380 Multipoint Acceleration Sensor in the Bladder Wall: A Novel Measure of Bladder Activity

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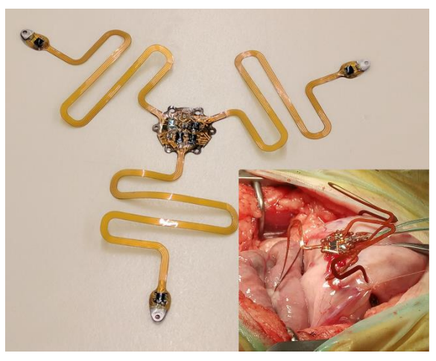
Abstract

Bladder wall movement patterns associated with bladder dysfunction are observed in muscle strips and isolated organs. This study investigates whether multiple acceleration sensors placed on the urinary bladder wall can detect bladder movements in vivo.
We implanted a sensing system in Gottingen minipigs containing 4 accelerometers and a submucosal pressure sensor. Consecutive awake voiding cystometry was performed with air-charged catheters in a standard urodynamic set-up as comparators. Measured acceleration signals were separated by frequency-based filtering resulting in linear acceleration and change of sensor orientation. This is the first report of bladder wall acceleration in a voiding animal model, demonstrating potential for long-term continuous measurement of motion.

Introduction

Spontaneous bladder wall activity plays an important role in the pathogenesis of detrusor overactivity. Observation techniques of movement in vivo are limited by duration and interruptions. Motion sensing by implantable accelerometers has been used in organs and whole organisms. In this preliminary study, we aim to develop and test the feasibility of a combined pressure and motion implantable sensor for the bladder wall in an awake animal model.

Methods and Materials



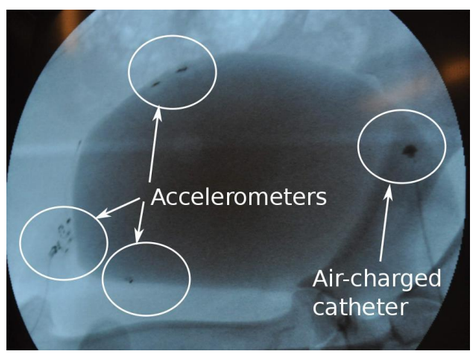


Figure 1. Acceleration measurement device, sensors are placed on three satellite arms and one on the central island.

In collaboration with the micro-electronic engineering department, we developed an implant with four accelerometers (Bosch BMA280) and a submucosal pressure sensor (MS5637) as shown in Figure 1.

Following surgical implantation and 7 days recovery, we performed weekly consecutive voiding cystometries. A 3-way air-charged urethral catheter and standard urodynamic set-up was used as comparator.

The acceleration signals consisted of high-frequency oscillatory bursts of linear acceleration and a baseline value. This baseline is determined by the orientation of a particular axis relative to gravity.

Change in baseline value (∆a) was calculated by subtraction of the start value from the end value. Total linear acceleration (TLA) from three axes of the same sensor was calculated by root mean square.

We estimated sensor orientations in to plot direction of acceleration vectors in a single 3-dimensional coordinate system (Figure 3).

Start of voiding was adapted from definitions of voiding phase 1 described by Andersson et al. as shown in Figure 2. We compared accelerometer measurements to adjacent 10-second premicturition periods. Values are mean +/- SD unless otherwise specified.

Results

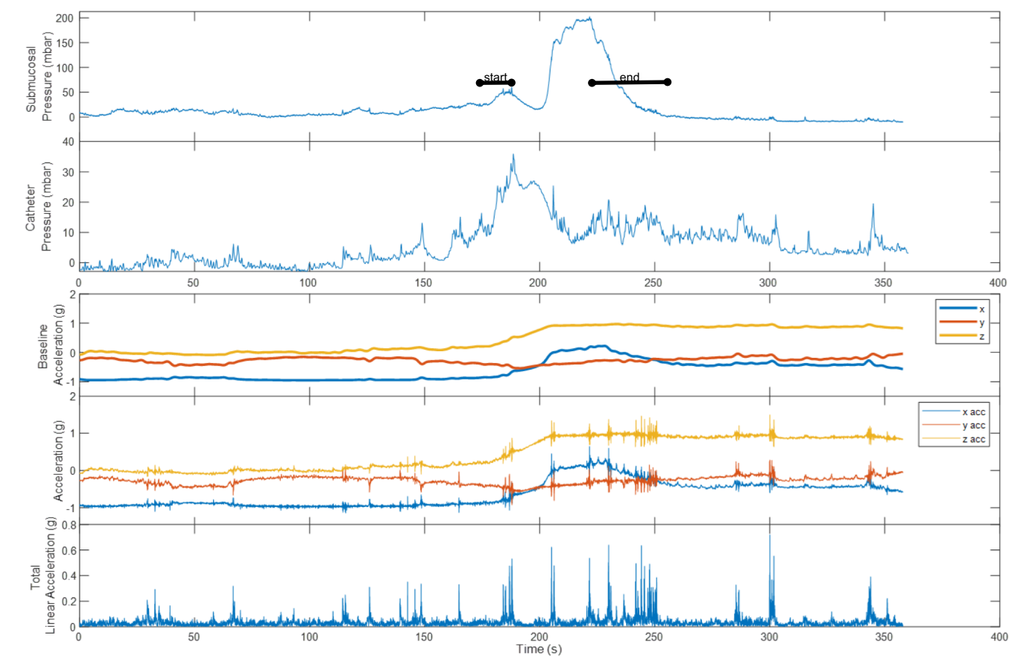


Figure 2. Data from a single voiding episode. Acceleration is separated at a cut-off frequency of 0.15 Hz into gravity component and linear acceleration. Magnitude of total linear acceleration is calculated by the following formula

$$TLA = \sqrt[2]{a_x^2 + a_y^2 + a_z^2}$$

We performed measurements on 19 voiding cycles with filling volume of 720 +/- 310 ml. In each measurement session, we observed 3 to 5 consecutive voiding events. Submucosal pressure differed from catheter pressure by -10.1 +/- 27.1 mbar and correlation between both measurement methods was 0.29 ($p<0.0001$). Pressure curves were markedly different after the first voiding peak. Correlation of pressure during the premicturition period until the first voiding peak was 0.52 ($p<0.0001$).

Largest magnitude of ∆a was observed in the z-axis of the sensor implanted in the bladder posterior wall compared to apical and lateral locations. Value of ∆a is higher during voiding compared to preceding premicturition periods (0.61 +/- 0.2 v 0.038 +/- 0.086 g). Linear acceleration activity occurred in bursts interspersed with periods of low activity. TLA at start of voiding was higher than the preceding period (0.068 +/- 0.021 v 0.049 +/- 0.027 g). Interval between maximum TLA correlated with interval between peaks of voiding pressure recorded by the submucosal sensor ($r=0.760$, $p<0.001$).

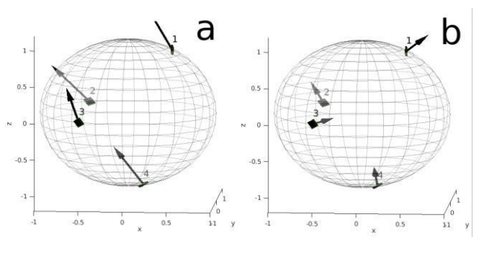


Figure 3. 3D vector visualization of movement acceleration signal. (a) shows acceleration in a similar direction and (b) is simultaneous acceleration in diverging directions.

Discussion

Submucosal pressure traces was more consistent on repeated voiding compared to catheter traces. In some cases, catheter sensitivity was decreased in subsequent micturitions.

Accelerometer measurements mark the start of voiding by increased TLA. Baseline accelerometer value during voiding reflects change in bladder wall orientation and volume. This also indicates quite clearly the emptying of the bladder at the end of the cycle.

Conclusions

This is the first report of acceleration data recorded in vivo from an awake voiding animal model from multiple sites in the bladder. We observed an increase in acceleration activity at the start of voiding and change in baseline acceleration during voiding. Analysis of the entire voiding cycle, integrating input of all four sensors will further establish the potential use of accelerometers in the study of bladder motion. This implantable device is the first step towards identifying autonomous bladder micromotions in situ.

References

Andersson, K.-E., Soler, R., & Füllhase, C. (2011). Rodent models for urodynamic investigation. Neurourology and Urodynamics, 30(5), 636–646. https://doi.org/10.1002/nau.21108