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Authors: Růžička, Vlastimil, and Růžička, Adam

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Three-dimensional modelling in arachnology as exemplified using *Porrhomma*-species (Araneae: Linyphiidae)

Vlastimil Růžička & Adam Růžička



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Abstract. Three-dimensional modelling has shown its importance in many fields, including zoological systematics. It is difficult to distinguish females of *Porrhomma egeria* Simon, 1884 and *P. campbelli* F. O. Pickard-Cambridge, 1894 according to only dorsal and ventral views of the vulva. The same is true for the pair *P. microps* (Roewer, 1931) and *P. profundum* Dahl, 1939. A caudal view is necessary to distinguish the vulvae of these species pairs. A 3D model combines all important views of the female genitalia (ventral, dorsal, lateral and caudal) into a single unit.

Keywords: 3D modelling, female genitalia, *Porrhomma egeria*, *Porrhomma campbelli*, *Porrhomma microps*, *Porrhomma profundum*, spiders

Zusammenfassung. Dreidimensionale Modelle in der Arachnologie am Beispiel von *Porrhomma*-Arten (Araneae: Linyphiidae). Dreidimensionale Modelle haben in vielen Bereichen eine Bedeutung, einschließlich der zoologischen Systematik. Die Weibchen von *Porrhomma egeria* Simon, 1884 und *P. campbelli* F. O. Pickard-Cambridge, 1894 sind lediglich nach der dorsalen und ventralen Ansicht der Vulva schwierig zu unterscheiden. Gleiches gilt für das Artenpaar *P. microps* (Roewer, 1931) und *P. profundum* Dahl, 1939. Die caudale Ansicht ist zur Unterscheidung der Vulven dieser Artenpaare notwendig. Ein 3D-Modell vereint alle wichtigen Ansichten des weiblichen Genitals (ventral, dorsal, lateral und caudal).

The spider genus *Porrhomma* Simon, 1884 is one of the most unpopular among arachnologists, because of the difficulty of species identification. Differentiating species represents a problem, particularly among females with similar genitalia. Usually, dorsal and ventral views of the vulva are provided (Thaler 1991); this is, however, insufficient in some cases. Růžička (2018) added lateral and caudal views to understand the spatial structure of the copulatory ducts and spermathecae in *Porrhomma*. To comprehend the complicated structure of copulatory ducts in *Habnia* C. L. Koch, 1841, Kovblyuk et al. (2017) used a schematic illustration of the copulatory ducts consisting of one line, which followed the spatial course of the ducts. We were inspired by Qing et al. (2015), who recommended 3D models and 3D prints to visualize important morphological characters in nematodes. Here, we (1) recommend the use of 3D models to describe and distinguish female genitalia in spiders and (2) document the advantage of 3D models in distinguishing two pairs of similar species belonging to the genus *Porrhomma*.

Material and methods

Specimen preparation and study

Spiders were examined with an Olympus SZX-12 stereomicroscope in 80 % ethanol. The vulva was separated from the opisthosoma using a scalpel and passed through 40 %, 20 % ethanol and distilled water to 10 % sodium hydroxide, which digests soft structures at room temperature. Subsequently, it was coloured in an ethanol solution of chlorazol black (for details see Růžička 2018).

Further details were studied with an Olympus BX-40 compound microscope, and photographs were taken with an Olympus C-5060 wide zoom digital camera mounted on the

microscope. The photos were montaged using CombineZP image stacking software. The photo was used as a background layer in the Inkscape Vector Drawing Program, the line drawing was prepared and the printed image was detailed by hand. A 3D model was created in Blender 3D, based on the combination of photos and line drawings. Spermathecae are brown, copulatory ducts are blue (cf. Figs 1 and 2 with Fig. 4 in Růžička 2018). The final model can be rotated and observed in the program from any angle.

Female genitalia

The female genitalia usually consist of sclerotized plates, copulatory ducts, spermathecae and fertilisation ducts. In *Porrhomma*, copulatory ducts start with a copulatory opening in the aperture. Behind a side loop, they continue by an ascending (in ventral view) part above the aperture wall to the median plane, closely under the integument. The spermatheca is formed at the end of the copulatory duct. It consists of a broader main sack with a slender appendix.

Results

Porrhomma egeria Simon, 1884 versus

Porrhomma campbelli F. O. Pickard-Cambridge, 1894

In these two species, the spermathecae are formed immediately behind the side loop under the ventral body wall, starting at the midway of the ascending part of the copulatory ducts. Appendices of *P. egeria* are oriented usually to the side (see Fig. 633.3 in Thaler 1991), appendices of *P. campbelli* are oriented usually to the median line (see Fig. 634.3 in Thaler 1991), but not in all cases; cf. Figs 8a and 9a in Thaler (1968). The main sacks of these two species are hardly distinguishable in ventral and dorsal views (Figs 1c, d; cf. also Figs 8a, b and 9a, b in Thaler 1968, and Figs 21D, F and 15D, F in Růžička 2018).

The principal difference between the form of the main sacks of these two species is visible in caudal view. In *P. egeria*, the main sacks end at the base of the appendices and the axes of their end part are convergent; i.e. they are directed towards the centre of the opisthosoma (Fig. 1a). In *P. campbelli*, the main sacks reach deeper inside the opisthosoma, they are cur-

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Vlastimil RŮŽIČKA, Czech Academy of Sciences, Biology Centre, Institute of Entomology, Branišovská 31, CZ-370 05 České Budějovice, Czech Republic; E-Mail: vruz@entu.cas.cz
Adam RŮŽIČKA, Mánesova 21, CZ-370 05 České Budějovice, Czech Republic; E-Mail: ruzicka.adam@email.cz

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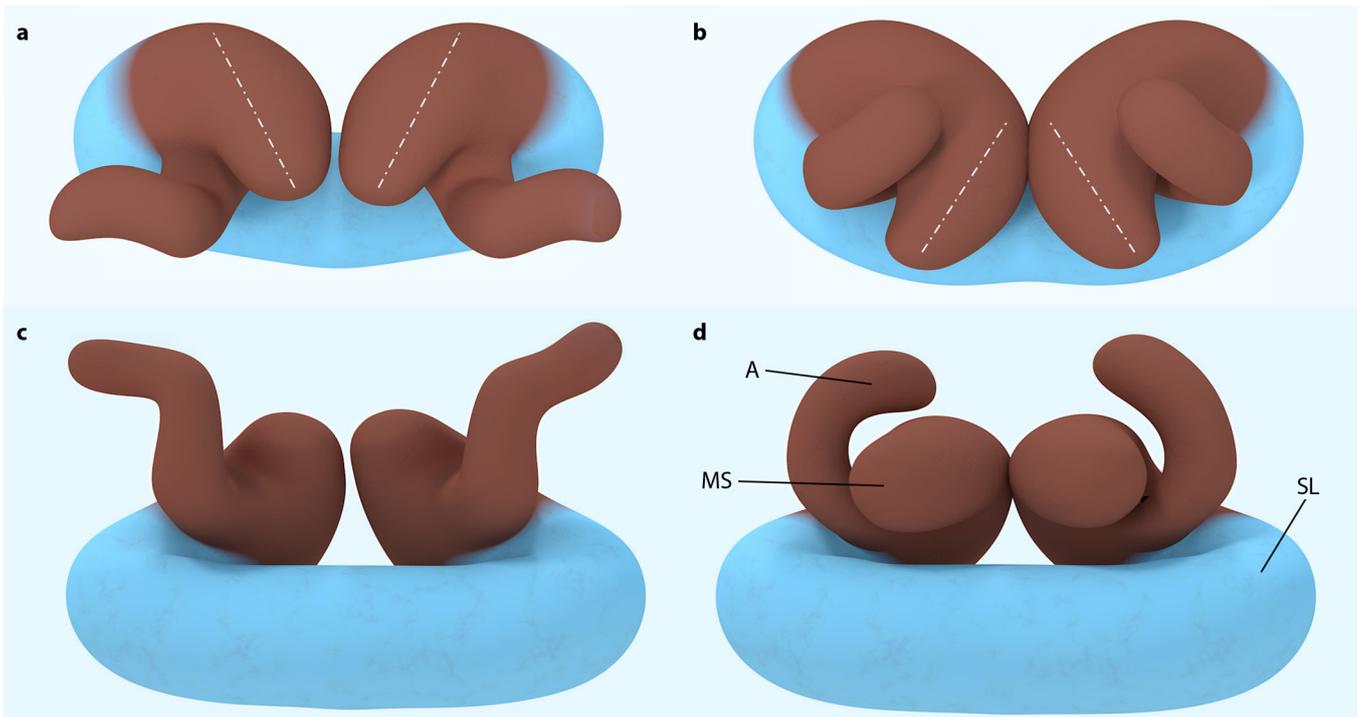


Fig. 1: A model of the caudal (a,b) and dorsal (c,d) views of the vulvae. **a, c.** *Porrhomma egeria*; **b, d.** *Porrhomma campbelli*. Abbreviations: A, appendix; MS, main sack; SL, side loop;  axes of the end part of the main sacks

ved around the appendices, and the axes of their end part are divergent; i.e. they are directed oblique laterally (Fig. 1b). In the 3D model, all these differences are clearly visible.

***Porrhomma microps* (Roewer, 1931) versus *Porrhomma profundum* Dahl, 1939**

In these two microphthalmic species, the copulatory ducts have a broad side loop and ascending part, and the sperma-

thecae are situated deeper in the opisthosoma. All species of the *microphthalmum*-group are characterised by a conspicuous fold, which is formed in the uppermost part of the vulva (Růžička 2018). Vulvae are hardly distinguishable in ventral and dorsal views (e.g., Miller & Kratochvíl 1940).

The main difference is visible in caudal view. The fold is very conspicuous in *P. microps* (Fig. 2a), but it is not as tight in *P. profundum* (Fig. 2b). Moreover, the inner branch

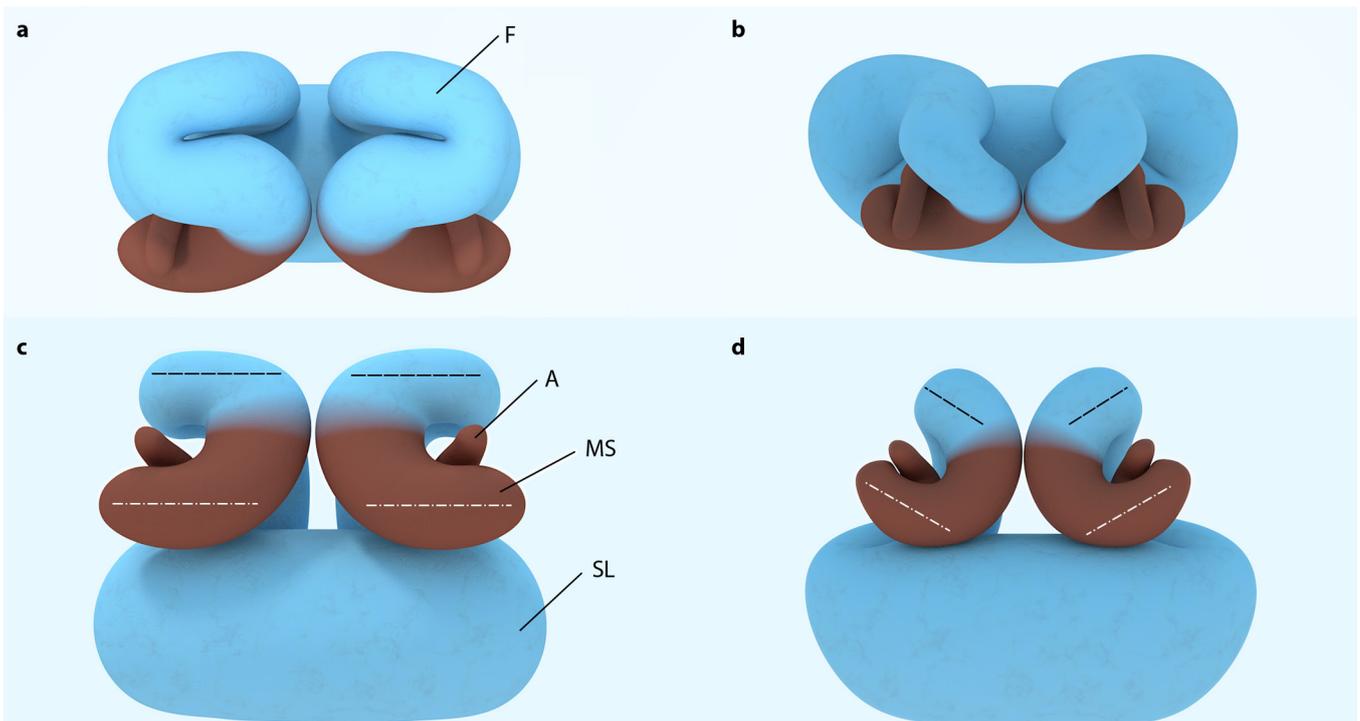


Fig. 2: A model of the caudal (a, b) and dorsal (c, d) views of vulvae. **a, c.** *Porrhomma microps*; **b, d.** *Porrhomma profundum*. Abbreviations as in Fig. 1. F, fold of the copulatory duct;  axes of the end part of the main sacks;  a course of the inner part of the fold

of the fold goes directly towards the median plane in *P. microps* (Fig. 2c), whereas it goes obliquely in *P. profundum* (Fig. 2d). The whole main sacks are oriented to the sides in *P. microps* (Fig. 2c), whereas they are oriented obliquely upwards in *P. profundum* (Fig. 2d). In the 3D model, all differences are clearly visible.

Models are freely available to view on:

<http://adamruzicka.cz/porrhomma/>

Discussion

A 3D model combines ventral, dorsal, lateral and caudal views and represents a good approach to understand the spatial structure of the vulva. The accuracy of the final reconstruction is not comparable to that using micro-computed-tomography and serial sectioning and visualization using 3D-reconstruction software (e.g. Runge & Wirkner 2016). 3D modelling is not meant to provide a completely realistic image, rather to present morphological aspects in a more comprehensible way.

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