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Estimation of the time since death in the early post-mortem period

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Primary task of medico-legal death time estimation is the reliable estimation of the time since death.

Criminal investigations get most efficient if this period of time is communicated to the police already at the place where the corpse is found.

Reliability as the most important principle can only be provided empirically by statistical analyses of mistakes of field studies.

The standard of death time estimation in the early post-mortem period is determined by scientific contributions by German-speaking institutes of legal medicine.

Methods of death time estimation based on cooling of the corpse show differences compared with other methods: The cooling of the corpse is mainly a physical process; the influence of biological processes (e.g. fever ante-mortal, hypothermia or post-mortem heat production) is relatively low, physical conditions (anatomy) are recognizable and can be considered in death time estimation. Temperatures of corpses are easily measurable even online. These might be the reasons for the fact that rectal temperature measurement of corpses was in the centre of scientific interest as a criterion for death time estimation quite early. The theoretical content of Rainy's publications [1] was more important than that of many publications which were published 100 years later. He transferred the Newton-rule of cooling to the cooling of corpses and, thus, he considered the environmental temperature. By measuring the temperature several times he could even determine experimentally the individual steepness of the temperature drop curve according to the Newton cooling coefficient. Additionally Rainy already identified the post-mortem temperature plateau [2] as declination of the single-exponential-model (Newton) and consistently designated

the calculated death time as minimum time. In 1955 Saram et al. [3] added a fixed additive term regarding the post-mortem plateau to the single-exponential-model and, thus, he could reproduce mathematically the temperature curves which he gained in environmental temperatures of about 30 °C until 12 h post-mortem (hpm) with a comparably low rate of mistakes. Fiddes and Patten [4] standardized the temperature drop relatively between 0 at death and 1 at complete temperature balance and the necessary times as well between 0 and 1. Thus, Patten could present a single standardized curve which he could explain theoretically. The standardized curve corresponded to the Newton-rule—but without considering the post-mortem temperature plateau; for practical use two temperature measurements were necessary in each interval. In 1958 Sellier [5] pursued a totally different approach to describe the temperature drop curve: He applied a thermodynamic model of a cylinder of infinite length to the cooling of corpses. The model function allowed informative derivation of the direction of the temperature gradient and of the influence of marginal conditions of cooling. Sellier himself thought that this model was too complicated for practical application. More recent theoretical developments of death time determination by consideration of cooling were published in 1998 and 1999 by Mall et al. [6,7] and are important regarding understanding as well as practical use. In 1953 Schwarz and Heidenwolf [8] presented the first analogous sigmoidal standard curve which was only valid for a single range of ambient temperature (17 + 3 °C) and should have been valid for any weight and cooling conditions (cloths, covering, etc.)—what it was not. These steps of standardization of cooling of corpses and limitation of death time were only partially a progress but they were also a step back. Thus, a real step forward in the mathematical description of the temperature drop curve and its practical use regarding death time determination could not be achieved in over 100 years since Rainy's model.

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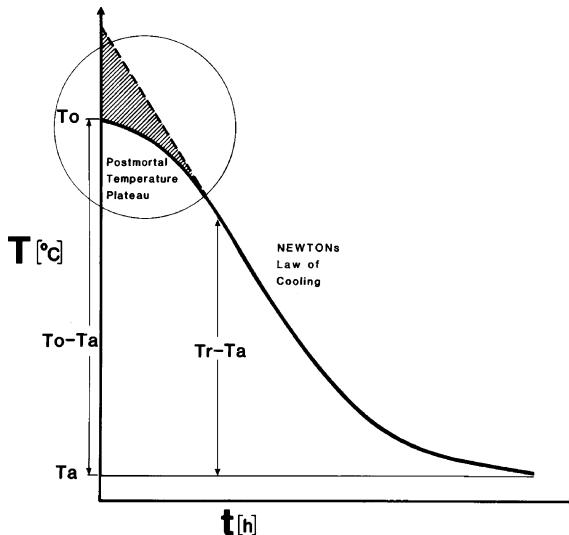


Fig. 1. Sigmoidal shape of body cooling. Mathematical description with a two-exponential-model by Marshall and Hoare [9].

It was not before the two exponential model of Marshall and Hoare of 1962 [9] that a real breakthrough could be noticed: The exponential term with exponent p stands for the post-mortem temperature plateau and that with exponent Z for the Newton-part of cooling after the plateau.

$$\frac{T - T_U}{T_0 - T_U} = \dots e^{-Zt} - \dots e^{-pt} = \frac{p}{p - Z} e^{-Zt} - \frac{Z}{Z - p} e^{-pt}$$

where T is the deep rectal temperature ($^{\circ}\text{C}$); T_0 is the rectal temperature at death, fixed at $37.2\text{ }^{\circ}\text{C}$; T_U is the ambient temperature ($^{\circ}\text{C}$), t is the time of death (h); $Z = 0.059 - 0.00059(0.8 A/M)$ with A , body surface according to DuBois and M , body weight; $P = -0.4$ (Fig. 1).

In 1974 Brown and Marshall demonstrated that more than two exponential terms complicated the model without leading to more precise results. With this model Marshall could individually determine time of death by a single measurement of the rectal temperature considering body proportions and (constant) ambient temperature under standardized conditions of cooling (unclothed, not covered, standing air, stretched supine position). Surprisingly, this breakthrough in death time determination did not meet with great response. The new model was only described in a general application report (James, Knight, 1965) and included in one textbook [10].

The two exponential formula was not used in practice before Henssge [11] (of Prokop's institute) modified it in 1981. Henssge presented a simplified method to determine the Newton cooling coefficient, he determined statistical figures of the deviation between calculated and real death times for cooling under standardized conditions [12]. Additionally he extended the application spectrum to different cooling conditions by using empirical body weight correc-

tion factors and—last but not least—Henssge published nomograms for reading the time of death instead of calculating it (Fig. 2).

$$\frac{T - T_U}{37.2 - T_U} = 1.25 e^{Zt} - 0.25 e^{5Zt}$$

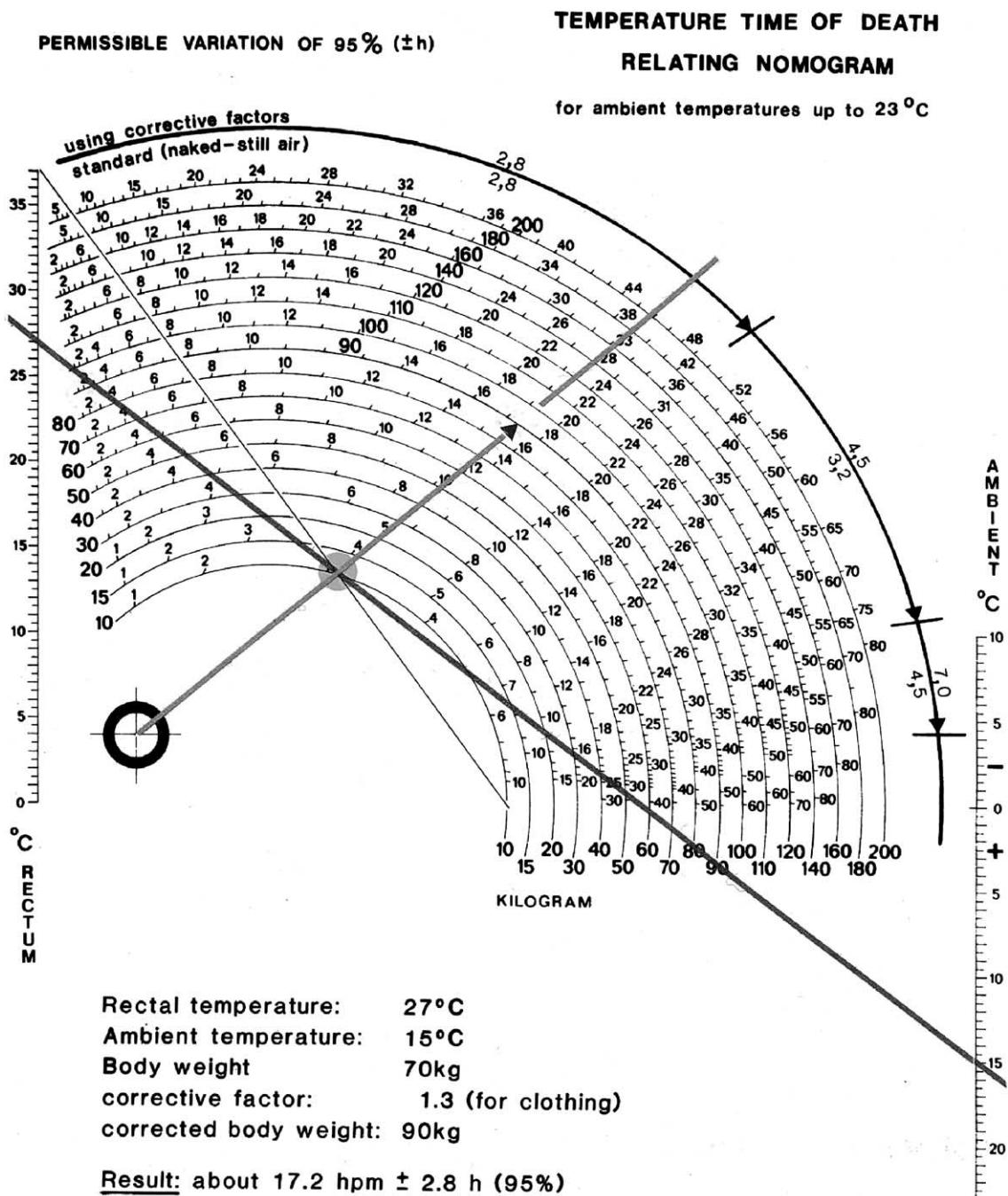
where Z is $-1.2815(f \times M^{-0.625}) + 0.0284$; f is the correction factor for cooling conditions deviating from standard; and M is the body weight (kg).

There are calculation programs for computerized calculation of death time “ t ” according to an iteration procedure.

The “nomogram-method” is included in most textbooks worldwide.

The application spectrum was extended by examinations of different typical cooling conditions like, for example, corpse in water [13], rapid change of ambient temperature (Althaus, Henssge, 1999), corpses on isolating subsoils or subsoils accelerating the cooling effect [14,15]. The statistical figures presenting the deviation between calculated and real times of death were determined also for these conditions. After development of a dummy which reproduces almost exactly the cooling of corpses the cooling can be simulated in any condition, for example, also at the location where the corpse was found [16]; Henssge, 1987). While single cases proved the applicability of the nomogram-method in standardized conditions on the cooling of child corpses other cases with thermically more isolated cooling conditions resulted in conclusive contradictions to lapses of time that were determined in criminal investigations. Systematic examinations found out that higher correction factors (e.g. for thicker cloths and/or blankets) have to be used for lower body weights [17]. Clear tabulations were established to relate the correction factors to the found cooling conditions and to determine the relation of correction factors to body weight [18]. All regulations are considered in a commercial computer program.

A multi-centre field study by Albrecht et al. [19] was a novelty on the field of death time research. In this study as well as in another monocentric field study [20,21] the statistics of error of the studies were proved under controlled cooling conditions. The results of these field studies substantiate the reliability of the nomogram method with a limitation of time of death to the specified 95% tolerance limits. Other comparable temperature-based methods are not known from literature. The nomogram method can be described as the leading method of death time determination in the early post-mortem interval. The rectal temperature measurement is the only relevant type of measurement except for measurement of the central brain temperature. The early systematic examinations by Lyle and Cleveland of 1957 [22] were developed further to a brain-temperature-death time-nomogram by examinations of Brinkmann et al. in 1976 and 1978 [23,24] and by Henßge et al. in 1984 [13,25–27]. The two-exponential-model by Marshall and Hoare [9] was also suitable for the mathematical description



Rectal temperature: 27 °C
 Ambient temperature: 15 °C
 Body weight 70kg
 corrective factor: 1.3 (for clothing)
 corrected body weight: 90kg

Result: about 17.2 hpm ± 2.8 h (95%)

Fig. 2. Application of the nomogram-method.

of the brain temperature drop curve.

$$\frac{T_{\text{Brain}} - T_U}{37.2 - T_U} = 1.135 e^{-0.127t} - 0.135 e^{-1.07t}$$

Up to 6.5 h post-mortem the most precise computation of time of death was achieved by the exclusive application of brain temperature, which gave a time of death within ±1.5 h

(95 % confidence limits). Between 6.5 and 10.5 h post-mortem the brain/rectum combined computation of time of death balanced in the ratio of 6 to 4 was the most precise one, at ±2.4 h. Beyond 10.5 hpm, the most precise computation of time of death was achieved by exclusive application of rectal temperature, and gave a time of death within ±3.2 h (Fig. 3).

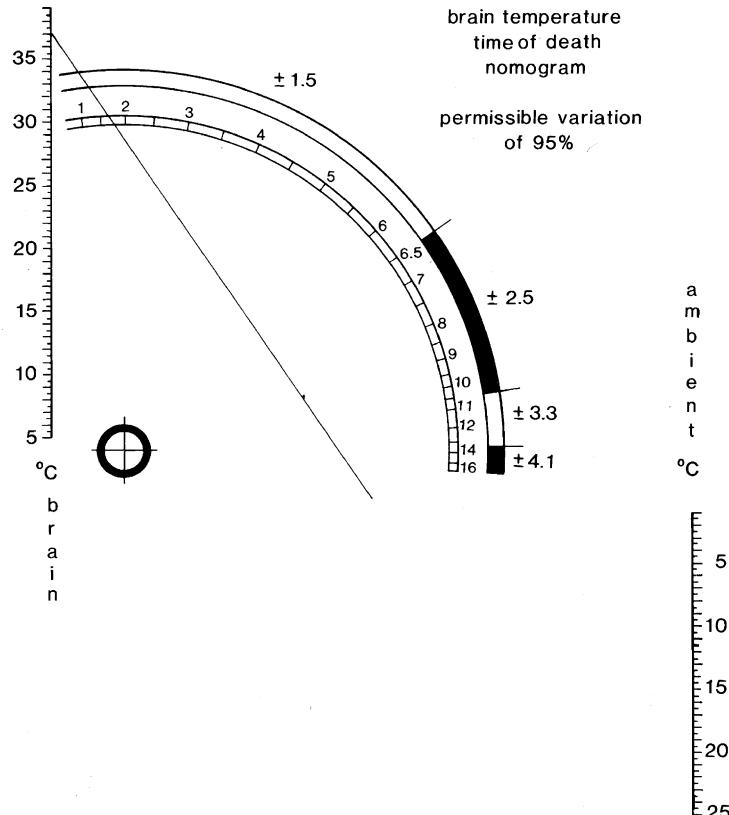


Fig. 3. Brain-temperature-time of death nomogram.

Apart from temperature measurement the theoretical most interesting and practical most efficient post-mortem changes giving information on the time of death are supravital reactions of tissue [28].

Examining the supravital reaction of the skeletal muscles to direct electric stimulation at the site of the crime contributes substantially to the limitation of the time of death directly after finding of the corpse [20,21]. Useful and practical methods were only presented by Klein and Klein in 1978 [29] and by Krause et al. in 1980 [30] who have statistically confirmed death time estimations examining a large number of cases (Fig. 3).

The principle of these examinations was as follows: Needle electrodes were inserted into the nasal part of the upper eyelid, the muscle was stimulated using constant current rectangular impulses of 10 mA duration, 30 ms in a repetitional rate of 50 per second. The muscular reaction was graded concerning the intensity and spread of movement distant to areas from the electrode. The visually noticeable different stages of intensity can be related to certain periods of death time (Fig. 4). They were repeatedly confirmed [31], also in field studies [20,21].

Since Galvani discovered the “animal electricity” in 1780 there have been many studies regarding the electrical excitability of muscles. 100 years later, in 1872, Rosenthal

[32] thought it could be a useful instrument for death time determination. Nevertheless this presumption became reality only another 100 years later when Prokop [33] made the suggestion in 1960. Various examinations followed, for example regarding electric excitability of the heart muscle [34] as well as of the skeletal muscles to indirect electric irritation (Krause et al., 1976), regarding the increase of the galvanic threshold of the skeletal muscle [35–37], the muscle of the iris [29]. The interdiction of injuring examinations (inserting of needle electrodes) before autopsy which exists in some of the Anglo-American legal systems can be done justice to by using surface electrodes. In 1972 Zink and Reinhardt [38] presented results of examinations regarding the electric irritability of the Orbicularis oculi muscle using surface electrodes; further examinations, for example, by legal-medical physicians of the Anglo-American legal area were not performed.

While all of the before mentioned examinations showed the muscle contractions resulting from electrical excitability only visually, Henßge et al. objectified the muscle reaction by implanted force transducers in 1984 and Madea performed systematic examinations: With increasing post-mortem interval the maximum force after excitation with the same current intensity decreases and the relaxation time increases due to the fact that the muscle contraction becomes

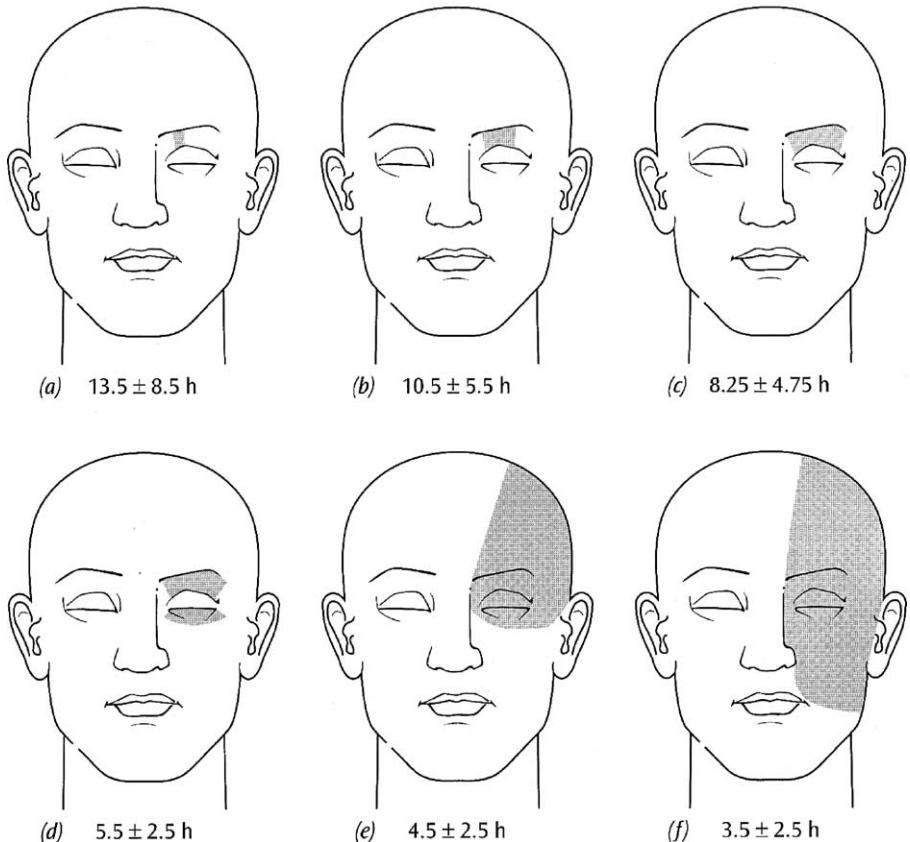


Fig. 4. Degrees of a positive reaction after stimulation of the Orbicularis oculi muscle according to Klein and Klein [29] with mean values and 95% limits of confidence (in hours). Stimulation of facial muscles by puncture electrodes inserted in the nasal part of the upper eyelid.

weaker and weaker. The relaxation time also shows an exponential correlation with the maximum force. Therefore a quotient of the relaxation time and the maximum force was devised which shows in the form of its natural logarithm a very strong linear relationship with the natural logarithm of the time since death. This quotient, called “force related relaxation time” allows up to 13 h post-mortem with 95% limits of confidence of ± 2.7 h a more precise death time estimation than any other supravital reaction (Fig. 5) [53].

The supravital mechanical excitability of the skeletal muscles does also contribute to the estimation of the death time interval [52].

The Zsako's phenomenon ([39]; Zsako, 1941) is a propagated excitation of muscle after mechanical excitation and can be seen only in the very early post-mortem interval up to 2–3 hpm. Thus, it is rarely seen in practice. In the following post-mortem interval the typical idiomuscular contraction can be observed which is of high practical relevance. Both supravital reactions were examined on large populations by Dotzauer in 1958 [40], by Popwassilew and Palm in 1960 [41] and by Semmler in 1979 [42] (consideration of storage temperature) and these examinations are the basis for

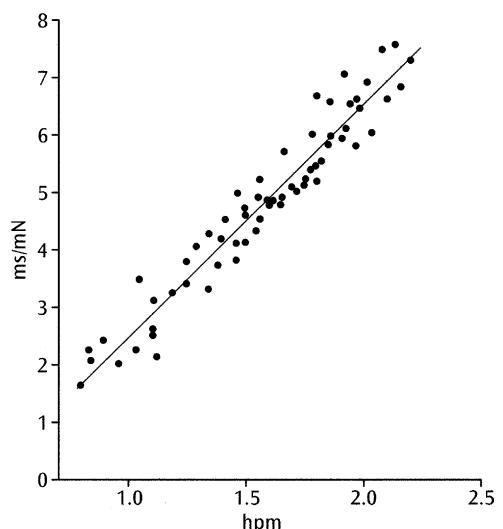


Fig. 5. Correlation of the natural logarithm of the force related relaxation time with the natural logarithm of the time since death. Strong linear relationship [37].

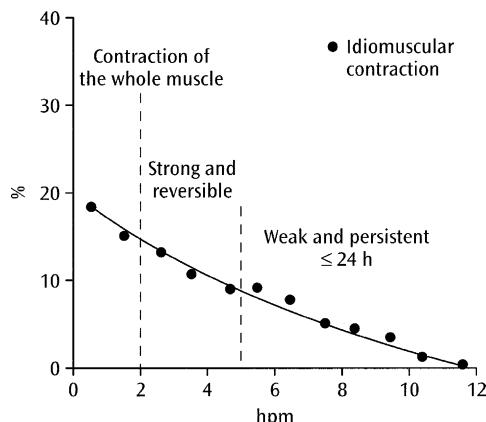


Fig. 6. Percentage frequency of positive results in mechanical excitability of skeletal muscles. The mechanical excitability is graded in three phases [40].

practical use also at the place where the corpse is found (Fig. 6) [52].

The basis of the examinations by Klein and Klein in 1978 [29] regarding the supravitral pharmacological excitability of the iris and the resulting conclusions was the examination of 5765 eyes of 3979 corpses. Its practical significance is the limitation of the time of death to 30 h (Mydriaticum Roche) and 46 h (Acetylcholine).

Livores and rigor mortis are the two criteria that have been examined the most but are of minor significance regarding reliable limitation of the time of death interval. In 1964 Mallach [43] analysed statistically the time assignments for the single criteria described in the literature from 1811 to 1960 (Rigor) and from 1905 to 1964 (Livores). Thus, he demonstrated their variation range. Schleyer [44,51] compiled the data in tables in 1975; the data of Table 1 regarding rigor mortis were slightly modified by Krompecher in 2002 [45]. Only these data should be used in practice (Table 2).

Further publications on rigor mortis that are relevant for death time estimation were published by Krompecher. He

Table 2
Hypostasis related to the time of death (hpm)

Stage	Mean	Standard deviation	Limits	
			Lower	Upper
Beginning	0.75	0.5	0.25	3
Confluence	2.50	1.0	1.00	4
Maximum	9.50	4.5	3.00	16
Thumb pressure	5.50	6.0	1.00	20
Complete shifting	3.75	1.0	2.00	6
Incomplete shifting	11.00	4.5	4.00	24

Lower and upper limits of variance computed from literature data (1905–1963). [5].

performed animal experiments with an objective measurement of rigor mortis. This method goes without breaking of the rigor mortis and, thus, serial measurements are possible. Electrical flow through at lifetime or after death (less pronounced) accelerates the start and the breaking of rigor mortis (2002, summary of the original works).

Already in 1888 Bierfreund [46] carried out animal experiments that showed the important influence of temperature on development and breaking of rigor mortis. In 1977 this influence was also proved by Forster et al. [47] in experiments with corpses.

While many examinations regarding single post-mortem changes were carried out simultaneous examinations of several post-mortal post-mortem changes for death time estimation were rarely performed. This is surprising since death time estimation on the basis of only one post-mortem change is not very precise. In 1950 Schorup [48] presented a complex method. Using balanced concentrations of lactic acid, urea and aminoacids in cerebrospinal fluid as well as axillary temperature the time of death was calculated. In 1956 Lundquist [49] reported on bad experiences with this method in cases of homicide.

In 1984 Henßge et al. [50] developed a complex method based on the nomogram method and completed by other criteria like lividity, rigor mortis, mechanical and electrical excitability of the skeletal muscles as well as

Table 1
Time course of cadavric rigidity

Rigor phase	Mean with standard deviation(s)	Hours postmortem				Number of publications evaluated	
		Limits of 95.5% probability (2 s)		Variations			
		Lower limit	Upper limit	Lower limit	Upper limit		
Delay period	3 ± 2	–	7	<1/2	7	26	
Re-establishment possible	Up to 5	–	–	2	8	–	
Complete rigidity	8 ± 1	6	10	2	20	28	
Persistence	57 ± 14	29	85	24	96	27	
Resolution	76 ± 32	12	140	24	192	27	

Mean and standard deviation calculated from the literature data of 150 years (1811–1960) by Mallach 1964 [43] (Schleyer [44] slightly modified).

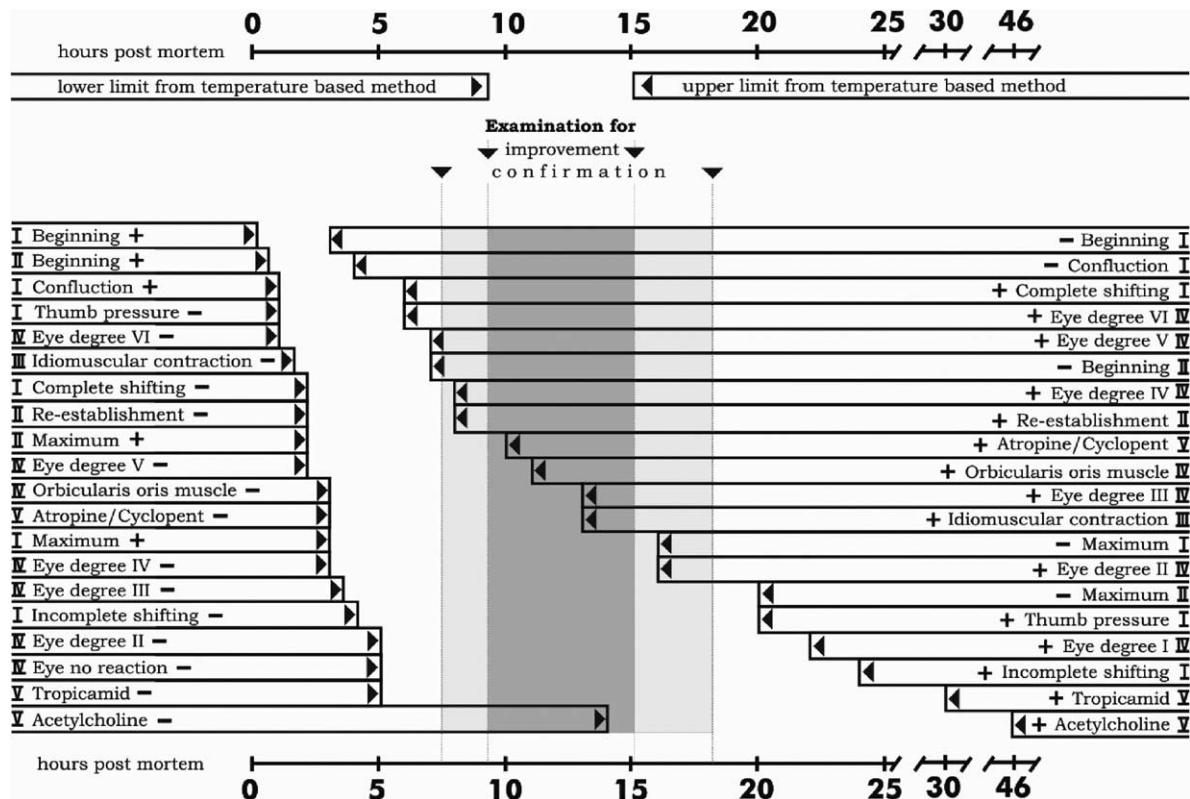


Fig. 7. Logistic of the “integrated method”. Only those criteria should be checked which can improve or confirm the time limits from the nomogram method in an actual case. When the nomogram method reveals a time since death between 10.2 and 15.8 h post-mortem the lower limit can only be raised after a negative result on the subconjunctival injection of acetylcholine. The upper limit can be narrowed down by several further criteria.

pharmacological excitability of the iris. This method was successfully used in 72 consecutive cases at the place where the corpse was found. It showed reliable and more precise limitations of the time of death than any single method alone [20,21] (Fig. 7).

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