Parametric Reconstruction for Impedance Cystovolumetry

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Abstract: A low-parametric reconstruction method for human bladder volume estimation has been developed and compared to the conventional image-based global impedance method. Main advantages of the new method are conductivity invariant volume estimate and increased accuracy for medium to high bladder volumes.

1 Introduction

In most applications of electrical impedance tomography (EIT), a tomographic image is sought. In some applications, however, the resulting images are processed to estimate a small set of parameters. One example is bladder volume estimation, where the reconstructed image is secondary and an accurate volume estimate is of greater importance. Previously, the linear correlation of global impedance (GI) calculated from reconstructed EIT images has been used to estimate volume [1]. However, this approach conflates changes in bladder volume with varying urine conductivity [2]. In this work, a new low-parametric reconstruction approach for EIT is presented and compared with the established GI method in terms of accuracy, influence of urine conductivity and noise stability.

2 Methods

Simulated EIT data for various bladder volumes and urine conductivities were generated in Matlab based on a simplified, anatomically inspired FEM-model using EIDORS and Netgen. Image reconstruction was carried out with EIDORS adapted for low-parametric reconstruction.

The model consists of a cylinder ø 30 cm containing an eccentrically placed sphere representing the bladder. Two rings of 32 electrodes are placed on the surface. Unit conductivity was assigned to the background. Parametric sweeps for bladder volume from 50 ml to 550 ml, bladder contrast from 1 to 3 and SNR from 10^1 to 10^4 were calculated. Bladder position was a function of radius.

For the GI method, images were reconstructed using the GREIT algorithm [3], and their total value summed (global impedance, GI). A cubic function relating GI and bladder radius was fitted to the results of the sweep at contrast 2 and SNR 10^4 and used for all radius estimations.

Direct low-parametric reconstructions were obtained with EIDORS's iterative Gauss-Newton solver with Tikhonov prior adapted such that the sought solution was limited to two parameters, the Jacobian was approximated with the perturbation method, and the forward solution was calculated using a 3D FEM. The sought parameters were the radius and conductivity contrast (w.r.t known background) of a single spherical target, whose position was a function of the radius.

3 Results

Table 1 shows the relative errors of the GI method (upper value in each cell) and the proposed parametric reconstruction (PR) (lower values). At low bladder volumes, both methods show high errors, but GI outperforms PR. For medium and high volumes, PR shows a clear advantage. Volume estimates based on PR show much lower sensitivity to varying urine conductivity (represented in terms for different image contrasts), but higher sensitivity to noise than those based on GI. While the error of GI is relatively constant at a high level, PR shows excellent results only if little noise is present (SNR 10^3–10^4).

4 Conclusions

Our results indicate that low-parametric reconstruction is a promising approach to bladder volume estimation in the face of unknown urine conductivity. For the purpose of preventing reflux to the kidneys and overflow incontinence, the poor performance at low volumes is not a severe drawback. The high sensitivity to noise – and therefore to such practical difficulties as inexact modelling of abdominal shape, electrode positioning and movement, as well as contact quality – is a drawback which we hope to address in the future by better regularization.

References

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Table 1: Comparision of relative radius errors in % for conventional GI (upper value) and new parametric approach (lower value).

	contrast	1				1,5				2				2,5				3			
	SNR dB	10	20	30	40	10	20	30	40	10	20	30	40	10	20	30	40	10	20	30	40
bladder volume [ml]	50	93	32	35	35	57	36	37	37	19	40	39	39	87	45	40	40	41	45	41	41
		267	-190	148	81	68	93	302	272	64	-64	518	-151	57	41	33	32	-183	36	43	43
	150	-36	0	0	0	51	13	4	4	18	12	7	8	33	10	11	11	62	18	12	13
		2	-1	-3	0	54	3	0	1	45	1	1	0	44	8	2	2	-11	-2	1	2
	250	14	-4	-10	-10	14	-7	-4	-5	-47	2	0	0	25	4	3	3	29	11	6	6
		-19	-3	0	0	15	-3	0	0	14	-1	0	0	-11	-6	1	0	17	-1	0	0
	350	-23	-14	-15	-15	5	-11	-9	-9	21	-9	-4	-4	7	-1	-1	0	13	6	3	3
		10	4	0	0	0	4	0	0	-22	1	0	0	-15	0	0	0	8	-2	0	0
	450	-10	-18	-19	-19	-4	-9	-12	-12	-11	-4	-7	-7	12	-4	-3	-3	5	1	0	0
		10	1	0	0	-3	-1	0	0	-18	-1	0	0	10	0	0	0	-18	0	0	0
	550	-10	-21	-22	-22	-1	-13	-15	-15	-1	-10	-10	-10	-2	-5	-7	-6	-19	-2	-3	-3
		-14	1	0	0	-5	-1	0	0	1	-1	0	0	-9	-1	0	0	2	1	0	0