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Comparison of different coefficients and units in rhinomanometry

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SUMMARY

The total information of a rhinomanometric measurement is given by the simultaneous registration of flow and pressure during respiration. For characterization of such a measuring curve different methods and units are used. Since no normalized procedure exists up to now, it is difficult to compare measurements of different authors. In this work the relation between various procedures is discussed and methods are given for converting different quantities. The units of the International System are discussed.

INTRODUCTION

In the last years compact rhinomanometers were developed and rhinomanometry begins to become a practical routine method. Generally, the transnasal pressure Δp and the corresponding volume flow $\dot{V}$ are measured simultaneously. Different measuring procedures are used. The "Committee Report on Standardization of Rhinomanometry" recommends the active method, in which the patients breathes normally (Clement, 1984). In passive rhinomanometry an artificial air flow is introduced into the nose or mouth of the patient. Depending on the procedure of measuring the transnasal pressure Δp the anterior or posterior method can be applied. In the first Δp is measured in the contralateral nostril or in the vestibulum nasi, and in the second in the mouth or oropharynx. In addition some special rhinimanometric methods are known for example using a plethysmograph. Due to the technical development of rhinomanometers these procedures have lost their importance.

In the scientific literature no unanimity is found about the coefficient characterizing a rhinomanometric measurement. The whole information of a measurement is obtained plotting the transnasal pressure Δp and the volume flow $\dot{V}$ simultaneously on a x-y-plotter or an oscilloscope. For a rapid comparison of different measurements coefficients are used which describe the rhinomanogram as precisely and completely as possible. Several bio-physical correct methods are known. Reading and comparing papers of different authors become difficult, because numerous coefficients and units are in use. In this paper various methods are compared and equations and tables are given for transformation of different rhinomanometric coefficients. Special attention is paid on the units of the new International System.

METHODS

Flow-pressure relationship

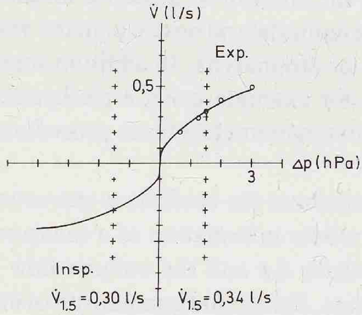
The main problem in comparing different coefficients of rhinomanometry is the knowledge of the flow-pressure relationship. Generally, the nasal airflow is turbulent. Only at a small transnasal pressure a transition form turbulent to laminar flow occurs. This region lies below a flow volume of 0.1 l/s and a pressure of 0.1 hPa (= 0.1 mbar). (This fact can easily be proven by estimating the Reynolds number.) During breathing this laminar region is passed rapidly and the precision of rhinomanometric measuring curves is generally not high enough to see this region, which is characteriźed by a linear flow pressure relationship. Thus, in practical rhinomanometry this laminar region is neglected by nearly all authors and a turbulent nasal airflow is assumed. In this case the transnasal pressure Δp is an exponential function of the volume flow $\dot{V}$

$$\Delta p = W \cdot \dot{V}^{x}. \tag{1a}$$

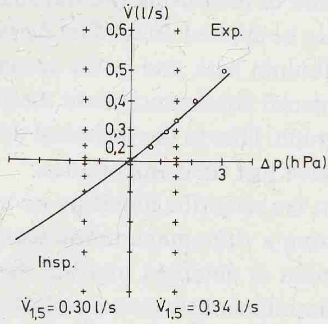
For a high turbulent flow the theoretical value for the exponent is

$$x = 2. \tag{1b}$$

The constant W is called coefficient of resistance (Lenz et al., 1983) or flow resistance (Fischer, 1969). The exponential function (1a and b) has the consequence, that at higher values of Δp a further increase of the pressure results in a small rise of the volume flow $\dot{V}$ only. This can be understood by the fact that additional turbulences are produced, which hinder the flow.



a. Linear coordinate system: The measuring curve consists of a parabola with two branches.



b. Quadratic coordinate system: The measuring curve consists of two straight lines.

Figure 1. Schematical normal rhinomanogram for one nasal side. Dependence of the volume $\dot{V}$ form the transnasal pressure $\Delta p = W \cdot \dot{V}^2$. The volume flow during inspiration is smaller than during expiration. The points in Figures a and b were calculated according to $\Delta p = W \cdot \dot{V}^{1.85}$ (supposing the same $\dot{V}_{1.5}$ value).

The experiences of many years of practical rhinomanometry confirmed the validity of equations (1a and b). In a detailed study on model noses an exponent

$$x = 1{,}85 \mp 0.06 \tag{1c}$$

was found instead of $x = 2$ of equation (1b) (Fischer, 1969). This difference is small and it is not clear if it occurs in vivo. In Figure 1 equation (1a) is plotted with $x = 2$. In addition some points are shown with $x = 1{,}85$ assuming the same $\dot{V}_{1.5}$ value (at $\Delta p = 1.5$ hPa $= 1.5$ mbar). The differences are within of the order of the experimental error of the measurements.

Thus, we may conclude that equation (1a) describes the nasal flow-pressure relation with sufficient precision. The question if $x = 2$ or 1.85 should be used is of less importance. In the equations, the figures and Table 1 we specify $x = 2$ and discuss the possible error in the appendix.

Table 1. Transformation of different scales in Rhinomanometry using the flow-pressure relationship $\Delta p = E \cdot \dot{V}^2$.
Example: $\dot{V}_{1.5} = 0.5$ l/s $= 500$ cm^3/s corresponds to $W = \Delta p / \dot{V}^2 = 6.0$ hPa/(l/s)^2 = 0.017 mm H_2O/(l/ min)^2 and $R_2 = 1.17$ cm H_2O/(l/s) and $R_{0.5\ l/s} = 3.1$ cm H_2O/(l/s), $R_{0.2\ l/s} = 1.22$ cm H_2O/(l/s).

$\dot{V}_{1.5}$			$\Delta p/\dot{V}^2$		R_2	$R_{0.5\ l/s}$	$R_{0.2\ l/s}$
l/s	l/min	cm^3/s	hPa/(l/s)^2	mm H_2O(l/min)^2	cm H_2O/(l/s)	cm H_2O/(l/s)	cm H_2O/(l/s)
0.10	6.0	100.	150.	0.424	15.7	76.43	30.6
0.20	12.0	200.	37.	0.106	6.2	19.1	7.7
0.25	15.0	250.	24.	0.068	4.3	12.2	4.9
0.30	18.0	300.	16.6	0.047	3.1	8.5	3.4
0.35	21.0	350.	12.2	0.035	2.3	6.2	2.5
0.40	24.0	400.	9.4	0.027	1.81	4.8	1.91
0.45	27.0	450.	7.4	0.021	1.43	3.8	1.51
0.50	30.0	500.	6.0	0.0170	1.17	3.1	1.22
0.55	33.0	550.	5.0	0.0140	0.96	2.5	1.01
0.60	36.0	600.	4.2	0.0118	0.81	2.1	0.85
0.65	39.0	650.	3.55	0.010	0.65	1.81	0.72
0.70	42.0	700.	3.16	0.0087	0.60	1.56	0.62
0.75	45.0	750.	2.67	0.0076	0.53	1.36	0.54
0.80	48.0	800.	2.3	0.0066	0.46	1.19	0.48
0.85	51.0	850.	2.1	0.0059	0.41	1.06	0.42
0.90	54.0	900.	1.85	0.0052	0.36	0.94	0.38
0.95	57.0	950.	1.66	0.0047	0.33	0.85	0.34
1.00	60.0	1000.	1.50	0.0043	0.29	0.76	0.31
1.05	63.0	1050.	1.36	0.0039	0.27	0.69	0.28
1.10	66.0	1100.	1.24	0.0035	0.24	0.63	0.25
1.20	72.0	1200.	1.04	0.0030	0.20	0.53	0.21
1.30	78.0	1300.	0.89	0.0025	0.17	0.45	0.18
1.40	84.0	1400.	0.77	0.0022	0.15	0.39	0.16
1.50	90.0	1500.	0.67	0.0019	0.13	0.34	0.14
2.00	120.0	2000.	0.42	0.0012	0.08	0.21	0.08

The coefficient W is different for in- and expiration, as shown in Figure 1a and b (Lenz et al., 1983). It is known, that special abnormities like stenosis of the nasal valve results in deviations from the exponential relationship of equations (1a) to (1c). These rare and special cases are not included in the discussion of this paper.

International System

According to the present international recommendations the new legal units should be used in medicine as soon as possible. The unit of pressure in the International System is Pascal (Pa). The normal air pressure is about 10^5 Pa = 1000 hPa = 1 bar = 1000 mbar. Since 1 Pa is a very small pressure it is proposed to use units of kPa or hPa = 100 Pa = 1 mbar (= 1.02 cm H_2O). Old and unlegal units are cm H_2O, mm H_2O and mm Hg. The unit of the flow volume is m^3/s, cm^3/s or l/s. The coefficient in rhinomanometry must be expressed using the mentioned units of the International System. (We prefer hPa and l/s.)

Coefficients in rhinomanometry

Schematical rhinomanograms from a normal person are shown in Figure 1. In Figure 1a a linear coordinate system for Δp and $\dot{V}$ was used, yielding a parabola with a separate branch for in- and expiration (equations 1a and 1b). With a new rhinomanometer measuring $\dot{V}^2$, a straight line results in the $\Delta p - \dot{V}^2$ diagram (Figure 1b) (Lenz et al., 1983).

For characterizing a rhinomanogram several procedures are possible: a: Giving a pair of value Δp and $\dot{V}$. (It can be seen from Figure 1b, that giving one point the whole straight line is known.) b: Giving the coefficient of resistance according to equation (1) $W = \Delta p/\dot{V}^2$ (W is the reciprocal rise of the straight rhinomanogram in Figure 1b). c: Giving the resistance $R = \Delta p/\dot{V}$ at a definite place of the curve. All three procedures were used in the past.

Survey of the literature

a. Giving $\dot{V}$ at 1.5 hPa: This value is used widely by manufactures of rhinomanometric instruments and in papers of Bachmann (1978) and Lenz (1983, 1984). The value $\Delta p = 1.5$ hPa (= 1.5 mbar = 1.5 cm H_2O = 15 $mm\,H_2O$) represents a typical mean pressure during respiration. We propose the symbol $\dot{V}_{1.5}$ (earlier papers $\dot{V}_{15}$). The quantity $\dot{V}_{1.5}$ gives a clear idea of the flow conditions and it has the advantage that $\dot{V}_{1.5}$ values of the right and left nasal sides can be added. The normal value for the total nose is according to Lenz et al. (1983). $\dot{V}_{1.5} = (0.67 \pm 0.16)$ l/s = (670 ± 160) cm^3/s. For one nasal side this values has to be devided by two.

b. Giving $W = \Delta p/\dot{V}^2$: Fischer (1969), Masing et al. (1974), Ey (1970), Dallimore and Eccles (1977) and others have found a quadratic flow-pressure relationship according to equations (1a and b) and they use the coefficient W of the parabolic curve of Figure 1a for characterizing their measurements. The older units (10^{-3} mm $H_2O/(l/min)^2$, 10^{-2} mm $H_2O/(l/min)^2$, cm $H_2O/(l/min)^2$) should be replaced e.g. by $hPa/(l/s)^2$. For the same coefficient various names and symbols were used, like W (Fischer, 1969; Lenz et al., 1983), λ (Ey, 1970) W_Q (Bachmann, 1982), a (Enzmann, 1982) and R. It is possible to calculate W from $\dot{V}_{1.5}$ and vice versa using equation (2)

$$W = 1.5 \text{ hPa}/\dot{V}_{1.5}^2. \tag{2}$$

Equation (2) shows a non linear relation between $\dot{V}_{1.5}$ and W. This makes the comparison of different papers difficult; for example a linear decrease of $\dot{V}_{1.5}$ results in a quadratic increase of W.
The handling of $W = \Delta p/\dot{V}_2$ leads to some difficulties. Measuring both sides of the nose separately (W_1, W_2) permits the calculation of the resulting value W_G in a rather complicated way

$$\sqrt{\frac{1}{W_G}} = \sqrt{\frac{1}{W_1}} + \sqrt{\frac{1}{W_2}}. \tag{3}$$

Thus, is not very reasonable to show the nasal cycle in a W-time diagram, because the sum $W_1 + W_2$ varies strongly with time (Lenz et al., 1985). However, using $\dot{V}_{1.5}$ values a nearly constant sum $V_1 + V_2$ is obtained.

c. Giving $R = \Delta p/\dot{V}$ at a certain point: Some authors use the nasal resistance $R = \Delta p/V$ in their experimental work. Without additional informations this is meaningless, because $\Delta p/\dot{V}$ varies during respiration. Characterizing the corresponding point on the rhinomanogram the other coefficients W or $\dot{V}_{1.5}$ can be calculated from the resistance R. Büsser and Schibli (1973) give $\Delta p/\dot{V}$ (in cm $H_2O/(l/s)$) for the total nose at $\dot{V} = 1$ l/s and for one side at $\dot{V} = 0.5$ l/s. A similar quantity is used by Schumann (1973). This procedure has the disadvantage that these flow volumes may not be reached in hindered respiration. Other authors give $\Delta p/\dot{V}$ at $\dot{V} = 0.2$ l/s. It is easy to calculate the nasal resistance from the coefficients W or $\dot{V}_{1.5}$

$$R = W \cdot \dot{V}_C, \tag{4}$$

where $\dot{V}_C$ is the flow volume for which R is given (e.g. $\dot{V}_C = 0.2$ l/s, 0.5 l/s or 1.0 l/s). It can be seen that W and R are proportional and no principal difference exists between these scales.
The total resistance R_G can be calculated from the resistance of both nasal sides R_1, R_2:

$$\frac{1}{R_G} = \frac{1}{R_1} + \frac{1}{R_2}. \tag{5}$$

This equation is known from parallel switching of electric resistors.

A very complicated system was proposed by Broms et al. (1982). It is supposed that the rhinomanogram is plotted in a special x-y-system (1 unit of Δp in cm H_2O is equal to 0.1 unit of $\dot{V}$ in l/s). In this x-y-system a circle is formed, passing through the coordinates given by 1 cm H_2O and 0.1 l/s. For the point of intersection between the circle and the rhinomanometric curve the value $R_2 = \Delta p/\dot{V}$ (in cm H_2O/ (l/s)) is given. This procedure is applied measuring one nasal side. If both sides are measured the scale of the x-axis is changed (0.1 l/s → 0.2 l/s). For a total understanding we refer to the original paper.
The relations between R_2 and the other coefficients W and $\dot{V}_{1.5}$ are rather complicated:

$$R_2 = \sqrt{\sqrt{2500 + 3.85\ W^2} - 50} \tag{6}$$

or

$$\dot{V}_{1.5} = \sqrt[4]{\frac{8.7}{100\ R_2{}^2 + R_2{}^4}} \tag{7}$$

Equations (6) and (7) are only valid if the units for W are inserted in cm $H_2O/(l/s)^2$ and $\dot{V}_{1.5}$ is given in l/s (at 1.5 hPa). Using the system of Broms (1982) it is rather difficult to calculate R^2 of the total nose from the corresponding values of both sides. (It may be mentioned that Broms does not use equation (1) for a normal rhinomanogram.)

RESULTS AND DISCUSSIONS

Using equations (2), (4) and (6) Table 1 was calculated. It is the aim of this table to transform the different coefficients and units characterizing rhinomanograms. Since up to now the International System was not used for $\Delta p/\dot{V}^2$ the new unit hPa/$(l/s)^2$ is added. Dallimore and Eccles (1977) uses the units cm $H_2O/(l/min)^2$. These units are not included in Table 1 since the values can be obtained by division with 10 from the 5th row of Table 1. Likewise R at 1 l/s is not shown, because it can be obtained doubling the value of row 7. All coefficients and units discussed can be found in literature which shows the necessity of standardization. In Figure 2 the relationship between $\dot{V}_{1.5}$, $\Delta p/\dot{V}^2$, R (at 0.2 l/s) and R_2 is plotted. Assuming equations (1a and b) as valid only a small difference can be found between R_2 (Broms) and $R_{0.2\ l/s}$. In addition R_2 and $\Delta p/\dot{V}^2$ show a similar behaviour within a constant of proportion. According to equation (4) the scale of W is exactly proportional to $R_{0.5\ l/s}$ or $R_{0.2\ l/s}$.
It may be concluded that in principle only two scales exist in rhinomanometry: $\dot{V}_{1.5}$ and $W = \Delta p/\dot{V}^2$. For both the units of the International System has to be used. $\dot{V}_{1.5}$ can be expressed in l/s. We recommend the units hPa/$(l/s)^2$ for $\Delta p/\dot{V}^2$ since hPa is equal to mbar which is widely used. The proposal to measure $\dot{V}$ in cm^3/s (5) leads to very small numbers for $\Delta p/\dot{V}^2$. Probably, the scale of $\dot{V}_{1.5}$ can be easier

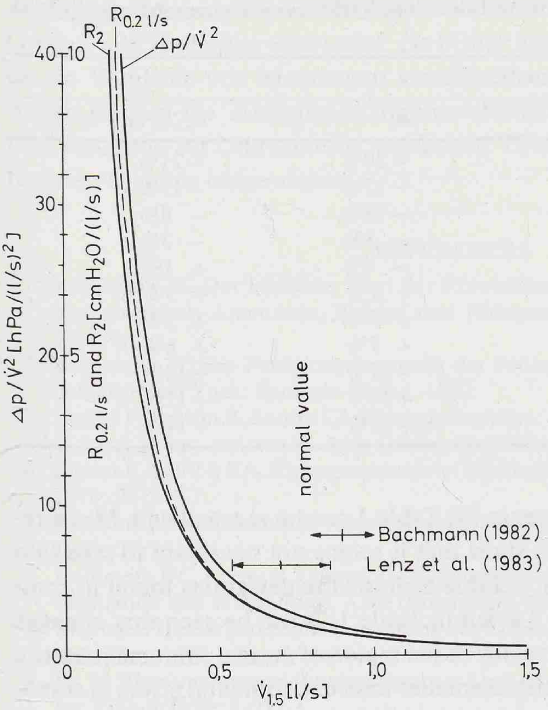


Figure 2.
Graphical comparison of different scales in rhinomanometry, showing the relationship between $\dot{V}_{1.5}$ and $W = \Delta p/\dot{V}^2$, R_2 (Broms) and $R_{0.2\ \mathrm{l/s}}$. It can be seen that R_2 shows only small deviation from $R_{0.2\ \mathrm{l/s}}$. In addition R_2 is proportional to W.

handled and understood than the other coefficients.
Besides of bio-physical and practical facts also electronic points of view should be considered in selecting a scale in rhinomanometry. Commercial rhinomanometers are available which give $\dot{V}_{1.5}$ and $W = \Delta p/\dot{V}^2$ directly. For rhinomanometer, which allows to measure the resistance R_2 defined by Broms microprocessors or minicomputers are necessary.

Appendix: Discussion of errors

In the equations, the figures and the table a quadratic flow-pressure relationship $\Delta p = W \cdot \dot{V}^2$ was assumed. In the following we show that small variations of the exponent have little influence on the results. Assuming the more general expression of equation (1a) $\Delta p = W \cdot \dot{V}^x$ the equations (2), (4) and (6) for calculation of Table 1 become:

$$W = 1.5\ \mathrm{hPa}/\dot{V}_{1.5}^{\,x} \tag{2a}$$

$$R = W \cdot \dot{V}_C^{\,x-1} \tag{4a}$$

$$R_2 \approx \left[\sqrt{\frac{2500}{W^2} + 3.85} - \frac{50}{W}\right]^{1-1/x} \cdot \sqrt{W} \tag{6a}$$

Table 2. Variation in % of the values of Table 1 using the flow-pressure relationship $\Delta p = W \cdot \dot{V}^{1.85}$.

	Variation in %		
$\dot{V}_{1.5}$(l/s)	$p/\dot{V}^2$	R_2	$R_{0.5\ l/s}$ and $R_{0.2\ l/s}$
0.1	− 31%	− 20%	− 21%
0.2	− 21%	− 17%	− 13%
0.3	− 17%	− 13%	− 8%
0.4	− 13%	− 8%	− 3%
0.5	− 10%	− 4%	+ 1%
0.6	− 9%	+ 1%	+ 3%
0.7	− 3%	+ 3%	+ 5%
0.8	− 3%	+ 7%	+ 6%
0.9	− 2%	+ 11%	+ 10%
1.0	0%	+ 14%	+ 12%
1.5	+ 6%	+ 23%	+ 14%

Using the value $x = 1.85$ of reference (9) Table 1 can be recalculated. Measurements with modern instruments show that it seems not necessary to take into consideration smaller values for x. Table 2 shows the deviations found in comparison with the results for $x = 2$ given in Table 1. It can be seen that changes between 0% and 20% occur. Especially in the region of normal rhinomanometric values, these variations are in general smaller than experimental errors in rhinomanometry. We conclude that transformation of rhinomanometric coefficients of various authors can be performed using Table 1 within the limits and errors discussed.

Expressions used

Δp = transnasal pressure
$R = \Delta p / \dot{V}$ = flow resistance
$R_{0.2\ l/s}$ = resistance at a volume flow of 0.2 l/s
$R_{0.5\ l/s}$ = at a volume flow of 0.5 l/s
$R_{1.0\ l/s}$ = at a volume flow of 1.0 l/s
R_2 = flow resistance according to Broms
$\dot{V}$ = volume flow
$\dot{V}_{1.5}$ = volume flow at a transnasal pressure of Δp=1.5 hPa = 1.5 mbar
$\dot{V}_C$ = volume flow (0.2 l/s, 0.5 l/s or 1.0 l/s, for which R is given
$R = \Delta p / \dot{V}^2$ = coefficient of resistance
x = coefficient in the flow-pressure relationship $\Delta p = W\dot{V}^x$

ZUSAMMENFASSUNG

Die vollständige Information einer rhinomanometrischen Messung liegt in der simultanen Aufzeichnung von Volumenstrom und Druck während des Atmens.

Zur Kennzeichnung dieser Meßkurve werden in der Literatur unterschiedlich Größen und Einheiten verwendet. Da bisher noch keine gültige Norm vorliegt, ist ein Vergleich von Messungen verschiedener Autoren schwierig. In dieser Arbeit werden die Zusammenhänge unterschiedlicher Kenngrößen diskutiert und Verfahren zur Umrechnung angegeben. Es wird auf die Einheit des Internationalen Systems hingewissen.

REFERENCES

1. Bachmann W. Der klinische Wert der Rhinomanometrie. Eine Analyse der Diskrepanz zwischen Anamnese, Befund und Rhinomanometrie. Lar Rhinol Otol 1978; 57:379.
2. Bachmann W. Die Funktionsdiagnostik der behinderten Nasen atmung. Berlin/Heidelberg/New York: Springer Verlag, 1982.
3. Broms P, Jonson B, Lamm CJ. Rhinomanometry. A system for numerical description of nasal airway resistance. Acta Otolaryngol (Stockh) 1982; 94:157.
4. Büsser E, Schibli RA. Rhinomanometrie: Methodik und Normalwerte. Dt Med Wschr 1973; 98:719.
5. Clement PAR. Committee report on standardization in rhinomanometry. Rhinology 1984; 22:151-5.
6. Dallimore NC, Eccles R. Changes in human resistance associated with exercise, hyperventilation and rebreathing. Acta Otolaryngol (Stockh) 1977; 84:416.
7. Enzmann H. Die praktische Bedeutung der Rhinomanometrie. Dt Ärzteblatt 1982; 79 (25):29.
9. Ey W. Rhinomanometric studies compared to body-plethysmographic measurements. Int Rhinol 1970; 8:21.
9. Fischer R. Physik der Atemströmung der Nase. Habilitationsschrift. FU Berlin, 1969.
10. Lenz H, Eichler J, Wegener U. Normalwerte der Nasenatmung gemessen mit einem neu entwickelten Rhinorhemanometer mit modifiziertem Prandt'schen staurohr und linearer Kenngrösze. Lar Rhinol Otol 1983; 62:405.
11. Lenz H, Theelen W, Eichler J. Untersuchungen zum Nasenzyklus mit Hilfe rhinomanometrischer Messungen. HNO 1975; 33:58.
12. Lenz H, Theelen W, Eichler J. Rhinomanometrische Messungen under schrittweiser körperlicher Belastung an Probanden mit normaler Nasenatmung. Lar Rhinol Otol 1984;
13. Masing H, Laacke R, Leykauf R. Nasal pressure flow studies in adults and children. Rhinology 1974; 12:137.
14. Schumann K. Zur direkter Messung des Nasenwiderstandes mit einem Koordinatenschreiber. Arch Ohr Nas KehlkHeilk 1973; 204:261.

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