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Electric Potentials in the Urological Cavity System and Parenchyma

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Summary. As in other hollow organs, there is a negative electric potential of about 10 - 30 millivolts in the cavity system of the human kidney compared with the interstitial spaces and the blood vessels. This can be demonstrated simply and without distress by means of a nephrostomy or ureteric catheter. Typical values were obtained under changing conditions including flushing with NaCl solution and particularly during furosemide diuresis with an increase in the negative potential of between 5 and 20 mV. Changes of intrapelvic or extrarenal pressure caused a slight increase of negative potential as well. In the presence of renal tumors with sufficient contact with the cavity system, a positive potential of between 5 and 40 mV was detected. An extension of diagnostic possibilities and perhaps indications and suggestions for future treatment can be expected.

Key words: Urological tumor potentials, electrophysiology, epithelial membranes, tubular epithelium electric potential

Electric potentials in hollow organs, corresponding to those of the limiting membranes of nerves and muscles have been known for some time. (1). In man, measurements have been made on the cornea, oral mucous membranes and salivary ducts, stomach, gallbladder, pancreas, intestine, vagina and rectum (3, 5, 6, 10, 11). In 1959 Kneuker (7) reported finding curves similar to the ECG, derived from the isolated rabbit kidney, which he denoted the electro-urogram. He also mentioned potentials within the cavity system without giving details.

The considerable negative potential, about 30 mV, in the lumen of the distal tubule and in the collecting tubule is a well defined part of present knowledge concerning renal physiology (6, 15, 16). Somewhat surprisingly, the use of the urological endoscope has been neglected in the measurement of potentials. Measurements of potentials in the renal pelvis were carried out in this instance over a period of 18 months, largely through a nephrostomy but also via a ureteric catheter and directly in the bladder (12). To some extent these gave typical and reproducible results, especially under the effect of furosemide and in the case of tumours.

Material and Methods

The measurements were made during the usual diagnostic and therapeutic procedures in hospital without causing the patient any further stress. Determination of the potential in the renal cavity was usually done through the liquid column of either the nephrostomy or ureteric catheter filled with draining urine or physiological NaCl solution. This catheter was connected to a non-polarising Ag-AgCl electrode by a Y-piece consisting of a silver wire 50 mm long, the front half of which was coated with molten silver chloride (7, 15).

The electrical resistance between the electrode and the renal pelvis when measured through a No. 14 nephrostomy catheter was approximately 50 000 ohms, through a No. 6 ureteric catheter 90 000 ohms and through a No. 5 ureteric catheter about 150 000 ohms. The reference electrode was fitted intravenously (i.v.) as a venous infusion was always in position. For this purpose, a plastic cannula fitted with an Ag-AgCl electrode was inserted into the rubber cuff of the flowing infusion. Thus a diffusion potential developed between the infusion needle filled with NaCl solution and the blood vessels, which, with this arrangement, appeared to be negligibly small and constant. As control, the potential of the sublingual mucous membrane was measured.

This was found to be a constant level of -15 mV, the same value as Knauf (9) established with a reference electrode lying in the subcutaneous tissue. Even after drawing blood into the electrode casing only a small change in potential of 3-4 mV was noted. After each test, the cavity electrode and the reference electrode were measured against each other to establish and correct for their individual potentials. The stability of the non-polarising electrodes was previously determined by comparative measurements in NaCl solution and urine for periods of up to 72 h. No alterations compared with the initial value were found (17). It was demmonstrated in each case that the Ag-AgCl was not damaged mechanically during the experiment and especially that the leads were free of air bubbles. The electrodes were sterilised by heating at 180°C for 60 min. The voltage measurements were made with an Ori transistorised millivoltmeter of 10^{12} ohm input resistance.

The diffusion potential developing at the junction of the urinary drainage catheter or ureteric catheter and the urine in the cavity system usually disappears when the cavity system, leads and electrodes are uniformly filled with the same solution. Otherwise the potential was determined by comparison at the end of the measurement and taken into account.

The flow potential appearing at the plastic tip of the electrode casing was also checked. Even during very rapid infusion or when rinsing the electrode case through the ventilation cannula, there was only a rise in potential of 2 to 3 mV, regarded as negligible. Therefore with normally flowing infusions, this has practically no effect on the values.

The experimental arrangement and the construction of the electrode is shown in Figs. 1 and 2.

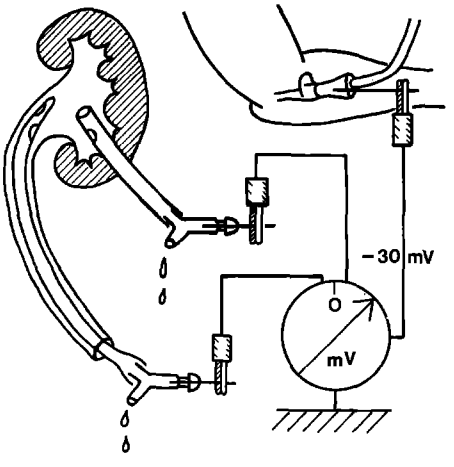

Fig. 1. Experimental arrangement. Nephrostomy catheter and ureteric catheter simultaneously in pyelon. Reference electrode in arm vein

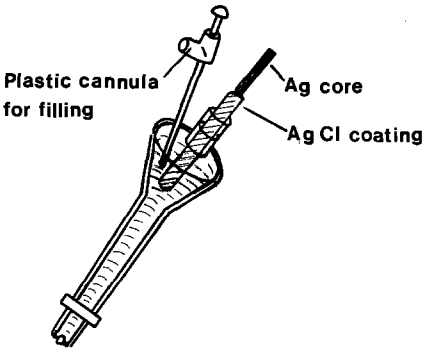

Fig. 2. Construction of electrode with Ag-AgCl electrode and plastic cannula for rinsing in rubber cuff of infusion with plastic cannula ("plextrocan", "braunula")

Altogether 31 series of measurements of potential were carried out in the urological cavity system in 27 patients. At first, these were in severely damaged kidneys with nephrostomy and ureterostomy, but later measurements were made in cases of pyeloplasty. Measurements were also made in the renal pelvis through a ureteric catheter and a few times through a ureteric catheter and nephrostomy simultaneously. Intraoperative values were determined with the electrode capsule lying directly in the ureter. Somewhat smaller values were found during measurement through the ureteric catheter than through the nephrostomy catheter, of the order of 2-3 mV less.

Results

The values in the cavity system lay between -6 and -87 mV, but in tumours, positive values up to +40 mV were recorded (Table 1). An increase in negative potential, nearly always occurred during rinsing and filling the cavity system with physiological NaCl, but this was relatively small in an approximately normal sized cavity system and normal

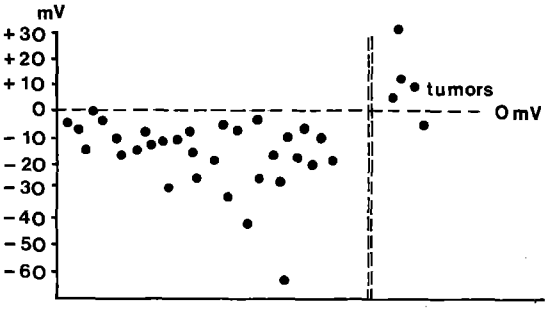

Table 1. Resting potentials in 37 series of measurements

sized papillae. It was, however, rather more marked in greatly enlarged cavity systems where there is considerable damage to, or loss of, parenchyma (Table 2). Moreover the magnitude of the changes in potential seemed to be dependent on the extent of the electrolyte shift caused by the rinsing, as Knauf also observed. This was especially true in relation to sodium and chloride

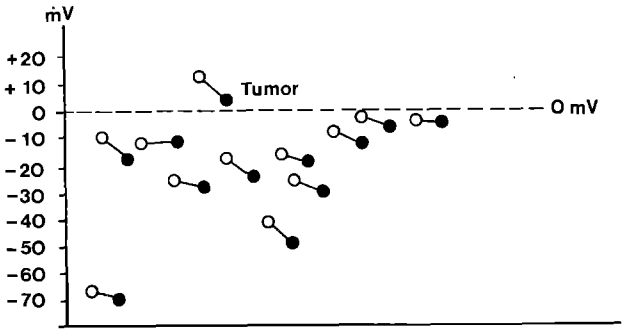

Table 2. Changes of electric potentials after flushing with 0. 9 % NaCl sol

ions but also to the anatomical features and condition of the epithelium which was sometimes altered by inflammation or scarring. It was also shown that during a rise in pressure in the cavity system e. g. when testing the drainage after pyeloplasty or in the gradual relief of long congested kidneys or in forced inspiration, a slight increase in negative potential was usually detectable. This was from -30 to -35 or -20 to -24 mV. In contrast to this, however, manual pressure on the kidney bed usually resulted in a slight fall in negative potential.

Measurements of potential were carried out on about half the patients before and during clinical perfusion and diuresis therapy, before and under the influence of furosemide (Lasix). A distinct increase in the negative potential always occurred after 10 mg furosemide were given intravenously. This was particularly marked when the tubular function was good and the cavity system relatively normal. It was always considerably more marked than the expected rise in value following the increase in sodium chloride content in comparison to the changes after filling with NaCl solution. Values were from -6 to -18 mV up to values of -65 to 87 mV. (Table 3). By chance, a positive potential was observed during the measurement of a single kidney with carcinoma of the renal pelvis and nephrostomy. This was constant in all the subsequent measurements, 6 in all. Values of up to 40 mV were obtained; these increased with the growth of the tumour until the cavity system was almost completely obstructed. From then on, as far as it was clinically possible, the potential was measured in all suitable kidney tumours. A positive potential

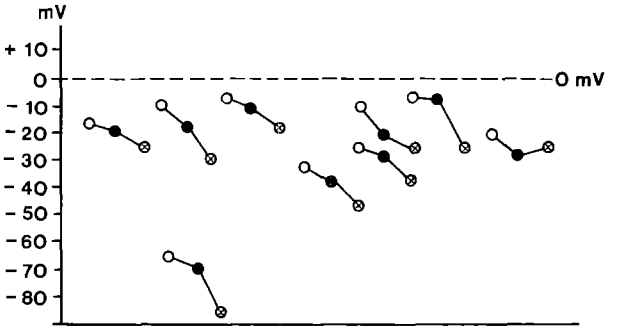

Table 3. Changes of potentials after flushing ● with 0. 9 % NaCl and during furosemide diuresis ⊗

was also found in the cavity system in 4 further cases, in each of which the tumour cells were in direct contact with the cavity system. Even in the parenchyma of the kidney affected with a tumour, the areas with tumour tissue showed a positive potential in contrast to the negative potential of the intact parenchyma both in situ and after extirpation.

Discussion

The relatively small number of cases investigated here under clinical conditions in which consideration for the patients was paramount and time was limited, does not yet enable a definitive statement to be made on the exact level and origin of the potential. This is especially so in comparison with the far more exact results of micropuncture (4, 16). Reference to this easy method of investigation and observation using urological techniques, without distress and risk for the patient, seemed to be of primary importance here.

It is not possible to define to what extent, if at all, the negative potential measured in the cavity system originates primarily from the epithelium of the cavity itself or from the papillae, collecting or distal tubules with an already confirmed negative potential. There is much to support this latter assumption in measurements of nearly normal anatomical and physiological conditions. In this context Grantham's results (4) may be mentioned. He established the existence of a considerable negative potential in the collecting tubules in the cortex of the rabbit kidney. It is unlikely that no transmission takes place through the channels in accordance with the cable law. In addition, the 100,000 collecting tubules and the millions of distal tubules of the normal kidney have a surface area many times that of the cavity system. This also explains why kidneys with enlarged cavity systems and severely damaged parenchyma showed smaller differences in potential under furosemide diuresis, in contrast to an increase in negative

potential after irrigation and filling with NaCl. There is much here to indicate that the distal and collecting tubules are a considerable source of the potential in the pyelon (renal pelvis). In addition, the changes in the potential seem to be dependent not only on the surface of the cavity system and the function of the parenchyma, but also on the electrolyte content of the urine produced during the investigation. It must also be borne in mind that the urine secreted under the influence of furosemide is in contact with a far greater surface of the cavity system, and especially of the collecting tubules and calyces, than the 0.9% NaCl solution introduced subsequently. Under clinical conditions, a mechanical separation, perhaps by interposition of a layer of oil or by strictly separate withdrawal from the papilla, is not possible with the often bizarre structure of most human kidneys. This could, however, still be explained by experiments on the uni-papillary kidney of the rabbit.

It is to be expected that indications for diagnosis of lesions of the renal parenchyma, for pharmacology and perhaps also for treatment will be provided by measurements of potential. The action of weak direct currents of suitable levels on the processes at the epithelial membrane is also conceivable, if it is considered that, contrarily, changes of electrolytes have an effect on potential differences.

The positive potentials found here from 9 series of measurements on 4 patients with renal tumours can be assessed as first indications only. Further systematic series of observations are absolutely essential and are already in progress. The cause of the positive or reduced negative potential could be based on the different metabolism of the tumour cells, or even on the greater content of metal ions in the tumour cells (14). Short circuits may also play a part (7). It must also be remembered that the positive potential of the tumour cells within the total cavity system can only be expressed in relation to the size and degree of contact. The positive potential must be higher than the negative potential of the collecting tubules and epithelium. Possibly the positive tumour potential could only be demonstrated in the calyx adjacent to the tumour. However, Schauble (13) found completely different values, notable increased negative potentials in the tumour. This can, however, be explained by the technique, because both the measuring electrode and the reference electrode were put into tissue preparations removed for pathological examination. In contrast to this, quite different membrane potentials occurred with the described method of measuring in living tissue and the introduction of the reference electrode into the lumen of the vein. This could explain the positive potentials measured in the kidney tumour tissues in contrast to the negative polarity found elsewhere in the functioning renal parenchyma. In view of the considerable difficulties in the diagnosis of renal tumours, especially those with poor vascularisation, in spite of the refined radiological methods, an additional pointer from the fairly simple measurement of potential would be valuable. Perhaps an intra-operative tumour differentiation, done rapidly by the measurement of potential, would also be of value.

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