Int J Legal Med (2012) 126:399–405
DOI 10.1007/s00414-011-0665-3

ORIGINAL ARTICLE

Estimation of the time since death: post-mortem contractions of human skeletal muscles following mechanical stimulation (idiomuscular contraction)

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Received: 15 November 2011 / Accepted: 27 December 2011 / Published online: 13 January 2012

Abstract The mechanically stimulated idiomuscular contraction of skeletal muscles is part of the widely used compound method for death time estimation and therefore represents an item of high relevance and practicability in forensic case work. However, data on the topic are scarce and inconsistent and the currently reported maximum time span for the occurrence of the phenomenon until 13 h post-mortem (hpm) is based on a single case report from the beginning of the twentieth century. Therefore, idiomuscular contraction following mechanical stimulation has been investigated in skeletal muscles of 270 cases with assured time of death at defined post-mortem time points between 7 and 15 hpm. Of all investigated cases, 45 (16.7%) showed a positive reaction with a preponderance of cases of sudden death. Our investigations confirmed the upper time limit of 13 hpm up until idiomuscular contraction could be stimulated. With every hour of the post-mortem interval, a 0.61-fold decrease of the phenomenon's occurrence was observed (95%CI, 0.52–0.72; $p<0.001$). Furthermore, several parameters showed significant correlations with the likelihood of the phenomenon's occurrence, namely stimulation of upper arm as opposed to the thigh ($p<0.001$), gender ($p=0.017$), and BMI ($p<0.001$). These findings for the first time give reliable evidence of a post-mortem time limit of mechanically stimulated idiomuscular contraction and therefore contribute to the future application of the method in forensic case work.

Keywords Time since death · Death time estimation · Legal medicine · Idiomuscular contraction · Compound method

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Introduction

The estimation of the time since death is an important issue in forensic casework. The widely used compound method combines temperature- and non-temperature-based methods. Among the latter, idiomuscular contraction (local muscular contraction at the site of mechanical stimulation of skeletal muscles) is commonly used and of high practical relevance in forensic casework [1]. However, only very few field studies have been published so far [2], and available data to support upper post-mortem (pm) time limits for the phenomenon are scarce and heterogeneous.

The first observation of the phenomenon on isolated human limbs was published by Dowler in 1846 [3]. Fubini [4] described muscular contractions following mechanical stimulation 9 h post-mortem (hpm) in a single case in 1884. In 1913, Chiari [5] reported on a case in which contractions could be initiated after 13 hpm. In the second half of the twentieth century, three studies on the phenomenon were published in German [6–8], therefore not being accessible to a larger readership. The authors described varying upper time limits of 8 to 12 hpm after which an idiomuscular contraction could be provoked. The upper time limit of 12

hpm can only be deduced from a figure included in the original publication by Dotzauer [6] but is not explicitly mentioned in the text. Nevertheless, the results are commonly cited in recent publications [1, 9, 10]. Notably, methodology and possible limitations do not appear to have been adequately covered in earlier descriptions of the phenomenon and in larger case series [6–8]. In particular, these studies do not provide sufficient information on the methods used to estimate the time of death in the investigated cases, which is crucial for the correct description of pm phenomena. Further details on the published literature concerning the topic are summarized in Table 1. Additionally, some authors of earlier studies did not clearly differentiate between Zsáko's phenomenon and idiomuscular contraction [11, 12].

While international textbooks on forensic medicine and pathology do not [13–15] or not in detail [16] refer to the phenomenon and its time limits, German textbooks describe an upper time limit of 8 to 12 hpm [9, 17, 18]. A recently published software program for the estimation of the time since death features the specification of an upper time limit of 13 hpm [19].

In aggregate, in published original research papers [6, 7, 9], the upper time limit varies between 8 and 12 hpm, while the sometimes reported upper time limit of 13 hpm is based on a single historic and poorly documented case report [5]. The aim of the present study was to clarify (1) the time-dependent frequency of pm contractions of human skeletal muscles following mechanical stimulation and (2) the upper time limit in a series of cases with known time point of death.

Methods

The pm contraction of human skeletal muscles following mechanical irritation was examined in 270 cases of deceased persons at defined pm time points between 7 and 15 hpm. All data were acquired in consecutive cases meeting the inclusion criteria between March and August 2011. Two hundred eight persons had died as patients of the University Medical Center Hamburg-Eppendorf and 62 persons had died following attempted resuscitation after witnessed collapse (sudden death). Inclusion criteria were a defined time point of death as documented by hospital staff or emergency doctors and age above 16 years. Exclusion criteria were injuries, edema or infections of the extremities (including hematoma), severe obesity that included the limbs, and preexisting muscular diseases. The cause of death or other preexisting diseases did not affect inclusion unless the area of investigation was thereby harmed or the patient had been administered with muscle relaxants prior to death.

In concordance with formerly described methods (Table 1), idiomuscular contraction was triggered by mechanical stimulation affected by a single forceful vertical percussion of the muscle's belly of the musculus biceps brachii and the musculus quadriceps femoris on both sides of the body (Fig. 1), meeting the requirements of everyday forensic practice, as described in current textbooks of legal medicine. The rounded handle of a steel chisel (Melcher, Germany, weight 319 g, diameter of the handle 2.5 cm, overall length 21 cm; Fig. 2) was used to trigger contractions. The presence of the local muscular reaction was detected by manual palpation after 20 s at the site of stimulation and recorded on a 3-point semiquantitative scale (no contraction, slight contraction, and strong contraction). Contraction was considered to be strong when it was easily detected by manual palpation (height about 1 cm or more) and in some cases even detectable by inspection (Fig. 3). Contractions of a lesser degree were considered to be slight. Prior to mechanical stimulation, the muscles were manually examined to detect preexisting irregularities of the muscle shape that might be mistaken for a muscular response to stimulation. All four examined muscles of the investigated cases were stimulated at the same time pm and repeated stimulations were not performed to avoid false results because of the preceding irritation. All experiments were conducted by one examiner (SW), some simultaneously with a co-examiner (SA).

In addition, the strength of rigor mortis at the time point of examination was assessed manually and classified as not detectable, slight (slight resistance), moderate, or intense (near maximum). The state of the limbs was classified as cachectic, normal, and obese. Age, gender, length, and weight of the bodies were recorded and BMI was calculated (underweight <18.5 kg/m², normal weight 18.5–24.9 kg/m², overweight 25–29.9 kg/m², obese >30 kg/m²). Before experiments, some bodies were kept in a cold store for various duration of time. Rectal temperature of the deceased was measured with a calibrated electronic thermometer at the time point of examination (Testo, Germany). In addition, we simultaneously recorded the surface temperature of the limbs with an infrared thermometer (Voltcraft IR 260-8S). Rectal and surface temperatures were included in the statistical analysis. During experiments the environmental temperature in the mortuary was 20–21°C.

The cause of death and the predominant underlying disease were derived from the death certificate and accompanying medical information. In cases of sudden death, information was scarce. Diseases were classified into six groups: cardiovascular, infectious, central, carcinoma, others, and unknown.

Data were analyzed using SPSS, Version 19.0.0. Generalized estimating equations with ordinal scaled outcome were calculated to estimate the effect of pm interval (hpm) on idiomuscular contraction. Being potential covariates, the variables age, gender, side of the body, state of the limbs, localization (upper arm, thighs), rectal temperature of the bodies, surface temperature of the limbs, cause of death, predominant underlying disease, source of the deceased

Table 1 Published case reports and experimental studies on mechanical idiomuscular contractions

References	Number of cases	Measurements	Source of deceased	Affirmation of the time point of death	Trigger used	Muscles examined	Max. post-mortal interval (hpm)
Dowler, 1846 [3]	43	Repeated blows (?) up to 10 hpm, no differentiation between different muscle reactions	n.d. ("nearly all yellow fever subjects")	n.d.	Shingle, cane, flat side of a hatchet or the operator's hand	Cadavers, limbs separated from the trunk	>10 (according to methodology not clearly defined)
Fubini, 1884 (according to Hofmann [4])	1	"Mechanical stimuli"	Executed 34 year-old man	Time of death penalty	n.d.	"Extremities"	9
Toulouse, 1903 (according to Näcke [20])	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3
Näcke, 1911 [20]	30	Repeated stimulations (up to 4 times)	Hospital, men with mental illness	n.d.	Percussor	M. deltoideus, M. biceps brachii, M. quadriceps femoris, M. pectoralis, M. serratus anterior, M. latissimus dorsi	3–4
Chiari, 1913 [5]	1	n.d.	n.d.	n.d.	Pinching with two fingers	M. biceps brachii sin.	13
Orsós, 1935 [27]	2	n.d.	Suicides	n.d.	Back of knife	M. biceps brachii	5
Zsakó, 1941 [12]	n.d.	n.d.	n.d.	n.d.	Percussor, 3 fingers	n.d.	4
Dotzauer, 1958 [6]	176	595 (unclear whether repeated or in different regions)	n.d.	n.d.	Back of knife (width: 5 mm, weight: 110 g)	M. biceps brachii	11.5–12 (deduced from Fig. 1 in original publication)
Popwassilew and Palm, 1960 [7]	102	137 (unclear whether repeated or in different regions)	n.d.	n.d.	Back of chisel (weight: 350 g, length: 40 cm)	M. biceps brachii	8
Semmler, 1979 [8]	102	Repeated stimulations (hourly measurement between 2–8 hpm)	96 hospital cases, 6 forensic cases	"The time point of death was known in all cases"	Percussor	Right thigh (not specified)	<8
Own results	270	4 stimulations per body at defined pm time points	Hospital cases and cases of sudden death	Hospital and emergency doctors documentation	Handle of chisel (weight: 319 g, length: 21 cm, diameter: 2.5 cm)	M. biceps brachii, M quadriceps femoris, left and right side of the body	13

n.d. not determined

Fig. 1 Mechanical stimulation of an upper arm by forceful percussion of the muscles belly

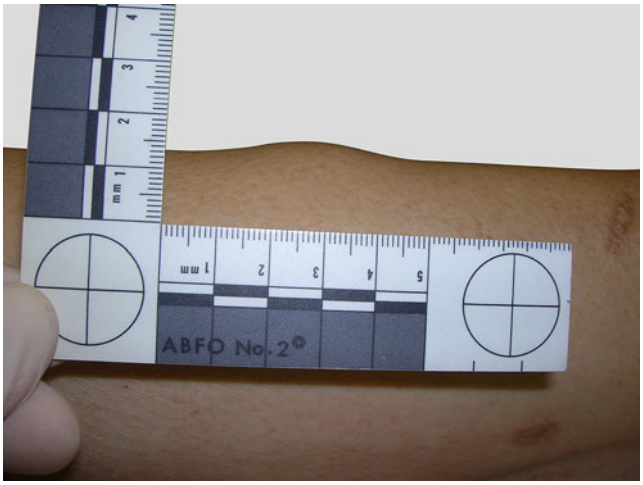

Fig. 3 Idiomuscular contraction: Local muscular contraction at the site of mechanical stimulation

(hospital, sudden death), strength of rigor mortis prior to testing, and BMI were included in the model. For statistically significant covariates, odds ratios (OR) with 95% confidence intervals (CI) were calculated. For reasons of practical applicability in current everyday forensic practice, data were reanalyzed using a dichotomous scale for idiomuscular contraction, classifying contraction as positive or negative, including the covariates mentioned above. Nominal p values are reported. p values<0.05, two sided were considered significant.

Results

We investigated 270 deceased at defined pm time points between 7 and 15 hpm (Table 2). Due to restrictions in single cases (amputation of limbs, injury, hematoma, etc.), a total number of 1,059 muscular stimulations was investigated. The majority of patients were male ($n=154$, 57.0%). Age ranged from 19 to 96 years (average 67.9 years). BMI ranged from 15.5 to 47.6 kg/m². According to the BMI, 13 deceased (4.8%) were underweight, 92 (34.1%) of normal weight, 87 (32.2%) overweight, and 78 (28.9 %) were obese. Based on visual classification, the limbs were cachectic in 27 (10%), normal in 185 (68.5%), and obese in 58 (21.5%) cases. Prior to stimulation, rigor mortis was not detectable in 8 cases (2.9%), slight in 48 cases (17.8%), moderate in 132 cases (48.9%), and intense in 82 cases (30.4%). Rectal temperature ranged from 11.7–38.6°C, whereas the surface temperature of the limbs ranged from 6.1–30.1°C.

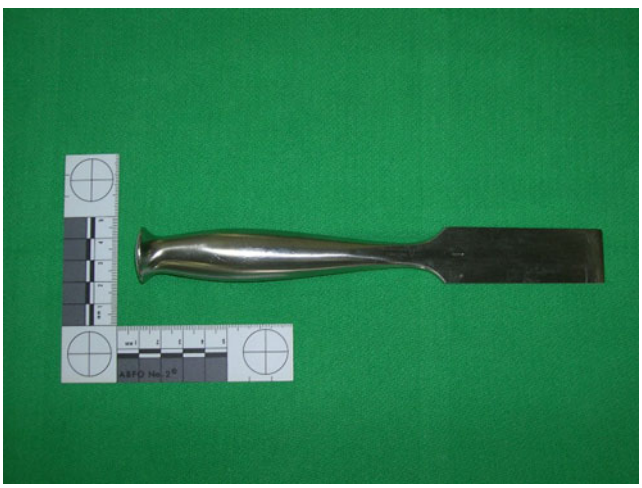

Fig. 2 Chisel used for mechanical stimulation

Of 270 investigated cases, 45 (16.7%) showed a positive idiomuscular contraction. Positive results were observed up to 13 hpm (Table 2). All four investigated muscles revealed a positive reaction in 6 cases, three muscles in 9 cases, two in 10 cases, and in 20 cases only one of the examined limbs was considered positive.

Strong contractions were observed up to 10 hpm. Of the 45 positive cases, contraction disappeared within 5 min in 21 (46.7%) and within 10 min in 6 deceased (13.3%). In 10 cases (22.2%), contractions persisted for more than 10 min (of these 10, contraction disappeared within less than 1 h in seven cases and notably persisted in either one case for 1, 8, and 23 h, respectively). Of the deceased with persisting contractions, nine were measured at an earlier pm interval of 7 to 10 hpm. In 8 of the 45 cases, the contraction disappeared immediately after the stimulus (duration less than 1 min).

Statistical analysis of the data revealed no significant influence of age, state of the limbs (cachectic, normal, and obese), rectal temperature, surface temperature of the limbs, cause of death, and side of the body. The analysis revealed the following significant correlations with the occurrence of idiomuscular contraction (Fig. 4): idiomuscular contraction

Table 2 Number of investigated cases and results for case groups (hospital cases, sudden death) at defined pm time points between 7 and 15 hpm

hpm	Case group	Idiomuscular contraction		
		n negative	*n* positive	*n* total
7	Hospital cases	13	5	18
	Cases of sudden death	0	12	12
	Total	13	17	30
8	Hospital cases	20	3	23
	Cases of sudden death	2	5	7
	Total	22	8	30
9	Hospital cases	22	4	26
	Cases of sudden death	2	2	4
	Total	24	6	30
10	Hospital cases	19	2	21
	Cases of sudden death	6	3	9
	Total	25	5	30
11	Hospital cases	21	2	23
	Cases of sudden death	6	1	7
	Total	27	3	30
12	Hospital cases	22	3	25
	Cases of sudden death	5	0	5
	Total	27	3	30
13	Hospital cases	22	2	24
	Cases of sudden death	5	1	6
	Total	27	3	30
14	Hospital cases	23	0	23
	Cases of sudden death	7	0	7
	Total	30	0	30
15	Hospital cases	25	0	25
	Cases of sudden death	5	0	5
	Total	30	0	30
Total	Hospital cases	187	21	208
	Cases of sudden death	38	24	62
	Total	225	45	270

was 2.85 times more likely to occur in men than in women (OR; 95%CI, 1.20–6.76; $p=0.017$) and 2.50 times more likely in upper arms than in thighs (OR; 95%CI, 1.49–4.20; $p<0.001$). The probability of the occurrence of idiomuscular contraction showed a 0.87-fold decrease with every BMI increase by one-scale point (95%CI, 0.81–0.94; $p<0.001$). With every hour of the post-mortem interval, the analysis revealed a 0.61-fold decrease in idiomuscular contraction (95%CI, 0.52–0.72; $p<0.001$).

The odds ratios for the appearance of a strong idiomuscular contraction vs. absence of contraction decreased from 0.04 (95%CI, 0.02–0.09) at 7 hpm to 0.004 (95%CI, 0.001–0.013) at 12 hpm and for slight idiomuscular contraction vs. absence of contraction from 0.16 (95%CI, 0.08–0.33) at 7 hpm to 0.02 (95%CI, 0.005–0.05) at 13 hpm, respectively. The analysis of the dichotomous approach (positive vs. negative contraction) showed no relevant impact on the main confounding factors, gender (OR 2.70; 95%CI, 1.12–6.53; $p=0.027$), localization (OR 2.03; 95%CI, 1.20–3.42; $p<0.001$), and BMI (OR 0.88; 95%CI, 0.81–0.95; $p=0.001$). Concerning the decrease in idiomuscular contraction with every hour of the post-mortem interval, the analysis displayed nearly identical results (OR 0.61; 95%CI, 0.52–0.73; $p<0.001$; Fig. 5).

While cases with a cause of death due to an infectious disease rarely showed positive results, there was a strong tendency for positive results in cases with a cardiovascular cause of death and a statistically significant increase in the probability of the occurrence of idiomuscular contraction in cases with a cause of death classified as “other” or “unknown” (Fig. 6).

Discussion

The currently reported upper time limit of 12 to 13 hpm for the occurrence of idiomuscular contraction following mechanical stimulation of skeletal muscles is mainly based on three publications, all with definite limitations. The results of Dotzauer [6] were not shown in detail and the upper time limit of 11.5 to 12 hpm could only be deduced from a figure given in the manuscript without any corresponding explanation in the text. Chiari [5] described an idiomuscular contraction of 13 hpm in a vaguely defined single case. Finally, Dowler [3], who reported a time limit of at least 10 hpm, conducted his investigations without a systematic

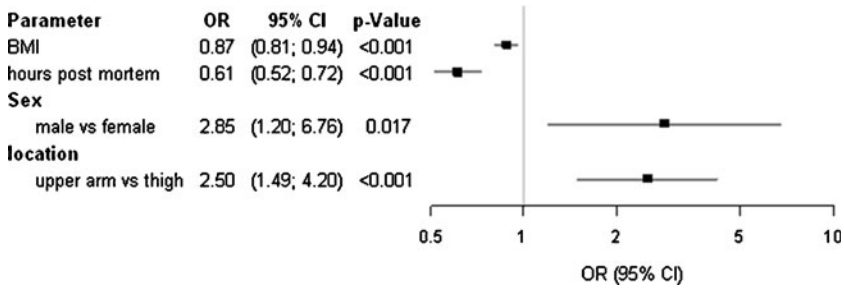

Fig. 4 Odds ratios (*OR*) and 95% confidence interval (*CI*) for statistically significant covariates influencing the occurrence of idiomuscular contraction

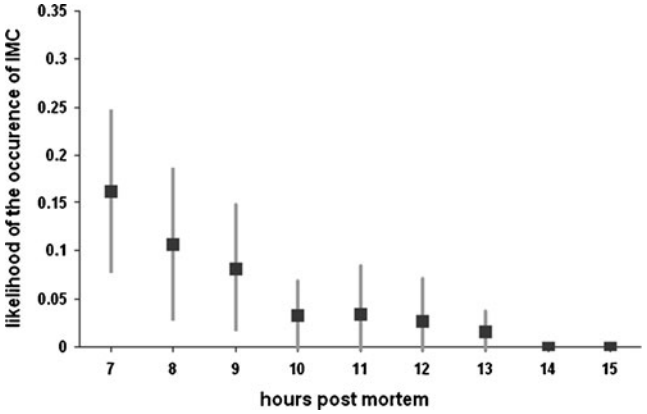

Fig. 5 Estimated likelihood and 95% confidence interval at defined post-mortem time points; 0.61 (OR; 95%CI, 0.52–0.73, $p<0.001$) fold decrease in the likelihood of occurrence of idiomuscular contraction (*IMC*) with every hour of the post-mortem interval

approach. Nevertheless, the method is commonly used as one factor in the compound method for the estimation of the time since death.

Our results therefore contribute to the future application of the method in forensic casework. Our results confirm the upper time limit of 13 hpm by investigating the largest case sample so far. The most recent publication on the subject is a doctoral thesis by Semmler, written in German [8]. The author reported on an upper time limit of less than 8 hpm for the occurrence of idiomuscular contraction. We believe that the difference to our results might be explained by the following: first, Semmler's results were obtained by examinations on the right thigh. Our results revealed a two and a half fold higher incidence of positive results on upper arms compared to thighs. Second, Semmler stimulated repeatedly until muscle reactions were absent in all cases. Thus the exhaustibility of the muscular contraction might have been another confounding factor, while we performed single stimulations at defined pm time points. However, when using electrical stimulation, Henssge [21] could not provide evidence for an influence of repeated excitations on pm contractions of skeletal muscles.

We observed a strong preponderance of idiomuscular contraction in male subjects. This observation might be explained by gender differences in muscular mass. Furthermore, we observed a decreasing likelihood for the occurrence of the phenomenon with a longer pm interval and an association with BMI (Figs. 4 and 5). In contrary to the findings of Näcke [20], we did not detect a preference of the right side of the body. As rectal and surface temperature of the bodies was of no significant influence, idiomuscular contraction appears to be a non-temperature dependent factor in the compound method of death time estimation. While most reports on the phenomenon did not provide sufficient information concerning the confirmation of the time point of death (Table 1), we examined cases of witnessed sudden death and deceased from a University hospital, providing sufficient information and documentation of the time of death.

At first sight, our observation of a strong preponderance of cases with other and unknown causes of death might be surprising. While the group of other causes of death was too heterogeneous to draw definite conclusions (consisting of e.g., acute renal failure, mesenteric ischemia, and liver cirrhosis), there is a possible explanation for the results in cases with an unknown cause of death. The majority of cases in this group were sudden death cases, which therefore seem to show an increased frequency of idiomuscular contraction (38.7% vs. 10.1% in hospital cases). While one might conclude that preexisting symptoms of illness might have led to reduced muscular activity prior to death in hospital cases and sudden death cases might share more characteristics with forensic cases, it is important to note that we are not able to evaluate the influence of the cause of death in the latter subgroup due to limited information, and the hospital and sudden death groups differed significantly regarding the causes of death ($p<0.001$; Fishers exact test). Nevertheless, cases with a cause of death related to infectious diseases and obese individuals rarely showed a positive reaction. This observation might point at a possible limitation of the method in these case groups.

In summary, our results for the first time give evidence of a post-mortem time limit of 13 hpm for local idiomuscular contraction following mechanical stimulation of skeletal muscles. It is important to note that the presence of the phenomenon might be used to determine a time since death of less than 14 hpm, while its absence does not allow any conclusions to be drawn about the death time, as we observed a positive reaction in only 16.7% of cases. As idiomuscular contraction could not be triggered reliably in all four investigated muscles of individuals showing positive results, our observations suggest that both upper arms and thighs should be investigated in forensic casework.

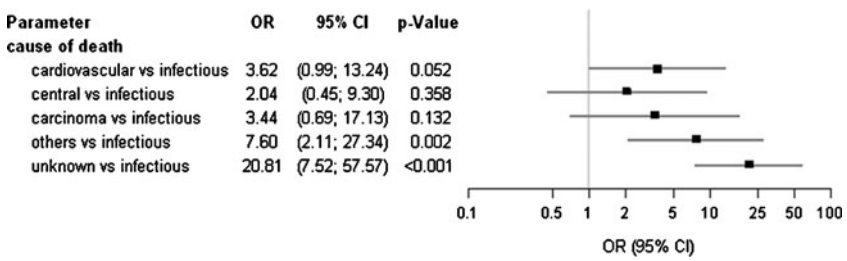

Fig. 6 Odds ratios (*OR*) and 95% confidence interval (*CI*) regarding the likelihood of occurrence of idiomuscular contraction in different causes of death compared to the group with an infectious cause of death

Recent publications on the estimation of the time since death have mainly focused on an advancement of the calculation of the time of death, experiments involving controlled cooling of bodies, and molecular mechanisms [22–26]. Our results show that a reevaluation of poorly defined additional factors used in forensic casework is of certain relevance and can improve the reliability when interpreting the findings in forensic cases.

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