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The prostatic urethra as a Venturi effect urine-jet pump to drain prostatic fluid

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ABSTRACT

Several experiments show that prostatic fluid is continuously produced and it is drained from the prostate during urination and ejaculation. The mechanism which causes prostatic fluid to drain from the prostatic acini during urination is currently unclear. Also in current opinion such structures of the prostatic urethra as the urethral crest and the colliculus seminalis have no apparent functional significance. This article describes a mechanism for the draining of the prostatic acini that involves these prostatic urethral structures. It is hypothesized that the prostatic urethra works as a pump using the Venturi effect, in which urine is the carrying or motive liquid during voiding, in order to drain prostatic fluid (the carried liquid) from the acini. The urethral crest and the colliculus seminalis take part in controlling flow rates and liquid pressures for this pump to be effective. The calculated estimation of a pressure drop in the region of the colliculus seminalis during micturition was obtained using morphometric and uroflowmetric data and was used to confirm this hypothesis of prostatic acini drainage. As a consequence of this, a previously unknown function for these intra-prostatic urethral structures is described.

Introduction

The prostate gland is a vital part of the male reproductive system. It produces and excretes much of the liquid portion of semen (about 30–35% of the semen ejaculate). The prostate mixes the fluid it produces with that from the seminal vesicles, which transport the sperm made in the testes. The composition of the prostatic fluid is vital for the well-being of the sperm cells after ejaculation.

The prostate is a gland surrounding the bladder neck and proximal urethra in the male. It has the shape of an approximately circular pyramid and lies on the pelvic musculofascial floor [1–3]. The base of this pyramid (which comprises the prostate gland) is connected to the bladder neck and the apex is surrounded inferiorly by the external sphincter, all surrounding the proximal (prostatic) urethra. These surrounding tissues comprise the main urinary continence mechanism in the male.

The prostatic urethra is the portion of the urethra that traverses the prostate. It originates in the region of the bladder neck and courses roughly 3 cm inferiorly. The posterior wall of the prostatic urethra contains the urethral crest. The most prominent aspect of this crest is the colliculus seminalis, or verumontanum (*veru*), where the paired ejaculatory ducts terminate at the lumen of the urethra. Current opinion concerning some structures within the prostatic urethra, such as the urethral crest and the colliculus seminalis, is that their functional significance is highly uncertain. In some publications it was suggested that the colliculus seminalis prevents oozing of semen from the seminal ducts and retrograde movement of semen during ejaculation. Other publications emphasized its role in the erectile mechanism and a possible contribution to the male orgasm. However none of these suggestions have been confirmed [4].

According to Deering et al. [5], the prostatic tissue contains three main components: glandular tissue, prostatic fluid, and fibromuscular tissue or stroma. Glandular tissue includes 25–30 small glandular units (acini) located in the periphery of the prostate. Each acinus is connected to the outside world by a tiny duct which opens into the urethra on both sides in proximity to the lower edge of the veru and under it. It should be noted, that there is no explanation why the mouths of the acinar ducts are mainly located in this region of the prostatic urethra. Prostatic fluid fills the lumina of the acini (glandular lumen). Epithelial cells surround the periphery of the acini and the luminal surfaces in the acini. Stromal tissue is composed of smooth muscle, connective tissue, fibroblasts, nerves, lymphatic and blood vessels. The stroma is mainly smooth muscle which surrounds each acinus.

Prostatic fluid drains into the acinar ducts and then into the urethra during ejaculation and micturition [6]. The smooth muscles of the prostate, at orgasm, contract like a sponge to squeeze the prostatic fluid from the acini via the ducts into the prostatic

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urethra [7]. However, during micturition, there is no contraction of the prostatic smooth muscles and so the mechanism of prostatic fluid drainage from the acini is unclear.

This raises at least two questions:

(1) If the function of the prostate, one organ of the male reproductive system, is so important, why has Mother Nature joined this gland with urinary tract as a part of the urinary excretory system?
(2) What mechanism causes prostatic fluid to drain during urination?

It is possible, that the answer to the first question is closely associated with the very unusual composition of prostatic fluid in comparison with other human body fluids [6,8]. This composition is vital to conserve sperm in optimum condition, till fertilization of an ovum occurs, and coincidentally it is harmful for prostatic cells [6,8–10]. So it is necessary to drain the prostatic acini continuously between ejaculations. Thus these excretory systems, including the urinary tract, are optimal for such purpose.

The answer to the second question may be as follows. From a physical point of view the anatomical picture of the prostatic urethra closely resembles the structure of a Venturi effect liquid-jet pump (Fig. 1). It allows us to assume that the prostatic part of the urethra works as a jet-pump in which the bladder liquid content is used as the carrying or motive liquid and during voiding the urine-jet pump acts to drain prostatic fluid from the acini. The pump works because of Bernoulli's principle, which states that an increase in the speed of steady flow of an effectively non-viscous liquid is accompanied by a decrease in its pressure. Necessary conditions to satisfy application of Bernoulli's principle, effective incompressibility and non turbulent flow, are satisfied by urine in the prostatic urethra. At the proximal part of the prostatic urethra the pressure in the liquid is lowest, because here the cross sectional area of the urethral canal contains the urethral crest, which decreases the luminal area of the urethral canal. Below, or distal to, the colliculus seminalis the pressure in the liquid is highest, because the urethral canal here contains hardly any of the urethral crest and so its luminal diameter reaches a maximum. The bladder content liquid entering the prostatic urethra is the motive or carrying liquid and as it passes along the prostatic urethra it causes a pressure drop in the region of narrowed lumen near to the colliculus seminalis. This drop in pressure sucks out the acinar ducts' contents, the mouths of which are mainly located in this region. Thus in this case, the prostatic liquid is the carried liquid. This application of Bernoulli's principle is called the Venturi effect.

The primary purpose of this study was to collect morphometric data about the prostatic part of the young, healthy, male adult

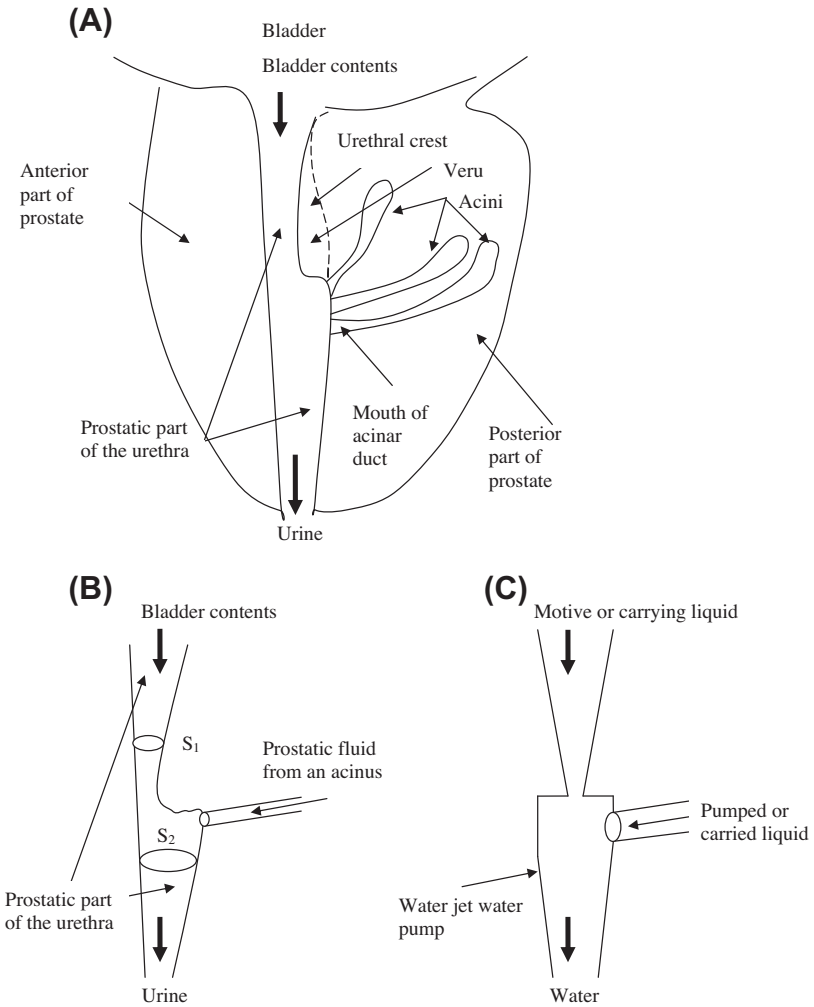

Fig. 1. Diagrammatic representation of (A) the prostate gland, (B) the prostatic part of the urethra, indicating its similarity with a conventional Venturi effect water-jet pump, and 1C a conventional Venturi effect water-jet water pump. S_1 and S_2 (B) are the area of the transverse sections of the urethral canal in the regions of the urethral crest and below the colliculus seminalis (*veru*), respectively.