THE NORMAL BLADDER AND ITS SPHINCTERS
AND THE CHANGES FOLLOWING SUPRAPUBIC PROSTATECTOMY.*

A STUDY BASED ON RADIOGRAPHIC FINDINGS.

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INCONTINENCE of urine following prostatectomy is encountered infrequently, and very rarely after suprapubic enucleation; it is more often met with after the perineal operation. The cause of this condition has not been definitely determined. The object of this study is to inquire into the mechanism of urination following suprapubic prostatectomy and to note the changes in the topography of the bladder resulting from this operation. It was believed that by such an investigation additional light would be cast upon the question of postoperative incontinence of urine.

As a preliminary it was deemed advisable to make a number of observations of the normal bladder, and of the condition of the bladder in prostatic enlargement, in order the better to correlate the findings.

THE NORMAL BLADDER.

A résumé of the literature dealing with the mechanism of the sphincters of the normal bladder shows that considerable discrepancy of opinion still exists concerning the rôles played by the internal vesical sphincter and the external sphincter, or compressor urethrae muscle.

A brief description of the anatomy of the bladder and its

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sphincters may aid in understanding some features to which I shall subsequently refer. Although individual opinions vary, it appears to me that Leedham-Greene presents the best summary of the standard anatomists, and I will therefore quote from his description:

"Anatomists while differing considerably in minor details, describe three more or less distinct constrictor muscles in connection with the bladder and urethra, though their opinions differ greatly as to the part these muscles play in maintaining the closure of the bladder. They are as follows:

"A. A slender ill-defined ring of oblique muscular fibres intermingled with elastic tissue, encircles the vesical opening, and is formed of unstriped or involuntary muscular tissue. According as to whether it is regarded as belonging to the bladder proper or to the prostate, it is called the internal vesical or internal prostatic sphincter.

"B. Below the internal sphincter some short transverse muscular fibres are present on the anterior or ventral surface of the lower or distal half of the prostate. They rapidly increase in length as they approach the apex of the prostate until they completely encircle the urethra. The majority of these fibres, chiefly composed of voluntary muscular tissue, are situated on the outer surface of the prostate. All these fibres together comprise the external prostatic or vesical sphincter of Henle, which according to Griffiths is merely the commencement of the constrictor urethra.

"And lastly, surrounding the membranous urethra, contiguous to the anterior portion of the external prostatic sphincter is that muscle, or group of muscles, best known as the compressor urethrae."

It is well recognized, that but two of these muscles are of importance in the act of micturition, the smooth muscle, involuntary internal vesical sphincter, and the striated voluntary compressor urethrae.

Concerning the topography of the normal bladder the following may be said. The most fixed portion of the bladder is the outlet, being firmly held by its attachments to the prostate and urogenital musculature. The position of the sphincter, of
course, varies according to the skeletal development, the musculature, the age of the patient and the condition of the neighboring organs; for it can readily be seen that tumors, congenital defects, prostatic enlargement, and other pathological conditions influence its location. According to Langer,\textsuperscript{3} the internal urethral orifice in a normal, slightly-filled bladder is between 2.2 and 4.5 centimetres from the posterior aspect of the symphysis. As the bladder distends the orifice is pushed downward. Richet locates the internal sphincter on a line from the under border of the symphysis to the fourth sacral vertebra; while Kohlrausch\textsuperscript{4} places it on a line from the upper border of the symphysis to the tip of the coccyx. All these observations were made upon the cadaver.

The contour of the normal bladder has long been the subject of much discussion. Most of the work in this connection has been carried out upon the cadaver by means of different methods. The bladder has been filled both from the urethra and from the ureters with wax, plaster of Paris, formalin and other solutions; it has been inflated with air, and has also been studied by means of frozen sections. As a result of these investigations the bladder has been variously described as being cylindrical, ovoid, elliptical or spheroid. It is evident, however, that the bladder is not equally distensible, for if it were so, its shape when filled would be round. Furthermore, Langer has carefully demonstrated that the region of the outlet is the least distensible, especially so at the trigone. His observations are borne out by the fact that in the markedly distended bladder there is but slight variation in the distance between the two ureters.

In 1905 a new method of studying the form of the bladder was devised by Völcker and Lichtenberg.\textsuperscript{5} They employed collargol injections combined with radiography, and as a result of their work concluded that the normal bladder when distended is invariably broader above than below, and is never round. Subsequently Leedham-Greene, using the same technic, reported that the radiographs he obtained showed the bladder to be oval in shape. His photographs, however, demonstrate a bladder round in form. More recently two articles have
appeared dealing with this subject; in the first, by Barringer and MacKee, the results obtained coincided with those of Völcker and Lichtenberg; in the second, by Uhle and MacKinney, the radiographs more closely resembled the round form of Leedham-Greene.

Turning now to the action of the sphincters when the bladder is fully distended, a study of the literature again discloses considerable difference of opinion; all authors, however, are agreed that in the moderately distended bladder it is the internal vesical sphincter that is active in retaining the urine. This diversity of opinion is due in part to the different methods employed. The earlier investigators worked on the cadaver. Thus Born, using ureteral injections of plaster of Paris, found that the closure took place at the internal vesical sphincter. From a series of anatomical studies Kohlrausch believed that folds of mucous membrane which he found near the internal urethral orifice acted as the sphincter. Barkow termed the internal urethral orifice, the annulus elasticus, and considered that the sphincter. Henle, however, showed that the action of this sphincter was not due to elastic fibres, but to smooth muscle, so that this constituted a true sphincter. Later anatomists and clinicians making their studies on animals and the living human being placed the seat of vesical closure at the external sphincter, the compressor urethrae muscle. Guyon, Ultzman, Finger and many others were of the opinion that in the distended bladder the internal sphincter was not of sufficient strength to retain the urine. They believe that when the bladder is distended the posterior urethra becomes part of it, forming a funnel-shaped outlet, with the closure taking place at the compressor urethrae muscle. These authors base their arguments in part upon the fact that in the fully distended bladder the urethra is from one and one-half to two centimetres shorter than when the bladder is but moderately filled. v. Zeissel, however, believes that this shortening is not sufficient to justify placing the closure at the compressor urethrae, for if this were so there should be at least four centimetres shortening; that is, the length of the prostatic urethra. More
recent writers (Ruggles, Wilson and McGrath) basing their opinions on the older methods of study continue to adhere to the belief that the compressor urethrae muscle is of paramount importance in retaining the urine in the fully distended bladder. Thus to quote one of these authors, Ruggles, "We all know, or ought at least, that the vesical sphincter is a comparatively weak muscle and that the only muscles by the action of which we are enabled to resist a strong desire to urinate is the external sphincter or compressor urethrae, which is a strong voluntary muscle."

The method of Völcker and Lichtenberg—collargol injections combined with radiography—offered the best physiological method of studying this much discussed question, and conclusions reached by its application appear to me to definitely solve this problem. As previously stated, Völcker and Lichtenberg showed that the bladder is broader above, narrowing down at the outlet; they also demonstrated in their collargol radiographs that the internal vesical sphincter is the sphincter that prevents the escape of fluid from the fully distended bladder; and they never observed a funnel-shaped formation. Later investigators (Leedham-Greene, Barringer and MacKee, Uhle and MacKinney) using a similar technic substantiated their findings. Oppenheim and Loew are the only observers who maintain that the closure takes place at the compressor urethrae. Their work, however, was done on monkeys, using bismuth injections; furthermore, their radiographs were rather indistinct in outline and by no means conclusive.

Before proceeding with the details of the work, I wish briefly to state that my observations on the normal bladder are in the main in concordance with the work of Völcker and Lichtenberg.

**TECHNIC AND RESULTS OF RADIOGRAPHIC EXAMINATIONS OF THE NORMAL BLADDER.**

These radiographic studies were begun two years ago. In the beginning three different positions were tried, the ventrodorsal (patient lying flat on back), the dorsoventral (patient on
Normal bladder distended with 180 c.c. of collargol, showing broad upper portion, narrowing at outlet.

Normal bladder distended with 225 c.c. of collargol.
Normal bladder of same patient as Fig. 2 taken in dorsoventral position; showing but slight variation from preceding one.

Normal bladder distended with 420 c.c. of collargol. Approaches round type of bladder. Urethra sharply demarcated.
**FIG. 5.**

Normal bladder, same patient as Fig. 4 taken with tube in oblique position, and showing how outlet is cut off by this method.

**FIG. 6.**

Bladder in prostatic hypertrophy; distended with 150 c.c. collargol; showing high location above symphysis with flattening of the base.
Bladder in prostatic hypertrophy; distended with 200 c.c. collargol. Numerous irregular shaped diverticulae present.

Bladder in prostatic hypertrophy; distended with 240 c.c. collargol; showing peculiar elongated shape.
Bladder in prostatic hypertrophy; distended with 240 c.c. collargol; showing high location above symphysis, broad, flat base, with urethra sharply demarcated.

Bladder in prostatic hypertrophy; distended with 180 c.c. collargol; showing irregular shape, high location above symphysis, and two diverticula.
Bladder in prostatic hypertrophy, distended with 300 c.c. of collargol, showing bulging and irregularity of base.

Bladder following suprapubic prostatectomy, 10 months after operation; showing a small funnel-shaped formation.
FIG. 13.

Bladder following suprapubic prostatectomy; 9 months after operation; showing funnel-shaped cavity continuous with bladder.

FIG. 14.

Bladder following suprapubic prostatectomy, 6 months after operation; showing collection of collargol in pouch formerly occupied by prostate.
Bladder following suprapubic prostatectomy, 1 1/2 years after operation; showing collection of collargol in cavity below and continuous with the bladder.

Bladder following suprapubic prostatectomy, 1 1/2 years after operation; showing collargol in cavity below and continuous with the bladder.
Bladder following suprapubic prostatectomy, 1½ years after operation; showing similar condition.

Bladder following suprapubic prostatectomy; same patient as Fig. 17 with bladder, however, containing half the amount of solution, and showing similar formation.
Bladder following suprapubic prostatectomy, 5 years after operation; showing large collection of collargol in cavity below and continuous with the bladder.
abdomen), and the lateral. The lateral views were very unsatisfactory owing to the density of the muscular and bony structures of the pelvis. The dorsoventral and ventrodorsal gave practically the same results, and the latter, the ventrodorsal position, because more convenient was adopted as a routine. The position of the X-ray tube is of considerable importance. The earlier radiographs were taken with the tube placed posterior and obliquely to a vertical plane passing through the symphysis pubis. It was found, however, that this position failed to give a good view of the outlet of the bladder. Subsequently, therefore, the tube was placed so that its focus was at a right angle to the plate, the rays striking the body just above the symphysis. A compression blend was used; but moderate compression was applied, however, so as not to distort the bladder. The medium used was a 5 per cent. solution of collargol which in the large majority of cases was found to be non-irritating. The solution was introduced through a catheter which was then withdrawn.

Twelve radiographic exposures of normal bladders were made and as the main object was the study of the sphincteric region, the bladders were fully distended.

The shape of the normal bladder was found to be variable, although the type most frequently encountered was that showing a broad upper portion, narrowing down toward the outlet. A few of the pictures closely approached the round type described by Leedham-Greene, while twice the bladder assumed an ovoid shape with the long diameter extending from the fundus to the base. Legueu 18 has recently described a reverse type, the bladder broad below, and narrow above, as characteristic of the normal bladder with the patient in the prone position. This type was not observed in any of the cases in my series. In the radiographs the urethra was invariably found to be sharply demarcated from the bladder, thus demonstrating that the internal vesical sphincter is the muscle that retains fluid in the distended bladder. The position of the internal sphincter was either on a level with the upper border of the symphysis pubis, or midway between the upper and lower borders.
Before beginning a study of the condition of the bladder following prostatectomy, it was considered desirable to take a series of radiographs on unoperated cases of enlarged prostate, in order to better determine the changes following the operation. Marked changes in the contour of the bladder were observed in these unoperated cases. They varied from the small contracted bladder to the larger, irregular, flaccid type. Vesical diverticulae, so frequently encountered in prostatic enlargement, were distinctly shown in several instances. Changes characteristic of prostatic enlargement are to be found at the base of the bladder. Instead of a broad upper part narrowing at the outlet, the opposite picture was seen. The inferior portion of the bladder was broad and flat or sinuous; at times an upward bulging, due to the gland projecting into the bladder, was observed. This flattening of the inferior portion of the bladder may be said to be characteristic of prostatic enlargement. The bladder was situated on a higher plane than in the normal, the level depending upon the size of the gland. Its base was found to be opposite the upper border of the symphysis, or more often one to two centimetres higher. The prostatic lobes could not be definitely demonstrated radiographically.

The question of sphincteric control in prostatic enlargement seems to me to be decisively settled by the radiographs. Wallace,\(^1^9\) in a recent publication, writes, "When a prostate enlarges the adenomatous mass sometimes makes its way through and distends the sphincter to such a degree as to render it probably useless. The question of whether the bladder is controlled by the internal or external sphincter remains unsolved. "My radiographs show conclusively, however, that even in the most extreme distention of the bladder the internal vesical sphincter is the seat of closure. When the marked changes in the sphincteric region with the resultant distortion are considered, it is really remarkable that the muscle retains so much of its functional activity."
THE CONDITION OF THE BLADDER FOLLOWING SUPRAPUBIC PROSTATECTOMY.

The mechanism of sphincteric control after prostatectomy is still imperfectly understood. Very few references to this subject are to be found in the literature, and the opinions expressed are not in accordance. Thus Hagner and Fuller in a recent publication state, "that the cause of the loss of control after prostatectomy is a debatable question. It is unquestionably due to the destruction of the muscle at the neck of the bladder, in the prostatic urethra, or in the membranous urethra." Squier is of the opinion that the internal sphincter remains intact and soon contracts to its normal calibre. Other authors, however, have placed the seat of bladder closure following operation at the compressor urethrae muscle. Thus Freyer, reporting an autopsy upon a patient who died twenty-two days after operation, found the bladder pear- or funnel-shaped, instead of globular, the inner surface of the urethra terminating at the triangular ligament. In a personal communication, Lilienthal states that he believes that the compressor urethrae forms the true sphincter of the bladder after prostatectomy.

As far as can be ascertained from a review of the literature but few attempts have been made to study the bladder after prostatectomy by means of radiography. Wallace, using a bismuth suspension, reported one case in which a skiagraph of the bladder was taken. His description is as follows: "The skiagraph shows the bladder cavity continuous with the cavity from which the prostatic adenomata were removed. As the prostate had a distinct intravesical projection the internal sphincter must have stretched considerably. Its situation is presumably at or just distal to the ledge or shelf forming the separation between the two cavities. If this presumption is right, the internal sphincter could not have had any effect in controlling the urine and it must be supposed that a man can have normal micturition without an efficient internal vesical sphincter." Another case, reported by Legueu, confirms Wallace's findings.
Thirty-eight patients upon whom suprapubic prostatectomy had been performed were selected for this study, and in all some seventy-five radiographs were taken. The technic employed was that previously described for the normal bladder. The radiographs were taken at various intervals following operation, ranging from two months to three years. A few of the patients were radiographed several times at successive periods after operation in order to determine if time played a rôle in changing conditions observed. No appreciable differences were noted beyond the fact that an increase in the capacity was evident in the small contracted bladder after appropriate treatment had been instituted.

Concerning the contour of the bladder it was noted that its broad base so characteristic of the unoperated enlarged prostate remained practically unchanged, occasionally, however, the bladder was found on a higher level than in the unoperated case. The vault of the bladder often assumes a pear-shaped form, probably due to adhesions between the bladder and the abdominal wall. The most interesting and important changes are to be found at the outlet of the bladder.

In a small proportion of the cases only a very slight funnel formation in the region of the internal sphincter was observed; in a very few instances no changes at the outlet were to be found. It is therefore evident that in this small group of cases the internal sphincter has not been sufficiently injured by the operation to interfere with its proper function.

In the great majority of the cases (28 in a series of 38 cases) the radiographs showed two distinct cavities, a larger superior one corresponding to the bladder proper, and a smaller inferior one extending from the lower margin of the bladder and continuous with it, to the region of the compressor urethrae. The latter corresponds to the defect left by the removal of the enlarged gland. The contour of this cavity varies from a round or oval to a funnel-shaped formation. The latter is more frequent, the broad base being superior. There can be only one interpretation to these findings—the internal vesical sphincter has either been destroyed by the operation, or its
function so impaired that it could not have had any effect in retaining the fluid in the bladder; this has been accomplished by the compressor urethrae muscle. In other words, the true sphincter of the bladder following suprapubic prostatectomy is situated at the membranous portion of the urethra. That this is so, I have been able to further prove by urethroscopic examinations of the posterior urethra; also by demonstrating that in these cases a catheter passed just beyond the compressor muscle completely empties the distended bladder without voluntary effort on the part of the patient. There can be no question that the compressor urethrae muscle acts as an efficient sphincter, for all of the cases in this series have excellent urinary control. That the collection of collargol found in the pouch formerly occupied by the prostate is not an overflow phenomenon caused by vesical distention is demonstrated by radiographs showing the same formation in the bladder but slightly distended. A careful examination of the radiographs reveals the fact that in some cases the two cavities are separated by a narrow isthmus. This would lead one to believe that in these instances the sphincter has either partially regenerated after the operation, or was incompletely destroyed by the operation. That the cavity left by the enucleation of the gland is not obliterated, and that the internal sphincter is not completely regenerated, is shown by the very definite radiographs after an interval of three years.

In conclusion it may be stated that

1. The internal vesical sphincter is the true sphincter of the normal bladder, and of the bladder in prostatic enlargement.

2. The external vesical sphincter, "compressor urethrae," is the functionating sphincter after suprapubic prostatectomy in the large majority of cases.

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