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ORIGINAL ARTICLE

Use of high frequency ultrasound to detect changes in skin integrity: An image evaluation validation procedure☆

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Summary
Objectives: High frequency ultrasound (HFUS) scanning may be used for prevention, detection and monitoring of pressure ulcers in patients at risk and is amenable for portable, bedside use by a variety of clinicians. Limited data are available about the criteria to determine an ideal image or measures of tissue changes representative of tissue injury. We developed and evaluated criteria for overall image quality and measures of tissue integrity.
Methods: In 40 mechanically ventilated adults in 3 ICUs, 241 HFUS sacral images were evaluated for agreement using criteria for overall image quality and tissue changes (dermal, hypodermal layer thickness and layer density).
Results: HFUS sacral images ($N = 241$) were evaluated in three analyses and showed poor agreement in all three analyses using the specific criteria for global quality, however when criteria were collapsed agreement was good to substantial. Evaluator agreement for layer thickness and layer density was also good.

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Conclusions: A global rating is adequate for identifying good images. Agreement for measurements of layer thickness and density were also good and may be useful to identify early changes in tissue integrity leading to tissue injury. Additional data are needed concerning the association of changes in layer thickness and layer density to eventual tissue injury.

Implications for Clinical Practice

The development of pressure ulcers is a costly complication of illness and patient care and the best preventive care strategies have been unable to completely eradicate them.

- Early identification of tissue changes that may eventually lead to tissue injury is critical to further reduce the incidence of pressure ulcers.
- High frequency ultrasound (HFUS) technology may identify tissue oedema, a potential first sign of changes in tissue integrity, however quality scans and accurate measurements are required.
- The criteria developed here may provide a standard method for clinician evaluation of image quality.
- HFUS generated measures of layer thickness and density can also be reliably obtained.

Introduction

Ultrasonography has been widely used in clinical practice as an inexpensive and portable diagnostic tool. Recently high frequency ultrasound (HFUS) using a 20 MHz probe has been used to provide images for both dermatologic practice and research to evaluate lymph nodes (Schmid-Wendtner and Burgdorf, 2005), chronic ulcers (Kuhn and Angehrn, 2009; Timar-Banu et al., 2001), skin lesions and tumours (Bessonart et al., 2005; Fornage et al., 1993; Jasaitiene et al., 2011; Schmid-Wendtner and Burgdorf, 2005). However, more limited data are available about the use of HFUS to evaluate the development of pressure ulcers (PUs).

Pressure ulcers are common and costly (Allman et al., 1986; Beckrich and Aronovitch, 1999; Bours et al., 2001; Cuddigan et al., 2001; Roadmap for Safety, 2003; US Department of Health and Human Services, 2000; Whittington et al., 2000), but methods to quantitatively evaluate patients at risk or identify early stages of pressure ulcer development, especially the more elusive, deep tissue injuries are limited (Black, 2005). Certain deep tissue injuries are currently thought to develop through a ''deep-to-superficial'' pattern resulting in delayed clinical recognition of significant and often extensive tissue changes (Black et al., 2007; NPUAP, 2008). Since deep tissue ulcers are difficult to identify, identification of quantitative measures to determine risk and early stage injury would be clinically useful.

HFUS scanning identifies the existence of a hypoechogenic subepidermal layer at the location of pressure ulcers (Andersen and Karlsmark, 2008) and may demonstrate soft-tissue damage and oedema before clinical signs are visible (Fornage et al., 1993; Quintavalle et al., 2006; Timar-Banu et al., 2001). The ability to identify early changes in deep tissues may enhance tissue injury prevention strategies. Changes in dermal echogenicity reflect alternations of dermal water content associated with inflammation. HFUS dermal echogenicity and skin water content using nuclear magnetic resonance were evaluated and HFUS was shown to be a sensitive method to assess dermal hydration and skin pathology associated with oedema formation (Gniadecka and Quistorff, 1996).

Visual skin assessments by clinical providers may not always correspond to changes in HFUS images. Quintavalle et al. (2006) compared HFUS from 119 long-term-care (LTC) facility residents at risk for PUs with 15 healthy volunteers. 55.3% of the images from LTC residents showed areas within the skin layers that were not visible, indicative of fluid or oedema, while those from healthy volunteer had homogeneous patterns of reflection. Most images (79.7%) with abnormal ultrasounds did not have documentation of skin erythema in the clinical record. More recently Porter-Armstrong et al. (2013) evaluated whether HFUS supported clinical skin assessment in an inpatient population by comparing HFUS to clinical assessments of heel and sacral skin. They found that qualitative classification of ultrasound images did not match outcomes yielded through the clinical skin assessment.

HFUS has been shown to identify deep tissue changes. To compare rates of visualised heel PUs to hidden injury using HFUS in geriatric medical patients, Helvig and Nichols (2012) evaluated 100 hospital patients and found that HFUS detected occult injury more often than visual assessment did. Yabunaka et al. (2009) in comparing HFUS images in patients with PUs to normal skin areas, found subcutaneous fat oedema in the ulcerated area and no oedema in normal skin areas; fat oedema was identified in all PUs, regardless of wound depth. Further, follow-up images showed that as the wounds improved, fat oedema was reduced. These authors suggest that the inflammation caused by pressure ulcers may have a greater effect on subcutaneous fat than any other tissue and that resulting oedema occurs early in the development of PUs, which can then be detected by HFUS (Yabunaka et al., 2009). In addition, HFUS has also been used to monitor healing of PUs in experimentally induced wounds in guinea pigs (Moghimi et al., 2010).

HFUS is increasingly marketed and used for the prevention, detection and monitoring of PUs in patients at