Ultrasound in Med. & Biol., Vol. ■■, No. ■■, pp. ■■–■■, 2017

0301-5629/$ - see front matter

https://doi.org/10.1016/j.ultrasmedbio.2017.08.936

● *Technical Note*

BLINDED COMPARISON BETWEEN AN IN-AIR REVERBERATION METHOD AND AN ELECTRONIC PROBE TESTER IN THE DETECTION OF ULTRASOUND PROBE FAULTS

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(*Received* 20 *June* 2017; *revised* 3 *August* 2017; *in final form* 9 *August* 2017)

Abstract—The aim of this study was to perform a blinded trial, comparing the results of a visual inspection of the in-air reverberation pattern with the results of an electronic probe tester in detecting ultrasound probe faults. Sixty-two probes were tested. A total of 28 faults were found, 3 only by in-air reverberation assessment and 2 only by the electronic probe tester. The electronic probe tester provided additional information regarding the location of the fault in 74% of the cases in which both methods detected a fault. It is possible to detect the majority of probe faults by visual inspection and in-air reverberation assessment. The latter provides an excellent first-line test, easily performed on a daily basis by equipment users. An electronic probe tester is required if detailed evaluation of faults is necessary. (E-mail: nick.dudley@ulh.nhs.uk) © 2017 World Federation for Ultrasound in Medicine & Biology. Published by Elsevier Inc. All rights reserved.

Key Words: **Ultrasound, Transducer, Quality assurance.**

INTRODUCTION

Ultrasound scanner quality assurance (QA) is recommended, and guidelines are provided, by professional bodies around the world (*e.g.,* American Institute of Ultrasound in Medicine [AIUM 2008; Goodsitt et al. 1998; Kollmann et al. 2012; Russell et al. 2010). QA is mandatory for some applications, for example, screening programmes in the United Kingdom (Dall et al. 2011; Hartshorne and Summers 2014; National Health Service [NHS 2016), and accreditation schemes requiring QA are in place in some countries (American College of Radiology [ACR] 2017; College of Radiographers, Royal College of Radiologists 2013).

The ultrasound probe is the most vulnerable part of the instrument, and there is evidence that compromised image uniformity is the most common fault observed. Hangiandreou et al. (2011) reviewed the results of a 4-y quality control programme in a single large radiology department, including more than 300 probes. Probe failure represented 88% of total failures, the remainder being scanner component failures. The most frequent failure was image uniformity (66%), assessed by looking for artefacts in images of a tissue-mimicking test object (TMTO) and the in-air reverberation pattern. A recent survey of the condition of 219 probes in 12 hospitals found that more than 1 in 3 probes were faulty and 1 in 8 probes were not fit for purpose (Dudley and Woolley 2016a).

Probe faults are therefore common and important to detect. Electronic probe testers such as FirstCall (Unisyn, Golden, CO, USA) and ProbeHunter (BBS Medical AB, Stockholm, Sweden) provide comprehensive results that both detect faults and indicate their likely origin (Martensson et al. 2009, 2010; Sipila et al. 2011).

Martensson et al. (2009) tested 676 probes using an electronic tester and found faults in 269 probes (40%), but did not state how many of these faults were visible by other means, for example, inspection of the in-air reverberation pattern. Sipila et al. (2011) tested 135 probes using an electronic tester and with a TMTO to assess image uniformity and made a physical inspection of each probe, finding a total of 52 faulty probes (39%). Twenty-one faults (40% of all faulty probes) were detected with the electronic tester, 20 (38%) with the TMTO and 34 (65%) by physical inspection. Three faults (6% of total faulty probes) were detected only with the electronic tester, 8 (15%) only with the TMTO and 21 (40%) only by physical inspection. Sipila et al. (2011) concluded that all tests, including the electronic probe tester, are necessary.

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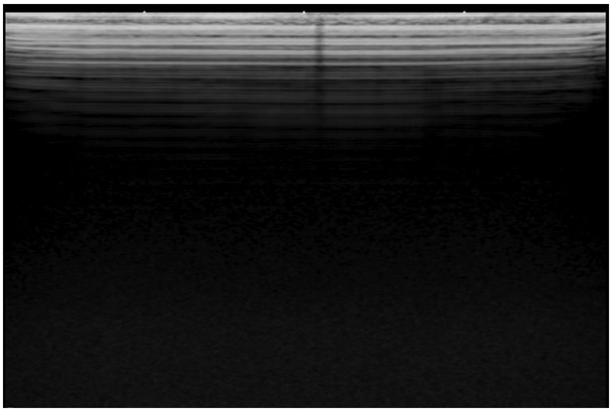

Fig. 1. Central dropout caused by a single element failure. The reverberation pattern also reveals signs of lens wear toward the ends of the array, indicated by reduced separation and intensity of reverberations.

Our experience using the FirstCall and comparing results with the in-air reverberation pattern is that the latter can detect a single non-functioning element, with appropriate adjustment of scanner settings. Figure 1 illustrates dropout caused by a single element failure. The "paperclip test" (Goldstein et al. 1989) and imaging of a TMTO may then be used to assess the severity and inform management of faults; for example, the paperclip test may or may not confirm element failure and a TMTO image may or may not reveal shadowing, but the physical origin of the fault may not be important unless considering a repair.

The aim of this study was to perform a blinded trial, comparing the results of a visual inspection of the in-air reverberation pattern with the results of an electronic probe tester.

METHODS

Multi-Medix carries a stock of used ultrasound probes from a range of manufacturers. Each probe is tested on arrival at the facility using a FirstCall electronic probe tester (Unisyn, Golden, CO, USA), with reports being stored in a database.

Electronic probe testing is performed by attaching the probe connector to a dedicated adapter. The probe is then mounted at the surface of a water bath with the probe face parallel to a steel reflecting plate. Three plates are available: a flat plate for linear and phased arrays, a plate with a large radius of curvature matched to typical convex arrays for abdominal use and a more tightly curved plate matched to typical endocavity probes. Under software control, each probe element, in turn, is driven by an excitation pulse; *via* the adapter, the returning echo is measured and the amplitude displayed. There is an initial alignment process, in which selected elements along the array are fired to allow multiplanar adjustment of the probe position until all elements are equidistant to the plate (achieved by timing of echo return). The entire array is then pulsed, one element at a time, and a sensitivity plot produced. The system then measures the capacitance of each element circuit and displays a capacitance plot; there are a number of probes for which FirstCall cannot measure capacitance. The capacitance results allow the user to determine whether low sensitivity is due to a short circuit, open circuit or damaged element. Additionally, the system provides plots of pulse width, centre frequency and fractional bandwidth for each element and pulse shapes and frequency spectra for three user-selected elements.

The FirstCall manual defines an acceptable probe array as having no more than four weak elements (40% to 75% of mean sensitivity), no more than two consecutive weak elements and no more than one dead element (<10% of mean sensitivity). For the purposes of this study a fault was defined as one or more dead elements, more than four weak elements or more than two consecutive weak elements to allow comparison between the methods in detecting element failure.

One of the authors (D.J.W.) managed routine probe testing; the other author (N.J.D.) was not involved in routine probe testing. For this study, D.J.W. provided N.J.D. with a selection of probes, some faulty and some without faults, across a range of manufacturers and probe types; N.J.D. was blinded to the FirstCall results. N.J.D. then connected the probes to appropriate ultrasound scanners and inspected the in-air reverberation patterns using the following settings. A clinical preset appropriate to the probe under test was selected; harmonics, beam steering, spatial compounding and any advanced image processing were disabled, and a single focus was moved close to the probe to minimise the width of the active aperture. Time gain compensation (TGC) was set to the default position where TGC slider controls are in the central position. Image scale, overall gain and transmit frequency were adjusted to optimise the display of any suspected anomalies in the reverberation pattern. Any suspected element failures were tested by running a paperclip or similar tool along the array, looking for a reduction in amplitude of the resulting "comet-tail" reverberation (Goldstein et al. 1989); the place where such a reduction was consistently observed was judged to represent one or more failed elements and recorded as a fault (dropout). Connectors were moved between ports to exclude connector/port faults as a cause of apparent element failure. Cables were manipulated in an attempt to identify cable faults as the source of element failure. In the absence of cable faults, isolated failed elements were recorded as non-specific element failure, that is, cause unknown, and multiple contiguous element failures were recorded as suspected array damage.

Where disruption of the reverberation pattern was seen, thought to represent delamination of the acoustic