</td>
<td>61.6*</td>
</tr>
<tr>
<td>First wire after third attempt</td>
<td>162</td>
<td>100.0</td>
<td>132</td>
<td>86.3</td>
<td>168</td>
<td>88.4*</td>
</tr>
<tr>
<td>Second wire in first attempt</td>
<td>64</td>
<td>87.7</td>
<td>29</td>
<td>76.3</td>
<td>87</td>
<td>77.0</td>
</tr>
<tr>
<td>Arterial puncture</td>
<td>1</td>
<td>0.6</td>
<td>22</td>
<td>14.4*</td>
<td>15</td>
<td>7.9*</td>
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</tbody>
</table>

Under LM, patients with goitre had a significantly lower success rate and longer cannulation times than those without. Specifically, the third attempt success rate was only 79% compared with 89% (Mann–Whitney U-test; P = 0.049) and the median cannulation time 230 s (range 25–1440) in comparison with 80 s (range 10–3600) (Mann–Whitney U-test; P = 0.012). The median number of cannulation attempts was 1 (range 1–10) for patients with goitre, less than that without goitre (median 1, range 1–20) but not significantly so (Mann–Whitney U-test; NS). The arterial puncture rate in patients with goitre was 17% and 9.1% without goitre.

Right and left IJV catheterizations were only significantly different for the first needle pass rate. This rate was lower...
There was no significant difference in this rate under pre-procedure US and both were high (left 83%, right 89%; \( \chi^2 \) test; \( P = 0.4 \)). Over all CVC recorded, there were 14% involved changes from the left to right and 4% from right to left. Under LM, 8% of changes resulted from unsuccessful cannulation attempts. Moreover, under LM, in patients with previous CVC, side changes occurred more often (15%) due to unsuccessful attempts. Under pre-procedure US, there were side changes in 6% of all patients and 13% of patients with previous CVC. However, these changes took place based on information derived from the pre-procedure US rather than because of unsuccessful attempts.

In total, 66 failures occurred under LM (Fig. 4). In 24 of these 66 cases, operators using LM requested rescue US. Rescue US examination required a median of 42 s (range 8 – 120). The puncture site was changed to the contralateral side in 10 patients due to a thrombosed or small calibre IJV or unsuitable anatomy. After rescue US, cannulation was achieved by first needle pass in 18 cases, and second needle pass in six cases. The cannulation time after rescue US was a median of 30 s (range 17 – 160). Unfortunately, nine of the 24 patients had already suffered arterial puncture before rescue US. The remaining 42 LM patients were eventually catheterized (maximum time 60 min).

**Discussion**

Pre-procedure US was associated with a higher success rate and safety of CVC. More first attempts were successful for pre-procedure US than for LM (88% compared with 58%). Cannulation times were also shorter with pre-procedure US (median of 39 (10 – 330) compared with 80 s (10 – 3600)). Pre-procedure US therefore enables to save time and reduce complications. It is less risky and may be more easily implemented than real-time US, the current recommended best practice.\(^3\)\(^5\) The superiority of pre-procedure US is even true for inexperienced operators using it. In fact, under pre-procedure US, they caused fewer complications than did experienced operators using LM. There is little appreciation of the value of US, although its benefits are known.\(^1\)\(^1\)\(^6\) Our study confirms these benefits in the context of routine practice.

Time is crucial to the operating schedule in clinical practice and ‘unnecessary time expenditure’ is one complaint against using US (real-time US in this case).\(^7\) However, even our inexperienced operators had shorter cannulation times under pre-procedure US than experienced operators under LM. Moreover, experienced operators took less time with pre-procedure US than with LM. Under LM, excessive times, >900 s, were common. Therefore, pre-procedure US may not only save time, contrary to prevailing opinion among practitioners, but it is also safer. A bonus is that pre-procedure US is not difficult.
to learn.\textsuperscript{10,11} The equipment is relatively inexpensive, and inexperienced operators achieve a better understanding of anatomy and the difficulty of conventional techniques, and in doing so, improve their skills.\textsuperscript{17}

Pre-procedure US avoids mechanical complications by directly revealing anatomical variations of the IJV such as its position relative to the carotid artery, thromboses, small calibre, or even its complete absence. Under LM, these are hidden and so cause problems.\textsuperscript{14-18,19} We found severe complications, pneumo- and haemothorax, only under LM.

One problem is the need for repeated cannulation when complications are encountered during LM. Multiple cannulation harms patients so reducing or eliminating them is a major patient benefit.\textsuperscript{10} The harm arises because multiple cannulation increases patient discomfort, vein damage, thrombosis, and catheter-related sepsis. Multiple punctures should be avoided and this may be achieved by pre-procedure US.\textsuperscript{20-23}

Pre-procedure US thus reduces unsuccessful attempts and in consequence the complication, occasionally fatal, that may follow failed attempts.\textsuperscript{19,24-28} There were also fewer complications under pre-procedure US in our study and this is also true elsewhere. There is little research directly comparable with ours but, in a randomized controlled study, pre-procedure US was far superior to LM.\textsuperscript{29} Real-time US was most successful but required more training and personnel than pre-procedure US.

Pre-procedure US was superior to LM in that there were significantly fewer complications under pre-procedure US in patients with risk factors. These risk factors were low BMI, goitre, and previous CV cannulation. The difference between pre-procedure US and LM that we found was not due to differential occurrence of risk factors in pre-procedure US and LM patients. Risks were, in fact, equally distributed between the two groups. Pre-procedure US thus has the potential, in clinical practice, to reduce complications associated with known risk factors.

Pre-procedure US specifically avoided the relatively high arterial puncture rates we found under LM for BMI < 21 kg m\textsuperscript{-2}. There was no effect, however, for patients with higher BMI. In addition, pre-procedure US avoided the high arterial puncture rate under LM for patients with goitre. Goitre is not known to reduce cannulation success rates, although a case of haematoma-induced airway obstruction\textsuperscript{13} suggests that it is a risk factor for IJV catheterization. Our results show that it is a risk factor under LM, but not under pre-procedure US.

Our arterial puncture rate under LM was only slightly higher in patients with previous CVC. Many of the complications due to previous CVC are related to their association with thromboses which make catheterization more difficult or even impossible.\textsuperscript{12,19}

Limitations

Our study took place in, and was intended to reflect, the real-world pressures of a university hospital. It is an observational, non-randomized, single-centre study. These two factors impose some limitations. We had no opportunity, for example, to standardize the circumstances under which operations were carried out. However, despite these limitations, we detected substantial differences between outcomes under pre-procedure US and LM. These differences are therefore robust to the pressures of clinical practice.

We were also limited by having only one investigator supervising operations. It is possible that operators took more care when the investigator was present. This would not have produced the superiority of pre-procedure US observed, however, unless those using pre-procedure US systematically took more care under supervision than when using LM. This is unlikely. We were also constrained to use pre-procedure US alone during the first 4 months and only LM thereafter. The differences between the two techniques could therefore have arisen from extraneous differences between the two time periods. Such extraneous differences are unlikely, however. Furthermore, the experience gained using pre-procedure US might be expected to improve performance of LM and so reduced the differences between the two techniques. If this occurred, it was still not sufficient to erase the superiority of outcome under pre-procedure US. Change in operator results over time is, nevertheless, something that might usefully be studied, even though we did not include it in our investigation.

Conclusions

Pre-procedure US for IJV catheterization is better than LM techniques and gives results similar to real-time US, currently the gold standard of clinical practice. This pattern remains true even for patients with risk factors and, regardless of operator experience in LM techniques, patients fare better under US. Pre-procedure US takes less time than LM techniques. The technique is relatively easy to learn and a second person is not required. We therefore recommend the replacement of LM techniques by pre-procedure US in clinical practice. Where LM techniques persist, rescue US should be applied after three unsuccessful attempts, after 10 min, or if complications occur. In general, if real-time US is not available, we urge the adoption of pre-procedure US in clinical practice for the benefit of patients.

Authors’ contributions

W.S. and J.A.K. contributed to the literature search; W.S., C.S., and S.G.S. performed the study design; J.A.K., C.S., and W.S. collected the data. J.A.K. performed the statistical analysis. W.S. created the first draft of the manuscript; and W.S., S.G.S., K.R., and J.A.K. participated in revising and preparing the final draft of the manuscript. W.S. has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files. All other authors have seen the original study data, reviewed the analysis of the data, and approved the manuscript.

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Declaration of interest
None declared.

References

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