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# Investigation into the visual perceptive ability of anaesthetists during ultrasound-guided interscalene and femoral blocks conducted on soft embalmed cadavers: a randomised single-blind study

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**An investigation into the visual perceptive ability of anaesthetists during analysis of ultrasound guided interscalene and femoral blocks conducted on soft embalmed cadavers.  
A randomised, single blind study.**



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<a href=https://www.nlm.nih.gov/mesh/MBrowser.html target=_new>Mesh keywords</a>:	Regional anaesthesia, Ultrasonography, Elastography

**Abstract**

**Background:** Errors may occur during regional anaesthesia while searching for nerves, needle tips and test doses. Poor visual search impacts on decision making, clinical intervention and patient safety.

**Methods:** We conducted a randomised, single-blind study in a single university hospital.

Twenty trainees and two consultants examined paired B-Mode and fused B-mode and elastography video recordings of 24 interscalene and 24 femoral blocks conducted on two soft embalmed cadavers. Perineural injection was randomised equally to 0.25ml, 0.5ml and 1.0ml volumes. Tissue displacement perceived on both imaging modalities was defined as “target” or “distractor”.

Our primary objective was to test anaesthetists’ perception of the number and proportion of targets and distractors on B-Mode and fused elastography videos collected during femoral and sciatic nerve block on soft embalmed cadavers. Our secondary objectives were to determine differences between novices and experts and between test dose volumes, and measure the area and brightness of spread and strain patterns.

**Results:** All anaesthetists recognised perineural spread using 0.25ml volumes. Distractor patterns were recognised in 133 (12%) of B-Mode and in 403 (38%) of fused B-Mode and elastography patterns,  $P < 0.001$ . With elastography, novice recognition improved from 12% to 37% ( $P < 0.001$ ) and consultant recognition increased from 24% to 53%,  $P < 0.001$ . Distractor recognition improved from 8% to 31% using 0.25ml volumes ( $P < 0.001$ ), and from 15% to 45% using 1ml volumes ( $P < 0.001$ ).

**Conclusions:** Visual search improved with fusion elastography, increased volume, and consultants. A need exists to investigate image search strategies.

## Introduction

Errors may occur during the visual search, recognition and decision making phases<sup>1</sup> of ultrasound-guided regional anaesthesia (UGRA) nerve block. Search errors are attributable to failure to see lesions that are normally noticed by anaesthetists.<sup>2</sup> With recognition errors, lesions are seen but confusing; and decision errors occur when a lesion is fixated on for long periods but the anaesthetist either does not recognise features or dismisses them.<sup>3</sup>

Elastography is an ultrasound-based technology that cross-correlates radio-frequency waves before and after tissue displacement and displays relative displacement (strain) in colour.

While conducting interscalene and femoral nerve block in cadavers<sup>4</sup> and patients<sup>5</sup> we noticed novel features on paired B-Mode and elastography ultrasound images in response to injection of test doses. Tissue strain intermittently presented as two patterns instead of one.<sup>6</sup> Additional patterns, termed distractors, were distinguished from primary target displacement patterns by brightness, size, position or movement.<sup>7</sup> In contrast, test doses as low as 0.25ml were always seen on B-Mode images, but distractor patterns much less so. Our impression was that elastography exhibited greater saliency, the extent to which a location differs from its surroundings, than B-mode images because: (i) key regions differed in brightness, colour, orientation, and motion; and that (ii) anaesthetists' visual attention was attracted towards these features.

Visual salience describes the visual processing mechanism that enables the brain to select important features that stand out from other items or locations<sup>8</sup> (Table 1). Saliency is associated with passive, automatic visual search or "bottom-up processing" rather than cognitive, goal driven "top-down processing"<sup>9</sup>. Consideration of both processes creates an saliency map, a topographic representation of relative stimulus strength and behavioural

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3 importance. This map is distributed throughout the visual cortex and linked via the  
4  
5 oculomotor system to eye movement and eye gaze<sup>10</sup>. Eye gaze characteristics such as  
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7 fixations and saccades are quantified using eye-tracking technology and are used in many  
8  
9 industries to measure technical performance.  
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14 Visual search and salience differ between experts and novices. Experts rely on bottom-up  
15  
16 processes that facilitate efficient search, albeit mediated by prior knowledge when  
17  
18 encountering novel stimuli<sup>9</sup>. Novices, in contrast, are primarily goal driven but can be  
19  
20 salience led to very obvious targets.  
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26 We hypothesised that improvements in novice visual perception were salience driven, and,  
27  
28 if so, would provide the evidence for investigation of the role of eye gaze technology and  
29  
30 augmented reality during simulator training. This approach could help train anaesthetists  
31  
32 better, target local anaesthetic more and improve patient safety.  
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36  
37 Our primary objective was to test anaesthetists' perception of the number and proportion  
38  
39 of targets and distractors on B-Mode and fused elastography videos collected during  
40  
41 femoral and sciatic nerve block on soft embalmed cadavers.  
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46 Our secondary objectives were to measure differences in perception between novices and  
47  
48 experts, between test dose volumes, and measure the area and brightness of spread and  
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50 strain patterns over time.  
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## Methods

### *Participants*

All trainee anaesthetists at basic, intermediate and higher levels of training working in Ninewells Hospital were invited to take part in this study along with two consultant subspecialists in regional anaesthesia. Our exclusion criterion for trainees was the prior use of elastography. The study was approved by the University of Dundee Committee on Non-Medical Ethics.

### *Software Development*

Elastography and its applicability to the diagnosis of intraneural injection is described in detail in a previous papers<sup>4, 6</sup>. In summary, our engineer converted colour elastography video frames to filtered and despeckled black and white images using MATLAB software (Natick, MA) and a grayscale threshold tool. Enhanced elastography patterns were fused onto corresponding B-Mode images. Tissue displacement in response to fluid injection was seen as a flowing translucent, white area, superimposed onto paired B Mode images. Fusion videos were converted to TIFF files and analysed using ImageJ (Wayne Rasband, Research Services Branch, National Institute of Mental Health, Bethesda, MD)

### *Conduct of block*

A single independent, experienced anaesthetist conducted 24 interscalene and 24 femoral ultrasound-guided nerve blocks, randomised equally using a software randomisation program to 0.25ml, 0.5ml and 1ml volumes to both sides of two soft embalmed cadavers. The physical properties of the soft embalmed Thiel cadaver and its functional alignment as a simulator of ultrasound-guided regional anaesthesia have been described<sup>6</sup>.

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3 Interscalene block was performed using a 100 mm needle (B.Braun, Sheffield, UK), in-plane  
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5 to a 5 to 10MHz ultrasound transducer, and embalming fluid deposited between the nerve  
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7 roots of C5 and C6. Femoral block was performed using a 50mm needle at 90° to the plane  
8  
9 of the same ultrasound transducer and injected below the fascia iliaca and superficial to the  
10  
11 femoral nerve. We recorded nerve blocks using a Zonare (Mountain View, CA) Z.one  
12  
13 ultrasound scan engine build release 4.2 with B-Mode ultrasound and proprietary  
14  
15 elastography. Blocks were recorded on DICOM imaging software.  
16  
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21 Before starting the study, participants were shown videos of interscalene and femoral block  
22  
23 using B-Mode and elastography ultrasound by one of two independent investigators.  
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25  
26 Participants deemed themselves ready for participation in the experiment. Each assessed 96  
27  
28 videos comprising 8 blocks performed at 2 sites on 2 nerves (interscalene and femoral),  
29  
30 using 3 volumes (0.25ml, 0.5ml, 1.0ml) and 2 imaging modes (B-Mode ultrasound and fused  
31  
32 B-Mode and elastography). Each video was played once to replicate practice. Patterns were  
33  
34 rated according to whether perineural fluid spread or strain tissue had occurred in isolation  
35  
36 or not. Distractors were defined as distinct patterns of spread or strain differing from target  
37  
38 perineural spread or strain by either size, movement or time. Our primary endpoint was  
39  
40 therefore recorded as a "1" or "2" corresponding to the number of events observed. We did  
41  
42 not ask trainees to refine their choice further because this study focused on the detection of  
43  
44 events and not their interpretation or impact on decision making. We did not know if  
45  
46 sufficient homogeneity existed between patterns that would have allowed ready, simple  
47  
48 classification by non-experts. For descriptive purposes, video examples of fluid spread and  
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50 strain patterns were categorised by two researchers at the end of the study in order to  
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52 minimise bias.  
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### *Area and Brightness Measurement*

The cross-sectional area and brightness of B-Mode fluid spread and strain patterns were measured on every fourth video frame (every 0.5s) by a single rater using ImageJ. To test the reliability of our data, two raters independently measured the area of fusion elastograms using the yellow tracing tool available on ImageJ. Duration of fluid spread or strain was defined as the time from the first visible evidence of tissue distention to tissue relaxation. Each image was calibrated to a standard  $7.28 \text{ pixels} \cdot \text{mm}^{-2}$ . Mean tissue brightness was calculated as the sum of the grey values between 0 (black) and 255 (white) of all the pixels within the region of interest divided by the number of pixels. Area and brightness measurements were log converted for analysis. Our secondary end-points were measurements of area ( $\text{mm}^2$ ) and brightness.

### **Statistical analysis**

Paired B-Mode and fused elastography images were analysed using McNemar's test and presented as differences in paired proportions. Predictors of area and brightness were assessed using a mixed effects regression model. Covariates included cadaver, right or left sided injection, injection sequence, type of block (interscalene and femoral), volume (0.25, 0.5 and 1.0ml) and imaging region of interest (perineural fluid spread, area of strain pattern). A stratified logistic regression model was used to analyse binary outcomes and take account of repeated measures. Data were analysed using Number Cruncher Statistical Systems (NCSS) 11, NCSS Inc., Kaysville, UT and LogXact 8, Cytel Inc., Cambridge, MA.



## Results

Twenty anaesthesia trainees and 2 consultant UGRA experts examined 48 paired B-Mode and fusion elastography videos, giving 2112 observations. Median (IQR) trainee anaesthesia experience was 3 (1 – 4) years. All participants recognised perineural spread or strain at all volumes between 0.25ml and 1ml.

Distractors were recognised in 133 (12%) of B-Mode and 403 (38%) fusion elastography videos, differences in paired proportions,  $P < 0.001$ . (Table 2). Use of fusion elastography improved novice recognition from 12% to 37% ( $P < 0.001$ ) and consultant recognition from 24% to 53% ( $P < 0.001$ ). Recognition of distractors improved from 8% to 31% using 0.25ml volumes ( $P < 0.001$ ) and from 15% to 45% using 1ml volumes ( $P < 0.001$ ).

Using stratified logistic regression, recognition of distractors was better with: fusion elastography Odds Ratio, OR (95%CI) 5.31 (3.14 – 8.96),  $P < 0.001$ ; consultant anaesthetists OR 3.84 (2.29 - 6.45)  $P < 0.001$ ; greater volumes of injectate OR 2.19 (1.11 – 4.31),  $P = 0.02$ ; and worse with interscalene block OR 0.58 (0.35 – 0.94),  $P = 0.03$  (Table 3). Area and brightness were greater with fusion elastography and with increased injectate volume (Table 4).

Three distinct strain patterns were categorised retrospectively by two additional experts in response to injection: (i) two areas of similar size, shape and brightness but spreading in opposite directions from the tip of the needle (Video 1); (ii) initial tissue displacement followed by a sudden reversal in flow and secondary displacement at the initial site of injection (Video 2); and (iii) tangential displacement away from the injection site (Video 3).

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3 Pattern (i) was observed during 7 femoral blocks. Pattern (ii) occurred 13 times with  
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5 interscalene and 5 times with femoral block, and pattern (iii) occurred once with each block.  
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## 14 **Discussion**

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16 This study showed improved perception of distractor tissue changes using fusion  
17  
18 elastography compared to B-Mode ultrasound. Perception was volume dependent and  
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20 better with experts compared to novices and with femoral block. Learning was facilitated  
21  
22 over a short period but not to the level of experts.  
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### 28 *Strengths and weaknesses of the study*

29  
30 The principal strength of our study is that our results align with that of Awh et al<sup>11</sup> who  
31  
32 proposed a framework for visual processing. We showed that a saliency-based approach  
33  
34 using white enhancement of strain patterns and differences in volume drew attention to  
35  
36 key targets for novices. Novice search and performance was enhanced in the short term,  
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38 but has potential to speed up learning curves with repeated practice.  
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44 We extended our fusion elastography work on soft embalmed cadavers that showed that  
45  
46 trainees were more likely to diagnose intraneural injection using fusion elastography<sup>4</sup>. Our  
47  
48 current study proved more difficult because trainees were expected to recognise low  
49  
50 volume tissue changes. Therefore, it is unsurprising that trainees could only recognise 62%  
51  
52 of distractor patterns compared to 80% of intraneural injections as in our previous study. All  
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54 trainees were able to detect perineural displacement on B-Mode images secondary to  
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3 injection of volumes between 0.25ml and 1ml (videos 1 to 3), an observation that agrees  
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5 with that of Krediet et al<sup>12</sup>.  
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14 We identified three distinct distractor patterns that varied in brightness, size and movement  
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16 to target patterns, and described them as bilateral, rebound and distal. Bilateral patterns  
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18 occurred in 7 femoral blocks, secondary to forceful needle nerve contact during out-of-  
19  
20 plane needle insertion (Video 1), and sideways spread of injectate. Forceful needle nerve  
21  
22 contact and nerve haematoma has been proposed as one cause of chronic nerve damage  
23  
24 after regional anaesthesia<sup>13</sup>. This observation suggests a need for investigation of the role of  
25  
26 elastography along with pressure monitoring in the diagnosis of forceful needle nerve  
27  
28 contact. We hypothesise that rebound phenomena represented movement and reflection  
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30 of fluid within fascial planes and therefore likely to contribute to clinical block. Video 2  
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32 provides an insight into the hydrodynamics of perineural spread, an aspect of regional  
33  
34 blockade that hitherto has not been investigated. An assumption exists in practice that flow  
35  
36 of local anaesthetic is unidirectional. Our results suggest otherwise for test doses. We  
37  
38 hypothesise that injectate distends tissue planes, but once wavefront pressure is insufficient  
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40 to open up fascial layers, it returns as a wave to the point of origin. There is a need to  
41  
42 investigate this phenomenon further using the range of volumes used. The distal pattern  
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44 seen in Video 3 is likely to be associated with excessive longitudinal strain secondary to  
45  
46 excessive transducer pressure, albeit we would expect that local anaesthetic deposition far  
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48 from the nerve would be associated with similar tissue changes. Our observations on  
49  
50 elastography confirm previous work that suggests a potential clinical role detecting test  
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3 doses. However, elastography should not be regarded as a surrogate for hydrolocation  
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5 because strain area was greater than hydrolocation area on B-Mode images. Strain reflects  
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7 relative displacement of all tissues during fluid injection, and tissue displacement depends  
8  
9 on tissue elasticity or stiffness.  
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14 We used elastography as an experimental psychological tool because it demonstrated white  
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16 areas of strain and spatial, temporal and dynamic changes using a standard ultrasound  
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18 transducer. Injections are presented as videos because tissue change using 0.25ml to 1ml is  
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20 difficult to see on static images. Use of two cadavers may be regarded as a weakness but we  
21  
22 had limited availability at the time of the study. The University of Dundee has now  
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24 converted to the whole-time use of soft embalmed cadavers and future studies will  
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26 randomise to different cadavers.  
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### 31 32 *Impact of Research*

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34 This work has increased understanding of the psychological mechanisms that underpin  
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36 performance during nerve block. Consideration of change blindness, a perceptual  
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38 phenomenon that occurs when a salient visual stimulus is introduced and the observer does  
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40 not notice, suggests trainee difficulty with target search.  
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44 We hypothesise that novices were reliant on cognitive learning, which may help detect  
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46 single distinctive targets, but that this compromised their performance during multiple-  
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48 target search tasks because the cognitive effort needed to match targets to expectations  
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50 was overwhelming<sup>15</sup>. In contrast, experts used an automatic global search strategy gained  
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52 by long-term exposure to repeated images<sup>16,17</sup>. Our results show that novices had  
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54 deficiencies in visual search and that improvement in visual attention was salience driven.  
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3 Visual search is quantifiable using eye tracking, a technology used in other industries to  
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5 quantify eye gaze fixations and saccades, and thus can create individual learning curves, and  
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7 investigate the transfer of visual search and image interpretation to decision making<sup>1</sup>. We  
8  
9 are quantifying the learning curves of trainee anaesthetists and expert regional  
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11 anaesthetists while conducting up to 60 interscalene blocks on the soft embalmed Thiel  
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13 cadaver in a mastery learning and dedicated practice environment. Eye gaze metrics provide  
14  
15 a graphical representation of rate of progress, patterns of learning over time, and  
16  
17 discrimination between good, average and poor performers, and between experts. We now  
18  
19 wish to investigate whether eye gaze metrics, along with item analysis of preprocedural and  
20  
21 procedural tasks provide a measure of transfer of skills from the simulator to the clinical  
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23 workplace two to three months later. Using the same metrics, we also wish to investigate  
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25 the best means of teaching on the simulator that translates best to practice.  
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33 An opportunity also exists to investigate which salient features are more likely to help or  
34  
35 hinder anaesthetists and discover how novices and expert anaesthetists interrogate images  
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37 and translate their impact to individual performance. The relative interaction of top-down  
38  
39 and bottom-up influences deserves investigation in regional anaesthesia.  
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#### 42 *Conclusion*

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44 We applied fusion elastography to training on the soft embalmed cadaver to guide novice  
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46 attention to salient features. This improved recognition of distractors in response to  
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48 perineural test doses. A need exists to investigate novice search strategies using eye  
49  
50 tracking technology to improve training and target local anaesthetic accurately and safely.  
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52

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#### Authors' Contributions and Authorship

AM Performed trainee study

JS Performed trainee study

MC Statistical analysis

MM Psychology advisor

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AS Bioengineer, wrote fusion elastography software and conducted anatomy studies  
RE Supervising Anatomist  
GC Medical Physics support  
GM Study design, wrote paper  
SM Study design, cadaver regional blocks and cadaver data collection, wrote paper

This study was presented at the Anaesthetic Research Society meeting in Clydebank, November 2016

For Peer Review

**A b s t r a c t**

**B a c k g r o u n d :** Errors may occur during regional anaesthesia while searching for nerves, needle tips and test doses. Poor visual search impacts on decision making, clinical intervention and patient safety.

**M e t h o d s :** We conducted a randomized, single-blind study in a single university hospital. Twenty trainees and two consultants examined paired B-Mode and fused B-mode and elastography video recordings of 24 interscalene and 24 femoral blocks conducted on two soft embalmed cadavers. Perineural injection was randomized equally to 0.25ml, 0.5ml and 1.0ml volumes. Tissue displacement perceived on both imaging modalities was defined as "target" or "distractor".

Our primary objective was to test anaesthetists' perception of the number



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6 and proportion of targets and distractors  
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8 on B-Mode and fused elastography videos  
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10 collected during femoral and sciatic nerve  
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12 block on soft embalmed cadavers. Our  
13  
14 secondary objectives were to determine  
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16 differences between novices and experts  
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18 and between test dose volumes, and  
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20 measure the area and brightness of spread  
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22 and strain patterns.  
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28  
29 **Results:** All anaesthetists recognized  
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31 perineural spread using 0.25ml volumes.  
32  
33 Distractor patterns were recognized in  
34  
35 133 (12%) of B-Mode and in 403 (38%) of  
36  
37 fused B-Mode and elastography patterns,  
38  
39  $P < 0.001$ . With elastography, novice  
40  
41 recognition improved from 12% to 37% ( $P$   
42  
43  $< 0.001$ ) and consultant recognition  
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45 increased from 24% to 53%,  $P <$   
46  
47 0.001. Distractor recognition improved  
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49 from 8% to 31% using 0.25ml volumes ( $P <$   
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6 0.001), and from 15% to 45% using 1 ml  
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8 volumes ( $P < 0.001$ ).  
9

10 **Conclusions:** Visual search improved with  
11  
12 fusion elastography, increased volume,  
13  
14 and consultants. A need exists to  
15  
16 investigate image search strategies.  
17  
18  
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23

#### 24 **Editor's key points**

- 25  
26 ● Elastography is an ultrasound-based  
27  
28 technology that cross-correlates  
29  
30 radio-frequency waves before and after  
31  
32 tissue displacement and displays relative  
33  
34 displacement (strain) in colour.  
35  
36  
37  
38
- 39 ● Compared with B-Mode ultrasound,  
40  
41 B-Mode plus elastography video recording  
42  
43 may facilitate appropriate peripheral  
44  
45 nerve blocks.  
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#### 54 **Introduction**

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6 Errors may occur during the visual search,  
7  
8 recognition and decision making phases<sup>1</sup> of  
9  
10 ultrasound-guided regional anaesthesia  
11  
12 (UGRA) nerve block. Search errors are  
13  
14 attributable to failure to see lesions that  
15  
16 are normally noticed by  
17  
18 anaesthetists.<sup>2</sup> With recognition errors,  
19  
20 lesions are seen but confusing; and  
21  
22 decision errors occur when a lesion is  
23  
24 fixated on for long periods but the  
25  
26 anaesthetist either does not recognise  
27  
28 features or dismisses them.<sup>3</sup>

29  
30 Elastography is an ultrasound-based  
31  
32 technology that cross-correlates  
33  
34 radio-frequency waves before and after  
35  
36 tissue displacement and displays relative  
37  
38 displacement (strain) in colour. While  
39  
40 conducting interscalene and femoral nerve  
41  
42 block in cadavers<sup>4</sup> and patients<sup>5</sup> we noticed  
43  
44 novel features on paired B-Mode and  
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6 elastography ultrasound images in response  
7  
8 to injection of test doses. Tissue strain  
9  
10 intermittently presented as two patterns  
11  
12 instead of one.<sup>6</sup> Additional patterns,  
13  
14 termed distractors, were distinguished  
15  
16 from primary target displacement patterns  
17  
18 by brightness, size, position or  
19  
20 movement.<sup>7</sup> In contrast, test doses as low  
21  
22 as 0.25ml were always seen on B-Mode  
23  
24 images, but distractor patterns much less  
25  
26 so. Our impression was that elastography  
27  
28 exhibited greater saliency, the extent to  
29  
30 which a location differs from its  
31  
32 surroundings, than B-mode images  
33  
34 because: (i) key regions differed in  
35  
36 brightness, colour, orientation, and  
37  
38 motion; and that (ii) anaesthetists'  
39  
40 visual attention was attracted towards  
41  
42 these features.  
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6 Visual salience describes the visual  
7  
8 processing mechanism that enables the  
9  
10 brain to select important features that  
11  
12 stand out from other items or  
13  
14 locations<sup>8</sup> (Table 1). Salience is associated  
15  
16 with passive, automatic visual search or  
17  
18 “bottom-up processing” rather than  
19  
20 cognitive, goal driven “top-down  
21  
22 processing”<sup>9</sup>. Consideration of both  
23  
24 processes creates a saliency map, a  
25  
26 topographic representation of relative  
27  
28 stimulus strength and behavioural  
29  
30 importance. This map is distributed  
31  
32 throughout the visual cortex and linked via  
33  
34 the oculomotor system to eye movement and  
35  
36 eye gaze<sup>10</sup>. Eye gaze characteristics such as  
37  
38 fixations and saccades are quantified using  
39  
40 eye-tracking technology and are used in  
41  
42 many industries to measure technical  
43  
44 performance.  
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8 Visual search and salience differ between  
9  
10 experts and novices. Experts rely on  
11  
12 bottom-up processes that facilitate  
13  
14 efficient search, albeit mediated by prior  
15  
16 knowledge when encountering novel  
17  
18 stimuli<sup>9</sup>. Novices, in contrast, are  
19  
20 primarily goal driven but can be salience  
21  
22 led to very obvious targets.  
23  
24  
25  
26  
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30

31 We hypothesized that improvements in  
32  
33 novice visual perception were salience  
34  
35 driven, and, if so, would provide the  
36  
37 evidence for investigation of the role of  
38  
39 eye gaze technology and augmented reality  
40  
41 during simulator training. This approach  
42  
43 could help train anaesthetists better,  
44  
45 target local anaesthetic more and improve  
46  
47 patient safety.  
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6 Our primary objective was to test  
7  
8 anaesthetists' perception of the number  
9  
10 and proportion of targets and distractors  
11  
12 on B-Mode and fused elastography videos  
13  
14 collected during femoral and sciatic nerve  
15  
16 block on soft embalmed cadavers.  
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23  
24 Our secondary objectives were to measure  
25  
26 differences in perception between novices  
27  
28 and experts, between test dose volumes,  
29  
30 and measure the area and brightness of  
31  
32 spread and strain patterns over time.  
33  
34  
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## 42 **Methods**

### 43 *Participants*

44  
45 All trainee anaesthetists at basic,  
46  
47 intermediate and higher levels of training  
48  
49 working in Ninewells Hospital were invited  
50  
51 to take part in this study along with two  
52  
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6 consultant subspecialists in regional  
7  
8 anaesthesia. Our exclusion criterion for  
9  
10 trainees was the prior use of elastography.  
11  
12 The study was approved by the University of  
13  
14 Dundee Committee on Non-Medical Ethics.  
15

### 16 17 *Software Development*

18  
19 Elastography and its applicability to the  
20  
21 diagnosis of intraneural injection is  
22  
23 described in detail in a previous papers<sup>4, 6</sup>.  
24  
25 In summary, our engineer converted colour  
26  
27 elastography video frames to filtered and  
28  
29 despeckled black and white images using  
30  
31 MATLAB software (Natick, MA) and a  
32  
33 grayscale threshold tool. Enhanced  
34  
35 elastography patterns were fused onto  
36  
37 corresponding B-Mode images. Tissue  
38  
39 displacement in response to fluid injection  
40  
41 was seen as a flowing translucent, white  
42  
43 area, superimposed onto paired B Mode  
44  
45 images. Fusion videos were converted to  
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6 TIFF files and analyzed using ImageJ (Wayne  
7  
8 Rasband, Research Services Branch,  
9  
10 National Institute of Mental Health,  
11  
12 Bethesda, MD)  
13

#### 14 15 16 *Conduct of block*

17  
18 A single independent, experienced  
19  
20 anaesthetist conducted 24 interscalene and  
21  
22 24 femoral ultrasound-guided nerve blocks,  
23  
24 randomized equally using a software  
25  
26 randomization program to 0.25 ml, 0.5 ml and  
27  
28 1 ml volumes to both sides of two soft  
29  
30 embalmed cadavers. The physical properties  
31  
32 of the soft embalmed Thiel cadaver and its  
33  
34 functional alignment as a simulator of  
35  
36 ultrasound-guided regional anaesthesia  
37  
38 have been described<sup>6</sup>.  
39  
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49 Interscalene block was performed using a  
50  
51 100 mm needle (B. Braun, Sheffield, UK),  
52  
53 in-plane to a 5 to 10 MHz ultrasound  
54  
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6 transducer, and embalming fluid deposited  
7  
8 between the nerve roots of C5 and C6.  
9

10 Femoral block was performed using a 50 mm  
11  
12 needle at 90° to the plane of the same  
13  
14 ultrasound transducer and injected below  
15  
16 the fascia iliaca and superficial to the  
17  
18 femoral nerve. We recorded nerve blocks  
19  
20 using a Zonare (Mountain View, CA) Z.one  
21  
22 ultrasound scan engine build release 4.2  
23  
24 with B-Mode ultrasound and proprietary  
25  
26 elastography. Blocks were recorded on  
27  
28 DICOM imaging software.  
29  
30  
31  
32  
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38

39 Before starting the study, participants  
40  
41 were shown videos of interscalene and  
42  
43 femoral block using B-Mode and  
44  
45 elastography ultrasound by one of two  
46  
47 independent investigators. Participants  
48  
49 deemed themselves ready for participation  
50  
51  
52 in the experiment. Each assessed 96 videos  
53  
54  
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6 comprising 8 blocks performed at 2 sites on  
7  
8 2 nerves (interscalene and femoral), using  
9  
10 3 volumes (0.25 ml, 0.5 ml, 1.0 ml) and 2  
11  
12 imaging modes (B-Mode ultrasound and  
13  
14 fused B-Mode and elastography). Each video  
15  
16 was played once to replicate practice.  
17  
18  
19 Patterns were rated according to whether  
20  
21 perineural fluid spread or strain tissue had  
22  
23 occurred in isolation or not. Distractors  
24  
25 were defined as distinct patterns of spread  
26  
27 or strain differing from target perineural  
28  
29 spread or strain by either size, movement  
30  
31 or time. Our primary endpoint was  
32  
33 therefore recorded as a "1" or  
34  
35 "2" [PubMed](#) corresponding to the number  
36  
37 of events observed. We did not ask trainees  
38  
39 to refine their choice further because this  
40  
41 study focused on the detection of events  
42  
43 and not their interpretation or impact on  
44  
45 decision making. We did not know if  
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6 sufficient homogeneity existed between  
7  
8 patterns that would have allowed ready,  
9  
10 simple classification by non-experts. For  
11  
12 descriptive purposes, video examples of  
13  
14 fluid spread and strain patterns were  
15  
16 categorized by two researchers at the end  
17  
18 of the study in order to minimize bias.  
19  
20  
21  
22  
23  
24  
25

#### 26 *Area and Brightness Measurement*

27  
28 The cross-sectional area and brightness of  
29  
30 B-Mode fluid spread and strain patterns  
31  
32 were measured on every fourth video frame  
33  
34 (every 0.5s) by a single rater using ImageJ.  
35  
36 To test the reliability of our data, two  
37  
38 raters independently measured the area of  
39  
40 fusion elastograms using the yellow tracing  
41  
42 tool available on ImageJ. Duration of fluid  
43  
44 spread or strain was defined as the time  
45  
46 from the first visible evidence of tissue  
47  
48 distention to tissue relaxation. Each image  
49  
50  
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5 was calibrated to a standard 7.28  
6  
7  
8 pixels. $\text{mm}^{-2}$ . Mean tissue brightness was  
9  
10  
11 calculated as the sum of the grey values  
12  
13 between 0 (black) and 255 (white) of all the  
14  
15 pixels within the region of interest divided  
16  
17 by the number of pixels. Area and  
18  
19 brightness measurements were log  
20  
21 converted for analysis. Our secondary  
22  
23 end-points were measurements of area  
24  
25 ( $\text{mm}^2$ ) and brightness.  
26  
27  
28  
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#### 34 **Statistical analysis**

35  
36 Paired B-Mode and fused elastography  
37  
38 images were analyzed using McNemar's test  
39  
40 and presented as differences in paired  
41  
42 proportions. Predictors of area and  
43  
44 brightness were assessed using a mixed  
45  
46 effects regression model. Covariates  
47  
48 included cadaver, right or left sided  
49  
50 injection, injection sequence, type of block  
51  
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5 (interscalene and femoral), volume (0.25,  
6  
7  
8 0.5 and 1.0 ml) and imaging region of  
9  
10  
11 interest (perineural fluid spread, area of  
12  
13 strain pattern). A stratified logistic  
14  
15  
16 regression model was used to analyze binary  
17  
18  
19 outcomes and take account of repeated  
20  
21  
22 measures. Data were analyzed using Number  
23  
24  
25 Cruncher Statistical Systems (NCSS) 11,  
26  
27  
28 NCSS Inc., Kaysville, UT and LogXact 8,  
29  
30  
31 Cytel Inc., Cambridge, MA.

## 32 33 34 35 36 **Results**

37  
38  
39 Twenty anaesthesia trainees and 2  
40  
41  
42 consultant UGRA experts examined 48  
43  
44  
45 paired B-Mode and fusion elastography  
46  
47  
48 videos, giving 2112 observations. Median  
49  
50  
51 (IQR) trainee anaesthesia experience was 3  
52  
53  
54  
55  
56  
57  
58  
59  
60 (1 - 4) years. All participants recognized

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5  
6 perineural spread or strain at all volumes  
7  
8 between 0.25 ml and 1 ml.  
9

10  
11 Distractors were recognized in 133 (12%) of  
12  
13 B-Mode and 403 (38%) fusion elastography  
14  
15 videos, differences in paired proportions,  $P$   
16  
17  $< 0.001$ . (Table 2). Use of fusion  
18  
19  
20  
21 elastography improved novice recognition  
22  
23 from 12% to 37% ( $P < 0.001$ ) and consultant  
24  
25 recognition from 24% to 53% ( $P <$   
26  
27  $0.001$ ). Recognition of distractors  
28  
29 improved from 8% to 31% using 0.25 ml  
30  
31  
32 volumes ( $P < 0.001$ ) and from 15% to 45%  
33  
34  
35 using 1 ml volumes ( $P < 0.001$ ).  
36  
37  
38  
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40

41  
42 Using stratified logistic regression,  
43  
44 recognition of distractors was better with:  
45  
46 fusion elastography Odds Ratio, OR(95% CI)  
47  
48 5.31 (3.14 – 8.96),  $P < 0.001$ ; consultant  
49  
50 anaesthetists OR 3.84 (2.29 – 6.45)  $P <$   
51  
52  $0.001$ ; greater volumes of injectate OR 2.19  
53  
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6 (1.11 – 4.31),  $P = 0.02$ ; and worse with  
7  
8 interscalene block OR 0.58 (0.35 – 0.94),  $P$   
9  
10 = 0.03 (Table 3). Area and brightness were  
11  
12 greater with fusion elastography and with  
13  
14 increased injectate volume (Table 4).  
15  
16  
17  
18  
19  
20  
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22

23  
24 Three distinct strain patterns were  
25  
26 categorized retrospectively by two  
27  
28 additional experts in response to injection:  
29  
30 (i) two areas of similar size, shape and  
31  
32 brightness but spreading in opposite  
33  
34 directions from the tip of the needle (Video  
35  
36 1); (ii) initial tissue displacement followed  
37  
38 by a sudden reversal in flow and secondary  
39  
40 displacement at the initial site of injection  
41  
42 (Video 2); and (iii) tangential displacement  
43  
44 away from the injection site (Video 3).  
45  
46  
47  
48  
49  
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51  
52 Pattern (i) was observed during 7 femoral  
53  
54 blocks. Pattern (ii) occurred 13 times with  
55  
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5 interscalene and 5 times with femoral block,  
6  
7  
8 and pattern (iii) occurred once with each  
9  
10  
11 block.  
12  
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## 21 **Discussion**

22  
23 This study showed improved perception of  
24  
25 distractor tissue changes using fusion  
26  
27 elastography compared to B-Mode  
28  
29 ultrasound. Perception was volume  
30  
31 dependent and better with experts  
32  
33 compared to novices and with femoral block.  
34  
35  
36  
37 Learning was facilitated over a short period  
38  
39  
40  
41 but not to the level of experts.  
42  
43  
44  
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### 47 *Strengths and weaknesses of the study*

48  
49 The principal strength of our study is that  
50  
51 our results align with that of Awh et  
52  
53 al<sup>11</sup> who proposed a framework for visual  
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6 processing. We showed that a  
7  
8 saliency-based approach using white  
9  
10 enhancement of strain patterns and  
11  
12 differences in volume drew attention to key  
13  
14 targets for novices. Novice search and  
15  
16 performance was enhanced in the short term,  
17  
18 but has potential to speed up learning  
19  
20 curves with repeated practice.  
21  
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29 We extended our fusion elastography work  
30  
31 on soft embalmed cadavers that showed that  
32  
33 trainees were more likely to diagnose  
34  
35 intraneural injection using fusion  
36  
37 elastography<sup>4</sup>. Our current study proved  
38  
39 more difficult because trainees were  
40  
41 expected to recognize low volume tissue  
42  
43 changes. Therefore, it is unsurprising that  
44  
45 trainees could only recognize 62% of  
46  
47 distractor patterns compared to 80% of  
48  
49 intraneural injections as in our previous  
50  
51  
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6 study. All trainees were able to detect  
7  
8 perineural displacement on B-Mode images  
9  
10 secondary to injection of volumes between  
11  
12 0.25 ml and 1 ml (videos 1 to 3), an  
13  
14 observation that agrees with that of  
15  
16  
17  
18 Krediet et al<sup>12</sup>.  
19  
20  
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29 We identified three distinct distractor  
30  
31 patterns that varied in brightness, size and  
32  
33 movement to target patterns, and described  
34  
35 them as bilateral, rebound and distal.  
36  
37  
38  
39 Bilateral patterns occurred in 7 femoral  
40  
41 blocks, secondary to forceful needle nerve  
42  
43 contact during out-of-plane needle  
44  
45 insertion (Video 1), and sideways spread of  
46  
47 injectate. Forceful needle nerve contact  
48  
49 and nerve haematoma has been proposed as  
50  
51  
52  
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54  
55 one cause of chronic nerve damage after  
56  
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5 regional anaesthesia<sup>1 3</sup>. This observation  
6  
7  
8 suggests a need for investigation of the  
9  
10  
11 role of elastography along with pressure  
12  
13 monitoring in the diagnosis of forceful  
14  
15 needle nerve contact. We hypothesize that  
16  
17 rebound phenomena represented movement  
18  
19 and reflection of fluid within fascial planes  
20  
21 and therefore likely to contribute to  
22  
23 clinical block. Video 2 provides an insight  
24  
25 into the hydrodynamics of perineural  
26  
27 spread, an aspect of regional blockade that  
28  
29 hitherto has not been investigated. An  
30  
31 assumption exists in practice that flow of  
32  
33 local anaesthetic is unidirectional. Our  
34  
35 results suggest otherwise for test doses.  
36  
37  
38 We hypothesize that injectate distends  
39  
40 tissue planes, but once wavefront pressure  
41  
42 is insufficient to open up fascial layers, it  
43  
44 returns as a wave to the point of origin.  
45  
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There is a need to investigate this

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6 phenomenon further using the range of  
7  
8 volumes used. The distal pattern seen in  
9  
10 Video 3 is likely to be associated with  
11  
12 excessive longitudinal strain secondary to  
13  
14 excessive transducer pressure, albeit we  
15  
16 would expect that local anaesthetic  
17  
18 deposition far from the nerve would be  
19  
20 associated with similar tissue changes. Our  
21  
22 observations on elastography confirm  
23  
24 previous work that suggests a potential  
25  
26 clinical role detecting test doses. However,  
27  
28 elastography should not be regarded as a  
29  
30 surrogate for hydrolocation because strain  
31  
32 area was greater than hydrolocation area on  
33  
34 B-Mode images. Strain reflects relative  
35  
36 displacement of all tissues during fluid  
37  
38 injection, and tissue displacement  
39  
40 depends on tissue elasticity or stiffness.  
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6 We used elastography as an experimental  
7  
8 psychological tool because it demonstrated  
9  
10 white areas of strain and spatial, temporal  
11  
12 and dynamic changes using a standard  
13  
14 ultrasound transducer. Injections are  
15  
16 presented as videos because tissue change  
17  
18 using 0.25ml to 1ml is difficult to see on  
19  
20 static images. Use of two cadavers may be  
21  
22 regarded as a weakness but we had limited  
23  
24 availability at the time of the study. The  
25  
26 University of Dundee has now converted to  
27  
28 the whole-time use of soft embalmed  
29  
30 cadavers and future studies will randomize  
31  
32 to different cadavers.  
33  
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#### 44 *Impact of Research*

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46  
47 This work has increased understanding of  
48  
49 the psychological mechanisms that underpin  
50  
51 performance during nerve block.  
52  
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54 Consideration of change blindness, a  
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6 perceptual phenomenon that occurs when a  
7  
8 salient visual stimulus is introduced and  
9  
10 the observer does not notice, suggests  
11  
12 trainee difficulty with target search.  
13  
14  
15 We hypothesize that novices were reliant on  
16  
17 cognitive learning, which may help detect  
18  
19 single distinctive targets, but that this  
20  
21 compromised their performance during  
22  
23 multiple-target search tasks because the  
24  
25 cognitive effort needed to match targets to  
26  
27 expectations was overwhelming<sup>15</sup>. In  
28  
29 contrast, experts used an automatic global  
30  
31 search strategy gained by long-term  
32  
33 exposure to repeated images<sup>16, 17</sup>. Our  
34  
35 results show that novices had deficiencies  
36  
37 in visual search and that improvement in  
38  
39 visual attention was salience driven. Visual  
40  
41 search is quantifiable using eye tracking, a  
42  
43 technology used in other industries to  
44  
45 quantify eye gaze fixations and saccades,  
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6 and thus can create individual learning  
7  
8 curves, and investigate the transfer of  
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10 visual search and image interpretation to  
11  
12 decision making<sup>1</sup>. We are quantifying the  
13  
14 learning curves of trainee anaesthetists  
15  
16 and expert regional anaesthetists while  
17  
18 conducting up to 60 interscalene blocks on  
19  
20 the soft embalmed Thiel cadaver in a  
21  
22 mastery learning and dedicated practice  
23  
24 environment. Eye gaze metrics provide a  
25  
26 graphical representation of rate of  
27  
28 progress, patterns of learning over time,  
29  
30 and discrimination between good, average  
31  
32 and poor performers, and between experts.  
33  
34 We now wish to investigate whether eye  
35  
36 gaze metrics, along with item analysis of  
37  
38 preprocedural and procedural tasks provide  
39  
40 a measure of transfer of skills from the  
41  
42 simulator to the clinical workplace two to  
43  
44 three months later. Using the same metrics,  
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6 we also wish to investigate the best means  
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8 of teaching on the simulator that translates  
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10 best to practice.  
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16 An opportunity also exists to investigate  
17  
18 which salient features are more likely to  
19  
20 help or hinder anaesthetists and discover  
21  
22 how novices and expert anaesthetists  
23  
24 interrogate images and translate their  
25  
26 impact to individual performance. The  
27  
28 relative interaction of top-down and  
29  
30 bottom-up influences deserves  
31  
32 investigation in regional anaesthesia.  
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### 39 *Conclusion*

40  
41 We applied fusion elastography to training  
42  
43 on the soft embalmed cadaver to guide  
44  
45 novice attention to salient features. This  
46  
47 improved recognition of distractors in  
48  
49 response to perineural test doses. A need  
50  
51 exists to investigate novice search  
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5 strategies using eye tracking technology to  
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8 improve training and target local  
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11 anaesthetic accurately and safely.  
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24 **A u t h o r s ' C o n t r i b u t i o n s a n d A u t h o r s h i p**

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26 A M P e r f o r m e d t r a i n e e s t u d y

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28 J S P e r f o r m e d t r a i n e e s t u d y

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30 M C S t a t i s t i c a l a n a l y s i s

31  
32 M M P s y c h o l o g y a d v i s o r

33  
34 A S B i o e n g i n e e r , w r o t e f u s i o n e l a s t o g r a p h y

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36 s o f t w a r e a n d c o n d u c t e d a n a t o m y s t u d i e s

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38 R E S u p e r v i s i n g A n a t o m i s t

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40 G C M e d i c a l P h y s i c s s u p p o r t

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42 G M S t u d y d e s i g n , w r o t e p a p e r

43  
44 S M S t u d y d e s i g n , c a d a v e r r e g i o n a l b l o c k s a n d

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46 c a d a v e r d a t a c o l l e c t i o n , w r o t e p a p e r

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This study was presented at the Anaesthetic  
Research Society meeting in Clydebank,  
November 2016

For Peer Review

Term	Description
<b>Visual search</b>	Task of looking for a target in a cluttered visual environment. Non-target items are termed distractors.
<b>Visual salience</b>	The distinct subjective perceptual quality which makes some items in the world stand out from their neighbors and immediately grab our attention.
<b>Guiding attribute</b>	Visual properties that can be used to direct deployment of attention.
<b>Saliency</b>	The extent to which a location differs is from its surroundings with respect to guiding attributes such colour, orientation, motion
<b>Saliency map</b>	A topographically arranged map that represents the visual saliency of a scene.
<b>Visual attention</b>	The process used to select stimuli
<b>Change blindness</b>	Failure to notice something different about a display
<b>Inattentional blindness</b>	Failure to notice a fully-visible, but unexpected object because attention was engaged on another task, event, or object.
<b>Bottom-up attention</b>	Factors that depend only on instantaneous sensory input, without taking into account the goals, personal history and experiences.
<b>Top-down attention</b>	Factors that take into account goals, personal history and experiences. Bottom-up salience can be modified by top-down goals of the searcher.

Peer Review

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Table 2. Number (n) and proportion (%) of distractor patterns identified (+) or not (-) by 20 trainees and 2 consultants on 1056 paired B-Mode and elastography images. Distractor features recognised on B-Mode images (n = 133) calculated from sum of column (a) and column (b). For example 30 (28 + 2) distractors seen on B-Mode images using 0.25mL. Distractor features recognised on elastography images (n = 403) calculated from sum of column (a) and column (c). For example 108 (28 + 80) distractors seen on elastography images using 0.25mL.

	(a) B-Mode (+) Elastography (+)	(b) B-Mode (+) Elastography (-)	(c) B-Mode (-) Elastography (+)	(d) B-Mode (-) Elastography (-)	% Difference in Paired Proportions (95%CI)	P-value
<b>Volume</b>						
0.25 mL	28 (8%)	2 (0%)	80 (23%)	242 (69%)	22% (18 – 27)	< 0.001
0.5 mL	43 (12%)	4 (1%)	93 (26%)	212 (60%)	25% (21 – 30)	< 0.001
1.0 mL	54 (15%)	2 (0%)	105 (30%)	191 (54%)	29% (24 – 34)	< 0.001
<b>Experience</b>						
Trainee	104 (11%)	6 (1%)	248 (26%)	602 (63%)	25% (22 – 28)	< 0.001
Consultant	21 (22%)	2 (2%)	30 (31%)	43 (45%)	29% (19 – 39)	< 0.001
<b>Nerve</b>						
Interscalene	58 (11%)	7 (1%)	114 (22%)	349 (66%)	20% (17 – 24)	< 0.001
Femoral	67 (13%)	1 (0%)	164 (31%)	296 (56%)	31% (27 – 35)	< 0.001

Table 3. Stratified logistic regression model for response = 2.

Analysis takes account of repeated measures. Predictors of improved recognition were elastography, consultant anaesthetists, femoral block and increased volume.

	Univariate analysis	P-value
	Odd Ratio (95%CI)	
<b>Nerve</b>		
Femoral	-----	
Interscalene	0.58 (0.35 – 0.94)	0.03
<b>Volume</b>	2.19 (1.11 – 4.31)	0.02
<b>Experience</b>		
Trainee	-----	
Consultant	3.84 (2.29 - 6.45)	<0.001
<b>Mode</b>		
B-Mode	-----	
Elastography	5.31 (3.14 – 8.96)	<0.001

Table 4. Cross-sectional area ( $\text{mm}^2$ ) and brightness (0 – 255) of tissue displacement following injection. Geometric mean (95%CI). Measures include bifid injection and rebound effect but not distal spread. Area and brightness greater with all volumes and blocks using fusion elastography.

	Area		P-Value	Brightness		P-value
	B-Mode	Elastogram		B-Mode	Elastogram	
<b>0.25ml</b>	14.4 (9.9 – 21.0)	27.0 (18.5 – 39.3)	<0.001	28.9 (24.9 – 33.5)	94.6 (81.5 – 109.9)	<0.001
<b>0.5ml</b>	19.5 (13.4 – 28.5)	57.2 (39.2 – 83.4)	<0.001	27.4 (23.6 – 31.8)	129.2 (111.1 – 150.1)	<0.001
<b>1ml</b>	22.5 (15.5 – 32.6)	47.3 (32.7 – 68.6)	<0.001	26.2 (22.6 – 30.4)	122.9 (106.0 – 142.5)	<0.001
<b>Interscalene</b>	15.3 (11.3 – 20.7)	33.5 (24.6 – 45.6)	<0.001	32.9 (29.3 – 37.1)	124.9 (110.7 – 141.0)	<0.001
<b>Femoral</b>	22.3 (16.4 – 30.4)	52.2 (38.6 – 70.7)	<0.001	22.9 (20.3 – 25.9)	105.0 (92.8 – 118.7)	<0.001