

An Animated Detailing of the Alimentary Canal of the Asian Citrus Psyllid, with Special Reference to the Configuration and Function of the Filter Chamber

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Among the superfamilies of the deprecated order Homoptera, particularly Auchenorrhyncha (cicadas, sharpshooters, etc.) and Sternorrhyncha (psyllids, whiteflies, aphids, etc.), the midgut and its ligations to the foregut and hindgut are complexed into a functional kidney that extracts the physiologically excessive volume of water from the foodstream of host plant sap, and shunts it directly to the hindgut for disposal. This process concentrates the foodstuff and obviates dilution of the hemolymph.

Among these taxa, the configurations of this structure are complex and diverse. The last formal review was included by AJP Goodchild (1966) in his landmark paper *Evolution of the Alimentary Canal in the Hemiptera*. Since then perhaps 50 papers dealing with filter chamber anatomy and physiology have been published.

Attention was first called to the Asian citrus psyllid digestive anatomy by Dr. Michael J. Davis of the University of Florida's Citrus Research and Education Center, Lake Alfred, Florida with his discovery that the organ and associated canals were covered with biofilms of the bacterium "*Candidatus* Liberibacter asiaticus, causal agent of citrus greening disease. This finding was followed by Cicero et al. (2009), Ammar et al. (2011a, b), and Brown et al. (2016) covering anatomy, localization and pathology.

As with most modern treatises in insect anatomy, terminology and descriptive text can be very dense and difficult for broader audiences to study, owing mostly to the incogitable complexity of the organ at the histological, cytological and biochemical levels. In response to this problem, we present an animated showcase of the Asian citrus psyllid alimentary canal in an easy to follow format that requires only a basic understanding of the insect digestive system.

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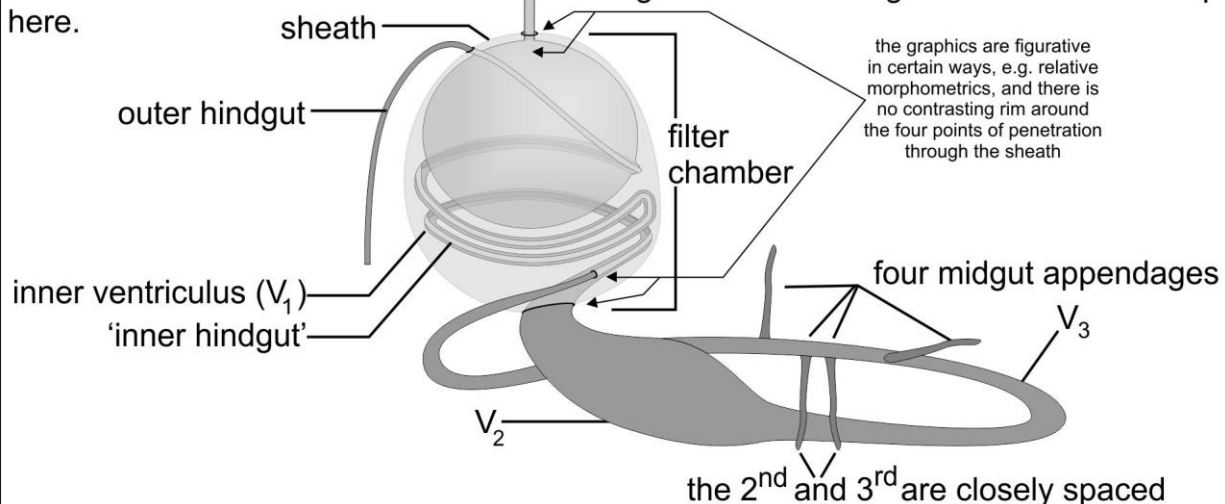
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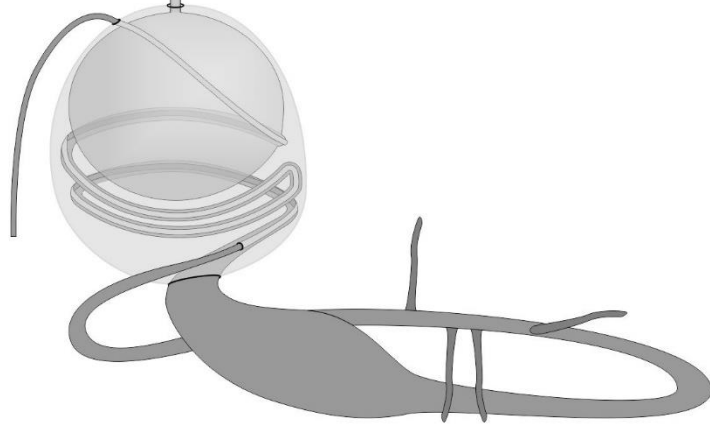
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The alimentary canal of the Asian citrus psyllid consists of a foregut, hindgut, and a highly modified midgut. The foregut is herein represented by the esophagus. The hindgut is herein represented by the 'outer hindgut'. The midgut consists of three ventricular sections (V_1 , V_2 , V_3), and a sheath that envelopes V_1 . V_2 and V_3 occur outside the sheath. The so-called 'inner hindgut' is a terminological issue not taken up here.

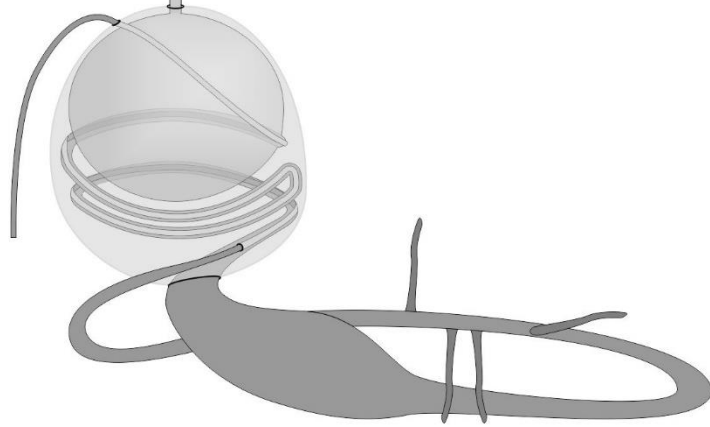


Segment 1. The esophagus is a thin ectodermal tube extending from the oral region, through the thorax, and into the abdomen where it empties into the filter chamber.

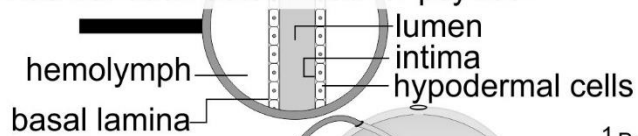


The filter chamber extracts excess water from imbibed phloem fluid and shunts it to the hindgut so that it doesn't dilute the foodstuff or the hemolymph.

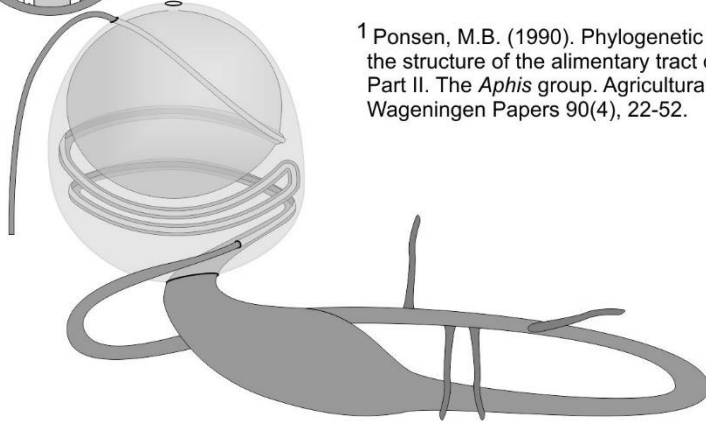
The esophagus and outer hindgut are more or less taught, confining the filter chamber to the base of the abdomen.



Since it is ectodermal, it has a cuticular intima that lines the lumen. In aphids, the exuvial esophageal intima remains in the foregut or is pushed back into the stomach¹ but this has not been determined for psyllids.



¹ Ponsen, M.B. (1990). Phylogenetic implications of the structure of the alimentary tract of the Aphidoidea. Part II. The *Aphis* group. Agricultural University Wageningen Papers 90(4), 22-52.

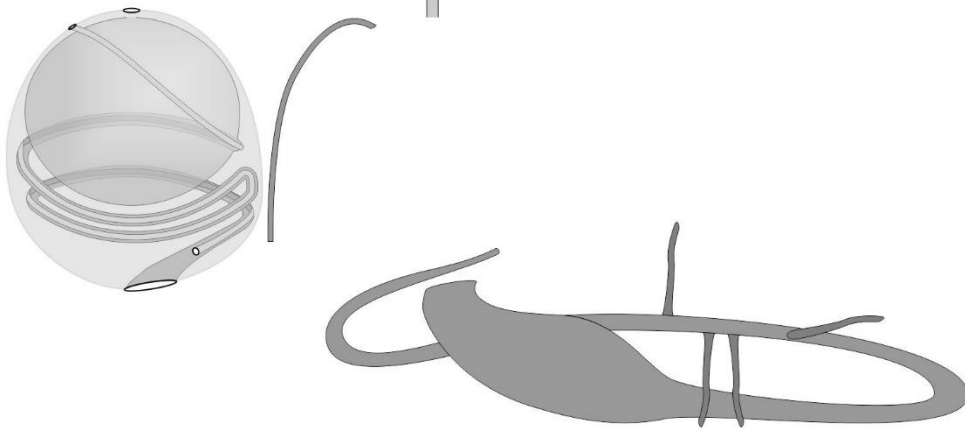


Segment 2: The filter chamber consists of two luminal component tubes enveloped by a sheath.

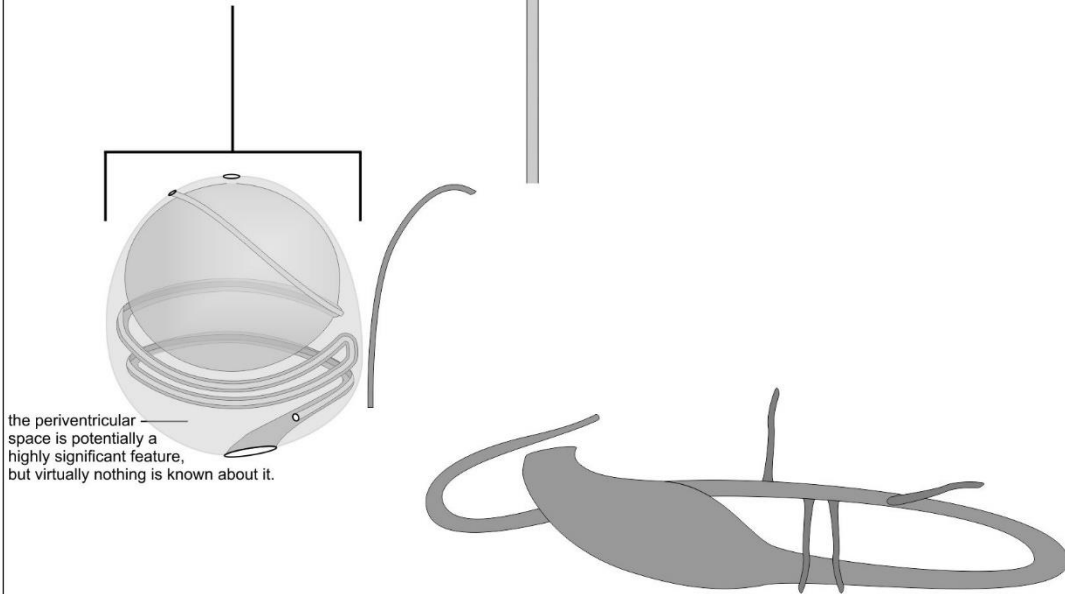
the **inner ventriculus**, also called the 1st ventriculus or V_1 , with its with two distinct sections, upper V_1 and lower V_1

the **inner hindgut**, also called the inner midgut or posterior midgut

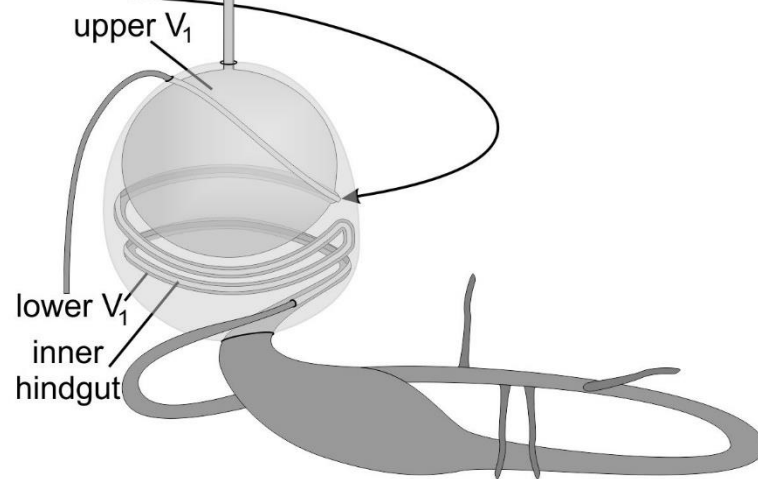
the **sheath**



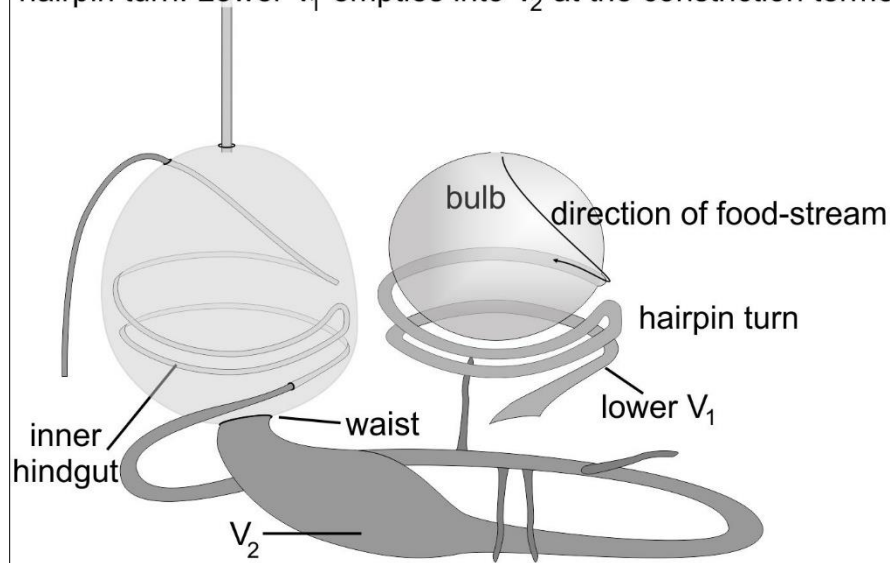
The filter chamber isolated



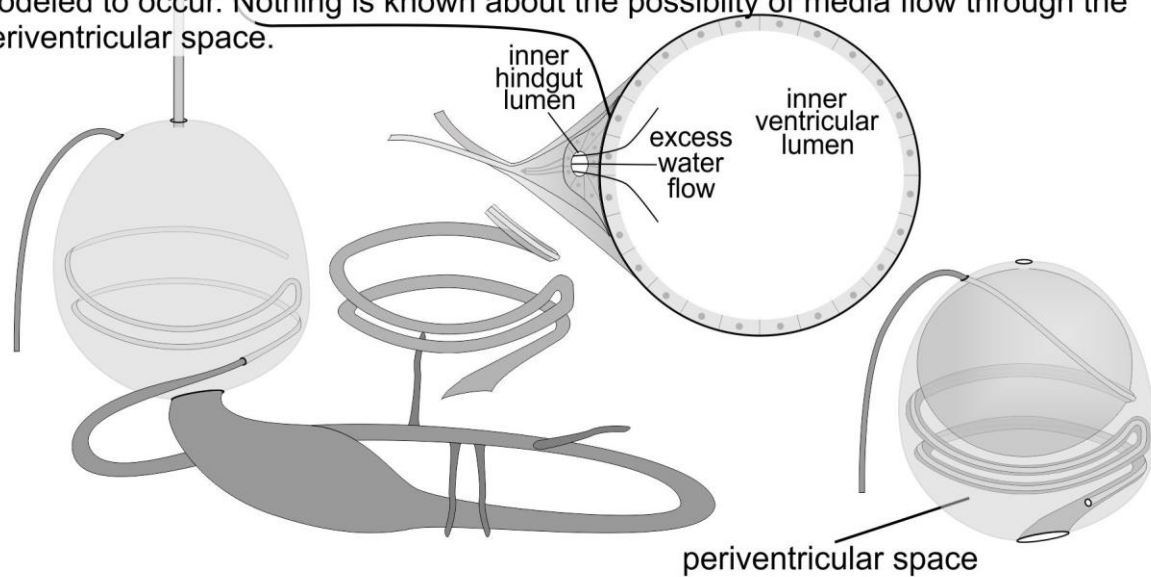
The inner, or 1st, ventriculus (V_1) consists of 'upper V_1 ', also called the 'bulb', that abruptly decreases in diameter where it continues as 'lower V_1 '. The bulb is in a homologous, or at least analogous, position to the midgut stomach of aphids.



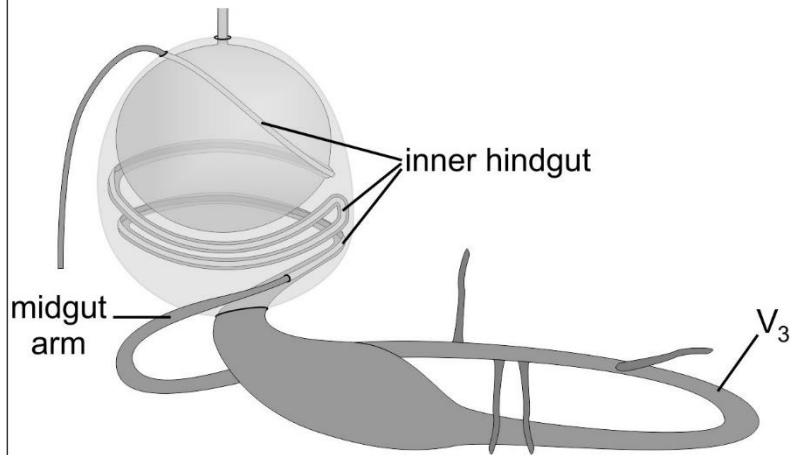
Lower V_1 winds around the bulb, herein drawn to the rear, and has a characteristic hairpin turn. Lower V_1 empties into V_2 at the constriction termed the "waist".



It is spindle-shaped and appressed against the full length of the inner ventriculus. Called the 'zone of contact', the interface is where translocation of excess water is modeled to occur. Nothing is known about the possibility of media flow through the periventricular space.

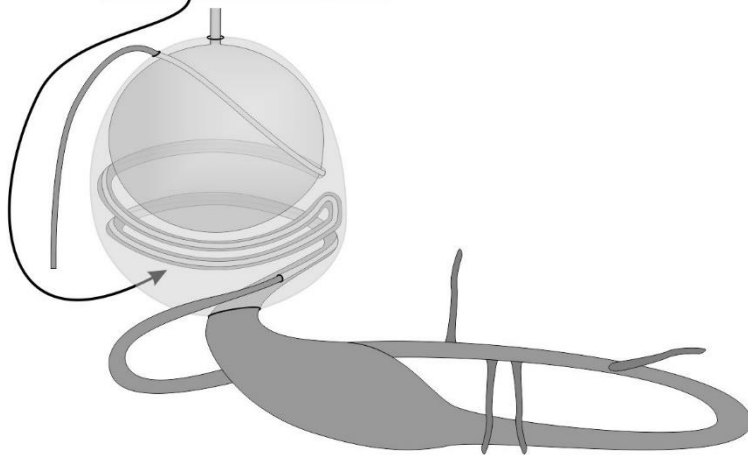


The inner hindgut is so termed for its function as recipient waste water from imbibed foodstuff, and recipient of waste products of digestion from the 'midgut arm' of the 3rd ventriculus (V_3 or the 'midgut loop').

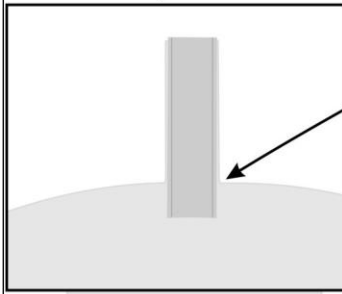


The filter chamber sheath is a thin envelope of unknown embryological origin and unknown permeability.

The sheath envelops the inner ventriculus, holding it together in its functional configuration and creating a periventricular space of unknown function and unknown fluid constituent.



The sheath may be cellular in nature¹. The presence of a basal lamina is indicated by its smooth, seamless continuity with the esophagus².

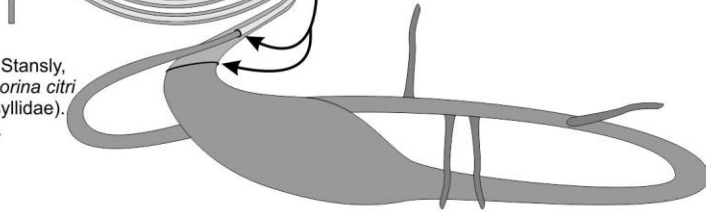


This continuity probably also occurs here

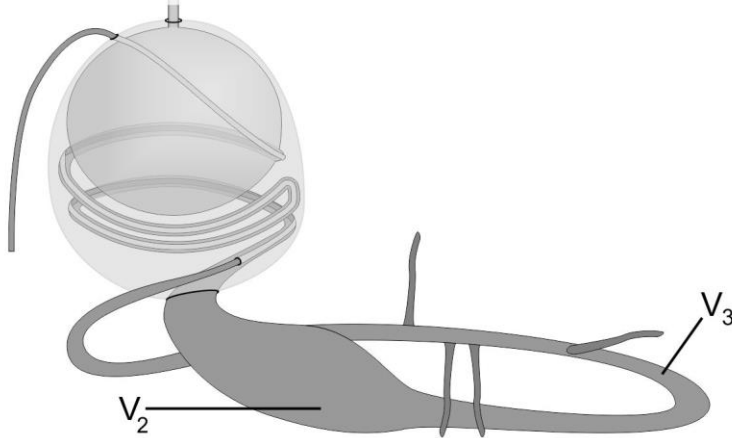
²Brown, JK, Cicero, JM, Fisher, TW 2016. Psyllid-transmitted *Candidatus Liberibacter* species infecting citrus and solanaceous hosts. Chapter 28:408, f. 28.6 IN: JK Brown, ed. Vector-mediated transmission of plant pathogens. American Phytopathological Society, St. Paul, Minn.

and here

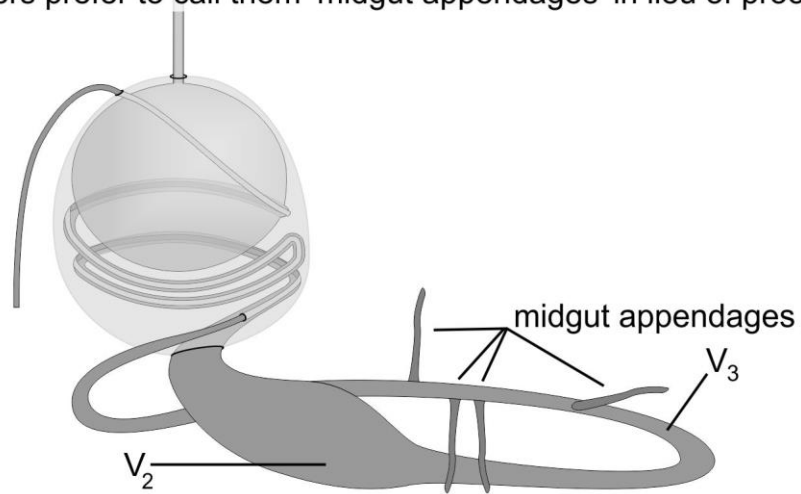
¹Cicero, JM, Brown, JK, Roberts, PD, and Stansly, PA (2009). The digestive system of *Diaphorina citri* and *Bactericera cockerelli* (Hemiptera: Psyllidae). Ann. Entomol. Soc. Am. 102(2):655, f. 4a.



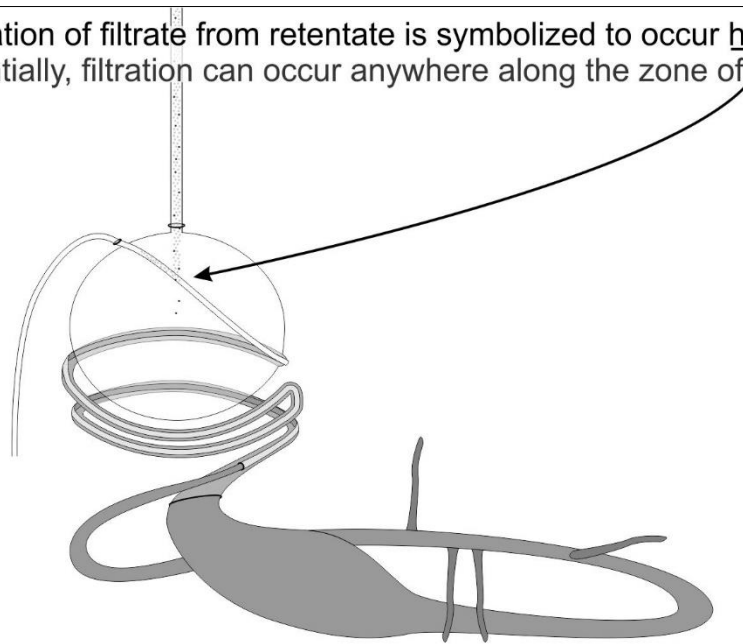
The 2nd ventriculus, or V_2 , is the least characterized of all the midgut components. By its size and the known function of V_1 and V_3 , namely water filtration and digestion, respectively, it can be inferred to function as a storage crop. Without it sustenance would be limited to the ongoing volume generated by V_1 . Since V_2 is continuous with the midgut loop, it may also function in digestion, but this consideration is unstudied.



The 3rd ventriculus, V_3 or 'midgut loop', is the organ of digestion. V_3 bears four short, stout appendages of controversial identity. Although they are not long and thin, nor located in the primitive position for Malpighian tubules, some authors consider them to be Malpighian while others prefer to call them 'midgut appendages' in lieu of proof of function.



In this sequence, separation of filtrate from retentate is symbolized to occur here, but it is expected that, potentially, filtration can occur anywhere along the zone of contact.



The foodstream passes down the esophagus and into the bulb. Water molecules (gray) and possibly other solutes are filtered into the inner hindgut while the retentate proteins and other foodstuffs (black) are passed to V_2 . Equipped with a visual model like this one, many questions can now be tabled.

the sheath is removed

