Frequency gradient in the autorhythmicity of the pyeloureteral pacemaker system[1]

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Summary. The pacemaker properties of the various regions of isolated segments of the rabbit renal pelvis were examined. The results show that pacemaker frequency and waveform of contraction change significantly within the renal pelvis. The highest frequency was encountered at the fornix, while the ureteropelvic junction is lowest.

Direct visual[2] and functional[3,4] observations indicate that the region proximal to the pelviureteral junction is responsible for the generation of pyeloureteral contractions. The rhythmicity of these contractions is remarkably constant, both in vivo[5,6] and in vitro in both the unicalyceal and multicalyceal kidney[7,8]. In the present paper an examination is made of the frequency characteristics of the component parts within the renal pelvis. This examination is undertaken in order to establish whether renal pelvic smooth muscle is uniformly and spontaneously active or whether there is a spatial variation in the frequency and waveform of the mechanical contractility within the renal pelvis.

Materials and methods. Kidneys obtained from 13 female New Zealand rabbits weighing 3-5 kg were used. A dose of 10^3 heparin was given peritoneally prior to terminating the animals with CO_2. No other anesthesia was used. The kidneys were removed and immediately incised along the lateral border in a plane midway between the anterior and posterior surface from upper to lower poles. The renal pelvis was removed by careful dissection from the renal cortex and medulla. It was further incised longitudinally, thus creating a flat fan-shaped section of the pelvis. This section was cut into 4 segments 2 mm wide beginning at the fornix. To facilitate uniform and reproducible dissection of the tissue, a grid of graph paper was used to estimate the exact position of the section. The 4 strips thus obtained were marked A, B, C, D, as shown in the inset of figure 1. Each strip was then placed in an oxygenated chamber, 95% O_2 and 5% CO_2, containing modified Krebs solution at 38 °C. The composition of the solution was NaCl (136 mM), $CaCl_2$ (2 mM), KCl (2.8 mM), $MgCl_2$ (1 mm), $NaHCO^3$ (25 mm), and KH_2PO_4 (0.6 mm). Mechanical activity was recorded by attaching 1 end of the strip to a FTO3 Grass transducer and the other end was tied to a fixed hook. An initial resting tension of approximately 0.5 g was given on all tissue preparations. Simultaneous recording of all 4 strips was accomplished by a Brush 4000 recorder. An equilibration time of 30-90 min was allowed before frequency measurements were taken. The mean frequency of contraction was computed by measuring the number of identifiable waves over a fixed period of time.

Results and discussion. All regions within the renal pelvis are spontaneously active with the exception of the area adjoining the ureterovesical junction. The contrasting patterns of mechanical activity are shown in figure 1. From this illustration it is apparent that region D, which is closest to the fornix, has the highest contractile frequency, while C and B are progressively lower. In this particular preparation the ureteropelvic region is inactive despite the fact that the preparation was observed over a period of 4 h. Among the 13 pyeloureters studied, 10 showed no spontaneous activity in region A while 3 developed some activity. A summary of the fundamental frequency characteristics of the 4 regions studied is shown in the table. It is apparent from this table that there is a 2-5fold increase in the pacemaker frequency of isolated segments within the renal pelvis.

In addition to the frequency gradient of the individual pyeloureteral segments A, B, C, D, there is a variation in the characteristics of the waveform of the mechanical contraction. The contractile patterns recorded from area D closely approximate the sucrose gap measurements made

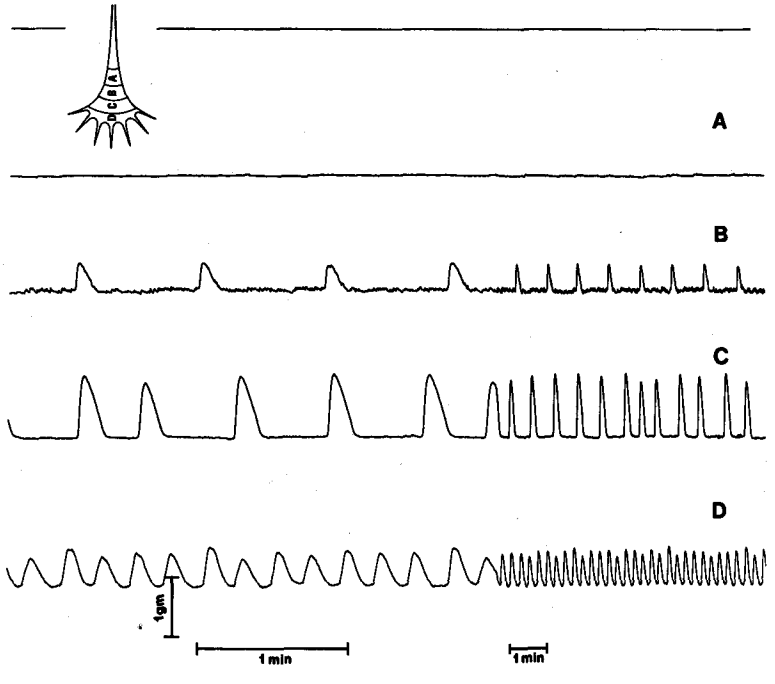

Fig. 1. Contrasting patterns of mechanical activity of intrarenal pelvic smooth muscle from 4 spatially consecutive segments. Region A is the segment closest to the junction between pelvis and ureter, while B, C and D constitute adjacent 2 mm wide bands, D being the most proximal to the fornix. In trace A there was no spontaneous contractile activity, while in B the frequency of contraction was approximately 0.1 H_z. Increasing frequency of contraction is shown in C and D, indicating a topological variation in the rate of spontaneous contraction within the renal pelvis. Trace D shows a characteristic pacemaker pattern, with the tension developing immediately after the falling phase of the previous contraction. Rapidly rising spike with little or no variation of tension between successive contractions are shown in C, B.

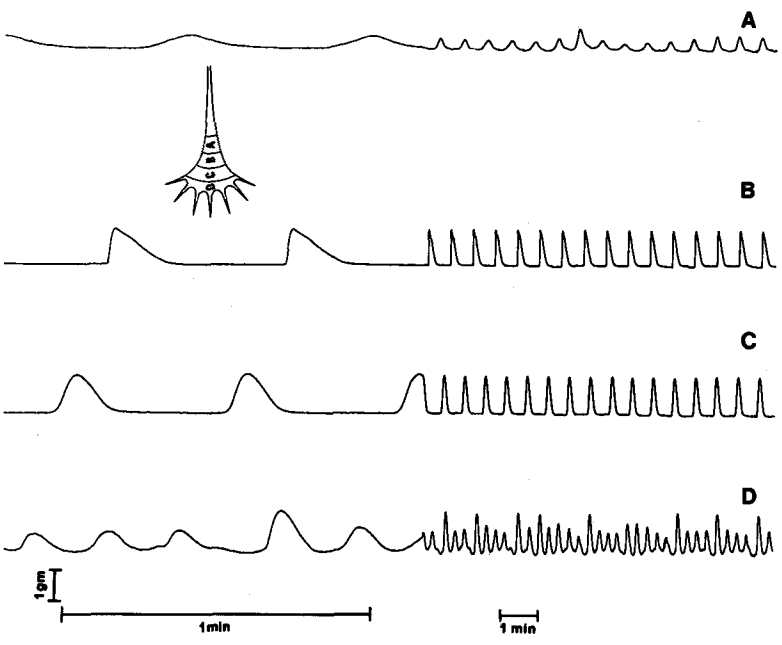

Fig. 2. Record showing the variation of spontaneous contractions of segments of renal pelvic smooth muscle. The existence of spontaneous activity at the ureteropelvic junction segment A, as well as in other segments, is illustrated.

Gradient in pacemaker rhythmicity of renal pelvic segments

Region	A	B	C	D
Rabbit No.				
1	0.0	0.024	0.031	0.072
2	0.0	0.056	0.063	0.077
3	0.0	0.026	0.030	0.094
4	0.0	0.036	0.060	0.074
5	0.029	0.030	0.031	0.064
6	0.023	0.040	0.056	0.068
7	0.0	0.025	0.041	0.068
8	0.0	0.023	0.040	0.058
9	0.0	0.035	0.051	0.080
10	0.034	0.036	0.056	0.076
11	0.0	0.050	0.054	0.078
12	0.0	0.034	0.054	0.075
13	0.0	0.053	0.080	0.095

Frequency is given in H_z.

by Zawalinski et al.[4] on the guinea-pig pyeloureter and are similar to those found in the SA node of the heart. In this context, the slow mechanical rise in tension observed in figure 1 (D) is analogous to the slow potential whose rate of rise increases leading to a spike. The records in figure 1 (B) and 1 (C) are similarly analogous to the microelectrode records of Golenhofen and Hannappel[3], demonstrating the gradual disappearance of the pacemaker potential, and the action potentials are characterized instead by a fast rate of rise. This degree of variability within the renal pelvis has not been demonstrated before, although it is known to exist in the gastrointestinal tract.

As shown in the table, 3 preparations - 5, 6, and 10 - originating from the ureteropelvic junction area show spontaneous contractility. In these segments the activity was recorded immediately upon suspension of the tissue on the transducers. The frequency and waveform characteristics from a renal pelvis showing spontaneous activity in all segments are shown in figure 2. Comparison of the 2 preparations shown in figures 1 and 2 illustrates the existence of a possible gradual variation of the characteristics of pacemaker cells in each segment demonstrated by Gosling and Dixon[9]. Thus, the waveform of figure 1 (C) corresponds more to that of figure 2 (B). The deviations in the shape of the contractile curve among these 2 illustrations possibly demonstrate variations in the precise location of the dissection in each pelvis, or spatial variability between different preparations. In addition, the irregular activity of segments obtained from regions A and D, shown in figure 2, could be due to either a number of pacemakers of slightly different fundamental frequency and/or phase. Observations made on preparations where segment D was further bisected show that the fundamental pacemaker frequency of contraction of each segment remains relatively constant, while the amplitude of contraction approaches a uniform sinusoid.

The results of this study demonstrate that the properties of the pyeloureteral smooth muscle are not only significantly different between renal pelvis and ureter[3-5,9], but also within the renal pelvis itself. These differences of intrapelvic variation have not been previously demonstrated. In an examination of the conduction velocities of various regions of the pyeloureter, Kobayashi[10] ignored the exploration of the intrapelvic structures, concentrating upon the calyx and ureter. The results of this study demonstrate that the transformation of activity between the slow waves of the uppermost segments of the calyceal system and the ureter is initiated within a few mm of the fornix.

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