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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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Mesh keywords:	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 phases¹ of ultrasound-guided regional anaesthesia (UGRA) nerve block. Search errors are attributable to failure to see lesions that are normally noticed by anaesthetists.² 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.³

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 cadavers⁴ and patients⁵ 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.⁶ Additional patterns, termed distractors, were distinguished from primary target displacement patterns by brightness, size, position or movement.⁷ 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 locations⁸ (Table 1). Saliency is associated with passive, automatic visual search or "bottom-up processing" rather than cognitive, goal driven "top-down processing"⁹. 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
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5 oculomotor system to eye movement and eye gaze¹⁰. 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
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16 processes that facilitate efficient search, albeit mediated by prior knowledge when
17
18 encountering novel stimuli⁹. 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
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48 experts, between test dose volumes, and measure the area and brightness of spread and
49
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^{4, 6}. 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 described⁶.

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2
3 Interscalene block was performed using a 100 mm needle (B.Braun, Sheffield, UK), in-plane
4
5 to a 5 to 10MHz ultrasound transducer, and embalming fluid deposited between the nerve
6
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.
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20
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.
24

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
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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 (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
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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
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22 over a short period but not to the level of experts.
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28 *Strengths and weaknesses of the study*

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30 The principal strength of our study is that our results align with that of Awh et al¹¹ who
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32 proposed a framework for visual processing. We showed that a saliency-based approach
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34 using white enhancement of strain patterns and differences in volume drew attention to
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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
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46 trainees were more likely to diagnose intraneural injection using fusion elastography⁴. Our
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48 current study proved more difficult because trainees were expected to recognise low
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50 volume tissue changes. Therefore, it is unsurprising that trainees could only recognise 62%
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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 al¹².
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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-
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20 plane needle insertion (Video 1), and sideways spread of injectate. Forceful needle nerve
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22 contact and nerve haematoma has been proposed as one cause of chronic nerve damage
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24 after regional anaesthesia¹³. 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
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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
31
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
39
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
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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
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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
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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
37
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 overwhelming¹⁵. In contrast, experts used an automatic global search strategy gained
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52 by long-term exposure to repeated images^{16,17}. 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 making¹. We
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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
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17 discrimination between good, average and poor performers, and between experts. We now
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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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41

42 *Conclusion*

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44 We applied fusion elastography to training on the soft embalmed cadaver to guide novice
45
46 attention to salient features. This improved recognition of distractors in response to
47
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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53 **References**

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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
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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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29 **Results:** All anaesthetists recognized
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31 perineural spread using 0.25ml volumes.
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33 Distractor patterns were recognized in
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35 133 (12%) of B-Mode and in 403 (38%) of
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37 fused B-Mode and elastography patterns,
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39 $P < 0.001$. With elastography, novice
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41 recognition improved from 12% to 37% (P
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43 < 0.001) and consultant recognition
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45 increased from 24% to 53%, $P <$
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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 ($P < 0.001$).
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10 **Conclusions:** Visual search improved with
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12 fusion elastography, increased volume,
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14 and consultants. A need exists to
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16 investigate image search strategies.
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24 **Editor's key points**

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

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6 Errors may occur during the visual search,
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8 recognition and decision making phases¹ of
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10 ultrasound-guided regional anaesthesia
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12 (UGRA) nerve block. Search errors are
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14 attributable to failure to see lesions that
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16 are normally noticed by
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18 anaesthetists.² With recognition errors,
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20 lesions are seen but confusing; and
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22 decision errors occur when a lesion is
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24 fixated on for long periods but the
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26 anaesthetist either does not recognise
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28 features or dismisses them.³
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30
31 Elastography is an ultrasound-based
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33 technology that cross-correlates
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35 radio-frequency waves before and after
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37 tissue displacement and displays relative
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39 displacement (strain) in colour. While
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41 conducting interscalene and femoral nerve
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43 block in cadavers⁴ and patients⁵ we noticed
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45 novel features on paired B-Mode and
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6 elastography ultrasound images in response
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8 to injection of test doses. Tissue strain
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10 intermittently presented as two patterns
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12 instead of one.⁶ Additional patterns,
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14 termed distractors, were distinguished
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16 from primary target displacement patterns
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18 by brightness, size, position or
19
20 movement.⁷ 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 locations⁸ (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”⁹. Consideration of both
23
24 processes creates an 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 gaze¹⁰. 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
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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 stimuli⁹. Novices, in contrast, are
19
20 primarily goal driven but can be salience
21
22 led to very obvious targets.
23
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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
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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
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42 **Methods**

43 *Participants*

44
45 All trainee anaesthetists at basic,
46
47 intermediate and higher levels of training
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49 working in Ninewells Hospital were invited
50
51 to take part in this study along with two
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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^{4, 6}.
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 described⁶.
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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
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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
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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
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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 Patterns were rated according to whether
19
20 perineural fluid spread or strain tissue had
21
22 occurred in isolation or not. Distractors
23
24 were defined as distinct patterns of spread
25
26 or strain differing from target perineural
27
28 spread or strain by either size, movement
29
30 or time. Our primary endpoint was
31
32 therefore recorded as a "1" or
33
34 "2" [PubMed](#) corresponding to the number
35
36 of events observed. We did not ask trainees
37
38 to refine their choice further because this
39
40 study focused on the detection of events
41
42 and not their interpretation or impact on
43
44 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
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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. 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 (mm^2) and brightness.
26
27
28
29
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33

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 interest (perineural fluid spread, area of
11
12 strain pattern). A stratified logistic
13
14 regression model was used to analyze binary
15
16 outcomes and take account of repeated
17
18 measures. Data were analyzed using Number
19
20 Cruncher Statistical Systems (NCSS) 11,
21
22 NCSS Inc., Kaysville, UT and LogXact 8,
23
24 Cytel Inc., Cambridge, MA.
25
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36 **Results**

37
38
39 Twenty anaesthesia trainees and 2
40
41 consultant UGRA experts examined 48
42
43 paired B-Mode and fusion elastography
44
45 videos, giving 2112 observations. Median
46
47 (IQR) trainee anaesthesia experience was 3
48
49
50 (1 - 4) years. All participants recognized
51
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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 using 1 ml volumes ($P < 0.001$).
35
36
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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
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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).
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51
52 Pattern (i) was observed during 7 femoral
53
54 blocks. Pattern (ii) occurred 13 times with
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5 interscalene and 5 times with femoral block,
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7
8 and pattern (iii) occurred once with each
9
10
11 block.
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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 Learning was facilitated over a short period
37
38
39 but not to the level of experts.
40
41
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46 *Strengths and weaknesses of the study*

47
48 The principal strength of our study is that
49
50 our results align with that of Awh et
51
52 al¹¹ 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 elastography⁴. 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
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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 al¹².
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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
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53
54
55 one cause of chronic nerve damage after
56
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5 regional anaesthesia^{1 3}. 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 We hypothesize that injectate distends
38
39 tissue planes, but once wavefront pressure
40
41 is insufficient to open up fascial layers, it
42
43 returns as a wave to the point of origin.
44
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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
34
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44 *Impact of Research*

45
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
16 We hypothesize that novices were reliant on
17
18 cognitive learning, which may help detect
19
20 single distinctive targets, but that this
21
22 compromised their performance during
23
24 multiple-target search tasks because the
25
26 cognitive effort needed to match targets to
27
28 expectations was overwhelming¹⁵. In
29
30 contrast, experts used an automatic global
31
32 search strategy gained by long-term
33
34 exposure to repeated images^{16, 17}. Our
35
36 results show that novices had deficiencies
37
38 in visual search and that improvement in
39
40 visual attention was salience driven. Visual
41
42 search is quantifiable using eye tracking, a
43
44 technology used in other industries to
45
46 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
9
10 visual search and image interpretation to
11
12 decision making¹. 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
7
8 of teaching on the simulator that translates
9
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.
33
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38

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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16 **R e f e r e n c e s**

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For Peer Review

Term	Description
Visual search	Task of looking for a target in a cluttered visual environment. Non-target items are termed distractors.
Visual salience	The distinct subjective perceptual quality which makes some items in the world stand out from their neighbors and immediately grab our attention.
Guiding attribute	Visual properties that can be used to direct deployment of attention.
Saliency	The extent to which a location differs is from its surroundings with respect to guiding attributes such colour, orientation, motion
Saliency map	A topographically arranged map that represents the visual saliency of a scene.
Visual attention	The process used to select stimuli
Change blindness	Failure to notice something different about a display
Inattentional blindness	Failure to notice a fully-visible, but unexpected object because attention was engaged on another task, event, or object.
Bottom-up attention	Factors that depend only on instantaneous sensory input, without taking into account the goals, personal history and experiences.
Top-down attention	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
Volume						
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
Experience						
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
Nerve						
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)	
Nerve		
Femoral	-----	
Interscalene	0.58 (0.35 – 0.94)	0.03
Volume	2.19 (1.11 – 4.31)	0.02
Experience		
Trainee	-----	
Consultant	3.84 (2.29 - 6.45)	<0.001
Mode		
B-Mode	-----	
Elastography	5.31 (3.14 – 8.96)	<0.001

Table 4. Cross-sectional area (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	
0.25ml	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
0.5ml	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
1ml	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
Interscalene	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
Femoral	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