The use of Electrical Impedance Tomography for Bladder Volume Monitoring in Nocturnal Enuresis

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Abstract
Nocturnal enuresis (bedwetting) is a common condition in children. While many options exist to treat the condition such as pharmaceuticals and the enuresis alarm, they are not without limitations. This paper explores the need for bladder monitoring of children with nocturnal enuresis, and proposes a solution in the form of a non-invasive, proactive electrical impedance tomography monitoring technology. This work also provides early results, including a sample of image reconstruction of the pelvis and bladder.

1. Introduction
Nocturnal Enuresis (NE) is defined as discrete episodes of urinary incontinence during sleep in children aged five and older [1]. The condition is one of the most common that affects children, with an overall prevalence between 9-12 % [2]. Nocturnal enuresis is two-times more frequent in boys than in girls [3]. The impact of the condition on the child is both medical and psychological. It can be a traumatic experience for a child [4]. In one study, children believed bedwetting to be the most stressful event after family fights and divorce [5]. Nocturnal enuresis also places a high burden on the immediate family [6]. Left untreated or unsuitably managed, the condition can persist into adulthood [7].

Current treatment options vary from education to alarm devices or drug therapies [8]. When initial treatments such as education, fluid restriction and motivation therapy have failed, active therapies may be prescribed. Active therapies include both pharmacological and alarm treatment solutions [8]. While pharmacological solutions have rapid effects in the suppression of urine production at night-time, discontinuation of the treatment results in a high relapse rate [4]. The preferred initial solution of using an enuresis alarm to detect the onset of urination during sleep is particularly effective in the long-term [8]. The alarm approach involves placing a moisture sensor in the child’s underwear and an alarm nearby. However, the alarm device only alerts the child after bedwetting has begun. Devices capable of waking the child before bedwetting have the potential to eliminate the occurrence of bedwetting and open new avenues for behavioural training.

Technologies based on ultrasound have been investigated for long-term bladder volume monitoring [9]. Unfortunately, these solutions are not without limitations. Bladder ultrasound devices can be bulky, costly and required expert-help to fit correctly [10-12]. Data recorded from these devices can have measurement errors as high as 25 % suggesting the clinical usage of such data needs to be interpreted with care [13].

Electrical impedance tomography (EIT) is a medical imaging technology around since the late 1970’s that has gained much interest in the last decade, particularly, for monitoring lung ventilation and perfusion [14]. The technology involves the injecting of small electrical currents into the body through several electrodes and measuring the resulting voltages to determine the conductivity distribution in the region of interest and in turn, producing a medical image. Electrical impedance tomography suffers a poor absolute image resolution compared to computer tomography and magnetic resonance imaging [15]. However, EIT performs quite well for time-difference imaging where non-changing tissues and image artefacts can be removed. This makes the technology suitable for long-term monitoring applications such as monitoring the expansion of the lungs or in this case, bladder volume changes. Also, urine has a high conductivity contrast relative to the surrounding tissues [12], making it possible to distinguish urine volume from the background tissues. As a result, EIT has the potential of providing a positive, preventative and non-invasive method for dealing with this condition.

In this preliminary work, a finite element model of the bladder embedded in the pelvis is examined, and image reconstruction is tested based on a full bladder scenario. Thus, this work demonstrates the promise of EIT as a potential solution for NE.

2. Methods and Results
The initial work on this project has involved validation of the medical need, creating simple finite element models (FEMs) and performing image reconstruction with the open-source EIT code base EIDORS [16]. Simulation data without noise was created on a simple elliptical cylinder to represent the pelvis boundary. The bladder was represented by a sphere as illustrated in Figure 1. The FEM consisted of 23241 tetrahedral elements with 16 electrodes equidistance in a ring around the boundary. An injection current of 1 mA was employed. Using the dual image reconstruction algorithm GREIT [17], a reconstructed image of the simulated data for a full bladder size of 500 ml was produced relative to a homogenous reference image. This reconstructed image is illustrated in Figure 2. From this image, it is clear that the bladder filled with urine is accurately reconstructed,
with the bladder visible with a significant contrast against the background.

Figure 1: 3D elliptical FEM representing the human pelvis with a meshed sphere representing the bladder.

Figure 2: Sample 2D image reconstruction of the full bladder (conductivity 1.75 S/m at 50 kHz [18]) formed from the dual image reconstruction GREIT algorithm. The homogenous reference image with the conductivity of 0.7 S/m at 50 kHz was used to mimic the highest conductivity value of the surrounding tissue, blood [18].

3. Conclusions
This paper has demonstrated the need for bladder volume monitoring for children with NE, and EIT is being investigated as a promising, proactive solution. A noise-free simulation example has also been presented, providing a baseline for determining bladder volume and testing existing metrics for classification of bladder fullness levels.

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8. References