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Mégnin re-analysed: the case of the newborn baby girl, Paris, 1878

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Abstract This paper analyses acarological evidence from a 130-year-old forensic investigation. It was the first case in forensic acarology, i.e., the first case where mites provided substantial information to estimate the post-mortem interval (PMI). In 1878, the mites found in the mummified body of a newborn baby girl in Paris, France, were studied by acarologist and forensic entomologist Jean Pierre Mégnin. Mégnin estimated around 2.4 million mites in the skull and identified them as *Tyroglyphus longior* (Gervais), a junior synonym of *Tyrophagus longior*. He suggested that the arrival of these mites at the corpse would have occurred by phoresy on carrier insects, roughly 5 months before the autopsy. There is no doubt about the identification of the mites, Mégnin was a highly respected acarologist. However, two main factors affecting the biology of *Tyrophagus* mites were not included in the original analysis. First, Mégnin stated that the mites were phoretic. However, he probably did not have access to information about the natural history of the species, because as a rule *Tyrophagus* mites are non-phoretic. Considering the omnipresence of *Tyrophagus* mites in soil, most likely the mites will have arrived almost immediately after death. Second, temperature was not taken into account during the estimations of the mite population growth rate. The new analysis is based on current knowledge of *Tyrophagus* biology and includes temperature, estimated following a handful of weather reports of the years 1877 and 1878. The new projections indicate that non-phoretic mites may have colonised the body just after death and the colony would have built up over 8 months, contrary to the 5 months proposed by Mégnin. This new lapse of time agrees with the PMI proposed by Brouardel: on 15 January 1878 he postulated the death of the newborn to have occurred some 8 months before the autopsy.

Keywords *Tyrophagus* · *Tyroglyphus* · Mite · PMI · Forensic · Forensic acarology

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Introduction

A historical report of a mummified body of a newborn child found in Paris in the winter of 1877–1878 provided acarological evidence that is still a matter of discussion (Brouardel 1879; Braig and Perotti 2009; Perotti et al. 2009a, b). What makes this case unique is the fact that it was the first time that mites were used to estimate a post-mortem interval (PMI). This is also only the second case in the history of forensic entomology in France. The estimation of the time of death of the newborn girl was based on a combination of the information provided by the insects and mites recovered from the corpse and the result of the autopsy performed by the pathologist. The fauna was represented by some caterpillars, but mostly by mites. Edmond Perrier, a professor at the Muséum National d'Histoire Naturelle, was consulted regarding the caterpillars. He identified the caterpillars as *Aglossa* sp. (Pyralidae, Lepidoptera). According to him and Mégnin, the moths and probably other insects might have arrived at the body in the previous summer (Brouardel 1879). Jean Pierre Mégnin, a member of the Société de Biologie and the Société de Médecine Légale de France, later the president of the Société Entomologique de France, was consulted for his expertise in acarology, to examine the mites found in the mummified child.

Mégnin found millions of specimens of what he stated to be a single species; he emphasised that the arrival of the mites at the corpse must have originally occurred by phoresy, i.e., they must have been carried and brought early on to the corpse by varies arthropods. In his own words he stated: "La colonie a eu pour origine quelques nymphes hypopiales apportées par des diptères, des coléoptères ou des myriapodes" [The colony has had its origin in some hypopial nymphs carried by dipterans, coleopterans or myriapods], "… et cela prouve que la momie, au moment où elle a été envahie par les acariens, était accessible aux insects venus de l'extérieur" [and that proves that the mummy, at the time when it was invaded by the acarines, was accessible to the insects coming from outside] (Brouardel 1879).

The acarological evidence according to Pierre Mégnin

Tyroglyphus longior Gervais was the species identified by Mégnin; this is the junior synonym of *Tyrophagus longior* (Gervais), a mite almost always associated with dry cheese and meat. This species belongs to the Acaridae (Astigmata) and was originally described as a mite of Gruyère and Dutch Gouda cheeses in 1844 by Paul Gervais, a contemporaneous French acarologist (Gervais 1844).

There are three documents that deal with the case of the newborn: a publication by Brouardel (1879), the section called "Deuxième application: Notre première étude médico-légale" of Mégnin's book "Le fauna des cadavers" (1894), and a section in the doctoral thesis of his student, Yovanovitch (1888). The three versions, although written with practically the same words subtly differ in substantial information, such as the source of information taken into account to estimate the generational time of the mites involved.

Mégnin indicated that he used a combination of observations made by a colleague, M. Fumouse (the name was incorrectly spelled; it should have been "Fumouze"), on *T. longior* and of his own previous observations of the biology of several sister species of *T. longior*, particularly *Tyroglyphus mycophagus* Mégnin, a species that he had described himself. In his report of the case, published in his book 15 years later (Mégnin 1894), Mégnin cites the observations of Fumouze "Ch. Robin—Journal d'anatomie, 1865" regarding the life cycle of *T. longior*. In other words, he makes reference to the work of a colleague to address the reproduction and rate of population growth of the species, which is the basic information to estimate the PMI. However, the 1865 edition of the book does not include any reference to Fumouze (nor Fumouse). A close review of all volumes of the Journal de l'Anatomie published between the years 1860 and 1873 (a total of 14 volumes, one per year) revealed a couple of unrelated contributions on Astigmata species by A. Fumouze and C. Robin. Probably the closest match to Mégnin's citation is the one published in 1867: "Mémoire anatomique et zoologique sur les Acariens des genres *Cheyletus*, *Glyciphagus* et *Tyroglyphus*" (Fumouze and Robin 1867). Interestingly, Brouardel correctly cites this article; he also uses the name Fumouze, but incorrectly spelled Perier (which should be Perrier) and the last name Mégnin (but without the accent). Yovanovitch also uses a wrong name, "M. Simouse" regarding Fumouze.

The major problem I found on the matter of the life cycle of the mite in question is that the only article attributable that is authored by Fumouze (and Robin) does not include any indication of the biological parameters of *Tyroglyphus* species, such as developmental times and/or reproduction and reproductive rates. And, despite careful reading of every single mite paper found in the collection along the 14 year-volumes, no article makes mention of the life history parameters of *Tyrophagus longior*. This finding casts doubt on the estimations of the number of generations of mites that took place in/on the newborn mummy. Still, Mégnin suggested that each female mite would produce five sons and ten females every 2 weeks. Thus, the first generation, considering a single couple as the founders would have produced 15 new mites, the 2nd generation 150 mites, the 3rd 1,500 mites, and so on (see the table in Perotti et al. 2009b). These calculations left us with 1,500,000 mites in 3 months. For the PMI Mégnin estimated a grand total of 2,400,000 mites. The volume of the skull infested with mites was $\sim$3,000 cm^3 (he counted 4 mites/mm^3, which gave him 800 mites/cm^2 on areas covered by a 2 mm thick layer of mites). According to his figures and projections on the generation times, he proposed approximately $\sim$5 months to be the time needed to build the $\sim$2.4 million specimens of living and dead mites (the analysis also considered the limitation imposed by space and food availability). He suggested that the body would have been exposed several months after death, and once exposed to the air, insects colonised it, bringing with them the phoretic mites. According to Mégnin, the massive mite colony was built up during the 5 months preceding the finding of the body, i.e., since the middle of autumn 1877 up to the beginning of winter 1878.

Reanalysing the evidence

Tyrophagus species are non-phoretic species

Tyrophagus longior, together with sister species of the genus *Tyrophagus* do not have a specialised second nymphal stage, the deutonymph, which is the phoretic stage. *Tyrophagus* species are not dispersed by phoresy. Other genera in the family Acaridae do have a phoretic deutonymphal stage, which is often called a hypopus (pl. hypopi or hypopodes; OConnor 1982; Perotti and Braig 2009; Perotti et al. 2009a). Because *Tyrophagus* spp. are non-phoretic, they spread by walking or transport by air currents. Rarely, adult mites might be carried by other animals, such as small rodents, helped by their long sticky setae (Perotti and Braig 2009).

Mégnin might have observed adults and immature stages (but not deutonymphs) of a *Tyrophagus* species. Unfortunately, he hasn't described or drawn a specimen of the mites found in this particular corpse, what makes it impossible to confirm the identity. It could have been possible that the mite community in the corpse included both non-phoretic and phoretic species. In the event of a phoretic species arriving in/around a corpse in the phoretic stage, there are several possibilities. Just by looking at the Astigmata section of the Table 1 in Perotti and Braig (2009) one can imagine that there could have been a wide diversity of mites landing from a large variety of insect species that would just have visited the corpse without participating in the decomposition process itself.

However, in the case study, the only insects found were moths of an *Aglossa* species; it seriously restricts the mites' carriers to one species. Only five species of mites are reported as phoretic on moths of the family Pyralidae (all mites belonging to the Mesostigmata and the Prostigmata); and only one mite species is known for an *Aglossa* species (*Aglossa costiferalis*; Treat 1975). There are no records of phoretic astigmatans on Pyralidae moths (Perotti and Braig 2009).

On the sister species used for the estimations of population growth

Tyroglyphus mycophagus Mégnin is the species that Mégnin suggested to be a sister species of *Tyrophagus longior*. However, there is no resemblance between the adults, larvae or nymphs, and (nowadays) the two species belong to two disparate genera. *Tyroglyphus mycophagus* have deutonymphs (Schulze 1924), whereas *Tyrophagus longior* have not.

Now *Tyroglyphus mycophagus* is recognised as *Sancassania mycophagus* (Mégnin 1874). It has also been considered as a synonym of *Caloglyphus berlesei* (Hughes 1976). The complications of mite systematics do not stop here. Samšiňánk indicated that the genus *Caloglyphus* Berlese should be treated as *Sancassania* Oudemans (Samšiňák 1960), then, according to Samšiňánk, this mite should be called *S. mycophagus*, although *Caloglyphus* (=*Tyroglyphus*) *mycophagus* is still in use. The genus *Caloglyphus,* now synonymised with *Sancassania*, belongs to the subfamily Rhizoglyphinae, whereas *Tyrophagus* belongs to the Acarinae.

Summarising, the estimation of the time of death of the newborn child was probably based on Mégnin's knowledge of the developmental biology of *S. mycophagus* (=*Tyroglyphus*, =*Caloglyphus*), a species morphologically and physiologically quite different from the mite on the corpse, *Tyrophagus longior* (Mégnin 1874; Schulze 1924).

The temperature thresholds and requirements for *Tyrophagus* development

Like all other arthropods, Acari are affected by the fluctuations of environmental conditions. Lacking vital information about the biology of the mite in question, the best potential candidate to compare the biology with and to estimate the generational time of *T. longior* would be a member of the same genus, perhaps another cheese mite that presents a very similar life history. *Tyrophagus putrescentiae* (Schrank) is one of the closest relatives of *T. longior*. This mite, originally known as *Acarus putrescentiae* Schrank, did not get the attention of Mégnin. The relation of these two species is quite close, and some acarologists claim they can even interbreed. The hybrids are viable, presenting characteristics of one or the other progenitor species. The temperature thresholds for reproduction and development fall around the same range for these two *Tyrophagus* species (Hughes 1976); with the lower temperature limits for development between 7 and 10°C and the higher limits between 35 and 37°C. At 10°C the mortality of larvae of *T. putrescentiae*, reared at optimal humidity levels is 93.6% (Sanchez-Ramos and Castañera 2001). Eraky (1995b) as well as

Table 1 The PMI of the case of the newborn baby girl, Paris 1878, based on mite evidence

Year	1877								1878
Month	May	June	July	August	September	October	November	December	January
Ambient temperature (°C)	5–25	5–25	5–25	5–25	5–10	5–10	~5	<5	≪5
Mégnin's									
Weekly rate of population growth, outside				7.5	7.5	7.5	0	0	
Weekly rate of population growth, cranium				0	0	7.5	7.5	7.5	
Total number of mites				~165	~16,650	~1,650,000	?	?	~2,400,000
Perotti's									
Weekly rate of population growth, outside	7.5	7.5	7.5	<7.5	0	0	0	0	0
Weekly rate of population growth, cranium	7.5	7.5	7.5	<7.5	≤1	≤1	<1	<1	0
Total number of mites	~165	~16,650	~1,650,000	~2,400,000	~2,400,000	~2,400,000	~2,400,000	~2,400,000	~2,400,000
PMI-months	0	1	2	3	4	5	6	7	8
	Death	←	←	←	←	←	←	←	Body found

Two lapses of time are presented, Mégnin's and Perotti's. Perotti's PMI analysis includes temperature and the colonization of the body by a non-phoretic mite. Mégnin's PMI analysis did not include temperature records and considered that phoretic mites have arrived in the body brought by insects ~5 months before the autopsy. For further explanation see the main text. Total number of mites includes the results of monthly projections plus parental load (living parents)

Kheradmanda et al. (2007) found the same lower temperature threshold for immature development of *T. putrescentiae* fed on different food types: 8.6 and 8.74°C, respectively. The life cycle of *Tyrophagus* is greatly influenced by the humidity levels as is the case with most dust mites which survive only at a relative humidity over ~60%. Reproduction of *T. putrescentiae* at 18°C, 80–90% RH and optimal feeding conditions gives a rate of increase of 1.09 per female per day (Eraky 1995a). Under these environmental conditions, ten female mites could increase in a week to become 18 individuals; in other words, 1 female will produce 1.8 offspring in a week. According to Hughes (1976), for both *Tyrophagus* species, the life cycle takes 2–3 weeks if the mites are exposed to 23°C and 87% RH.

Tyrophagus longior will persist longer and survive over *T. putrescentiae* at low temperatures; however, it will stop development and reproduction. As mentioned above, *T. longior* is particularly found in the cool temperate regions of the world (Hughes 1976). This is probably the reason why Mégnin recovered *T. longior* instead of *T. putrescentiae* during that cold winter. There are no reports of life tables of *T. longior* at temperatures <10°C, most of the attempts to work with the mites exposed to this and lower temperatures have failed simply because the mites do not survive.

According to the prevailing weather conditions in Paris at the time of the body's decomposition, the mites occurring on/in the body of the baby girl must have been able to survive long periods at cold, often freezing temperatures. Independent climatic records from the years 1877 and 1878 indicate unusually low temperatures for Paris for the summer and the autumn of 1877, with summer records down to 5–6°C. The beginning of the winter of 1878 was also characterized by freezing periods triggered by an "el niño" effect (http://la.climatologie.free.fr/intemperies/tableau4.htm). Those were the seasons considered in the investigation. A similar trend of low temperature records was also reported for other European regions (http://www.wirksworth.org.uk/A14WEATH.htm).

The proportion of sexes of *Tyrophagus*

Important aspects of the biology of a species are the reproductive and the genetic systems. A species that produces more female offspring will show a higher reproductive rate than one that has similar numbers of males and females (Futuyma 1998). Adaptive sex ratio distortions fluctuate over time and are often specific to local habitats and environmental conditions; there are very rare documented examples of established deviations from the stability of frequency-dependent selection of Fisher's equal sex ratio in diplodiploid sexual species (Fisher 1930; Perotti et al. 2004).

Tyrophagus mites, as most studied Acaridae, are diplodiploid (Wrensch and Ebbert 1993). Most life table surveys on *Tyrophagus* species indicate a sex ratio around 1:1. Exceptionally, skewed sex ratios have been mentioned in only two reports out of hundreds of studies on *Tyrophagus* mites (Hughes 1976; Eraky 1995b). Diplodiploid arthropods that reproduce sexually and show female bias in isolated populations are extremely rare and normally the product of the drive of a selfish genetic element or the result of the manipulation of a reproductive parasite. In mites, endosymbiotic bacteria such as *Wolbachia pipientis* are able to induce cytoplasmic incompatibility and parthenogenesis in populations of haplodiploid species (Perotti and Braig 2005). Few species of diplodiploid sexual arthropods have shown a conserved female bias as a species attribute. Perhaps the most notorious example of permanency of female bias over time– centuries– and over space– around the globe—is the case of the human louse (Perotti et al. 2004). In diplodiploid mites with sexual reproduction, a case involving a sex ratio distorter has not yet been reported.

Mégnin assumed that females of *T. longior* generate twice the number of females to males. Again, this information was not found in any of the volumes checked of the Journal de l'Anatomie, including his own article on *T. mycophagus* (Mégnin 1874). There is still the possibility that he observed this rare phenomenon in his lab population of *T. mycophagus*, and that his estimations and projections were based on a rare case of a female biased population.

Summing up

For the calculation of the PMI, two main factors escaped the attention of Mégnin when analysing the mite colony:

1. *The mites on the body were from a non-phoretic species*. Let us assume that the corpse was infested by only one species of mite, *Tyrophagus longior*, as identified by Mégnin. Then the mites must have arrived primarily walking, because they are non-phoretic. There indeed is a high chance that they were already present in the area. If mites are present where a body is deposited, colonization of a corpse may occur very shortly after death. Non-phoretic mites, particularly the common inhabitants of soil and grassland (like *Tyrophagus* spp.) are normally in place when a body is deposited, whereas phoretic forms arrive to a corpse only when their carriers reach it. Thus, the arrival of phoronts will often be delayed.
2. *The original estimation of PMI did not take into account the effect of temperature on mite population development*. If we look at the information provided by the contemporaneous reports of the weather, the rate of increase of *Tyrophagus* populations on semi-exposed and exposed corpses, during the 5 months preceding the finding of the corpse (autumn and winter 1877) was likely to be at its minimum, if anything! However, Mégnin estimated the number of generations according to a maximum, which is likely to happen in warm or optimum temperature conditions, such as over the summer. The population growth proposed by Mégnin was 7.5 mites/week at 25°C. This agrees with other records but from populations presenting even sex ratios. At temperatures $\leq$10°C (like for the autumn and winter of the present case), the development of *Tyrophagus* mites stops, they do not moult, do not reproduce and many do not survive.

I propose the following scenario: The body of the baby girl was wrapped in linen and abandoned on the ground. The non-phoretic *Tyrophagus longior* colonised the body almost immediately by penetrating the minute openings of the fabric. Table 1 indicates the months of the years 1877/1878 when decomposition of the newborn took place and the approximate rates of population growth for a *Tyrophagus* population according to Mégnin. The table compares Mégnin's PMI proposal with a new suggested PMI, based on a combination of Mégnin's growth rate (for a female biased population, which is rare) and a crucial factor: temperature. In that case, the 2.4 million mites found on the corpse could have been the product of rapid population growth induced by a period of mild temperatures. The only period with mild temperatures was likely the summer of 1877, notwithstanding the records of periodically low temperatures of around 5–6°C, suggesting that it was a rather irregular summer. These unstable temperature conditions were followed by an unusually cold autumn and winter which can explain why a great portion of the mites from the corpse were found dead; mites survived by concentrating in the central parts of the skull, being able to reproduce at slow rates due to the cold records. Therefore, based on the biology of

Tyrophagus species and considering temperature as a decisive factor for mite development, the new analysis suggests that the colony of mites in/on the body built up along 8 months, opposing Mégnin's estimation of 5 months.

Interestingly, taking into account other factors that he didn't disclose, Brouardel concluded that the estimate of the time of death of the baby child was up to around 8 months before the autopsy, which was conducted the 15th of January of 1878 (Brouardel 1879).

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