Transcription of the Narration of the Embryology of the Urinary System

Introduction:

The development of the urinary system and reproductive system will be covered together over the course of the next two PowerPoint presentations. This is because in humans and other amniotes for that matter, which are vertebrates with a self-contained egg, the two systems share common embryonic origins and developmental pathways. These embryonic origins and the resulting adult anatomy are the result of a complex path of evolutionary novelty and cooption of existing systems. The urogenital system in humans is therefore sort of a complicated, hacked together system, one that achieves the relatively simple task of getting gametes, sperm and egg, and urine, excretory fluid, out of the body. The first of these two lectures will cover the urinary system.

Details of urogenital development: Embryonic Origins 1: The urogenital system develops from mesoderm situated between the paraxial mesoderm (of which the somites are derived from) and the lateral mesoderm. This band of mesoderm is therefore referred to as the Intermediate Mesoderm (IM).

Details of urogenital development: Embryonic Origins 2: During the fourth week, the folding of the embryo carries the IM ventrally and it loses its connection with the somites. A longitudinal ridge of IM develops on either side dorsal aorta. This is the urogenital ridge, which is highlighted here in orange.

Details of urogenital development: Embryonic Origins 3: Note that later in the 4th week, the urogenital ridge and the nephrogenic cord correspond topographically in the developing embryo. The urogenital ridge is divided based on whether it develops into the urinary or genital system. The nephrogenic cord gives rise to the urinary system and we will focus on that part first.

Details of urogenital development: Urinary System – Nephrogenic Cord Segmentation: Segmentation of the nephrogenic cord and the development of the kidneys begins in the 4th week and progresses in a wave-like fashion caudally. The pronephros appear early in the 4th week. They are transitory but the pronephronic duct, which connects the pronephros to the cloaca, persists and is used by the next set of kidneys. The 2nd kidney to develop, the mesonephros, appear late in the 4th week and function until the final permanent kidney has developed. The mesonephric duct is the source of the collecting part of the permanent kidney in both males and females. It is also the source of the vas deferens, seminal vesicles and ejaculatory duct in males. These are efferent ductules derived from the mesonephric tubules. The permanent kidney, the metanephros begin developing early in the 5th week and begins function around week 9.

Details of urogenital development: Urinary System – Division of the Metanephros: The permanent kidney has a dual embryological source: the ureteric bud, also known as the metanephric diverticulum, and the metanephric mass. From the ureteric bud is derived the collecting system of the kidney, which includes the ureter, the renal pelvis, the calices, and the collecting tubules. The metanephric mass gives rise to the excretory system – the nephrons.

Details of urogenital development: Urinary System – Excretory Units: Development of the collecting and excretory systems is a process of dual or mutual induction. The former derives from the mesonephric duct via the ureteric bud; the latter from the caudal most segment of the nephrogenic cord called the metanephric blastema (see earlier slides). The branching of the metanephric diverticulum depends on an inductive signal from the metanephric mesoderm, and differentiation of the nephrons depends on the induction by the collecting tubules. This happens at the site of the red arrow. The components of
The excretory system are outlined here. The Glomerulus is a capillary tangle that is surrounded by the Bowman’s Capsule. Together they form the renal corpuscle. A renal corpuscle plus an excretory tubule (not tubercle) make up a nephron, which is shown in the blue bracket. A nephron plus its collecting duct makes up a uriniferous tubule.

The permanent kidney begins to function by around 8 weeks. By 11-13th weeks, roughly 20% of the nephrons are working. Urine formation continues throughout fetal life. Urine is excreted into the amniotic cavity and mixes with the amniotic fluid. By birth, normally all of the approximately 1 million nephrons are formed. Subsequent enlargement of the kidney is really an elaboration, therefore, of the existing nephrons and associated vessels.

Details of urogenital development: Urinary System – Rotation & “Ascent” of the Kidneys: Here we see, moving left to right, a schematic of the rotation and the “ascent” of the kidneys. The metanephric kidneys develop close together in the pelvis. As the abdomen and pelvis grow the kidneys gradually come to lie in the abdomen and move farther apart. They attain this adult position by the 9th week of development. This migration, which is really just a relative ascent, is a result mainly of the growth of the embryo’s body caudal to the kidneys. So really it is mostly that the caudal part of the embryo is growing away from the kidneys more so than the kidneys are progressing higher up in the abdomen. As the kidneys ascend, they rotate medially almost 90 degrees, such that by the 9th week the hilum is directed anteromedially. Note that the suprarenal (or the adrenal) gland develops independently of the kidneys, and only after “ascent” of the kidneys do they come into contact. Vessels that supply the kidney develop and then are re-absorbed normally during the ascent, during which time the hili rotate to face medially.

Details of urogenital development: Urinary System – Potential Errors in Development: Things can go wrong in the development of the kidney. Here is just a sampler of the potential errors that can occur during development. We will go into more detail in the upcoming slides.

URINARY SYSTEM – COMMON ABNORMALITIES: This is the short list of the common developmental abnormalities that you should definitely know something about.

URINARY SYSTEM – COMMON ABNORMALITIES – Supernumerary Vessels: Duplication of vessels is very common. Roughly 25% of people have more than one, which is to say a supernumerary, renal artery on a given side, and 2-4 arteries is not uncommon. Vein duplication occurs at a much lower frequency. Presumably, these are persisting vessels that failed to resorb during the ascent of the kidney. Occasionally, one of these vessels impacts on the outflow of urine as a structural obstruction as we see in the top right illustration.

URINARY SYSTEM – COMMON ABNORMALITIES – Unilateral Renal Agenesis: Unilateral renal agenesis is most likely due to the failure of a ureteric bud to develop from the mesonephric duct. Unilateral agenesis occurs in 1/1000 people, with 75% of these being males. Bilateral agenesis occurs 1/3000 people and is lethal. “Oligohydramnios” (a small amount of amniotic fluid in the sac) is a symptom since the fetus continues to drink the fluid without excreting anything out.

URINARY SYSTEM – COMMON ABNORMALITIES – Ectopic Kidney 1: Ectopia refers being “out of place.” An ectopic kidney is any kind of kidney that is not in its normal location. Here we see a right ectopic kidney still trapped in the pelvis. Again, note that the development of the adrenal gland (the cortex from mesoderm) (the medulla from the sympathetic nervous system) occurs independently of kidney development.
URINARY SYSTEM – COMMON ABNORMALITIES – Ectopic Kidney 2: Here we see another form of kidney ectopia. In this case we see a discoid or pancake kidney. Fusion of the kidneys likely resulted in the retention of the kidneys in the pelvis.

URINARY SYSTEM – COMMON ABNORMALITIES – Ectopic Kidney 3: Horseshoe kidneys occur 1/500 to 1/600 people, but up to 7% of females with Turner’s Syndrome express this form of ectopic kidney. Pediatric cancers of the kidney are more common in individuals with this type of ectopic kidney. Here notice how the inferior mesenteric artery traps the fused kidneys during ascent.

URINARY SYSTEM – COMMON ABNORMALITIES – Ectopic Kidney – Crossed Renal Ectopia: Here we see another kind of ectopic kidney. This is a crossed renal ectopia. The left kidney migrated to the right side and fused with the right kidney. Note the crossed ureters. This type of ectopia may have no symptoms.

URINARY SYSTEM – COMMON ABNORMALITIES – Pelvic Kidney and Divided Kidney with Bifid Ureter: Here we see combined kidney abnormalities. On the left there is a pelvic kidney and on the right there is divided kidney with a bifid ureter. The divided kidney is likely the result of an incomplete division of the ureteric bud during development.

URINARY SYSTEM – COMMON ABNORMALITIES – Malrotation of kidney and bifid ureter with supernumerary kidney: Here is another combined kidney abnormality. On the left you see an improperly rotated kidney. Note that the hilum still points laterally. On the right there is supernumerary kidney with a bifid ureter. This kidney abnormality was likely the result of a complete division of the ureteric bud but incomplete division of the developing ureter. Incomplete division of the ureter can lead to infections via asynchronous contractions and subsequent stagnation of urine is one of the 2 parts.

URINARY SYSTEM – COMMON ABNORMALITIES – Supernumerary kidney resulting from two ureteric buds: Here you see another example of a supernumerary kidney, this time resulting from two ureteric buds. Note how each kidney has its own ureter.

URINARY SYSTEM – COMMON ABNORMALITIES – Common Sites of Ectopic Ureteric Orifices 1: Here we see the common sites of ectopic ureteric orifices in males on the left, and females on the right. The downside to ureteric duplication and ectopia of ureteric orifices is incontinence in females. This is because the openings cannot be controlled by the sphincter urethrae.

URINARY SYSTEM – COMMON ABNORMALITIES – Common Sites of Ectopic Ureteric Orifices 2: Here is another slide showing the common sites of ectopic ureteric orifices in females. Note that the possible sites of ectopic opening are in the vagina, urethra and the vestibule.

URINARY SYSTEM – COMMON ABNORMALITIES – Polycystic Kidney: Here is an image of a polycystic kidney. There are at least 2 congenital varieties of polycystic kidneys, in which the functional tissue is sacrificed by the development of fluid filled cysts. The most common type is an autosomal dominant, which occurs in 1/500 – 1/1000 people, that progressively destroys the kidney, leading to dialysis and surgical replacements by adulthood. An autosomal recessive form is less common and more lethal. An
An extremely severe condition known as “multicystic dysplastic kidney” occurs rarely when collecting ducts and nephrons never develop at all – just cysts surrounded by undifferentiated cells.

**COMPLETING THE EXCRETORY SYSTEM – Formation of the Urinary Bladder and Urethra 1:** We now move away from abnormalities in development and shift our attention to the completion of the excretory system by way of the formation of the urinary bladder and urethra. The formation of these structures takes place through partitioning of the cloaca. Recall that the cloaca (= “sewer”) is that part of the hindgut. The cloaca is divided during development into an anterior urogenital sinus, to later become the bladder and the urethra, and a posterior anorectal canal. The cloaca is partitioned by 3 wedges of mesenchym: one is a coronal wedge known as Tourneux’s Fold, and the others are paired Rathke folds that “pinch off” the end of the cloaca. The result is an anterior (ventral) urogenital sinus and a posterior (dorsal) anorectal canal. In the images we see here, which span the 5th week to the 8th week of development, note the allantois, a diverticulum of the hindgut, is continuous with the developing urinary bladder, at least initially.

**COMPLETING THE EXCRETORY SYSTEM – Formation of the Urinary Bladder and Urethra 2:** Here we see the difference between the two sexes with females on the left and males on the right. Most of the male urethra and all of the female urethra is derived from the endoderm of the urogenital sinus. In males, the distal end of the urethra, the part within the glans, is derived from ectoderm. A cord of ectodermal cells extends from the tip of the glans to meet the endodermal spongy urethra.

**COMPLETING THE EXCRETORY SYSTEM – Septation of the Cloaca: Details:** The complete septation of the cloaca requires coordinated behavior between the three mesenchymal folds discussed previously: The Tourneux fold, and the left and right Rathke folds. Note as I mentioned, the Taurneux fold proceeds anteroventrally, while the right and left Rathke folds pinch toward the midline creating the urorectal septum.

**COMPLETING THE EXCRETORY SYSTEM – Problems: Septation of the Cloaca 1:** Problems can arise in septation of the cloaca by way of the failure of the Tourneux or Rathke folds to form properly. This may result in the development of a fistula between the rectum and the bladder.

**COMPLETING THE EXCRETORY SYSTEM – Problems: Septation of the Cloaca 2:** A number of varieties of possible fistulae can occur if the partitioning of the cloaca is incomplete or improper.

**COMPLETING THE EXCRETORY SYSTEM – Problems: Urachal Anomalies:** As I noted earlier, the allantois is initially continuous with the bladder. If the allantois fails to undergo complete involution into a fibrous urachus, then there is the potential for infection and communication between the bladder and the outside world. These urachal anomalies can take a number of forms several of which are shown here: the top being the formation of urachal cysts; the middle that is an urachal sinus, or an opening between the bladder and the adult umbilicus; and third is a patent urachus or urachal fistula that connects the bladder and umbilicus.