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# Traumatic Kidney Rupture in Hydronephrosis

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Summary. The hydrostatic pressure, intrapelvic volume, and specific elasticity and strength of strips of tissue from the parenchyma and the pelvis of eight hydronephrotic kidneys were investigated and compared with the tissue characteristics of the pelvis of four control kidneys. Hydronephrosis manifested itself by a sixfold reduction of tissue strength, and dynamically by a ninefold reduction of the energy absorptive capacity of the parenchyma as compared with the pelvis. Its further response to trauma appeared to be influenced by internal pressure, the law of mass variation, and the energy absorptive capacity of surrounding anatomical structures. The vulnerability of the hydronephrotic kidney in situ depends on its volume and topography, the parenchyma being the part that may be regarded as the site most predisposed to rupture.

Key words: Hydronephrotic kidneys, mechanical load capacity, kidney rupture.

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## Introduction

The increased vulnerability of the hydronephrotic kidney as compared with the normal kidney is a known fact; even a minor trauma can result in injuries of some consequence.

The object of the present investigation is to examine the tissue characteristics of eight hydronephrotic kidneys and to compare them with four control kidneys. The results of the measurements are expected to provide indications as to the properties of various kidney tissues in regard to static and dynamic loads.

## Specimens and Method

All eight hydronephrotic kidneys were in the third stage of irreversible, aseptic hydronephrosis (3) or histopathologically in the stage of collagenic fibrosis (1).

The following investigations were carried out:

Measurement during surgery of the hydrostatic internal pressure. Exposure of the kidney, transparenchymal or pelvic puncture with a Braun syringe (No. 2). Measurement of the internal pressure with a Braun venotonometer calibrated prior to the operation (cm wc = centimeter water column).

Postoperative determination of the intrapelvic volume of fluid. Following nephrectomy, complete emptying of the kidney by means of an aspiration syringe and subsequent filling with physiological saline solution (ml).

Measurement of elasticity and strength of the wall of the hydronephrotic kidney. Two strips of tissue 1-5 mm wide and of random length were taken from both the parenchyma and pelvis of each specimen (parenchymal mean thickness 2.5 mm; pelvic mean thickness 1.1 mm). The physical characteristics of a total of 32 samples were examined. Each strip of tissue was clamped between two pairs of pressure plates of a measuring device and subjected to an increasing load until it broke transversely. Thus it was possible to test both the specific elasticity ( $\varepsilon$ ) and the specific strength ( $\sigma$ ) of the tissue as well as to determine the quantity of the specific breaking stress.

The specific elasticity ( $\varepsilon$ ) of each strip of tissue was calculated from the relation of the increase in length ( $\Delta$ ) to the total length of the strip (L) as follows:

$$\varepsilon = \frac{\Delta\ L}{L} \times 100\ (\%)$$

The specific strength of the tissue ( $\sigma$ ) was obtained from the weight (G) of the load at the moment of breaking and the cross section (thickness times width = D x B = A) of the test strip as follows:

$$\sigma = \frac{G}{A} \quad \left(\frac{p}{mm^2}\right)$$

Comparative tests using the same methods were carried out on strips of tumour-free tissue strips from the pelvis (mean pelvic thickness 0.8 mm) of four hypernephroma kidneys as to their specific elasticity ( $\varepsilon$ ) and specific strength ( $\sigma$ ). Similar tests with tissue strips from the kidney parenchyma were not possible owing to the fact that no strips suitable for measurement could be obtained from undiscended normal parenchyma of tumor kidneys.

## Results

The mean hydrostatic pressure in eight hydronephrotic kidneys was 11 cm wc with a standard deviation (SD) of 6. The mean fluid volume was 311 ml.

The test of tissue characteristics showed, immediately before breaking, a specific elasticity ( $\varepsilon$ ) for the parenchyma of 19 % (SD = 3 %) and for the pelvis of 23 % (SD = 6 %), while the specific tissue strength ( $\sigma$ ) was found to be 90 p/mm$^2$ (SD = 17 p/mm$^2$) in the parenchyma and 480 p/mm$^2$ (SD = 65 p/mm$^2$) in the pelvis. The pelvic strips of the control kidneys showed a specific elasticity ( $\varepsilon$ ) of 37 % (SD = 8 %) while the specific tissue strength ( $\sigma$ ) was 405 p/mm$^2$ (SD = 75 p/mm$^2$) (Table 1, Figs. 1 and 2).

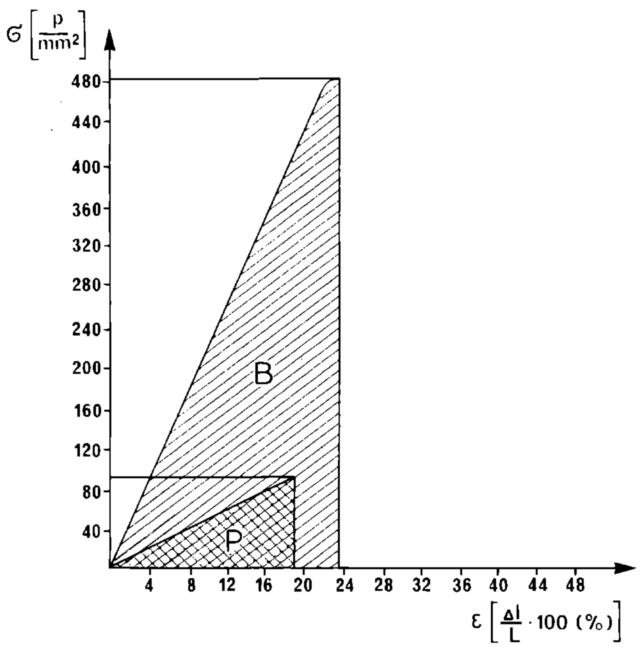


Fig. 1. Comparative stress-strain diagram of strips of tissue from the parenchyma (P) and the pelvis (B) of eight hydronephrotic kidneys: 1. Least wall stability in the parenchymal wall section. 2. High energy absorption capacity in the pelvic region (hatched area B as compared with crosshatched area P). $\sigma$ = specific strength of tissue, $\varepsilon$ = specific elasticity of tissue

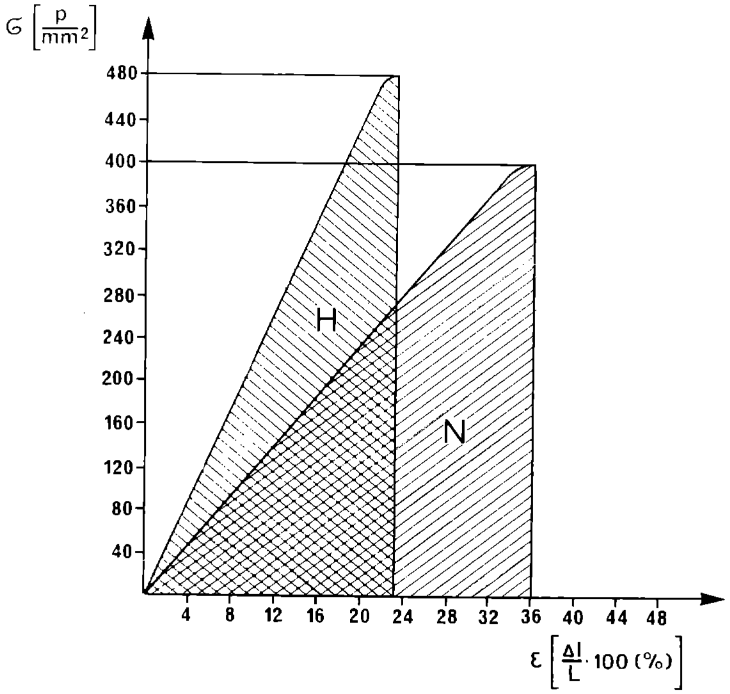


Fig. 2. Comparative stress-strain diagram of strips of tissue from the pelvis of eight hydronephrotic kidneys (H) and four control kidneys (N): In the pelvic region of the hydronephrotic kidney there is an increase of tissue strength accompanied by loss of tissue elasticity in comparison to the control kidney

Table 1. Results of the measurement of hydrostatic pressure (P) and intrapelvic volume (vol) as well as of the specific elasticity ( ε ) and specific strength ( σ ) of strips of tissue from the parenchyma and the pelvis of eight hydronephrotic kidneys and from the pelvis of four control kidneys

| | | 8 hydronephrotic kidneys | | | | 4 control kidneys | |
|---|---|---|---|---|---|---|---|
| | | Renal parenchyma | | Renal pelvis | | Renal pelvis | |
| | | M[a] | SD[b] | M | SD | M | SD |
| P | (cm wc) | 11 | 6 | 11 | 6 | - | - |
| Vol | (ml) | 311 | 170 | 311 | 170 | - | - |
| ε | (%) | 19 | 3 | 23 | 6 | 37 | 8 |
| σ | ($\frac{p}{mm^2}$) | 90 | 17 | 480 | 65 | 405 | 75 |

a Mean value
b Standard deviation

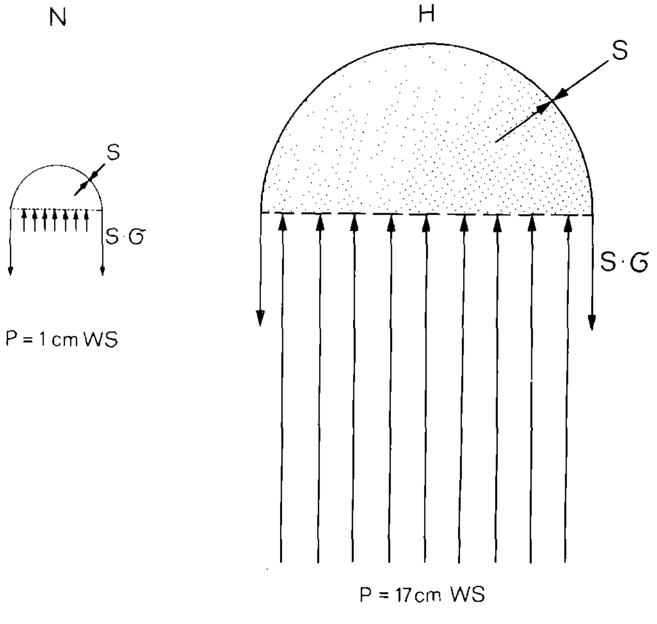
## Discussion

The development of hydronephrosis is accompanied in the pelvis by an increase of 20 per cent in tissue strength and a loss of more than 30 per cent of tissue elasticity, whereas the parenchyma, the tested strips of which were twice as thick, has six times less specific tissue strength ( σ ) and 25 per cent less specific tissue elasticity.

It thus follows that statically the least wall stability is to be expected in the parenchyma of the hydronephrotic kidney.

In contrast to the normal kidney the entire wall of the hydronephrotic organ is exposed to increased internal pressure as a result of the greater volume. This can be illustrated by a simple approximate calculation:

If we assume a volume of 5 ml for the control kidney and 450 ml for the hydronephrotic kidney, the diameter of the pelvis, idealized as a sphere, would be 2.13 and 9.5 centimetres respectively, the smaller being subjected to an internal pressure of 1 cm wc, the larger to one of 17 cm wc. If we consider that the compressive force integrated over a diametral plane must keep balance with the normal force distributed over the circumference of the pelvic wall, then the formula shown in Fig. 3 applies. If we now substitute the above values, we obtain for the normal force s x σ exerted on 1 centimetre of the circumference a value of 0.53 p/cm for the pelvis of the control kidney and a value of 40.3 p/cm for that of the hydro-



$$S \cdot \sigma \cdot \pi \cdot D = P \cdot \pi \frac{D^2}{4}$$

$$S\sigma = \frac{P \cdot D}{4}$$

Fig. 3. Influence of internal pressure (P) and volume (vol) on the static load of the pelvic walls of hydronephrotic (H) and control (N) kidneys: Increase of vulnerability dependent on internal pressure and volume. s x σ = normal force acting on 1 cm of the circumference, P = internal pressure (cm wc), D = diameter (cm)

nephrotic kidney. Since in both cases the pelvis has approximately the same wall thickness s, the specific loads correspond to these forces, i. e. are roughly in the ratio of 1 : 75.

In the parenchyma of the hydronephrotic kidney, too, the normal force s x $\sigma$ acts on every centimetre of the circumference. As, however, the wall thickness s of the parenchyma of the hydronephrotic kidney is roughly twice that of the pelvis, it follows that the specific load is only half that of the pelvis. The probability of a rupture, therefore, is primarily to be expected in the parenchyma, as here the breaking stress only amounts to about 14 per cent of that of the pelvis, and this difference by far exceeds the specific load.

Much more complicated than the static behaviour is the dynamic action of a blunt trauma on a hydronephrotic kidney. Decisive for its tendency to rupture is its behaviour at the moment of the blow. In other words, the occurrence or extent of an injury will depend on how much collision energy the tissue can absorb without tearing.

The energy absorption capacity of the parenchyma or the pelvis of the hydronephrotic kidney is proportional to the respective area B or P in the stress-strain diagram (Fig. 1). Here, too, the parenchyma proves to be clearly inferior to the pelvis. An estimation of the areas shows a ratio of approximately 1 : 9. A comparison between the pelvic tissue of the hydronephrotic and the control kidney reveals that owing to the lesser elasticity of pelvic tissue there is a slight decrease in energy absorption capacity in a ratio of 1 : 0. 92 in favour of the hydronephrotic kidney.

It must be assumed that in the case of equal blows the healthy kidney, due to its smaller size and more protected position, has to absorb considerably less collision energy. If a normal kidney weighing 120 grames and a hydronephrotic kidney weighing 600 grames were to fall to the ground then the relation of the energies would correspond to that of the masses, i. e. in this instance would have a ratio of 1 : 5. It must indeed be assumed that this ratio will shift to the further disadvantage of the hydronephrotic kidney, due to the simple fact that owing to its smaller size the normal kidney is in a better position to avoid the blow, and the surrounding structures (thorax, musculature of the back, adipose capsule) can absorb the collision energy, whereas a hydronephrotic kidney would more or less be subjected to the full force of the blow. For the hydronephrotic organ which has practically the same energy absorption capacity in the pelvis as the normal kidney, this means a much heavier dynamic load and a greater hazard in the case of trauma.

Thus, in case of direct or indirect trauma an injury is primarily to be expected in the parenchyma. Furthermore, volume and topography of the hydronephrotic and thus already damaged kidney are directly related to its vulnerability. These observations agree with Küster's (2) principle of the hydraulic compression occurring in the event of direct trauma as well as with the mechanism of the law of mass variation in case of indirect trauma as described by Rehbein (4).

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