Going with the flow: Novel insights into the composite nature of water flow in roots

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Context Root radial conductivity (k_r) constitutes a major hydraulic resistance for water in the soil-plant-atmosphere continuum. Yet, the complex organization and regulation of sub-cellular elements such as **aquaporins** and **plasmodesmata** limit our understanding of this system.

Goals Unify root hydraulic principles **across scales** & reinterpret experiments under the light of an **explicit root hydraulic anatomy** model (MECHA)

Model description

MECHA computes water flow across plasmodesmata, cell walls and membranes throughout a root cross-section (panels **d**, **e**, **f**).

Aggregating fluxes at higher scales yields root segment properties (panels **g**, **h**).

Model parameters

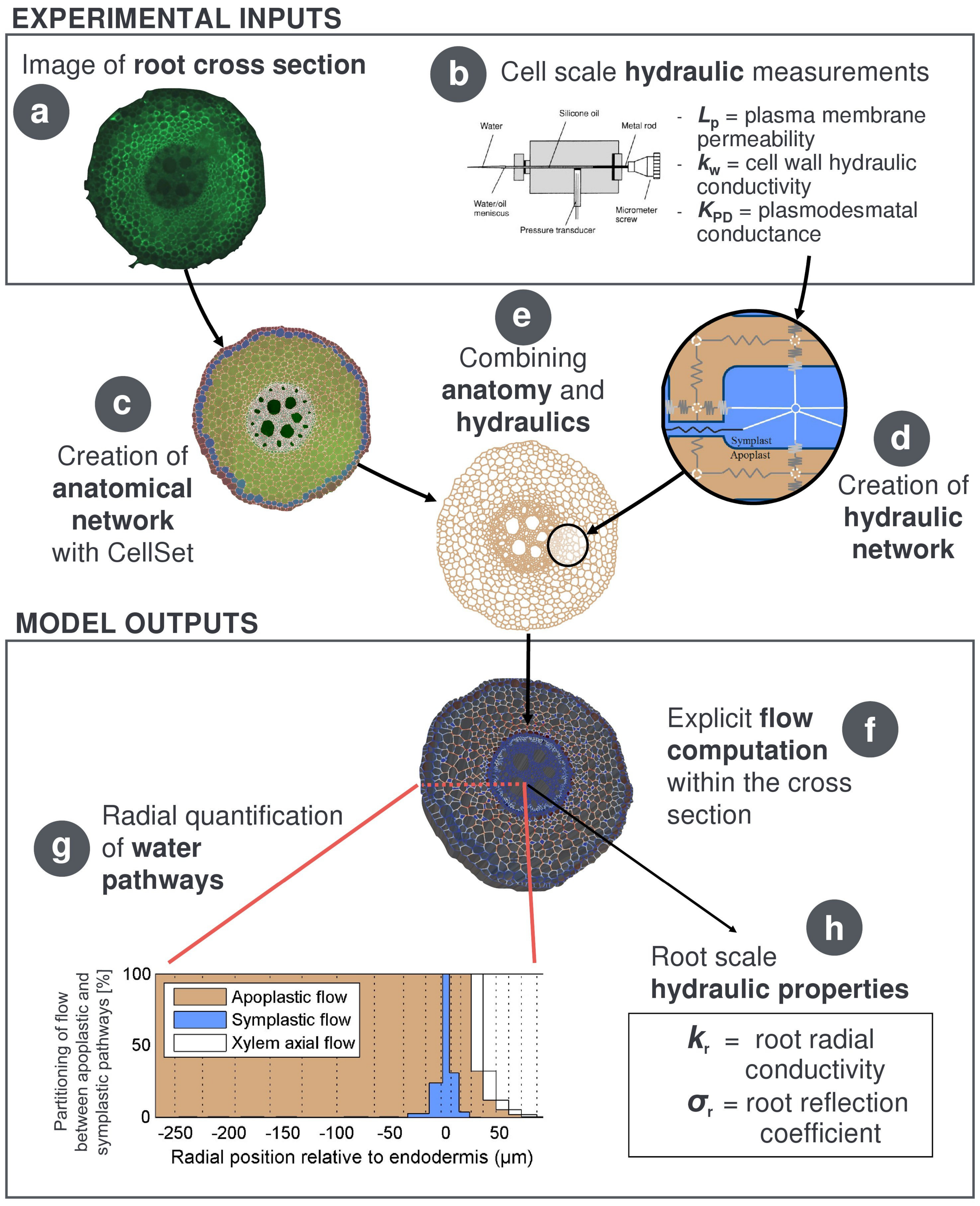
Root anatomical pictures digitized with the software CellSet (panels **a**, **c**).

Cell hydraulic properties from the literature (panel **b**):

Wall k_w $m^2 s^{-1} MPa^{-1}$
Low: $1.4\ 10^{-10}$ High: $7.7\ 10^{-8}$

Plasmodesmata K_{PD} $m^3 s^{-1} MPa^{-1}$
Low: $6.1\ 10^{-19}$ High: $3.5\ 10^{-18}$

Membrane L_p $m\ s^{-1} MPa^{-1}$
Default: $5.3\ 10^{-7}$

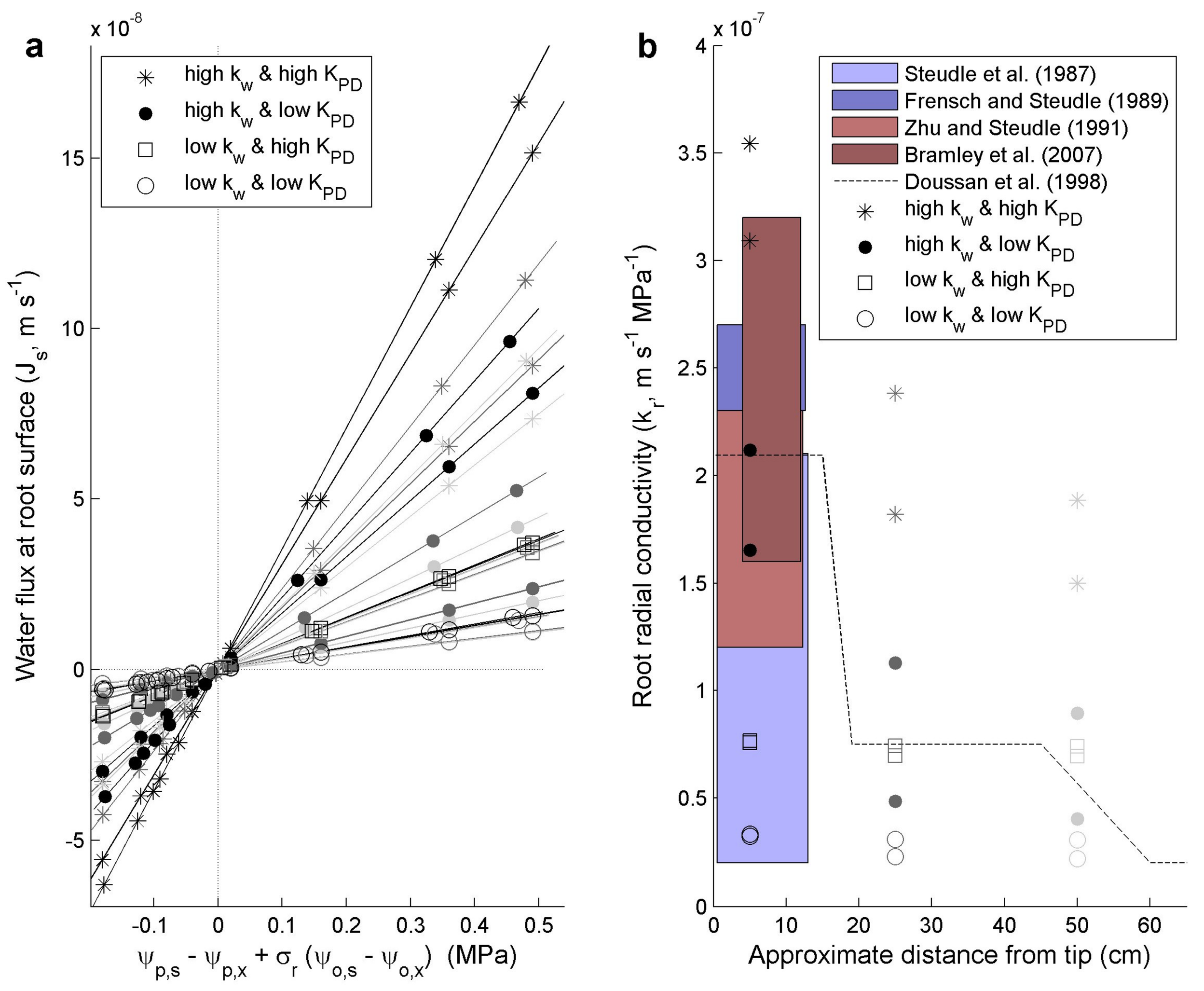


Schematic overview of the parametrization, core, and outputs of the "Model of Explicit root Cross-section Hydraulic Anatomy": MECHA

① Hydraulic theories are compatible across scales !

Water fluxes at root surface simulated from cell hydraulic principles (symbols in panel **a**) match the simplistic root cylinder model of Fiscus & Kramer (1975) (lines in panel **a**), regardless of apoplastic barrier leakiness.

Upscaled root k_r match empirical measurements when using relatively high k_w and low K_{PD} values from the literature (see legend in panel **b**).



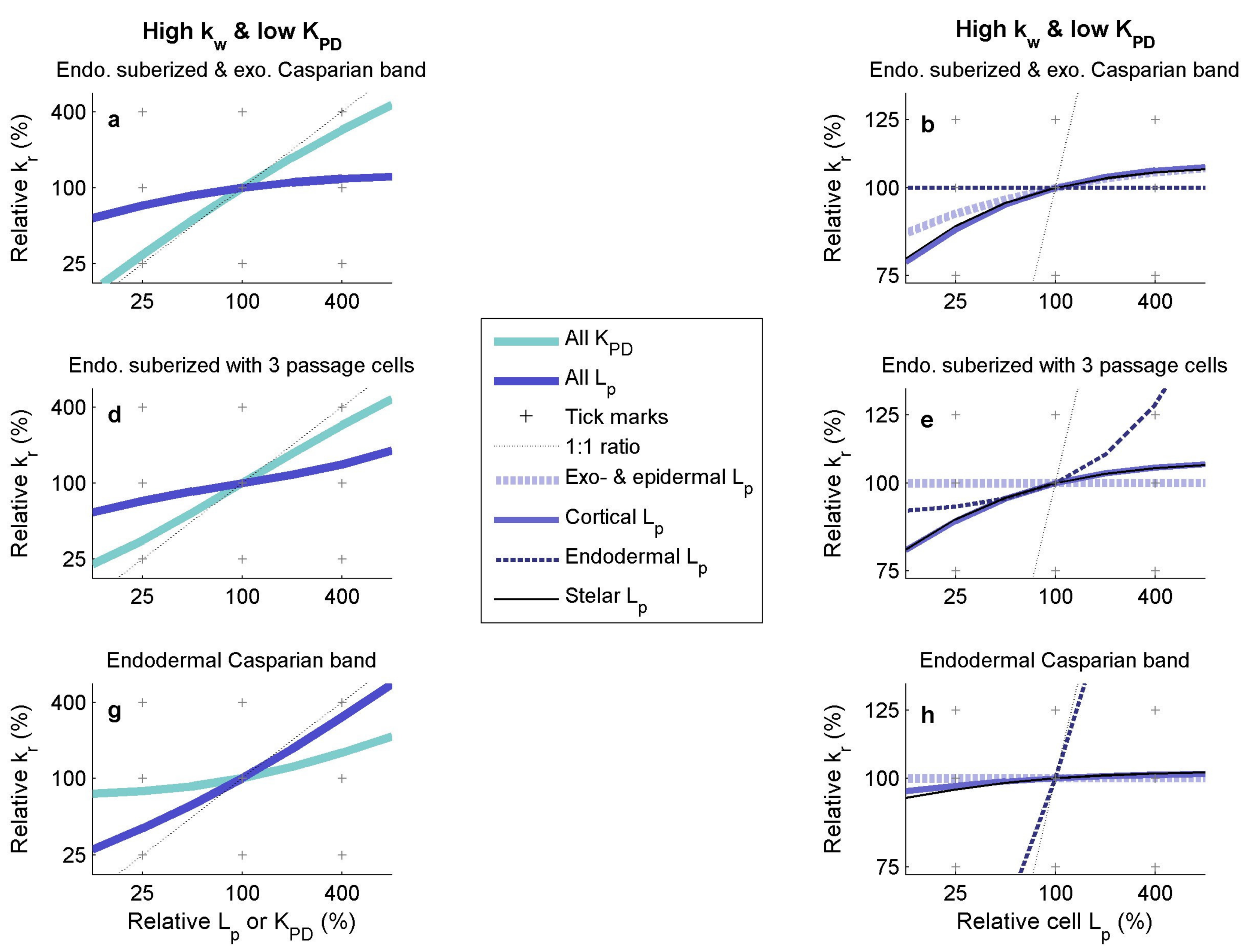
(a) Water fluxes predicted from both scales (b) Comparison of measured and predicted k_r

② Root k_r can be independent from cortical cell L_p !

In the root region bearing a simple endodermal Casparian strip, cell L_p is the main property controlling root k_r (panel **g**).

Endodermal L_p controls 69% of k_r variability, while cortical L_p controls less than 1% (slopes in panel **h**) → Explains why k_r may vary independently of cortical L_p (Hachez et al., 2012).

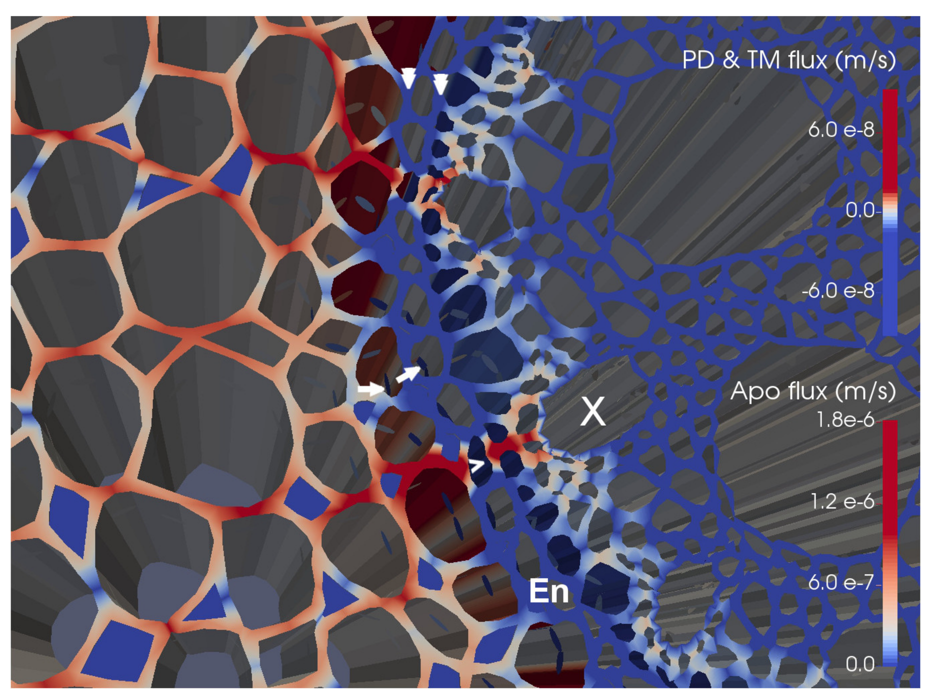
In suberized regions of the root, plasmodesmata would become the main driver of root k_r (up to 73% of the sensitivity, panel **a**).



Sensitivity analysis of k_r to L_p and K_{PD} in all cells (left panels) and in specific cell layers (right panels) at several levels of apoplastic barrier deposition

③ Plasmodesmata would massively contribute to radial water flow !

Water converges toward passage cells, where transmembrane flow (see > symbol) represents 10% of the total flow. Plasmodesmata (see → symbols in the figure) are responsible for 90% of radial flow at the endodermis.



Cell scale apoplastic, transmembrane, and plasmodesmatal fluxes (resp. transversal, longitudinal surfaces and ellipsoids).

References:

Couvreur V., Faget M., Lobet G., Javaux M., Chaumont F., Draye X. (2017) "Novel multiscale insights into the composite nature of water transport in roots" **bioRxiv** 147314; https://doi.org/10.1101/147314

Fiscus E. L., Kramer P. J. (1975) "General model for osmotic and pressure-induced flow in plant roots" **Proc. Natn. Acad. Sci. U.S.A.** 72(8): 3114-3118

Hachez C., et al. (2012). "Short-term control of maize cell and root water permeability through plasma membrane aquaporin isoforms" **Plant Cell Environ.** 35(1): 185-198.

Web application: plantmodelling.shinyapps.io/mecha/

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