Quantification of Bladder Wall Irregularity in Pediatric Patients via the Convex Hull

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Hypothesis

We hypothesized that a novel metric based on the convex hull could distinguish normal bladders with smooth walls from irregular/trabeculated bladders resulting from chronic outlet obstruction.

Introduction

Pediatric patients with congenital bladder outlet obstruction are at an increased lifetime risk for irreversible damage to their kidneys and end-stage renal disease requiring hemodialysis and/or renal transplantation. The pathway of damage occurs via the following pathway: Chronically increased intravesical pressure/volume over time causes remodeling of the bladder wall characterized by bladder wall hypertrophy, which is accompanied by decreased bladder wall compliance. Bladder wall muscular hypertrophy in the short time permits the lower urinary tract to overcome the obstruction and thus allow for full emptying. Morphological changes accompanying this process are trabeculation, cellule formation and diverticula. Trabeculations are seen on cystoscopy as a coarsely interwoven appearance to the mucosal surface formed by muscular bundles with deposits of interstitial collagen. Chronically high pressures can lead to small outpouchings of mucosa between layers of hypertrophied bladder wall muscle called cellules. Over time and with continued obstruction these enlarge to form more overt protrusions called diverticulae. Sonographically, the composite of these changes can be broadly classified as irregularities in shape.

The time window between the appearance of bladder wall hypertrophy and the development of renal damage affords an opportunity for either surgical, medical and/or catheterization-based intervention. This is due to the fact that the bladder wall hypertrophy phase of damage is often reversible if treated in a timely fashion. Thus a method to track the level of bladder wall damage quantitatively via an automated approach may afford a valuable additional metric to guide the timing of intervention so as to avoid or delay long-term irreversible renal effects.

Methods

Ultrasound images from a cohort of 16 patients, half of whom had chronic kidney disease levels of 4 or 5 while the other half had normal renal function, were analyzed. For each patient image, the bladder lumen was segmented from the surrounding soft tissues. The convex hull of the bladder lumens was computed. The difference in area between the convex hull and the bladder lumen scaled by bladder lumen area was then calculated for each image. This quantity, denoted by $T$, was hypothesized to serve as metric for the degree of bladder wall irregularity, which is normally manifested chiefly by trabeculations.
Results

The average T value was higher for diseased than healthy patients by roughly a factor of three (0.15 with 95% confidence interval of [0.11, 0.19] versus a mean value of 0.05 with 95% confidence interval of [0.03, 0.07] for normal bladders). This disparity is statistically significant, with a p-value of less than 0.01 (Figure 1).

Discussion

This proof-of-principle study introduces a metric for the degree of bladder wall irregularity. Such an automated quantity has not to our knowledge previously been introduced.

Our approach has not accounted precisely for urine volume; this could in future work be tightly controlled via catheter-based instillation as is routinely performed during urodynamics studies. Additionally, we have used axial slices, but future application of the method via midline sagittal views with appropriate segmentation of the posterior bladder segment would provide a more standardized sampling. Although we have shown a numerical difference between normal, smooth bladders and very trabeculated/irregular bladders, the broader long-term goal is more specific quantification, in particular to follow patients over time. This would likely require standardization of volumes and slice selection/segmentation as stated above. Ideally, future imaging protocols would emphasize good contrast in pixel intensity between lumen and surroundings for better segmentation that may be completely automated if there is very good contrast. In other words, our method will likely be most useful -- and in future work will be applied to -- patients followed over several years and associated with their progression of disease.

An additional manifestation of bladder damage is bladder wall thickening, which like contour irregularity is also dependent on intravesical volume. This feature may be added to future calculations to give a more complete evaluation of bladder wall damage. An additional venue for further work could employ three-dimension bladder ultrasound, which could provide direct volume measurements. Generalization of the convex hull approach to three dimensions should be straightforward.

Conclusion

Our results confirm that it is possible to calculate a value for bladder wall irregularity that can separate normal from diseased bladders.
References


Keywords

Bladder Trabeculation, Bladder Wall Hypertrophy, Outlet Obstruction, Renal Scarring, Pediatric Bladder