A mathematical model for the proliferation of bacteria in the urinary bladder due to enlarged prostate

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Summary Urinary retention due to enlargement of the prostate (prostate hypertrophy) leads to increased proliferation of bacteria in the bladder. This in turn increases the infection rate. The reason is that the enlarged prostate presses on the urine channel and tends to close it. Thus the out flux of the bladder consists of repeatedly small amounts of fluid during a day. A mathematical dynamic model with differential equations is developed for the proliferation of bacteria in the urinary bladder (vesica urinary). The model accounts for how this proliferation is associated with varying amounts of mass of urine within the bladder. Parameters are estimated from published data and analytical and numerical results are presented. The relationships between the proliferation of bacteria within the bladder and the type of urinal out flux from the bladder are examined. The proliferation is shown to depend on the amount of mass of urine and the out flux of urine from the bladder. In the normal situation the bladder is drained successfully which also drains the bacteria. In the abnormal situation the bladder drains only partly. Despite frequent urination, substantial urine mass in the bladder on the average allows bacteria to proliferate and increase in number through time. The simulations depend on the numerical values of the parameters which again depend on the prostate condition of each male adult under scrutiny. By determining the parameters for each male, the dynamic model can be used as a powerful tool by which the proliferation of bacteria in the bladder can be studied and controlled by different means. Three clinical advices are provided. First, try to achieve that the proliferation rate of bacteria in the bladder is as small as possible, e.g. through altering the pH or chemical composition within the bladder. Second, try to achieve that the out flux of urine from the bladder is substantial, through sufficient drinking. Third, try to achieve that the mass of urine in the bladder is as small as possible, through sufficient urination. The intrinsic parameters for each male can be used to pinpoint the actual out flux during a day necessary to keep the number of bacteria in the bladder low. Suggestions for how to test the model are briefly presented.

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Introduction

Prostate cancer is the most common malignancy among men in the western world [1]. Most men
experience progression of the prostatic hyperplasia by reduction of the flow rate by 2% every year and an increase in the international prostate symptom score by 0.18% every year. Predictions of the disease progression are prostatic specific antigen $>1.5$ ng/ml and prostatic volume $>30$ g [2].

Often, before the onset of cancer, enlargement of the prostate (prostate hypertrophy) leads to serious urinary retention. The reason is that the enlarged prostate presses on the urine channel and tends to close it. This means that the urinary bladder can be drained only when the internal fluid pressure of the bladder is high. Thus the out flux of the bladder consists of repeatedly small amounts of fluid during a day. On the average the bladder thus stays almost full all the time. This stands in contrast to the normal situation where the bladder is drained almost completely during the urination process. The total out flux integrated over a day is roughly the same for the abnormal and the normal situation.

Jacobsen et al. [3] considered the natural history of prostatism, focusing on risk factors for acute urinary retention. They found that "lower urinary tract symptoms, depressed peak urinary flow rates, enlarged prostates and older age are associated with an increased risk of acute urinary retention in community dwelling men". The risk factors of human prostate cancer are quite varied, and so is the research. Bostwick et al. [4] categorize into "(1) epidemiology (endogenous factors [family history, hormones, race, aging and oxidative stress] and exogenous factors [diet, environmental agents, occupation and other factors, including lifestyle factors]); (2) animal and cell culture models for prediction of human risk (rodent models, transgenic models, mouse reconstitution models, severe combined immunodeficiency syndrome mouse models, canine models, xenograft models, and cell culture models); (3) biomarkers in prostate cancer, most of which have been tested only as predictive factors for patient outcome after treatment rather than as risk factors; and (4) genotoxic and non-genotoxic mechanisms of carcinogenesis". Most of the data regarding risk relies on epidemiologic studies, but animal and cell culture models offer promise in confirming some important findings.

Trachtenberg [5] considered treatment of lower urinary tract symptoms suggestive of benign prostatic hyperplasia in relation to the patient’s risk profile for progression. He suggested adding a 5α-reductase inhibitor to the α1-AR antagonist to obtain maximum relief of symptoms, and ideally to halt the progression of the disease. Also, patients at very high risk of progression, with severe obstruction, that is poor maximum urinary flow rate and high postvoid residual urine volume, are potential candidates for immediate surgery. De la Rosette et al. [6] analyzed the relationships between lower urinary tract symptoms and bladder outlet obstruction. They found no "correlation between a wide range of symptoms and the results of free uroflowmetry and pressure and flow studies". They claim that "from symptoms alone, it is not possible to diagnose bladder outlet obstruction".

In the last decade, the management of lower urinary tract symptoms due to prostatic hyperplasia has changed. The management involves a cascade of non-invasive treatments. The choice depends on balancing symptom severity and bothers with benefits, risks and side effects [7,8]. Harlan et al. [9] studied four typical management options (percentages in brackets): radical prostatectomy (47.6%), radiation therapy (23.4%), hormonal therapy (10.5%), and watchful waiting (18.5%). Further, Potosky et al. [10] analyzed health outcomes after prostatectomy and radiotherapy and found differences in urinary, bowel, and sexual functions.

There are some basic components to fluid management. Dehydration should always be avoided. Uncertainties pertain to the overall fluid intake. Some suggest drinking from 1.5 to 2 l of water per day, while others suggest that 3 l per day afford health benefit [2,11].

One clinical advice during urinal infections is to increase the amount of urine produced during a day [12]. But the patient should avoid or moderate the intake of caffeine and alcohol which may have a diuretic and irritant effect on the bladder [8]. Hebert et al. [13] considered nutritional and socioeconomic factors in relation to prostate cancer mortality, and found support for "the current dietary guidelines and hypothesis that grains, cereals, and nuts are protective against prostate cancer". They suggest further research on the impact of soy products. More generally, Clinton and Giovannucci [14] have reviewed the research of the impact of diet and nutrition on prostate cancer. Causes are a "culmination of a complex series of initiation and promotional events over a period of decades and under the influence of many interacting genetic and environmental factors". Another proposed advice is to make changes in the acidity (pH) of the urine. Most bacteria prefer a specific pH, and when increasing or decreasing the pH the proliferation in the bladder could be made smaller. For example, Giovannucci [15] found that "diets high in dairy products and meats are related to higher risk of prostate cancer incidence or mortality in most ecologic, case-control, and prospective studies". The causal link is that "high intakes of calcium and phosphorus, largely from dairy products, lower circulating 1,25(OH)2D
level, and sulfur-containing amino acids from animal protein lower blood pH, which also suppresses 1,25(OH)2D production\(^\text{2}\).

Vollmer and Humphrey [16] analyzed tumor volume in prostate cancer and serum prostate-specific antigen using a compartmental model and first-order kinetics to develop the mathematics necessary to relate serum prostate-specific antigen (PSA) to tumor volume. They "found that the resulting model fit well the observed kinetic data of PSA measured after biopsy or prostatectomy". The model also predicted a linear relationship between PSA and the sum of volumes of benign and malignant tissues. More generally, Swanson et al. [17] considered the use of quantitative modeling to help understand prostate-specific antigen dynamics and other medical problems.

The approach in this article falls within this latter modeling tradition which gradually emerges. Bacteria frequently find their way into the urinary organs. Urinary retention often leads to serious infections of bacteria in the urinary organs. The proliferation of bacteria is in this article assumed to take place in the urinary bladder itself. It is believed that the main reason for the increased infection rate during urinary retention is that the concentration of bacteria in the bladder becomes much higher.

This article studies the proliferation of bacteria more closely by using a combination of simple cell proliferation dynamics and fluid flow. By construction of such a model we have a powerful tool by which the proliferation of bacteria in the bladder can be studied and controlled by different means.

Experiments have been carried out to test the effect of different clinical approaches. Although this literature is quantitative and technical in nature, with suggested polynomials describing the phenomena, lacking is to our knowledge the study of this dynamics by using ordinary differential equations. This approach is to our knowledge not so common within the field of medical science, but has been quite common in other fields of science\(^\text{2}\).

It is always difficult to decide how many parameters or parametric functions to use to model a physical/biological phenomenon. From one point of view a simple model can be too simplistic to grasp the whole phenomenon, but from another point of view a simple model can frame subsequent research by identifying and focusing on key relationships between basic variables. Also, models with few parameters can provide considerable insight, with disadvantage associated with grouping many different phenomena together, while those with a greater number of parameters may fit the data better, at the expense of providing less insight and probably less predictability. Simple deterministic equations often lead to powerful qualitative results with important threshold behavior.

In Section "The model" we present the mathematical model. Section "Analyzing the model and clinical advice" analyzes the model, presents clinical advice, and threshold analysis. Section "Parameter estimation" estimates the parameters. Section "Simulations" shows numerical simulations. A more advanced analysis is performed compared to Sections "Analyzing the model and clinical advice" and "Parameter estimation". Section "Suggestions for how to test the model" presents suggestions for how to test the model. Section "Conclusion" concludes.

The model

Let \( m \) be the mass of urine in the bladder. The following model applies

\[
\begin{align*}
\dot{m}(t) & \equiv \text{mod} \quad \alpha(t) - \beta(t) \\
\text{Derivative mass} & \text{Influx in kg per time unit} \quad \text{Outflux in kg per time unit}
\end{align*}
\]

(1)

where "mod" means model assumption, and \( t \) is time. This article studies the effect of very simple in flux values \( \alpha(t) \), and we consider out flux values \( \beta(t) \), both with dimension kg per time unit. We assume that the organism simply performs different constant values in time.

During the normal situation the bladder is drained up to 99\% during urination. During the severe abnormal situation the bladder is drained with much smaller values, for example as low as 10\%, or within the range 10–50\%.

Let \( N(t) \) be the number of bacteria in the bladder at time \( t \). We assume that the total mass of the bacteria is small compared to the mass of fluid in the bladder and can be neglected. The number of bacteria in the bladder is given by the well-
known logistic equation, which is modified, to include out flow of bacteria, to read
\[
\frac{dN(t)}{dt} = \mu N - \frac{vN^2}{m} - N_{\text{out}}(t)
\]
The logistic equation specifies the proportional presence of \(N\) on the right hand side to allow for exponential growth, and the square negative presence of \(N\), that is \(N^2\), due to competition between the bacteria which constrains unbounded growth of \(N\). The parameter \(\mu\) (dimension per time unit) is the proliferation rate of bacteria, which in turn affects the infection rate. The parameter \(v\) (dimension kg per time unit) scales the intensity of the competition between the bacteria. As the mass in the bladder increases, the bacteria get more space within which to operate, and the competition with other bacteria for space, nutrients, flourishment, and thus survival becomes less severe. Thus \(v/m\) expresses the actual intensity of the competition between the bacteria. Without out flux of bacteria and without internal competition between the bacteria, \(v = 0\), the concentration \(C = N/m\) grows exponentially with time since only the first term on the right hand side of (2) applies. Not included in the classical logistic equation, but included as a third term on the right hand side of (3), is the out flux \(N_{\text{out}}(t)\) of bacteria from the bladder. The out flux is simply the number of bacteria leaving the bladder per time unit, and there is thus no need for a scaling parameter for this third term.

The bacteria can be expected to distribute themselves evenly and homogeneously throughout the mass of the bladder. As urine mass leaves the bladder, so do bacteria, and we assume a proportional relationship. That is, the number of bacteria leaving the bladder is assumed to be directly proportional to the out flux \(\beta(t)\) of urine of the bladder, as expressed in (1). The out flux of bacteria has dimension kg per time unit, which we divide with the mass \(m\) of the bladder to express out flux per time unit. We thus express \(N_{\text{out}}(t)\) as
\[
N_{\text{out}}(t) = \frac{N}{m} \beta(t)
\]
which is the number of bacteria leaving the bladder per time unit.

Let us consider a steady state situation where on average over a certain time interval the out flux from the bladder balances and thus equals the influx. Also assume that the number of bacteria in the bladder is constant over this time interval. This implies \(\beta = \text{const} = \beta_0\), \(m = \text{const} = m_0\), where subscript 0 denotes the steady state situation. \(\beta_0\) is the steady state out flux (kg per time unit) from the bladder and \(m_0\) is the steady state mass of urine in the bladder. Using the steady state assumptions \(N(t) = 0\), \(m(t) = 0\) in (1)−(3) gives
\[
\alpha = \beta_0, \quad m = \text{const} = m_0, \quad (a),
\mu \frac{N}{m} - \frac{vN^2}{m^2} - \frac{N}{m} \beta_0 = 0, \quad (b)
\]
Solving (4b) gives the equilibrium solution
\[
N_{\text{eq}} = 0 \quad \text{or} \quad N_{\text{eq}} = \frac{C_{\text{eq}}}{\beta_0/m_0},
\]
where \(C_{\text{eq}} = \frac{\mu}{v}\)

\[\text{Analyzing the model and clinical advice}\]
In Eq. (5) the expression \(\mu - \beta_0/m_0\) is of particular interest. It expresses the proliferation rate \(\mu\) minus the steady state out flux per mass unit \(\beta_0/m_0\). The expression \(\mu - \beta_0/m_0\) is large when the proliferation rate is large, the steady state out flux is small, and the steady state mass of urine in the bladder is high. We refer to this as the abnormal situation. It is characterized by substantial proliferation of bacteria, too little urination, and/or substantial average presence of urine in the bladder. The individual subject to this abnormal condition typically urinates frequently, but experiences limited success in doing so. This means that the mass of urine in the bladder gets moderately reduced with high frequency, with intervening buildup of mass between each urination.

As a characteristic of the abnormal situation it is easy to show mathematically that when \(\mu - \beta_0/m_0 > 0\), the equilibrium \(N_{\text{eq}} = 0\) is unstable. Thus a small perturbation out of this equilibrium causes the number \(N\) of bacteria to move up to the second and potentially more detrimental equilibrium concentration \(C_{\text{eq}} = (\mu - \beta_0/m_0)/v\). This second equilibrium is always stable. Thus every solution will move towards this second equilibrium when \(\mu - \beta_0/m_0 > 0\). This equilibrium could in principle be too high to be accepted by the organism. That is, the second equilibrium solution for the number of bacteria per kg in the bladder can be above the tolerance level for the individual. Such a high concentration of bacteria may cause infection and sickness in the abnormal situation.
Let us contrast this with the normal situation where \( \mu - \beta_0/m_0 < 0 \). It is characterized by limited proliferation of bacteria, sufficient urination, and/or limited average presence of urine in the bladder. The individual subject to this normal condition typically urinates at lower and more normal frequency levels, and does so more successfully. This means that the mass of urine in the bladder gets virtually eliminated at normal frequency levels, of course with intervening buildup of mass between each urination. The average amount of urine mass in the bladder is of course positive, but it is smaller than for the abnormal situation due to the successful drainage. Eq. (5) implies that when \( \mu - \beta_0/m_0 \leq 0 \), only the equilibrium \( N_{eq} = 0 \) is possible. Furthermore, this equilibrium is stable when \( \mu - \beta_0/m_0 \leq 0 \). The organism is not infected by bacteria when \( N_{eq} = 0 \). Let us formulate this as a property.

**Property. The abnormal situation with a positive equilibrium concentration** \( C_{eq} = N_{eq}/m_0 = (\mu - \beta_0/m_0)/v \) of bacteria arises when \( \mu - \beta_0/m_0 > 0 \). The normal situation with a zero equilibrium concentration \( C_{eq} = 0 \) of bacteria, which means absence of bacteria \( N_{eq} = 0 \), arises when \( \mu - \beta_0/m_0 \leq 0 \).

Let us use this property to formulate a clinical rule or objective.

**Clinical rule.** For the abnormal situation where \( \mu - \beta_0/m_0 > 0 \), achieve a transition to the normal situation where \( (\mu - \beta_0/m_0) \leq 0 \).

The objective in this rule can be achieved in three different manners related to adjusting the three parameters \( \mu, \beta_0, m_0 \).

1. Try to achieve that the proliferation rate of bacteria in the bladder is as small as possible. This corresponds to achieving small values of \( \mu \).
2. Try to achieve that the out flux of urine from the bladder is substantial. This corresponds to achieving large values of \( \beta_0 \).
3. Try to achieve that the mass of urine in the bladder is as small as possible. This corresponds to achieving small values of \( m_0 \).

Regarding point 1, proliferation of bacteria in the bladder can be expected to depend on a variety of factors, such as the pH level of the urine, the chemical composition of substances in the bladder, the pressure within the bladder, and the temperature of the urine. A close scrutiny of these factors may lead to mechanisms to reduce \( \mu \). For example, the pH in the urine may be altered from normal values, or the chemical composition of substances in the bladder may be altered through drugs, nutrition, or altered physical activity patterns.

Point 2 can be achieved by substantial drinking. There is obviously an upper limit for how much an individual can drink. Although this limit is flexible, unusually much drinking can have negative health consequences. For example, it may thin out the blood, drain needed minerals and other substances from the body, alter the pH level in the body, and cause undue pressure on vital organs. Some of these negative consequences can be compensated for, such as drinking fluids with suitable nutrients and pH level, but all the consequences cannot be compensated for.

Point 3 can be achieved by frequent urination, and attempts of successful drainage which may possibly be affected by drugs and other means. For example, tea is known to facilitate drainage. The composition of the nutrients consumed by the individual, and the surrounding temperature, pressure, humidity, and other factors may also affect drainage in manners that can be investigated.

Observe the sense in which points 2 and 3 pull in opposite directions. Increasing the amount of drinking is a double-edged sword. On the one hand it increases the out flux of urine from the bladder. But on the other hand it increases the average mass of urine in the bladder, unless the frequency of urination is increased to compensate. Relating to point 1, substantial drinking causes a substantial amount of bacteria to leave the organism. If the rate by which bacteria leave the organism is large compared with the proliferation rate of newly generated bacteria, such substantial drinking is beneficial.

Consider the steady state situation where the mass of the urine in the bladder is on the average some constant value \( m_0 \). Also assume that the out flux of urine is approximately on the average \( \beta_0 \). This gives the critical threshold parameter \( \mu - \beta_0/m_0 \) analyzed above. If the average mass of urine in the bladder increases to a new value, say \( m_0' \), for some reason, the out flux of urine in the bladder should increase to the value \( \beta_0' = \beta_0(m_0'/m_0) \) if the same critical threshold parameter is to remain the same. That is, an increase (or decrease) in \( m_0 \) should be compensated with an equal increase (or decrease) in \( \beta_0 \) to ensure the same threshold.

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3 One of the authors is familiar with one case where a female high school graduate drank too much water during her graduation celebration days where awards are given for challenging behavior of various kinds. Although water has the neutral pH value 7, her unusually high water consumption on this one occasion altered the overall pH level in her body, causing epilepsy from which she suffered for at least four years after the incident, and likely still suffers due to the apparent permanency of the affliction.
For both the normal and the abnormal situation the necessity of urination usually kicks in for a specific mass of urine in the bladder. During the normal situation the bladder is drained completely, or virtually completely. Thus on the average the normal steady state value for the average mass of urine in the bladder is lower than the abnormal steady state. Roughly one half is a good estimate. Thus one could say that, during the condition of an enlarged prostate, the individual is on the threshold of feeling the necessity of urination almost all the time, the mass of urine in the bladder is on the average roughly a factor of two larger than in the normal situation. Roughly one half is a good estimate. Thus one could say that, during the condition of an enlarged prostate, the individual is on the threshold of feeling the necessity of urination almost all the time, the mass of urine in the bladder is on the average roughly a factor of two larger than in the normal situation. Roughly one half is a good estimate.

Parameter estimation

Let us estimate some numerical values of the parameters. The amount of urine in the bladder is around 0.4 kg when the necessity of urination kicks in. The amount of urine leaving the bladder during a day is around 1.5 kg for an average male adult. Assuming that individuals at the threshold of feeling the necessity of urination almost all the time, also are at the threshold of being infected by bacteria, gives that

\[ m_0 = 0.4 \text{ kg}, \quad \beta_0 = 1.5 \text{ kg/day} \]

\[ \mu - \beta_0/m_0 = 0 \Rightarrow \mu = \beta_0/m_0 = 3.75/\text{day} \]  

Thus we have found a numerical value of the bacteria proliferation parameter \( \mu \).

In addition experiments indicate that the concentration of bacteria in the bladder can be as high as \( 10^8 \) per kg during sickness. Assuming this value to be an equilibrium when \( \beta_0 \approx 0 \) (closed bladder), gives that

\[ N_{eq}/m_0 = 10^8/\text{kg} = \mu/\nu \Rightarrow \nu = \mu/10^8/\text{kg} \]

\[ = 3.75 \times 10^{-8} \text{ kg/day} \]  

Thus we have found a numerical value for the last parameter. Figs. 1 and 2 show the equilibrium concentration plotted as a function of the out flux from the bladder and plotted as a function of the average mass of urine in the bladder using our parameters.

Simulations

In the last section we showed some analytical results and found some threshold criterion. In this section we will use the model to simulate numerically more advanced studies of the phenomena.
For the in and out flux from the bladder we apply the following model

\[ a = a_0 = \text{const.} \]

\[ \beta(t) = (0.1 \text{ kg/s})B, \quad \text{if} \quad m \geq m_M, \quad B = 1, \quad B = B \]

\[ \text{if} \quad m < a m_M, \quad B = 0, \quad B = B \]

\[ m_M = \begin{cases} 0.4 \text{ kg, normal} \\ 0.5 \text{ kg, abnormal} \end{cases}, \quad a = \begin{cases} 0.01 \text{ normal} \\ 0.7 \text{ abnormal} \end{cases} \]

(9)

The if statement is of the form If (x, then y, else z) in Eq. (9). \( B \) is a closing parameter. \( B = 0 \) gives that the bladder is closed for out flux. \( B = 1 \) gives that the bladder is open for out flux.

The If-notation means that the equation after the first comma applies if the condition is satisfied, while the equation after the second comma applies if the condition is not satisfied.

**Fig. 3** shows the mass of urine in the bladder for the normal situation. The bladder drains with 99%, that is \( a = 0.01 \). We observe the cyclic behavior of the mass in the bladder, almost down to zero mass due to successful urination. During the normal situation the exponential growth of urine in the bladder is lower than the out flux. Assuming a substantial initial presence of bacteria, \( N = 100 \), at time \( t = 0 \) (which may be exogenously imposed or due to prior infection), the number of bacteria first increases to around \( N = 280 \) as the mass in the bladder increases. At the first urination the bacteria are simply flushed out, never to emerge again, causing \( N = 0 \). This is seen in **Fig. 4**.

During the abnormal situation the bladder only drains with 30%, that is \( a = 0.7 \). This scenario is seen in **Fig. 5**, with more frequent urination. Cyclic behavior of the mass in the bladder is preserved, but substantially less successful urination causes the mass in the bladder never to fall below a threshold substantially above zero.

**Figure 3** Normal situation: The mass \( m \) of urine in the bladder in kg as a function of time \( t \) in days. \( \mu = 3.75/\text{day}, \ \nu = 3.75 \times 10^{-6} \text{ kg/day}, \ m_M = 0.4 \text{ kg}, \ a = 0.01 \).

**Figure 4** Normal situation: The number \( N \) of bacteria in the bladder as a function of time \( t \) in days. \( \mu = 3.75/\text{day}, \ \nu = 3.75 \times 10^{-6} \text{ kg/day}, \ m_M = 0.4 \text{ kg}, \ a = 0.01 \).

**Figure 5** Abnormal situation: The mass \( m \) of urine in the bladder in kg as a function of time \( t \) in days. \( \mu = 3.75/\text{day}, \ \nu = 3.75 \times 10^{-6} \text{ kg/day}, \ m_M = 0.5 \text{ kg}, \ a = 0.7, \ N(0) = 100, \ m(0) = 0.001 \text{ kg} \).

**Figure 6** Abnormal situation: The number \( N \) of bacteria in the bladder as a function of time \( t \) in days. \( \mu = 3.75/\text{day}, \ \nu = 3.75 \times 10^{-6} \text{ kg/day}, \ m_M = 0.5 \text{ kg}, \ a = 0.7, \ N(0) = 100, \ m(0) = 0.001 \text{ kg} \).
This considerable presence of mass in the bladder allows the number $N$ of bacteria in the bladder to proliferate. This is seen in Fig. 6. The number of bacteria oscillates due to repeated urination, but on average $N$ increases with detrimental impact on the male adult subject to the abnormal situation.

The solution of the equation set is very dependent on the numerical values of the parameters.

**Suggestions for how to test the model**

Future research may test the model. Tests may either be conducted on human males, or on other suitable humanoids, primates, and mammals. Testing on non-humans to some extent allows exposure to a larger range of techniques, and the application of healthy control groups. Typical steps are in vitro research, animal research, clinical research on chosen populations, and clinical research on large groups to ensure validity and generality, with double-sided blind testing.

Let us think about testing in the following manner. A population of individuals of varying age, race, fitness, and other differences is placed under scrutiny. For each male the parameters in the model are determined empirically. The amount of bacteria in the bladder is determined by analyzing the content of the urine. The amount of mass in the bladder before and after urination is determined by various techniques, such as measuring the mass of urine leaving the bladder during urination, or applying photographic imaging. Once all the parameters in the model have been determined for each individual, the figures presented in this article for the variables can be generated which constitutes the profile for each individual. The individuals are then placed into categories with similar individuals grouped together. Various treatment techniques, e.g. photographic imaging techniques, can then be proposed for each group of individuals.

One possibility is as follows: Select $M$ individuals with various kinds of prostate condition. Divide the individuals into $N$ groups dependent on similarities in the prostate condition. Each group $i$ thus consists of $M_i$ members with similar prostate conditions, where $M_1 + M_2 + \ldots + M_N = M$. Assume that $X_i$ different treatments seem appropriate for each group with $M_i$ members, where $X_i \subseteq X$, and $X$ is the set of all possible treatments for prostate conditions. This means that a given treatment may well be suitable for several groups. That is, the characteristics of each group is analyzed, earlier praxis, experience, and know how are applied, and $X_i$ treatments are chosen for the $M_i$ members. The $X_i$ treatments are allocated on the $M_i$ members so that $M_i/X_i$ members (an integer value) receive each treatment. As the $X_i$ treatments progress in parallel on the $M_i$ individuals, new parameters are determined for each individual, and new profiles for each individuals are determined by analyzing the equations and plotting the figures for the various variables. Over time it can gradually be determined which of the $X_i$ treatments is most successful for each group of $M_i$ individuals. The model may thus lead to theory building for how to treat individuals with a prostate condition.

**Conclusion**

Urinary retention commonly leads to an increased infection rate and thus proliferation of bacteria. A mathematical dynamic model is constructed based on the theory of differential equations for the proliferation of bacteria in the urinary bladder (vesica urinary). The model accounts for how this proliferation is associated with varying amounts of mass of urine within the bladder. Parameters are estimated from published data and we present analytical and numerical results. The relationships between the proliferation of bacteria within the bladder and the type of urinal out flux from the bladder are examined. Despite its simplicity we show that the model can provide realistic predictions.

In the normal situation the bladder is usually drained around 99% at appropriate time intervals, which drains most or all bacteria. Simulations show how the amount of bacteria may decrease to zero despite initial presence of bacteria, and despite repeated buildup and drainage of urine mass in the bladder. In the abnormal situation the bladder drains substantially less, perhaps with only 30%. Despite frequent urination, substantial urine mass in the bladder allows bacteria to proliferate, and actually increase through time in an oscillating manner.

The simulations are very dependent on the numerical values of the parameters which depend on the prostate condition of the male adult under scrutiny. By determining the parameters for a given male, the dynamic model can be used as a powerful tool by which the proliferation of bacteria in the bladder can be studied and controlled by different means. Suggestions for how to test the model are briefly presented.

The article presents three clinical advices expressed as objectives that can be obtained through adjusting three essential parameters in the model. First, try to achieve that the proliferation rate of
bacteria in the bladder is as small as possible, e.g. through altering the pH or chemical composition within the bladder. Second, try to achieve that the out flux of urine from the bladder is substantial, through sufficient drinking. Third, try to achieve that the mass of urine in the bladder is as small as possible, through sufficient urination. For a given male the model can be used to determine his intrinsic parameters in order to pinpoint the actual out flux during a day necessary to keep the number of bacteria in the bladder low.

References

[12] wikipedia.com; urinary tract infection.

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