Critical evaluation of mathematical formulas describing the nasal air stream by air flow simulation and computational fluid dynamics (CFD)

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Formulas frequently applied in clinical rhinology

- 1. HAGEN-POISEUILLE

$$\boxed{R = \frac{8\eta l}{\pi r^4}}$$

Basic formula in fluid dynamics describing the flux through tubes

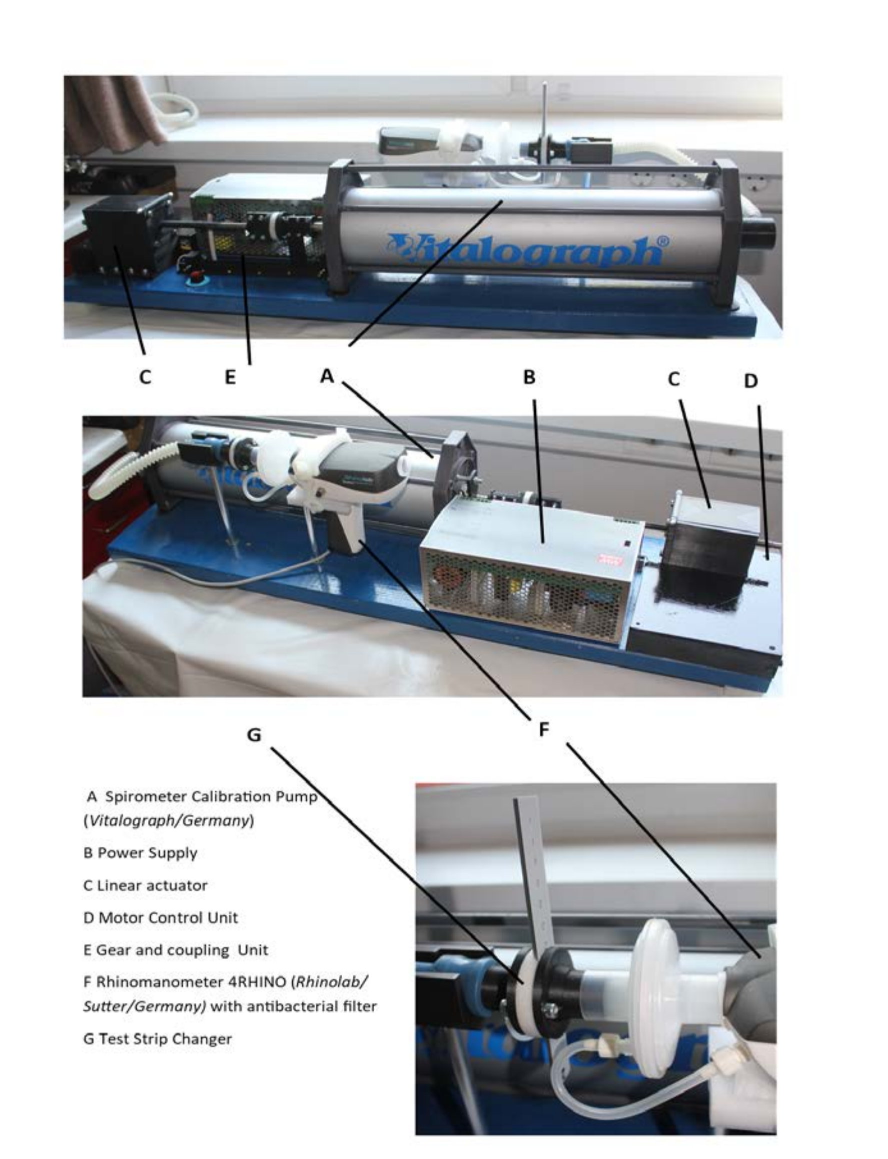
- 2. KIRCHHOFF´S rule

$$\boxed{R_{Tot} = \frac{R_{right}\, R_{left}}{R_{right} + R_{left}}}$$

Calculates the total electric resistance from 2 parallel electric resistors. Applied in rhinology for the calculation of total nasal resistance from 2 unilateral resistances because the measurement of the total nasal resistance by posterior rhinomanometry is sometimes unreliable

Simulation of the nasal airstream as tool for reproducibility and quality management

- Since 1989, i.e.during the development of the rhinomanometers CARIMA,HRR 2,HRR3 and 4RHINO also simulators for the visualisation of the nasal air stream have been developed by us.The analysis of different typical cavities lead to the creation of types in rhinomanometry
- Contemporary step motors and linear actuators can be used to set up precisely working pumps which are digitally controlled by appropriate programs. These techniques are integrated in the „Artificial Noses“ ARNO 4 and ARNO 5.

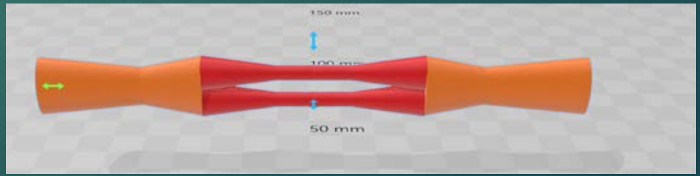


Application of simulators

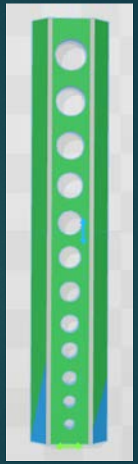
- Controlling the measurement results of different rhinomanometers and correction of the calibration under dynamic conditions
- Simulating the nasal air stream through different streaming bodies comparable to the anatomy of the nose
- Generating reproducable flux to check the dependency of pressure and flow from shape, length and diameter of the streaming body

Tube, symmetric funnels

Tube, asymmetric funnel

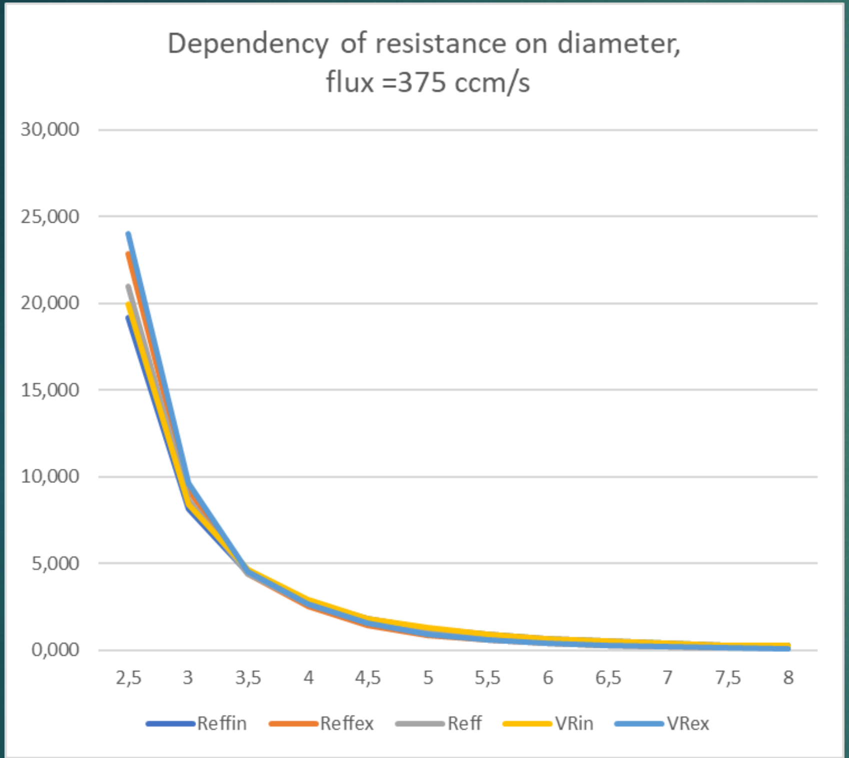


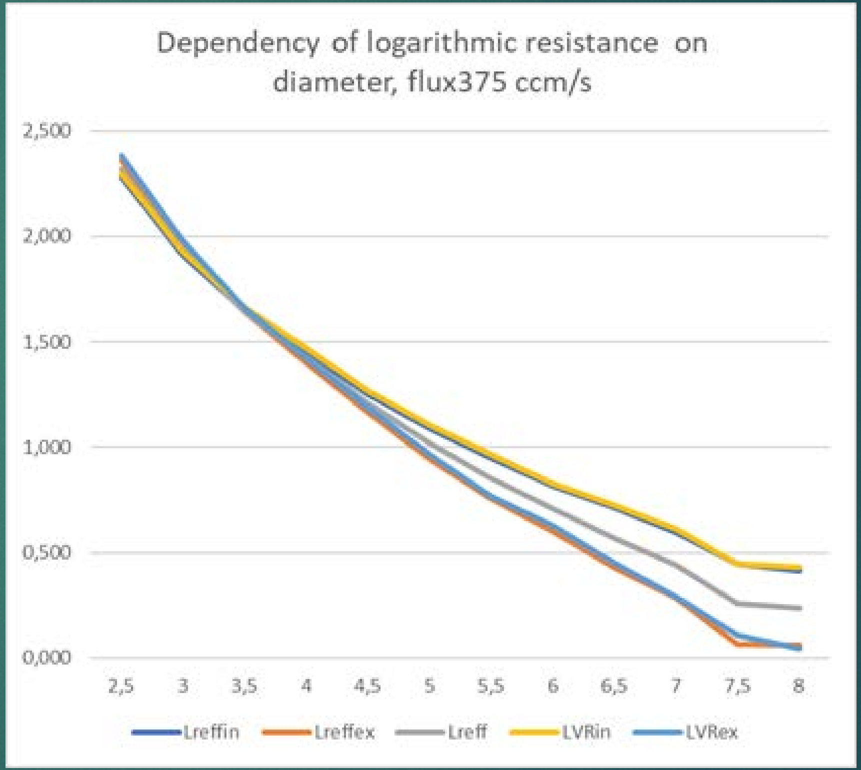
2 parallel tubes, 2 funnels



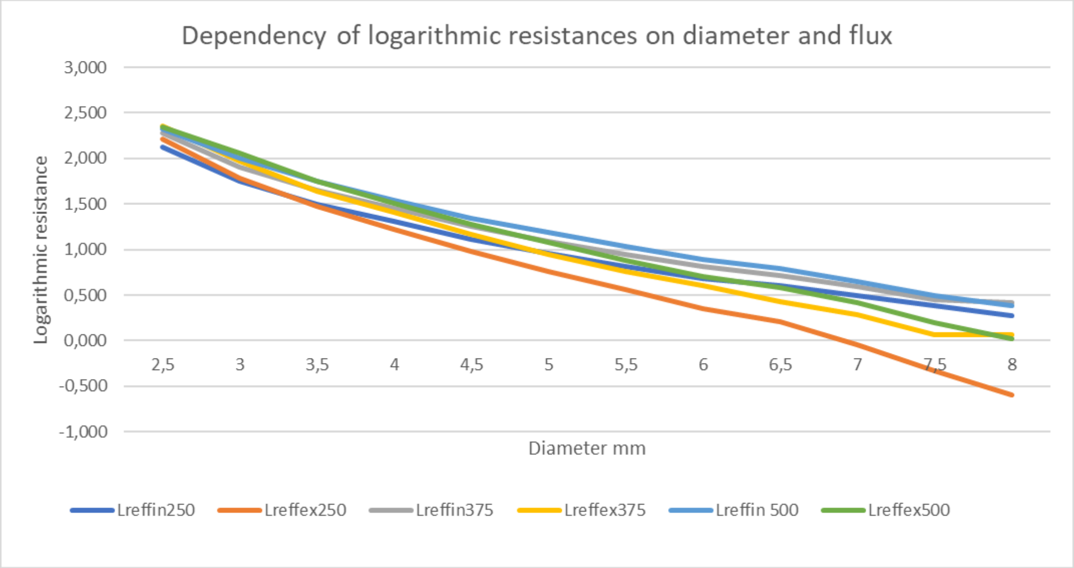
Holestrip, 2.5-8 mm thickness 3.5mm

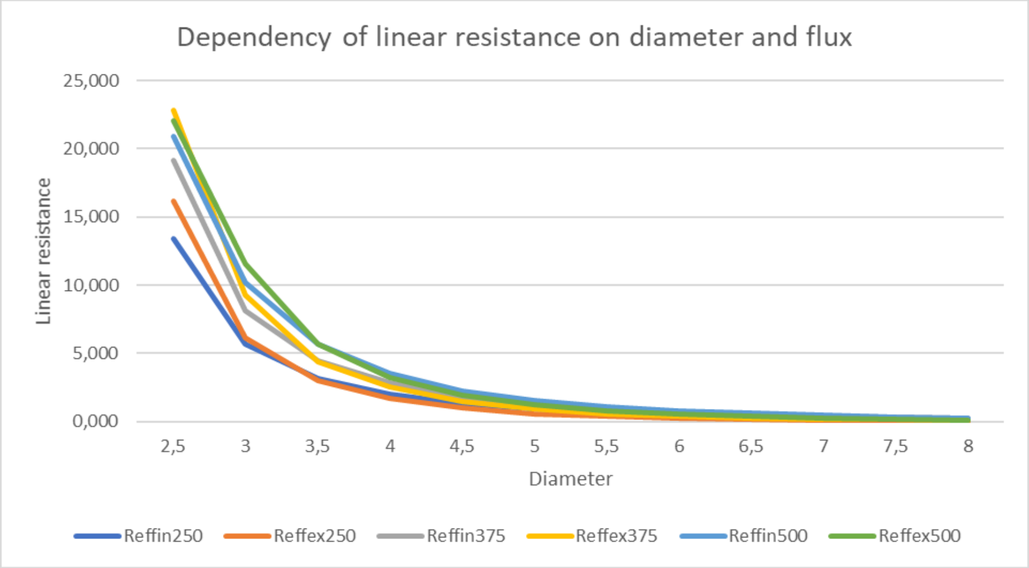
Testing resistance parameters depending on diameters and flux in orifices

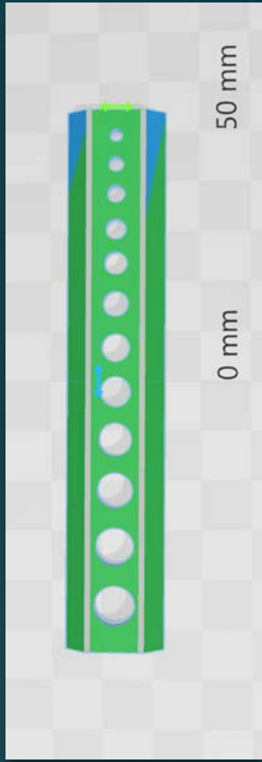




Results 1: Dependency of resistance on diameter and flux in orifices







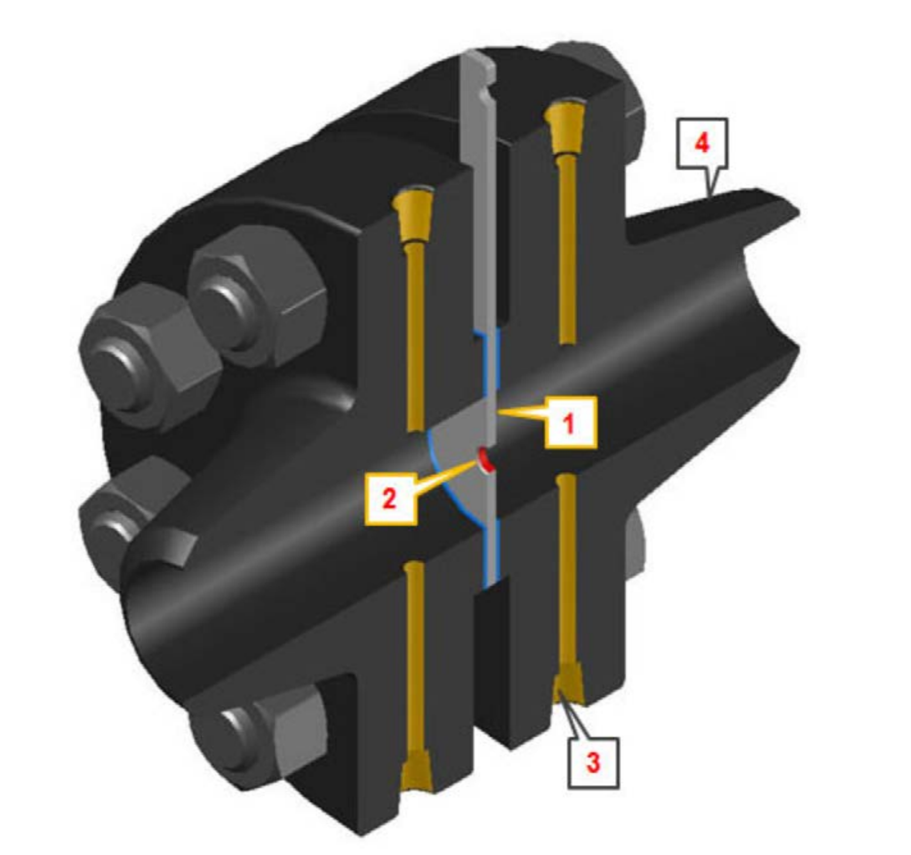
Exponential decrease of resistances with increasing orifice diameter d_O:

$$R = \frac{8\rho\dot{V}}{\alpha^2\pi^2 d_O^4}\left(1 - \frac{d_O^4}{d_P^4}\right)$$

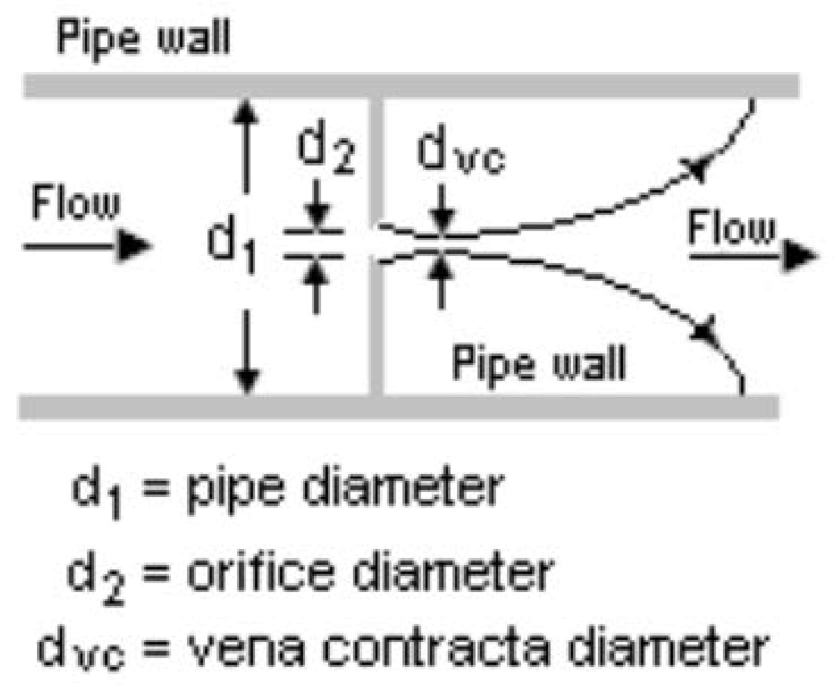
d_O: orifice diameter; d_P: pipe diameter; ρ: density;
$\dot{V}$: volume flux; α: coefficient of discharge

The nose is not comparable with a tube but with an ORIFICE PLATE!

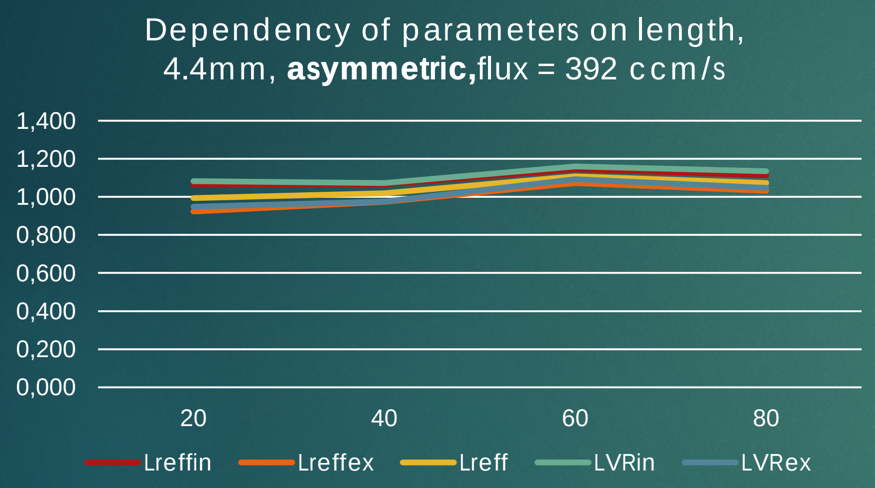
Orifice plate

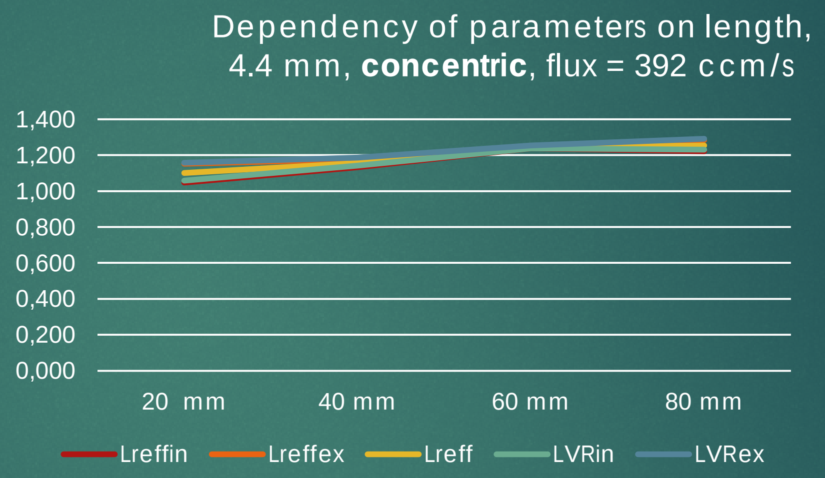


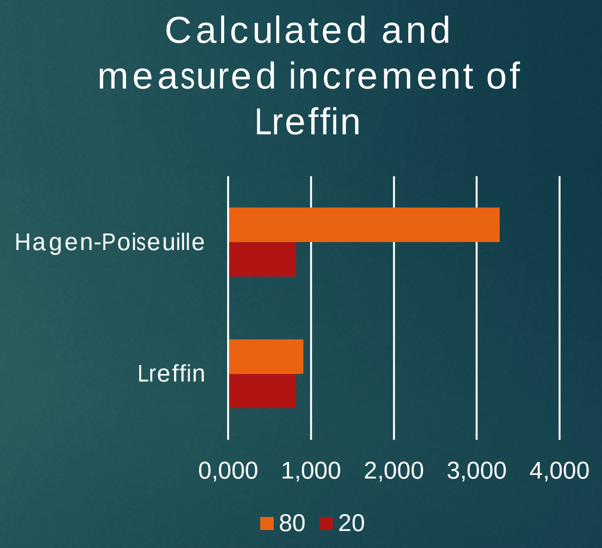
1. Orifice Plate 2. Hole in Plate
3. Tappings 4. Orifice flange



Dependency of resistances on length







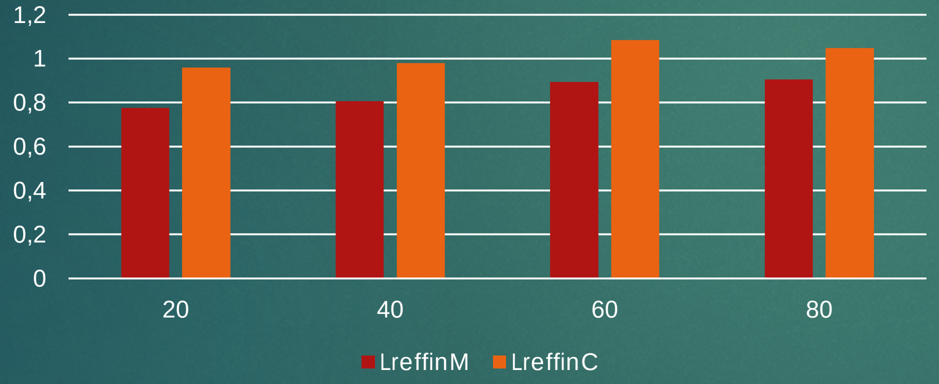
The HAGEN-POISEUILLE´s law is only capable of estimating the increment of resistance in fully developed pipe flows!!

Testing the validity of KIRCHHOFF´s rule for the estimation of bilateral / total resistance from 2 unilateral measurements

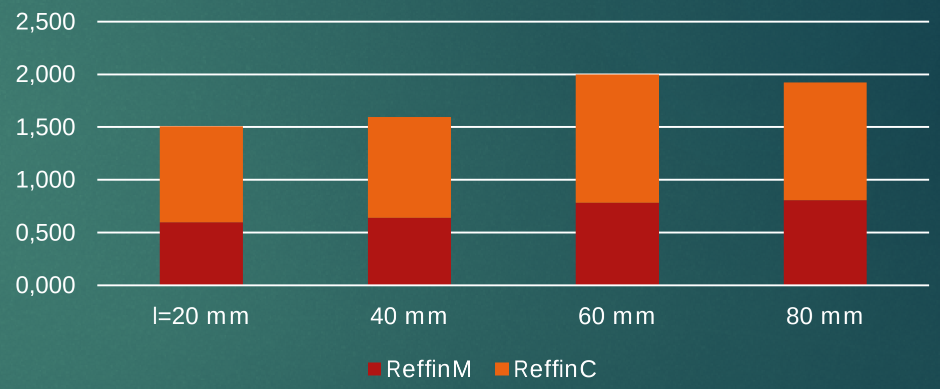
$$R_{Tot} = \frac{R_{right}\, R_{left}}{R_{right} + R_{left}}$$

Differences % of measured bilateral data	
Reffin	Lreffin
52,3	23,5
48,9	21,4
55,6	21,5
39,0	15,8

Difference measured vs. calculated bilateral logarithmic resistances, diameter 3.1 and 4.4 mm



Difference measured vs. calculated bilateral resistances, diameter 3.1 and 4.4 mm



Kirchhoff´s rule is an estimation of total nasal resistance always indicating higher values as measured: prefer posterior rhinomanometry if possible!

Clinical conclusions

- Surgery of nasal obstruction has to open the causing stenosis in FULL LENGTH or all subsequent stenoses : the diameter determines the resistance
- Consider influences by elasticity !
- The calculation of total nasal resistance included in rhinomanometry programs is an estimation with errors up to >50% higher values of linear resistance values and up to 25% higher logarithmic values according to 1 obstruction class.
- Always compare either measured or calculated values !