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Anatomic basis of micturition and urinary continence

Muscle systems in urinary bladder neck during ageing

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Summary: Dorschner et al [5-9] have described the unique function and form of several different muscle systems of the urinary bladder neck. If these systems have different functional responsibilities, then the muscles must undergo different ageing processes, as stated in the theory of function-dependent ageing. One characteristic of histologic ageing is the change over time in the proportion of muscle cells to connective tissue, a phenomenon we have demonstrated in both the ciliary muscle and in the two muscle systems of the small intestine [20]. Using an SIS-Image Analysing System, we have now measured automatically the ratios of muscle cells to connective tissue in sections from several regions of the urinary bladder neck, taken from 50 male and 15 female cadavers. Our results confirm new functional explanations of the different muscle systems in the bladder neck. The relative volume of muscle cells in both the sphincter trigonalis m. and the dilator urethrae m. diminishes continuously with age. In the ejaculatorius m., however, the volume of muscle cells first increases until beginning at the end of the third decade, it decreases until senescence. As was presumed, the proportion of muscle cells in the detrusor vesicae m. does not decline during the later decades. The volume of muscle cells and fibers in both urethral sphincter muscles, however, decreases with age, beginning in early childhood.

Bases anatomiques de la miction et de la continence urinaire Les systèmes musculaires du col vésical au cours du vieillissement

Résumé : Dorschner et al [5-9] ont décrit la fonction et la configuration de plusieurs groupes musculaires distincts au niveau du col vésical. Si les systèmes musculaires ont des responsabilités fonctionnelles propres, les muscles doivent subir différents processus de vieillissement, comme l'affirme la théorie du vieillissement fonctionnellement-dépendant. Un trait du vieillissement histologique est le changement avec le temps de la proportion des cellules musculaires par rapport au tissu conjonctif, un phénomène que nous avons démontré à la fois dans le m. ciliaire et dans les deux systèmes musculaires de l'intestin grèle [20]. Utilisant un système d'analyse d'images (SAS), nous avons mesuré dans ce travail les proportions de tissu cellulaire conjonctif et musculaire sur des coupes à plusieurs niveaux du col vésical, à partir de 50 cadavres masculins et 15 féminins. Nos résultats confirment les nouvelles théories d'ordre fonctionnel concernant les différents groupes musculaires du col vésical. Le volume des cellules musculaires dans le "m. sphincter du trigone" et dans le "m. dilatateur de l'urètre" dimimue de façon constante avec l'âge. Dans le "m. éjaculateur", cependant, le volume des cellules musculaires augmente tout d'abord, puis au début de la troisième décade, diminue jusquà la vieillesse. Comme celà était prévisible, la participation des cellules musculaires dans la musculeuse de la vessie ne diminue pas pendant de nombreuses décades. Le volume des cellules et des fibres musculaires, toutefois diminue avec l'âge, en commençant dès l'enfance.

Key words: Urinary tract — Micturition — Muscle, smooth — Histologic ageing — Histomorphometry

Dorschner et al [5-9] describe several different muscle systems of the distal urinary tract, each of which has a different function, e.g. the sphincter trigonalis (vesicae), the dilator urethrae, the smooth "sphincter urethrae" and the "ejaculatorius m.". If these systems have separate and different functional responsibilities, then they must undergo different ageing processes, as stated in

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the theory of function-dependent ageing [10]. One characteristic of histologic ageing is the decline over time in the proportion of muscle cells to connective tissues. This has been conclusively demonstrated in both the ciliary m. and in the muscle of the small intestine.

If we compare the composition of a ciliary m. section from a child with that of an elderly man, we see, over time, a regression of muscle cell volume, coupled with a proliferation of connective tissues. Using the point-counting method, we measured the proportion of muscle cell volume to connective tissue volume in sections. We then adapted exponential functions to the scatter plots, from which we took the derivatives with respect to time. As a result, we were able to estimate for each year of life the rate of ageing in the ciliary muscle [1, 20]. This process of measurement and analysis was also performed on sections of muscle tissue from the small intestine [21]. Here, the comparatively different and functionally less important outer longitudinal layer shows, over time, the predicted loss in muscle cell volume in connection with the proliferation of connective tissues. The functionally more important circular layer, however, does not show this change. We next measured automatically the muscle cell - connective tissue ratios in sections from several regions of the urinary bladder neck. Our objective was to see whether or not differences in the ageing process exist between the several muscle systems of the urinary bladder neck described by Dorschner et al. Based upon the theory of function-dependent ageing, if differences in the histologic processes of ageing can be shown, then functional differences between the muscle systems must exist.

Material and methods

The samples used in this study were obtained from autopsies of 50 male and 15 female subjects. Subject age ranged from 0 and 93 years. In order to preserve the tissue topography, we removed en bloc the urinary bladder, urethra (including either the bulb of the penis, seminal vesicles and prostate or the vagina and uterus), rectum and pubic symphysis. These organs were fixed in a 4% formalin solution. Using a specially-built microtome (Tetrander Jung), we then cut sections with a thickness of 10 µm.

In order to best describe the various muscle systems of the distal urogenital tract, serial sections were made in transverse, frontal and sagittal directions. The transverse plane was gradually adjusted, according to the curvature of the urethra. Every fifth section was stained for muscle and connective tissue content using the Crossman method. For purposes of histomorphometry, only those sections were chosen for further use in which the particular muscle system under consideration was clearly observable. The total number of stained specimens was therefore reduced to a smaller number of selected specimens, from which measurements were made. The relative volumes of muscle cells and connective tissue in these sections were finally measured with an automatic Image-Analysing System (firm SIS). The Harvard Graphics 3.0 program was used for drawing the scatter plots and regression lines, the statistical program SPSS for Windows 5.0 for correlation and regression analysis and testing the resulting coefficients.

Results

Musculus detrusor vesicae

Eighteen samples of this muscle system were suitable for measurement. Disregarding any differences between layers (inner and outer longitudinal, middle, circular), we measured the proportions of muscle cells to connective tissues across the entire width of these muscle sections. Great intra-individual and inter-individual variation in this parameter was found. Nevertheless, based on this parameter, we observed distinct and different stages of ageing. Fig. 1a shows this result. The lowest percentage of muscle cell volume (32%) was in a section from a newborn; obviously, the muscle cells continue to differentiate after birth. We see, however, beginning with the end of babyhood, a decrease in the scatter plot and in the corresponding regression line. This decrease is statistically significant. Sections from older adults, however, do not show a decline in the scatter plot. This was to be expected as the sections of urinary bladder wall measured all came from males; not only does prostatic hypertrophy influence the macroscopic appearance of the musculature, but also the continuous demands on the reservoir and voiding functions of this muscle system check the regression of relative muscle cell volume [15].

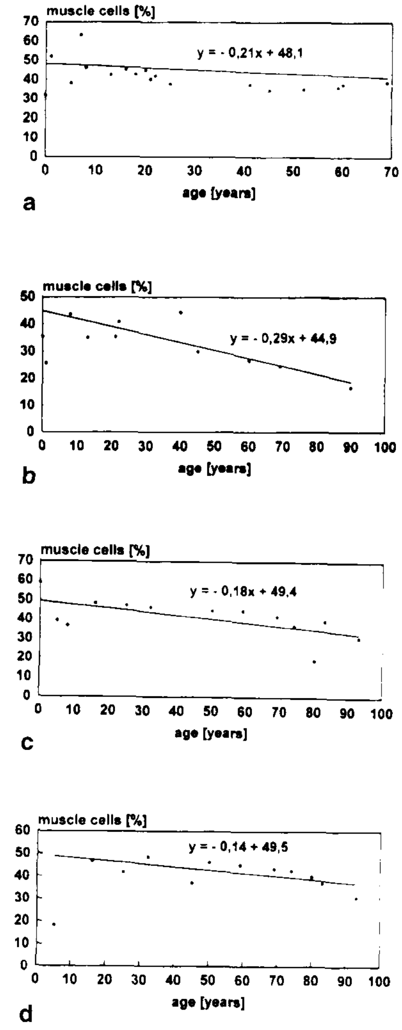
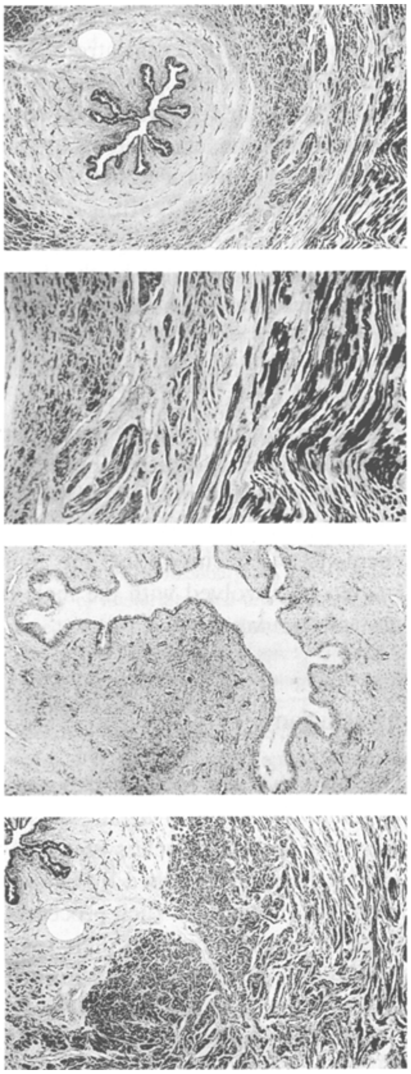


Fig. 1-d
Relative volumes of smooth muscle cells during ageing, corresponding regression formulae. **a** Detrusor m. **b** Sphincter trigonalis (vesicae). **c** Smooth urethral sphincter. **d** Ejaculatorius m.

Volumes relatifs des cellules musculaires lisses durant le vieillissement, correspondant à la formule de régression. **a** M. detrusor. **b** Sphincter du trigone vésical. **c** Sphincter lisse de l'urètre. **d** "M. éjaculateur"



Figs. 2-5
2 Cross section of the male urethra at age 16. Cyst to the right of the smooth sphincter and striated sphincter. Magnification x 9. **3** Higher magnification (x 17.5) of the right part of **Fig. 2**. Smooth sphincter (*on the left*), striated sphincter (*on the right*). **4** Crista urethralis, male at age 7. Magnification x 36. No m. ejaculatorius. **5** Wall of urethra near the cyst in **Fig. 2**. Well-developed m. ejaculatorius traversed by a vessel (*center*). Magnification x 17.5

2 Section transversale de l'urètre, chez un garçon agé de 16 ans. Kyste à la partie droite du sphincter lisse et du sphincter strié. Agrandissement x 9. **3** Agrandissement plus important (x 17,5) de la partie droite dans la **fig. 2**. Le sphincter lisse *à gauche*, le sphincter strié *à droite*. **4** Crête urétrale, garçon agé de 7 ans. Agrandissement x 36 pas de "m. éjaculateur". **5** Paroi de l'urètre proche du kyste dans la **fig. 2**. Le "m. éjaculateur" est bien développé et pénétré par un vaisseau (*au milieu*). Agrandissemnt x 17,5

Musculus sphincter trigonalis (vesicae)

The muscle system of the trigonum vesicae consists of two parts: the interureteric musculature and the ring-shaped trigonal musculature [4, 6]. The latter is named the m. sphincter trigonalis or m. vesicae. We were able to analyse 11 male samples (Fig. 1b). Initially, during childhood, the proportion of muscle cell volume increases. Then, beginning with the second decade and continuing into old age, the volume of muscle cells diminishes. We describe this decline using linear regression analysis, excluding newborn and one-year-old subjects. The slope of the regression line [muscle cell volume (%) = 44.9 - 0.29 age (years)] is statistically significant ($\alpha = 0.003$). The relative muscle cell volume decreases here by 3% per decade. This proves therefore that, within this occlusive system, maturation processes occur only during childhood.

The two parts of the musculus sphincter urethrae

In the female, as well as in the male, the outer striated urethral sphincter always borders on a layer of smooth muscle cells in the direction of the urethra [3, 7, 16, 18, 23, 25]. In order to distinguish between the two parts of the muscle, the terms m. sphincter urethrae transversostriatus (striated muscle) and m. sphincter urethrae glaber (smooth muscle) have been suggested. We were able to measure 11 samples of the striated muscle and 12 samples of the smooth muscle (Figs. 2, 3). In both forms, muscle volume is highest after birth (about 50%) and then decreases, as shown in Fig. 1c. The corresponding regression equations are :

$y = 46.9 - 0.19\ x$ (striated muscle)
$y = 49.4 - 0.18\ x$ (smooth muscle).

Despite the small number of samples, we were able to statistically verify the decline in relative muscle cell volumes ($\alpha = 0.01$). Based on these measurements, the volume of muscle cells and fibers diminishes here by 2% per decade. These two muscle systems, and the correlated mechanism of occlusion, reach maturity during the first years of life.

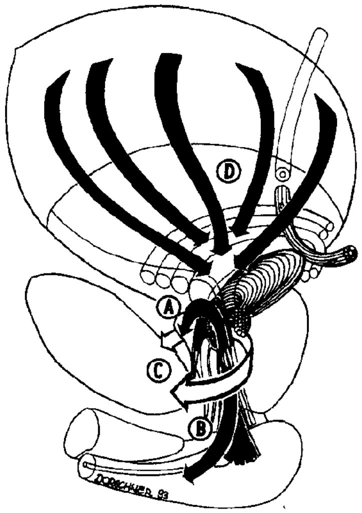


Fig. 6
Process of micturition. The dilator urethrae m. stretches the relaxed sphincter trigonalis m. Due to the movement of the latter forwards and downwards the bladder neck opens like a funnel (*A*). At the same time relaxation of the sphincter urethrae m. is brought about (*C*). The lower part of the ventral urethral muscle system is able to contract the urethra caudally (*B*). Now the urine put under pressure by the detrusor m. (*D*) is able to traverse the urethra [8]

Processus de la miction. Le "m. dilatateur de l'urètre" étire le m. sphincter du trigone relaché. Compte tenu du mouvement en avant et en bas, le col de la vessie s'ouvre comme un entonnoir (*A*). Celà occasionne au même moment, le relachement du m. sphincter de l'urètre (*C*). La partie inférieure du système musculaire de l'urètre ventral est suceptible de contracter l'urètre en arrière (*B*). L'urine mise sous pression par le m. detrusor (*D*) est capable de traverser l'urètre [8]

The ventral and dorsal longitudinal urethral muscle layer

Dorschner et al [8] name the ventral longitudinal muscle system of the urethra the "m. dilator urethrae". This muscle system, which lies immediately adjacent to the lumen, has as origin the lower pubic symphysis and, in males, the bulb of the penis. Cranially, this m. dilator urethrae crosses the ventral m. sphincter trigonalis (vesicae). We measured the proportion of muscle cell volume to connective tissue volume in 8 subjects, ranging in age from 5 to 93 years. Sections from subjects belonging to the early childhood age-group are missing here, whereas, in other muscle systems (m. detrusor, m. sphincter trigonalis), we were able to prove an initial increase in muscle cell volumes. Both the scatter plot and the graph of the regression function decline at a steady rate. The corresponding regression equation is:

$y = 41 - 0.27\ x\ (\alpha = 0.004)$.

Dorschner et al [9] term the dorsal longitudinal muscle system of the urethra the "m. ejaculatorius" because of this muscle's presumed involvement in the process of ejaculation. In males, is a direct continuation of the ejaculatory duct musculature, and is therefore restricted to the portion of urethra below the colliculus seminalis. In females, the corresponding muscle cell bundles run longitudinally outside the sphincter system. At an early age in males, only fine muscle cells may be seen within the urethral crest (Fig. 4). With adolescence, the dorsal longitudinal muscle system develops fully (Fig. 5). Later, slight regression takes place (Fig. 1d).

Discussion

With respect to the m. detrusor vesicae, we must emphasise that all of its inner-layered muscle cell bundles end at the internal urethral orifice. These results contrast with the results of those authors [12, 13, 14, 22, 24] who describe a continuation of the inner longitudinal layer to the urethra. Only in the fetus does such a continuation really exist [2]. Furthermore, there is no involvement of the lamellae of the detrusor muscles in the formation of the sphincter muscle of the urinary bladder. A morphologic basis for the widely reported functional contribution of the detrusor muscle to active continence [11, 19] simply does not exist.

Only two muscle systems actually leave the urinary bladder. These muscles fix the bladder in the pelvis. Dorsally, either the m. vesicoprostaticus or the m. vesicovaginalis forms a portion of the medial bundle of the outer dorsal longitudinal layer. Ventrally, the mm. pubovesicales have as origin a special node (nodus vesicae), consisting of muscle bundles from all the outer longitudinal muscle bundles (collare vesicae). The mm. pubovesicales extend to the lower region of the symphysis. This muscle structure is already well-developed in neonates [5].

Muscle bundles in the bladder trigone connect both ureters and cause the mucosa of the bladder to heap up to form the interureteric ridge. The m. sphincter trigonalis does not extend to the urethra; rather, it embraces the internal urethral orifice elliptically. This muscle system, alone, occludes the internal urethral orifice [4]. The marked distribution of prostatic tissue in the caudal regions of the m. sphincter trigonalis in males is reason to believe that this muscle has a double function. The first, as stated above, is to maintain continence. The second, performed during ejaculation, is both the prevention of retrograde ejaculation and the induction of prostate-secretion release. Our measurements confirm these beliefs. It is more than doubtful that the trigonalis muscle is the main factor underlying continence [3, 16, 18]; one need only consider the case of those patients in which the sphincter trigonalis has been irreparably damaged during surgical procedures [17]. With this in mind, we believe that the smooth urethral sphincter muscle, within and adjacent to the striated voluntary urethral sphincter muscle, is also an important factor for maintaining continence.

The occlusive function, however, has not yet been fully described. It is therefore necessary to name and to discuss three structures capable of occluding the urinary bladder. The first is the sphincter trigonalis, which has already been described. The second, already also named, is the smooth urethral sphincter, which we believe is not only the important, but also the crucial factor behind continence maintenance. Due to the muscle's involuntary innervation, the smooth urethral sphincter is capable of permanent function, and is therefore, responsible for preserving long-term continence. The third structure, the striated sphincter urethrae, is in contrast capable of voluntary stoppage of micturition and responsible for avoiding stress incontinence.

We believe that the functional role of the ventral longitudinal muscle system in the ventral wall of the urethra (m. dilator urethrae) is the initiation of micturition. Its contraction stretches the relaxed fibers of the m. sphincter trigonalis. Due to the forward and downward movement of the latter, the bladder neck opens and assumes a funnel shape. At the same time, relaxation of the m. sphincter urethrae is brought about. The urine, put under pressure by the detrusor m., is now able to pass through the urethra (Fig. 6).

A separate and distinct dorsal longitudinal muscle system also exists in the dorsal wall of the urethra. Based purely on anatomic considerations and the fact that this muscle system is well-developed only during sexual maturity, it seems to be conclusive that this muscle system is involved with the male process of ejaculation.

Conclusion

Our objective was to see whether or not different processes of ageing exist between the several muscle systems of the urinary bladder described by Dorschner et al. We proved that such processes do exist in accordance with their specific involvement in different functions (continence, micturition, ejaculation). There were no exceptions to this. Thus, based on the theory of function-dependent ageing, our results support a new functional concept of the several muscle systems in the urinary bladder neck as summarised in the discussion.

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