Renal Stone Model
System Dynamics Approach

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Abstract

A clearly defined etiology for urinary calculi has not yet been established. In this paper, a primary System Dynamics model is presented to a better understanding the process of renal stone formation. The paper attempts to explain why in most patients who have recurrent formation of calculi, urinary excretion of calcium is normal, and why can not be over emphasized on hydration in the prevention of urinary calculi.

Introduction

Natural systems are made up of the organization of particles whose interactions determine the properties and behavior of the system. Human mind with all its wonderful powers can only assemble a few of numerous relations which exists between the parts of a complex system, simultaneously. System Dynamics is a method for simulating the behavior of the system using control theory and computer.

Up to now System Dynamics has been applied to several biomedical problems (Brush 1985, Foster 1971). In this paper, a simple System Dynamics model is presented to analyze the formation process of renal stone. The paper is divided into five sections. The first section sets the dynamic problem, the second one presents the construction of the model, response to treatment are analyzed at several point in section three, finally, the conclusion comes in section four.

Dynamic Problem

The history of renal calculus returns back to almost 7000 years ago. It is a very common global problem. The patient with renal calculi have been faced with broad spectrum of complications.

Many attempts have been made to establish the etiology of this condition but the mechanism of the calculus formation and development remains obscure. It is obvious that there are many factors which are involved in the formation of calculi. But probably the complicated effects of these factors together in a biological environment make the proper diagnosis of this problem more difficult. Here are a summary of some important theoretical points in the calculus formation in the urinary system which include:

1-Saturation and super saturation of some of substance in the urine eventually cause the precipitation crystals.

2-Presence of certain factors in the urine which probably can play important roles in stone formation.

3-Loss of substances in urine with inhibiting effects on stone formation.

4-Accumulation of different urinary crystal in the development of calculus.

5-The relationship of the time of the remaining primary nucleus or reduced rate of urine flow which can increase the chance of enlargement of the stone.

6-The urine PH which has an effect in dissolving or precipitating the minerals.

80 to 90 percent of urinary calculi contain some of calcium salts. Therefore the calcium is considered to be the major substance in the formation of urinary stone. The calcium metabolism in the human body depends on its intestinal absorption and renal excretion. There is also a relationship between the calcium metabolism and other factors such as endocrine glands, vitamins and bone metabolism. The urinary stone formation is also influenced by the amount water excretion by the kidneys which can either dilute or concentrate the urine.

Despite the complicated biological metabolism of the calcium and water in the human body, it can be started in the beginning in a simple model then the other physiological factors can be added to this model.

Model Construction

A simple dynamic model is presented to analyze the formation process of renal stone. The dynamic model is made up of three sections; Water, Calcium, and Stone. The water and calcium sections present their circulations in the body, while stone section describes the formation process of stone in the kidney. The dynamic behavior of the model is the result of interaction between these three sections. The response of the important variables to treatment at several points i.e.: different intensity levels, are simulated for a period of 48 hours.

A) The Water Section

Figure 1 shows the circular flow of water in the body. Let the amount of the intake water to be MW, in the model the beginning is from when it enter the assimilation part of digestive system. The assimilation is done in an hour (WA is the amount of water which is being assimilated). After assimilation, the amount of water in the body (W) increases, this increase results in the increase of the water excretion (TWL is the amount of water which is excreted). So there is a relationship between the amount of excreted water and the amount of water in the body. The water excretion decreases the water level.

Body losses water in three ways: From the kidneys, through the skin, from the lungs. Urine excretion is equivalent to its normal amount modified by the current water level, by a multiplier that summarize the renal response to blood volume. The water loss via the skin and lung is equivalent to their normal amount, modified by the current water level.

The necessary amount of water for the body is determined by considering equilibrium amount of water and a proportion of difference between the equilibrium amount of water and the amount of water in the body. It decreases with an increase in the water level. The necessary amount of water is taken within 3 hours.

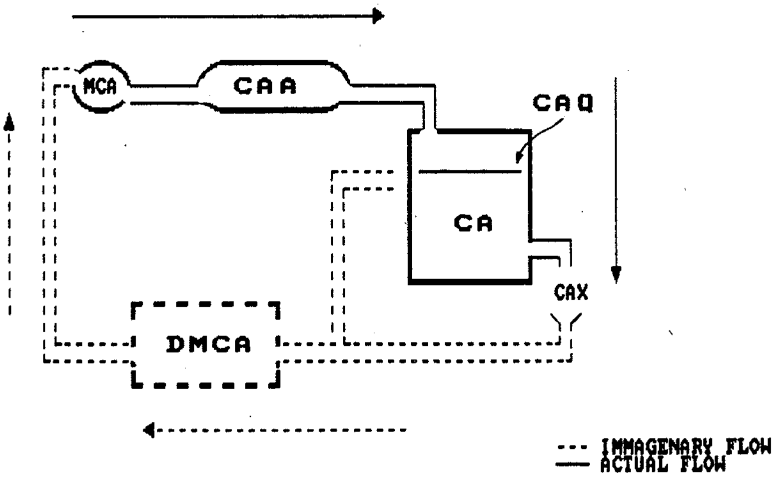


figure 2-a: Circular Flow of Calcium in Body

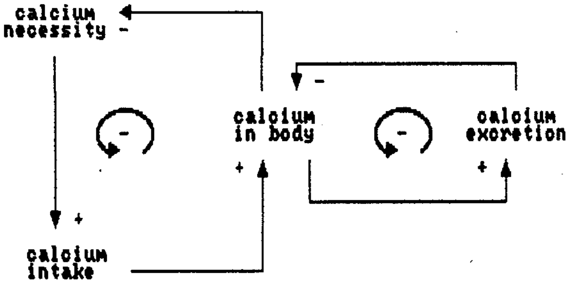


figure 2-b : Causal Loops of Calcium Circulation in Body

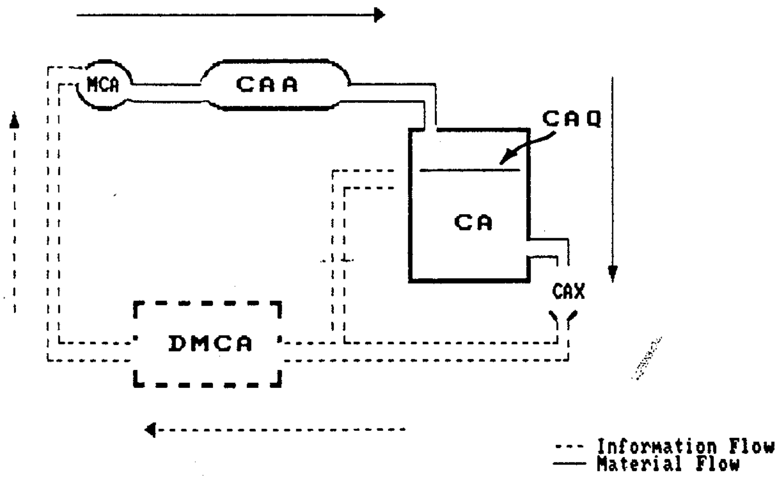


figure 2-a : Circular Flow of Calcium in Body

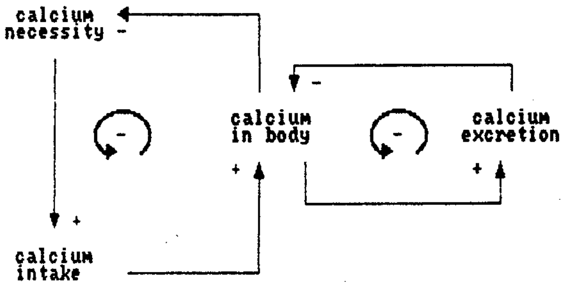


figure 2-b : Causal Loops of Calcium Circulation in Body

B) The Calcium Section

Figure 2 shows the circular flow of calcium in the body which is very similar to what was said about water. Assume the amount of calcium entered the body through the food intake to be MCA, again the beginning is the assimilation part of digestive system. Here the assimilation takes place in 4 hours (CAA is the amount of calcium which is being assimilated). After assimilation, the amount of calcium in the body (CA) increases and results in the increase of the calcium excretion (CAX). The rate of calcium excretion is equivalent to its normal amount and change with the current calcium level in the body, proportionally. The calcium excretion decreases the calcium level.

The necessary amount of calcium in the body (DMCA) is determined by considering the excreted amount of calcium and a proportion of deference between the equilibrium amount of calcium (CAQ) and the current amount of calcium in the body (CA). It decreases with an increase in the calcium level. The necessary amount of calcium is taken within 6 hours.

C) The Stone Section

By considering the amount of urine and the amount of the excreted calcium per unit of time, the urinary calcium is determined. Since 80 to 90 percent of renal stone contain some of calcium composition, the amount of calcium in the urine has an important effect on the formation of stone. When the urinary calcium is normal and there is no stone in the kidney, there will be no concretion either. The size of the stone is also an important factor in the continuance of the concretion. The calculus decreases the threshold level of the stone formation, it's because the existence of stone increases the chance of collision between the calcium particles. In order to decreases this chance the urinary calcium should be reduced. The threshold level of the stone formation is the amount calcium in the urine for which the probability of collision of the particles and calculus is so small that can be ignored. Thus, if the urinary calcium is equal to threshold level of stone formation the calcium particles will not join up and the stone will not be enlarged. Otherwise, the particles will be collide and join up and make the size of the stone larger and larger (Figure 3).

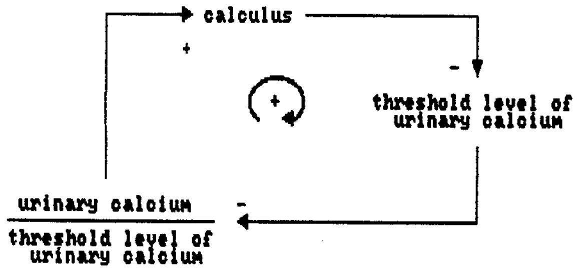


figure 3 : Causal loop of renal stone formation

Model behavior

The existence of the stone in the kidney reduces the threshold level of stone formation. The urinary calcium will be more than the threshold, if the calcium and urine excretion both stayed unchanged. As a result the collision of calcium particles with each other and with the stone will be more probable, and that results in the enlargement of the stone. The enlargement of the stone reduces the threshold to less than the former level, for a larger size of stone the more probable is the collision of the particles.

Assuming the amount of calcium in the urine to be relatively constant, a decrease in the threshold level results in an enlargement in the size of the stone. (See the curve "A" in figure 4).

Selection of the treatment

The amount of the calcium in the urine should be reduced in order to prevent the continuation of the enlargement of the stone. This can be done either by increasing the amount of the excreted urine per unit of time or by decreasing the amount of the excreted calcium per unit of time or both together.

"B" and "C" curves in figure 5 show the effect of 5 and 10 percent increase in water intake on the urine excretion. The drinking begins at time 0 and continues for 48 hours.

The "B" curve of figure 6 shows the effect of one percent decrease in calcium intake on the calcium excretion. This decrease at time 0 for 48 hours slowly decreases the amount of the excreted calcium.

The "B" curve in figure 7 shows the urinary calcium when the water intake is increased by 5 percent and the calcium intake is reduced by one percent. "C" shows the urinary calcium when there is an increase of 10 percent in the drinking water and a decrease of one percent in the calcium intake.

The "B" and "C" curves of figure 4 show the mass of the formed stone in the same interval when there is an increase of 5 percent and an increase of 10 percent in the drinking water and decrease of one percent in the calcium intake.

As can be seen in figure 4, the formation of stone may be slowed down by increasing the drinking amount of water intense so that the curve of the formed mass of stone is shifted from "A" to "B" and form "B" to "C" within 48 hours.

The formation of the stone can further be slowed down by an additional increase in the amount of water along with an additional decrease in the amount of calcium.

"D" and "E" curves in figure 5 show the effect of an increase of 20 percent and an increase of 40 percent in the drinking water on the urine excretion. As the graph shows the increase of the drinking water causes an oscillation in the excreted amount of urine. The reason for this oscillation, is that both the capacity of the urine excretory system and body's ability to keep more than equilibrium amount of water for along time are limited.

The "C" curve of figure 6 shows the effect of a decrease of 5 percent in the taking calcium on the calcium excretion. The decrease in the taking calcium causes a smooth oscillation in the calcium excretion. The reason is that the body's ability to cope with an amount of calcium less than equilibrium amount is limited.

The "D" and "E" curves in figure 7 show the urinary calcium when there is an increase of 20 percent and an increase of 40 percent in the drinking water along with a decrease of 5 percent in the taking calcium.

Figure 4:

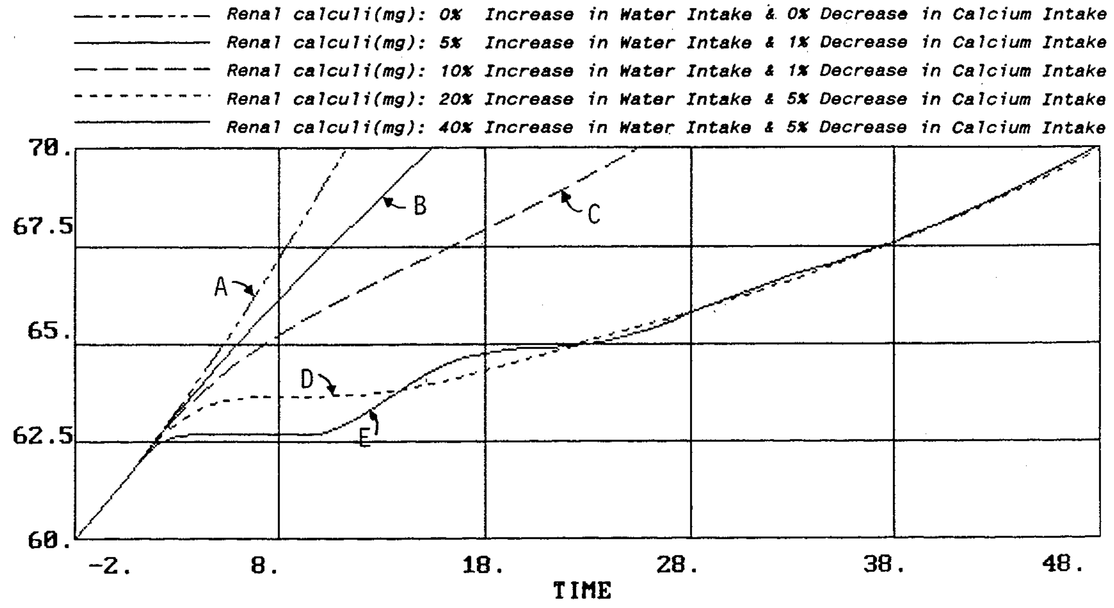


Figure 5:

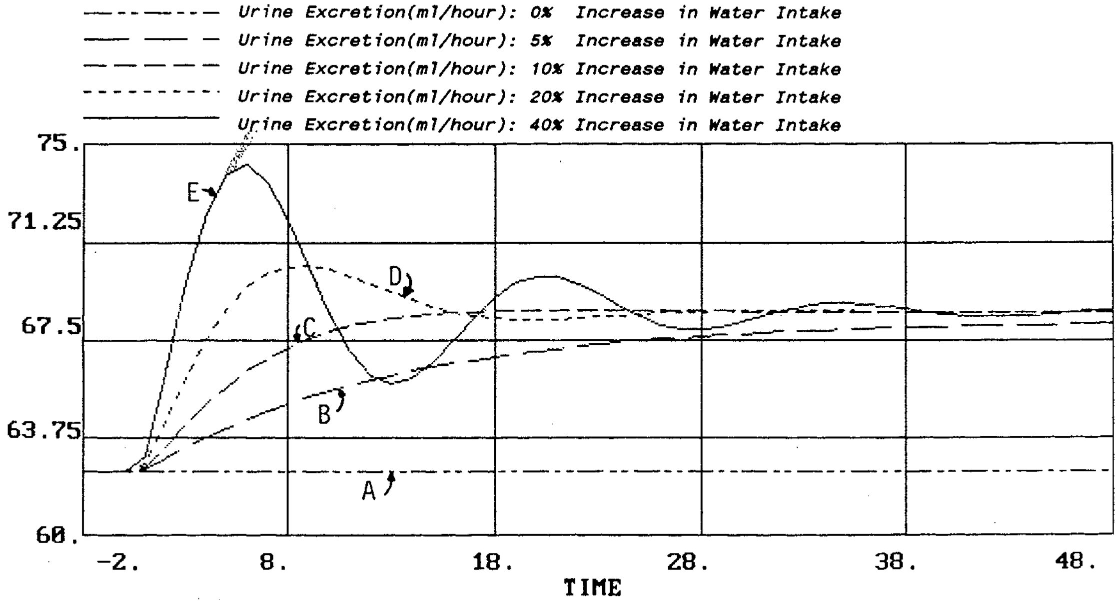


Figure 6:

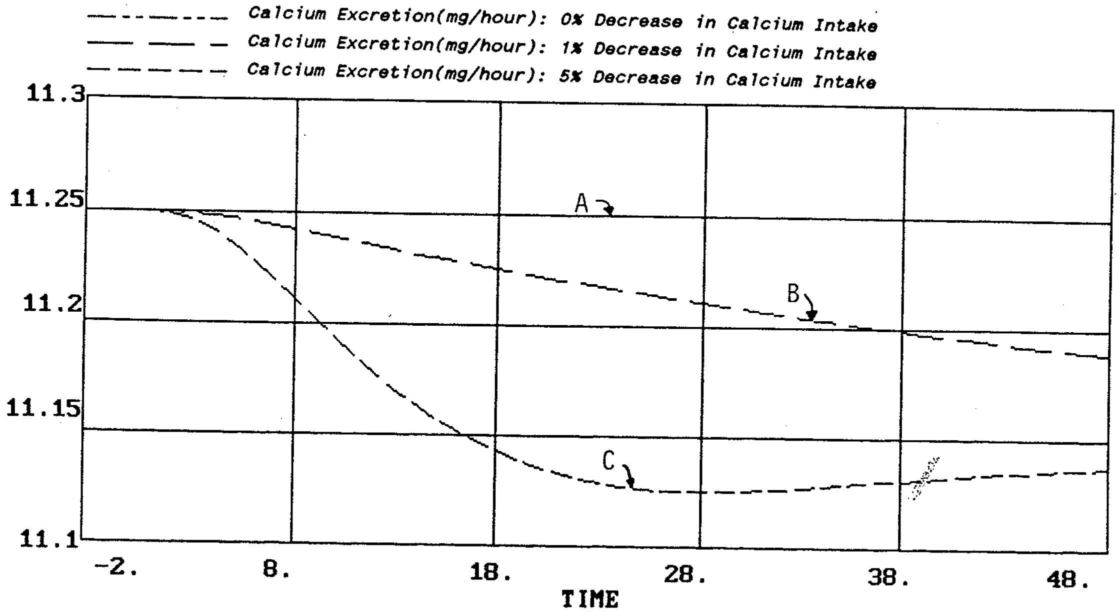


Figure 7:

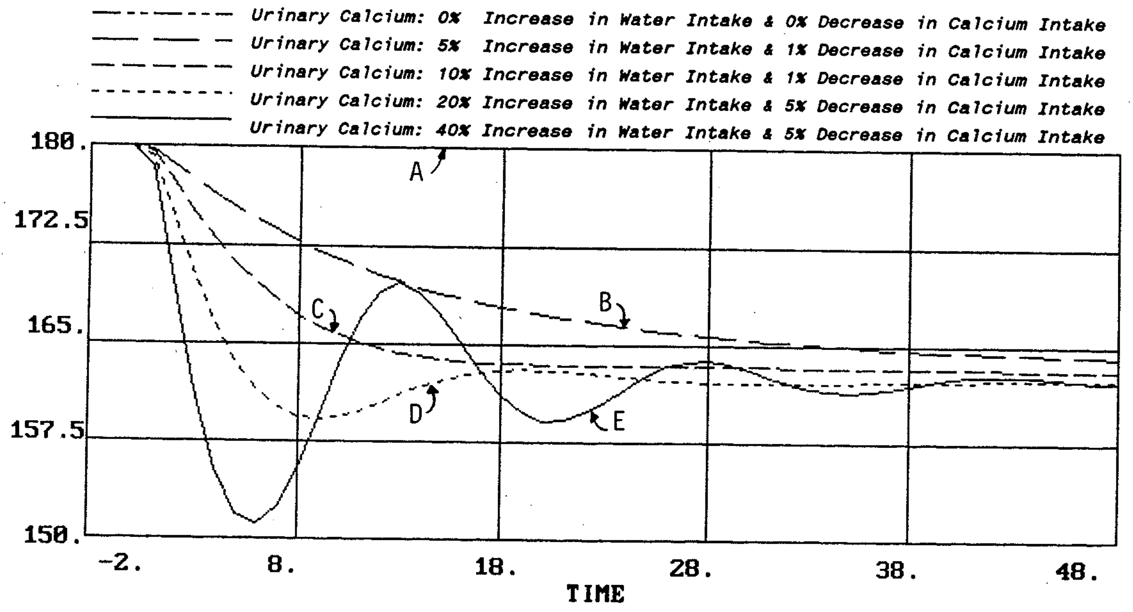


Figure 8:

10% Increase in Water Intake & 0% Decrease in Calcium Intake

—- - —- - — Renal calculi(mg): Adjustment Time of Water Intake = 1

———— Renal calculi(mg): Adjustment Time of Water Intake = 3 (Normal)

— — — — - Renal calculi(mg): Adjustment Time of Water Intake = 6

40% Increase in Water Intake & 5% Decrease in Calcium Intake

— - — - — Renal calculi(mg): Adjustment Time of Water Intake = 1

———— Renal calculi(mg): Adjustment Time of Water Intake = 3 (Normal)

- - - - - - Renal calculi(mg): Adjustment Time of Water Intake = 6

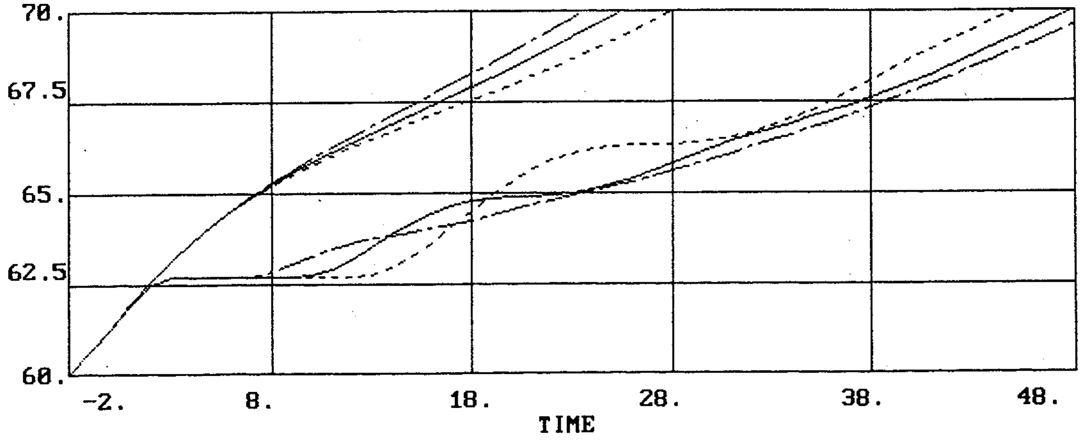


Figure 9:

10% Increase in Water Intake & 0% Decrease in Calcium Intake

— - — - — Urine Excretion(ml/h): Adjustment Time of Water Intake = 1

———— Urine Excretion(ml/h): Adjustment Time of Water Intake = 3 (Normal)

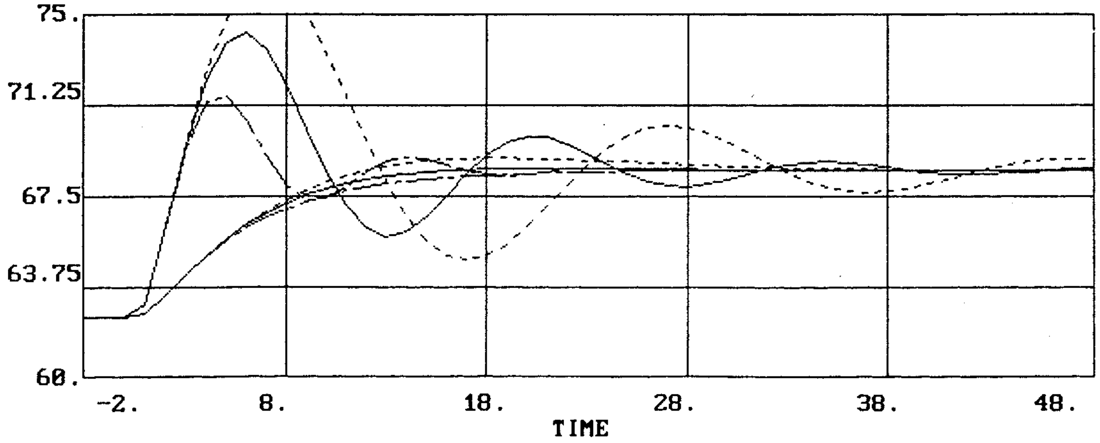
— — — — - Urine Excretion(ml/h): Adjustment Time of Water Intake = 6

40% Increase in Water Intake & 5% Decrease in Calcium Intake

— - — - — Urine Excretion(ml/h): Adjustment Time of Water Intake = 1

———— Urine Excretion(ml/h): Adjustment Time of Water Intake = 3 (Normal)

- - - - - - Urine Excretion(ml/h): Adjustment Time of Water Intake = 6



The "D" and "E" curves in figure 4 show the mass of the formed stone in each of those conditions. The rate of concretion aggravates when there is a decrease in the urine excretion.

When the increase in the water taken is accompanied with a decrease in the adjustment time, the amplitude of the oscillation in urine excretion will decrease and that will make the rate of concretion slower (See figures 8 and 9).

Conclusion

A preliminary model has been developed to analyze the formation process of renal stone. Given its structure, the model gives reasonable response to multiple external input, as treatment, including different maintenance amount of calcium and water.

The model shows, when the taking of water increases drastically the excreted amount of urine oscillates. It may aggravate the rate of concretion. The reason for this oscillation in urine excretion is that both the capacity of the urine excretory system and the body's ability to keep more than equilibrium amount of water for a long period of time are limited. Shortening the drinking intervals will decrease amplitude of oscillation in urine excretion and will cause slower rate of concretion.

The model also show, how concretion in the sufferer of renal stone may continue even though the amount of calcium in their urine is less than its amount in the urine of normal people. The calculus decrease the threshold level of stone formation. It's because the existence of stone increases the chance of collision between the calcium particles. The enlargement of stone will continue because the amount of calcium in the suffere's urine is still more than its threshold level.

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