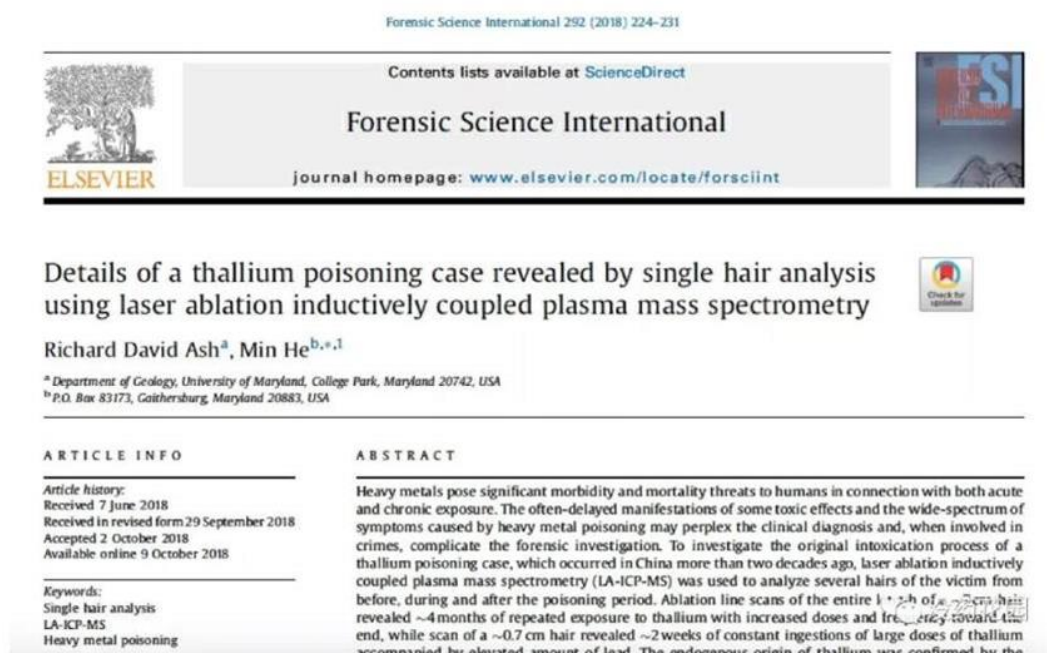


Thallium poisoning case of Zhu Ling (V): Analysis of 2018 paper

I mentioned in the fourth article that the first time was a chronic intoxication caused by multiple, small doses, but the second time was an acute intoxication caused by a large oral dose. This was my judgment based on her symptoms after reading many cases of thallium poisoning and relevant papers.

For the sake of time, I saved the "number of poisonings" analysis last week for this post. Since then, I've been informed of a paper published in Forensic Science International in 2018 that used Zhu Ling's hair for analysis.

[Insert picture: abstract of said 2018 paper]



This paper provides extremely important and startling new information. The discussion in this article is based on this paper as well as the timeline organised in the first three articles. I will try my best to write it in a clear way for ease of understanding.

Appreciation goes to an active Tsinghua alumnus for creating the tables, my cousin who is engaged in scientific research at the CDC in the US, and a number of professionals for their comments.

1. Frequency and method of poisoning

Zhu Ling had obvious symptoms on two occasions, but no one could tell whether this was caused by two large doses of poisoning, or the continued absorption of small doses of thallium poisoning until a toxic dose was accumulated.

Why does Sun Wei (translators' note: identified as Jasmine Sun in Australia, Zhu Ling's classmate and roommate at Tsinghua University) want everyone to help her prove that Zhu Ling was poisoned all at once in November 1994, and that her subsequent illness was only due to the lack of timely treatment over months?

[Insert picture: an email from Sun Wei to her friends requesting assistance in finding literature relevant to the lack of treatment for thallium poisoning]



This is because, if it was a one-off intoxication, Zhu Ling had a wide range of activities and contacts before the first symptoms appeared, and her friends from the

folk orchestra, boyfriend, and off-campus friends, among others, all had the opportunity to poison her.

Many people are convinced that the roommate was the murderer, precisely because Zhu Ling returned to campus on February 20, 1995, and spent only about eight days on campus, during which she was mostly in the dormitory because of her weakness and pain. So, (1) how many times was Zhu Ling poisoned? (2) how was the poisoning done by the murderer? (3) where was the poison added?

Zhu Ling's hair might be able to answer these questions.

After learning that Zhu Ling had been poisoned, Zhu Ling's parents collected her hair from the blanket she was wearing and stored it properly.

Zhu Ling lost all her long hair at the end of December 1994, then some new hair grew out; by March 1995, all the old and new hair fell out again. Based on the length of each hair, it is possible to estimate when they fell out separately.

More than 20 years later, Richard David Ash, a professor at the University of Maryland in the US, and Min He got those hair of Zhu Ling and analysed the distribution of heavy metal content in the hair using ICP-MS (Inductively coupled plasma-Mass Spectrometry). Since hair grows at a uniform rate, the thallium content on each section of a strand of hair can show the dose and frequency of the murderer's poisoning. The paper was informative and shocking.

Four-month-long poisoning

A strand of 7-cm-long hair (ZL1995H9) reveals that ***Zhu Ling was first poisoned over a period of four months.*** Since this strand of hair was shed on a blanket in Zhu Ling's home, the shedding would have occurred sometime between December 12, 1994 (when Zhu Ling returned home) and December 23 (when she was admitted to Tongren Hospital). This strand of hair shows an interval of 55 mm between the first and the last intoxication, implying a period of about 4 months.

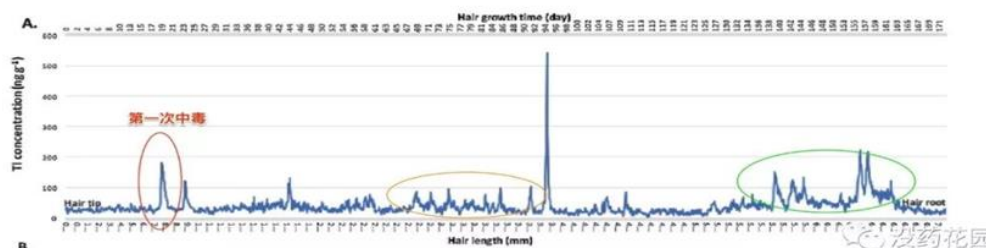
Since everyone's hair grows at a different rate, this time is an estimate by the authors of the paper based on the average hair growth rate of 18-35 year old Asian women.

In total, there were 25 toxin peaks in this strand of hair over a 4-month period (thallium levels 20 times above baseline are considered peaks).

The graph shows that after Zhu Ling first absorbed the toxicity of thallium in mid- to late-August, she was then poisoned occasionally over several dozen days. Between late September and early October, the intoxication became intensive with a

frequency of about every two days (yellow circles). Overall, these dozen poisonings were at relatively low doses, partly excreted and partly stored in the tissues, and caused no significant health problems.

[Insert picture: concentration of thallium in Zhu Ling's hair, annotated with circles indicating each period of intoxication]



R.D. Ash, M. He/Forensic Science International 292 (2018) 224–231

However, in the middle of this strand of hair (around mid-October), there was a sudden intoxication at a very unusual dose, 200 times above the baseline. ***This was also the highest dose of intoxication for Zhu Ling in the entire process.*** Corresponding to this, in October 1994, she experienced two brief episodes of blindness.

So how did the base value fall back down so quickly after this high dose of intoxication? Why did it peak for only two days, as did the previous small-dose intoxication? This may indicate that Zhu Ling was strong and healthy at the time and had a high capacity to detoxify herself.

In addition, there are some lower peaks a few days following the highest peak, which I personally believe to not be new intoxication, but rather that due to the previous dose being too large for the tissues to absorb, the thallium returned to the bloodstream and be redistributed so as to get into the hair again, creating secondary and tertiary peaks. (This is also a pattern I have noticed while going through the literature. Please correct me if I'm wrong.)

Reference for the redistribution mechanism of thallium: "Thallium is absorbed at different rates in different tissues and redistribution occurs over time, so that thallium can accumulate very uniformly in tissues and organs."
<http://www.cem.org.cn/rhtml/20151103/index.htm#R-20>

Moore D, House I, Dixon A. Thallium poisoning. Diagnosis may be elusive but alopecia is the clue[J]. BMJ, 1993, 306(6891): 1527-1529.

After this large dose of thallium absorption by Zhu Ling, no further thallium absorption occurred for some time. However, in late November, she suddenly began to be intoxicated frequently in large doses.

Since early-December (three weeks before her hair fell out), Zhu Ling absorbed thallium in increasingly large doses, 50-80 times higher than the baseline; and more frequently, with only 2 days between each intoxication (green circle).

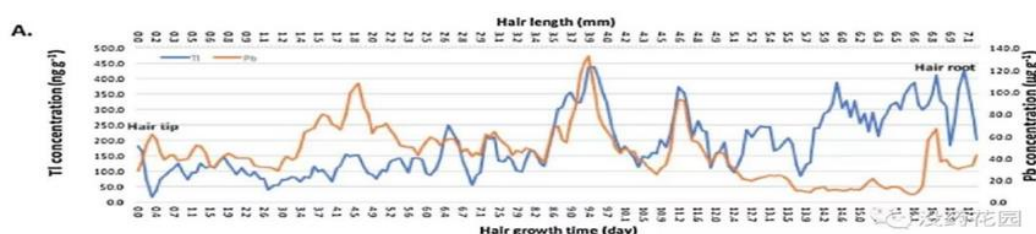
Correspondingly, she developed visible systemic symptoms of thallium poisoning: stomachache, vomiting, nausea (such gastrointestinal symptoms generally occur more quickly after oral thallium intake), tingling in the tips of her hands and feet (increasing peripheral neurological symptoms), and hair loss.

The authors of the paper believe such associations to indicate a change in the intoxication mechanism from other approaches to oral ingestion, and from chronic to acute.

Two-week of mass poisoning with higher levels of lead than thallium

Another important evidence was a short 0.7 cm hair (ZL1995H5) with an approximate growth cycle of 2 weeks. It is known that Zhu Ling returned to campus on February 19, 1995, and was admitted to Peking Union Medical College Hospital (PUMCH) on March 15 after returning home on March 7 with acute poisoning symptoms and losing all of her newly grown hair. Therefore, this hair was shed on the bed at home between March 7 and March 15. Working backwards, this hair grew after returning to school during winter break, just enough to show what happened during Zhu Ling's second intoxication. The test results showed many peaks crowding this less-than-1-cm-long hair, all with doses 50-180 times higher than the baseline value and on an increasing trend (blue line). Most of the peaks were only 6-18 hours apart.

[Insert picture: concentration of thallium and lead in Zhu Ling's hair]



R.D. Ash, M. He/ ForensicScience International 292 (2018) 224–231

Even more surprisingly, this strand of hair shows that she also experienced lead intoxication (orange line) during this period. The peaks of lead and thallium coincide in several places, but the doses of lead are higher than those of thallium!

Continued absorption of thallium in large doses caused acute intoxication, which corresponded to her symptoms after she was taken to the hospital in March: stomach pain, pain in both feet to the point of not being able to stand, confusion, seizures, convulsions, and then a coma for five months.

However, lead can also attack the central and peripheral nerves, causing symptoms similar to those of thallium poisoning, such as pain, muscle weakness, convulsions, seizures, and coma, although through a different mechanism.

Lead poisoning also aggravated some of the victim's symptoms at the time. Overall, however, thallium is more acutely toxic than lead, so that the overall symptoms were later relieved, although only thallium was targeted for detoxification.

2. What does the paper data indicate?

I can't describe how moved I was when I first saw the chart from 2018, which probably was mostly out of the awe for the life force.

Although Zhu Ling's intelligence is only that of a 6- or 7-year-old child, with near-complete loss of speech, and inability to recall, think and state who was the potential murderer, her hair kept a record of what the murderer has done to her.

I tried to match these data with Zhu Ling's symptoms described in news reports, in order to look for the specific time and pattern of the murderer's poisoning acts. The result of this experiment should be accurate, because those peaks in her hair don't lie; but there are too many factors that could affect the interpretation.

First of all, everyone's hair grows at a different rate. If Zhu Ling's hair grows faster or slower than the average, there will be variation in the corresponding dates.

Second, thallium intoxication has an incubation period that is as short as a few hours and as long as a few days, and each person could show different symptoms. For example, a 23-year-old Japanese female student was repeatedly dosed with thallium sulfate in her tea by another female. Beginning the day after the last intoxication, she experienced fatigue and muscle pain that gradually spread downwards from her thigh. On the seventh day, she went to see the doctor after experiencing numbness in her toes, soreness in her lower legs, dizziness, stomachache, and hair loss. That is, the stomachache came after the leg pain.

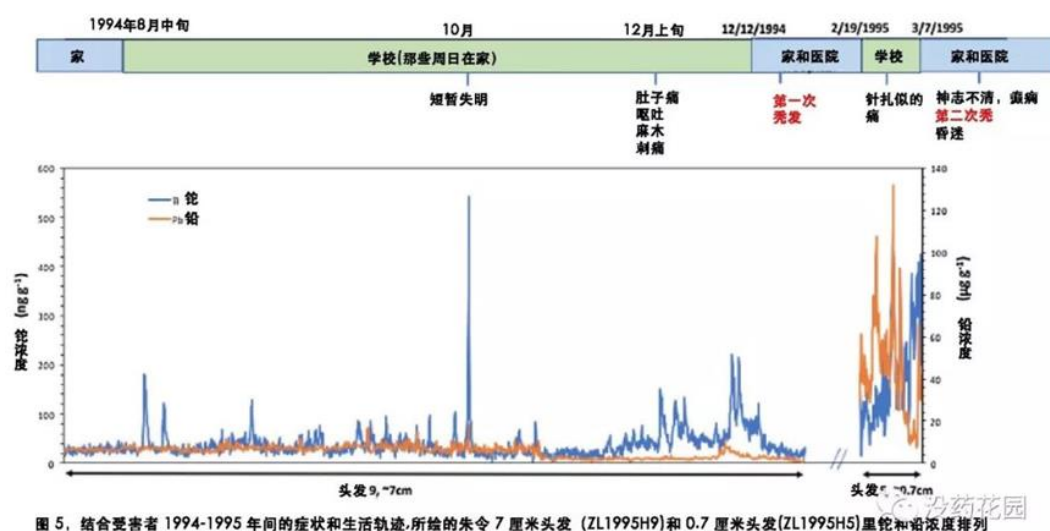
Reference: Yumoto T, Tsukahara K, Naito H, Iida A, Nakao A. A Successfully Treated Case of Criminal Thallium Poisoning. J Clin Diagn Res. 2017;11(4): OD01–OD02. doi:10.7860/JCDR/2017/24286.9494

Furthermore, consistent with the literature mentioned before, thallium that reaches the tissue without being fully absorbed at once tends to return to the blood, bringing about a secondary peak. Such peaks are indistinguishable from those of later intoxication.

Finally, only a rough time frame of when Zhu Ling's hair fell out on her bed at home could be determined, but not precisely confirmed.

Below is the chart accompanying the paper (translated to Chinese); it is sorted based on the average hair growth rate of 18-38 year old Asian women.

[Insert picture: said chart in Chinese]



Despite a lot of uncertainties, we still calibrated the chart after considering various factors such as Zhu Ling being home on Sunday, media reports of her condition improving and worsening, time of her hair loss, and her hair growth rate.

According to the chart we arranged, Zhu Ling's hair growth rate is above average, which in my opinion is in line with her health as a 21-year-old and a national second-class athlete.

It also means that the bottom line may need to be shortened slightly to the right after the tail (time of her hair loss) is fixed at a certain point.

3. Analysis by MoYaoHuaYuan

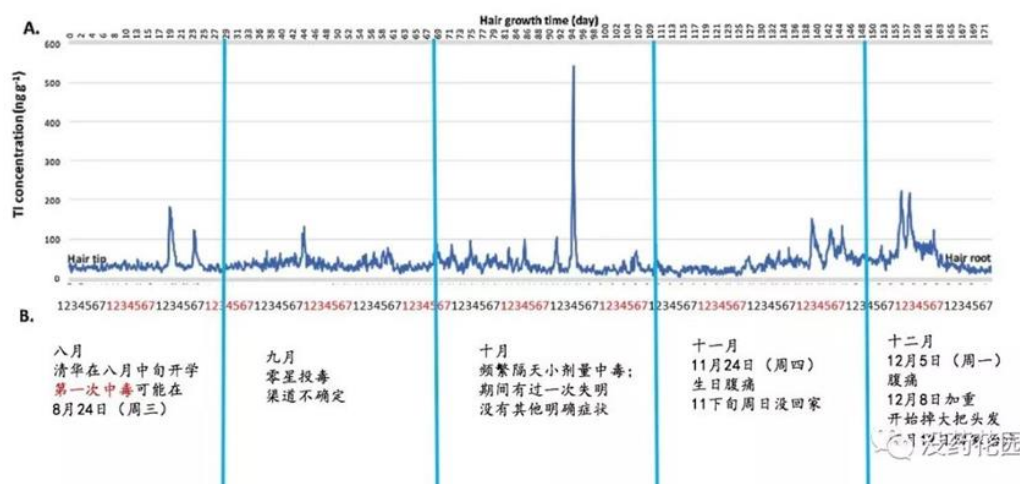
i. Zhu Ling was poisoned earlier than expected

Zhu Ling first got poisoned not long after returning to the university in mid-August 1994.

Although she enlisted the help of teachers at Tsinghua and was unable to check the 1994 school calendar, it is speculated that in mid-August it was likely that Tsinghua probably had started school while there was no official class. Another suggestion is there was a short school term. In a word, everyone else living in her dorm was back on campus.

After calibration, Zhu Ling was probably poisoned around August 24th.

[Insert picture: concentration of thallium in Zhu Ling's hair, annotated with month and potential poisoning instances. The obscured sentence is about going home for treatment on December 12.]



So, when was Sun Wei first exposed to the thallium salts? At present, I can only find a general reference, "In September 1994, Sun Wei entered Aijun Tong Professor and Longdi Li Professor research group as an intern" (Yangcheng Evening News).

Does it mean that Sun Wei was only exposed to the thallium salt in September? Not necessarily.

Firstly, there was only general or rough information released by media, far from accurate.

Secondly, the other members of this group are three graduate students and a fifth male student. Generally speaking, students like Sun Wei who just rose to the third year and whose professional performance was not that good would not be easily

selected into the group. She should have contacted the group for the internship late as in the second semester of the second year or during the summer vacation.

Thirdly, students are supposed to read relevant papers and know about the purpose of the experiment before entering the research group. Therefore, Sun Wei certainly already knew which chemicals would be used in the group. Since thallium is a highly toxic substance, before interns officially taking part, Professor Tong is also bound to train the students, especially the novices, and clearly inform them of the toxicity and the way of poisoning. Therefore, there is a greater probability that Sun Wei owned a key and free access to the laboratory during the summer vacation. (Usually, graduate students' experiments still go on during the summer vacation.)

If Sun Wei can prove that there was absolutely no chance for her to be legally exposed to thallium salt before the beginning of September, she could defend herself from being a suspect.

But if the thallium salt suffered theft case, Sun Wei had at least two advantages over others: She knew that the lab kept the thallium salt while others could hardly know. It's easy for her to find out about the other members of the lab while it's hard for an outsider.

Now that the police had found the invoice for the thallium salt purchased by the Tsinghua research group, they could at least determine the earliest time the lab owned thallium salt.

In the first draft of Sun Wei's statement, she twice emphasized that Zhu Ling was poisoned ***at the end of 1994***.

"More importantly, I offered to quit the Chinese folk band at the beginning of my junior year (September 1994) because of the heavy schoolwork... ***Zhu Ling got sick at the end of 1994.***" (Sun Wei's Statement 2015/12)

"Zhu Ling was poisoned at the end of 1994, and the thallium poisoning was confirmed in April 1995." (Sun Wei's Statement 2015/12)

There are two interpretations for her words.

In fact, it's out of my expectation that Zhu Ling got poisoned that early. I believe before the paper released, most of all supposed that Zhu Ling was poisoned either on her birthday or in October 1994 when she suffered brief blindness for the first time.

In this condition, what does it mean that she was poisoned not long after returning to school?

1. ***It shows that the murderer had resented Zhu Ling for long.*** If there was new contradictions between the two occurred in the second semester of the third year, it is unlikely to develop into such a severe level in a few days, prompting the murderer to decide to poison Zhu Ling quickly. While it's almost impossible to be triggered by contradictions during her high school years or even earlier because it's also not possible for someone to bear such intense hatred in mind for that long without taking action. What makes sense is that the conflicts between the two was left over during the sophomore year or the summer vacation.

2. As analyzed in the previous article, it is impossible that K (the supposed murderer) happened to hear of that there is thallium salt here at the lab and took the opportunity to steal it. Consider Zhu Ling had been poisoned within a few days of returning to school, making the possibility of K being able to do so even lower.

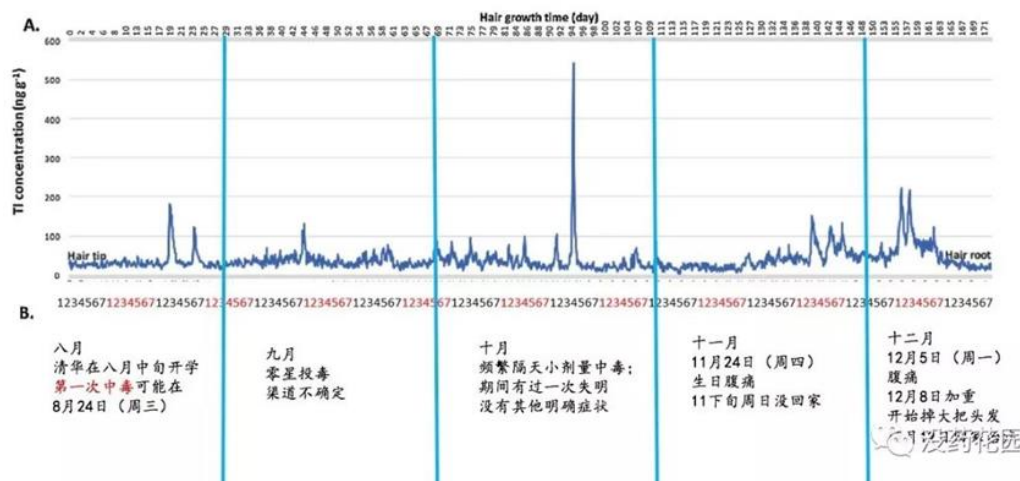
To sum up, my suggestion is that ***since Zhu Ling got poisoned right at the beginning of the semester, indicating the murderer had hated Zhu Ling for some time, and the motive to poison her had been formed during the summer vacation at latest. He or she had access to the thallium salt in mid-late August.***

ii. The murderer tried to remain the poisoning under cover

Zhu Ling was poisoned shortly after returning to school in mid-August. At the beginning three months or more, due to the slight amount of each poisoning absorption, coupled with her body tissues were of healthy condition, there was no obvious symptoms shown. ***It is consistent with how chronic poisoning develops***—with mild symptoms that may not be noticeable for weeks or even months at the beginning.

Since Zhu Ling had not developed gastrointestinal symptoms until the end of November (symptoms occurred quickly if the poison being taken orally), it might suggest at first she absorbed the poison via skin, mucous membranes, etc.

[Insert picture: concentration of thallium in Zhu Ling's hair, annotated with month and potential poisoning instances. The obscured sentence is about going home for treatment on December 12.]



Discussion 1: Poisoning through Toiletries

Previous research shows that, "thallium levels in the body are similar regardless of the route of exposure (dermal, intraperitoneal, oral, intravenous, inhalation, intramuscular) and are proportional to the dose of exposure." (Reference: Zhang Dongsheng, Wang Zishi, Qin Yuhui. Metabolism and toxicology of thallium[J]. (Foreign Medicine:Hygiene, 1985, 3:141-145.)

Of course, it will be washed off through showering and hair washing, the amount absorbed may not be as high as consumption.

Regarding whether noticeable remains could form and alert the victim, many readers left their opinions at the end of the last article:

[Insert picture: a reader's explanation that thallium chloride wouldn't form observable residuals in shampoo or body wash]



再说氯化铊沉淀吧。理论上，离子积一大于溶度积便产生沉淀，先是形成一个分子的沉淀，然后越来越多。但是要形成肉眼可见的沉淀，离子积要远远大于溶度积才行。比如透明水溶液中，要想生成宏观上的、肉眼可见的氢氧化锰沉淀，锰离子与氢氧根的离子积必须是溶度积 10^5 （十万倍）以上。洗发液或沐浴露中，氯离子与铊离子的离子积只是溶度积的十余倍，再加上是有颜色的膏体，所以完全不用担心会产生肉眼可见的沉淀。

2019-11-22 17:07:07

☆ 不 回 ...

没药花园

If the murderer did put thallium in the hygiene products, Zhu Ling's showering and hair washing should follow a routine, so how could it be that sometimes there is a gap of 20 days of not being poisoned, but sometimes poisoned every one or two days over another 20 days? There are so many possibilities that couldn't be discussed one by one. I personally believe that the murderer poisoned different mediums progressively.

If the shampoo was poisoned, Zhu Ling would have pumped most of the thallium on her hair when she first used the shampoo returned to campus in August (thus the high dose of poison in the first time), and pumped little thallium afterwards. This possibility could be ignored.

If everyday products like face wash and facial cream became poisoned in October, it could lead to the experience of frequently being poisoned by a small dose later. In some day of October, Zhu Ling applied the face wash as usual, but accidentally got some into her eyes or there was a cut somewhere, leading to a hike in the absorption level (corresponding to the tallest peak).

[Insert picture: a list and some thoughts of possible mediums poisoned]

所以最后留下的可能投毒渠道如下：

消化道吸收：中药、热饮

皮肤吸收：洗发水、沐浴液、口红、隐形眼镜液

（凶手可能在其中一至多个中投毒）

我个人的想法是：凶手第一次投在浴液等地方，导致朱令多次使用后发生慢性中毒；第二次投在饮食中，造成急性中毒。

 没药花园

I didn't mention things like face wash and facial cream in my last article, because I didn't see them on the list of missing items and thought what's left would have gone through testing and ruled out by the police. But I checked with those that are close to Zhu Ling's parents, and the parents actually couldn't confirm what items were left by

Zhu Ling in her dormitory either, so the list of missing items reported on news is very likely to be incomplete.

Discussion 2: Poisoning through Contact Lens Solution

In mid-October, Zhu Ling went temporarily blind once (some say twice). What does this have to do with being poisoned? “Acute thallium poisoning will show symptoms after 12-24 hours of being in contact. **Early clinical symptoms include nausea, vomiting, colicky or dull pain in the abdomen, diarrhea, and more**, with gastrointestinal bleeding in some serious cases; after 2-5 days, symptoms shown include symmetrical soreness, numbness and pain in fingers (toes) that gradually increase and progress proximally towards the heart. Light touch of the skin becomes extremely painful, leading to the inability to stand and walk. The condition progress to include limb paralysis and muscle atrophy. The cranial nerves are pressured when poisoned by thallium, for instance, **vision loss**, ophthalmoplegia, and facial nerve palsy. The symptoms of chronic thallium poisoning and acute thallium poisoning are mostly similar, but with milder clinical symptoms. Acute poisoning are mostly caused by consumption through the mouth, and chronic thallium poisoning are mostly caused by occupational exposure...*being in contact with thallium-containing chemicals could also cause infectious retinitis, retrobulbar neuritis, optic atrophy, and more*” (New Progress on the Current State and Treatment of Thallium Poisoning).

The dose of poison in mid-October was 200 times above the baseline, the highest one among all the poisoning Zhu Ling has experienced. If such a large dose was consumed through mouth, theoretically the early symptoms would include gastroenterological reactions: vomiting, stomachache, and abdominal pain; or nervous symptoms: pain in the limbs; but Zhu Ling only experienced an unusual temporary loss of vision, which came back after 1-2 days, and there didn't seem to be other systemic symptoms.

This is indeed puzzling. Experts so far, including the authors of the 2018 paper, believe this instance of poisoning was not through the digestive tract. Then, the only possible absorption channels are membrane and skin contact. The authors of this paper infer that in this instance, Zhu Ling's absorption of poison was possibly through the contact lens solution. But would eye contact of thallium really lead to temporary blindness?

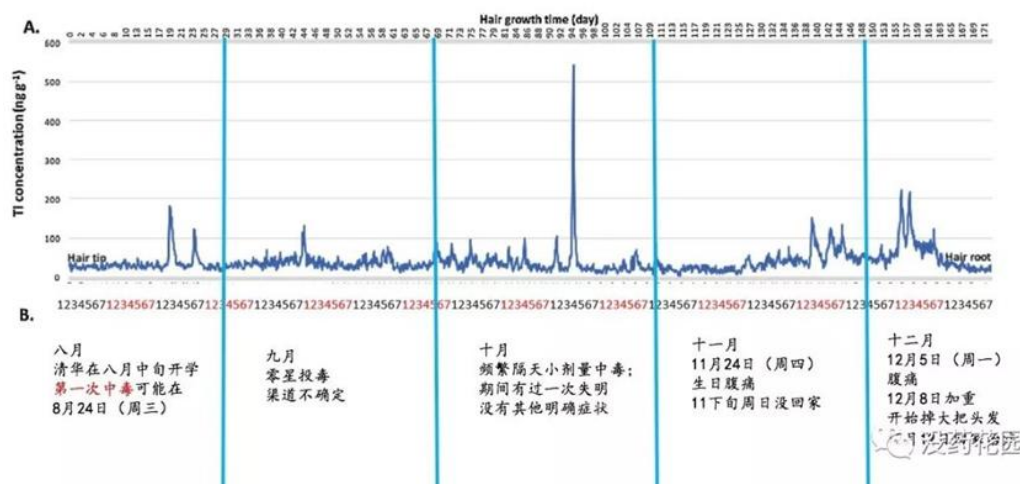
One view is that, if thallium could penetrate skin and membrane, why not eyes and the surrounding skin? If it could, then this channel is like others. So, Chen Zhenyang's response was, “There will be blindness and whole-body reaction” (February, 2007).

Another view is that, acute eye exposure is unlikely to cause local or systemic symptoms, except mild local irritation. (See the first CDC citation). **“Acute eye exposure** is unlikely to result in any local or systemic effects other than **mild local irritation.”**

Then, does being in contact with diluted thallium solution count as “**acute eye exposure**”? How high should the concentration of thallium be, for the eyes to feel irritated after being in exposure? All of these are unclear. I spent heaps of time searching in Chinese and English and found no cases. Perhaps nobody would ever conduct such an experiment. So, if the contact lens solution was indeed missing, I would lean towards the first view: it will cause vision problems and whole-body reaction, just like absorbing through other channels. It can't be ruled out that Zhu Ling experienced pain in her legs and abdomen, but they were mild and didn't draw her attention as much as blindness.

A different inference can be made: the offender started poisoning the contact lens solution in October, but due to the doses being small, Zhu Ling never experienced pronounced irritation and continued to wear as usual, leading to her being poisoned in small doses between early- to mid-October.

[Insert picture: concentration of thallium in Zhu Ling's hair, annotated with month and potential poisoning instances. The obscured sentence is about going home for treatment on December 12.]



But one day between mid- to late- October, perhaps due to cornea abrasion, the absorption level hiked (corresponding to the tallest line). Upon entering the body, thallium initially affected her optic nerve and caused blurred vision. Although thallium also flowed to the gastrointestinal tract with blood, she wasn't alarmed by the discomfort as her gastrointestinal system was healthy.

From this chart, she seems to have stopped using an everyday product that contained thallium after going temporarily blind, so she wasn't observably poisoned for three weeks after the tallest peak.

The paper provided an important piece of information: Zhu Ling usually wore contact lens, and had to switch to glasses after the blindness incident. (This is consistent with the observation I made in the last article to the photo of Zhu Ling performing.)

Taken altogether, she is very likely to be poisoned through contact lens, stopped wearing them, and had a while of being free from poisoning.

Discussion 3: the murderer was experimenting and exploring the dose

As I wrote previously, a quarter spoonful of thallium salts or 20 ml of solution (given the concentration of thallium solution used in Sun Wei's experiment) can be lethal.

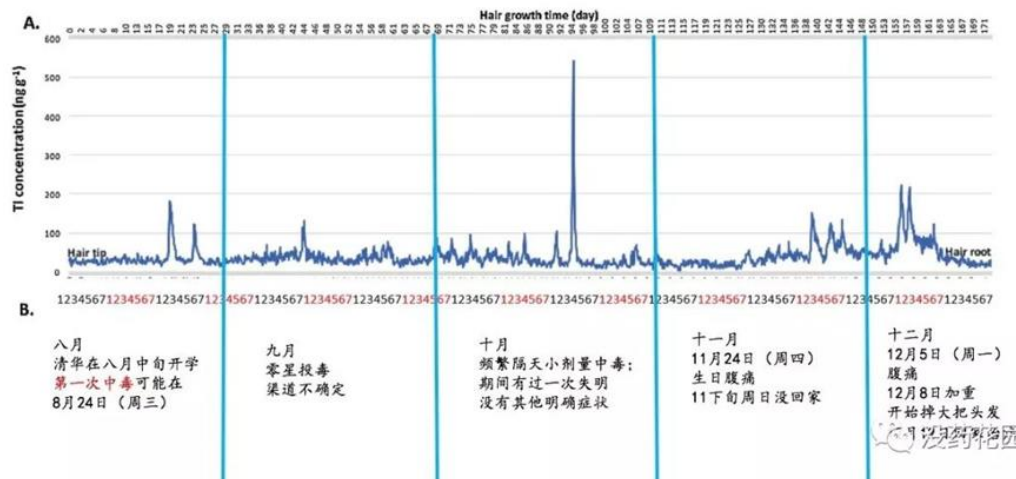
The murderer's choice to poison through skin contact and control of the dose suggests the murderer had done research on the amount needed for thallium poisoning. An example is the poisoning case by Wang Xiaolong, a chemistry student at Peking University, where he weighed 200 mg precisely and dosed for multiple times to see how the victim reacted. It could be concluded that: 1) death was not the initial purpose of the murderer, but rather for Zhu Ling to be in pain, to suffer, to become seriously ill, and to disappear from the murderer's sight; when the murderer realized there seemed to be no effect, the murderer increased the dose; 2) the murderer was concerned; sought discreetness and not wanting the poisoning to be discovered, which doesn't align with the psychological profile of someone trying to frame another.

iii. Change of poisoning method or dose in late-November

On December 5, 1994, Zhu Ling's father held a belated celebration for Zhu Ling's birthday. Zhu Ling showed severe abdominal pain during the meal and couldn't eat. Several news agencies also reported the meal to have happened on November 24, 1994. (Unable to be confirmed due to conflicting information.)

Currently, based on our reasoning arrangement, Zhu Ling started experiencing frequent small doses of poisoning around mid-November. On the eve of her birthday on November 24, 1994, she began experiencing large doses of poisoning. By December 5, 1994, there is also a corresponding peak in poisoning levels in the chart.

[Insert picture: concentration of thallium in Zhu Ling's hair, annotated with month and potential poisoning instances. The obscured sentence is about going home for treatment on December 12.]



Zhu Ling already stopped wearing contact lens at that time, the question arises whether the murderer increased the dose in other skin-contact methods; or the method was changed to poisoning through food and drinks? The author of the paper believed it to be the latter. But there is no doubt that the murderer did not passively await the results after one poisoning incident, but continued to escalate the actions.

Why did the murderer become more and more aggressive after waiting for three months? The December 9, 1994 gala was the most important event for Zhu Ling in the first semester of her third year, which she spent all of her spare time on. On that night, she would appear in almost every performance except for others' solo performances. The murderer knew that Zhu Ling would shine on the night of December 9, tormented by this thought, hoping to ruin Zhu Ling's most cherished opportunity by preventing her from taking the stage. The murderer waited for three months, during which nothing happened except for the quickly-recovered temporary blindness, and considering that the thallium applied to toiletries may have been used up, the murderer judged that skin absorption was not yielding satisfactory results. Consequently, the murderer switched to poisoning through food or significantly increased the dosage. Zhu Ling's body couldn't detoxify in time, and the thallium accumulated over several months started attacking various organs. This corresponds to the severe stomach pain Zhu Ling experienced on Monday, December 5, 1994.

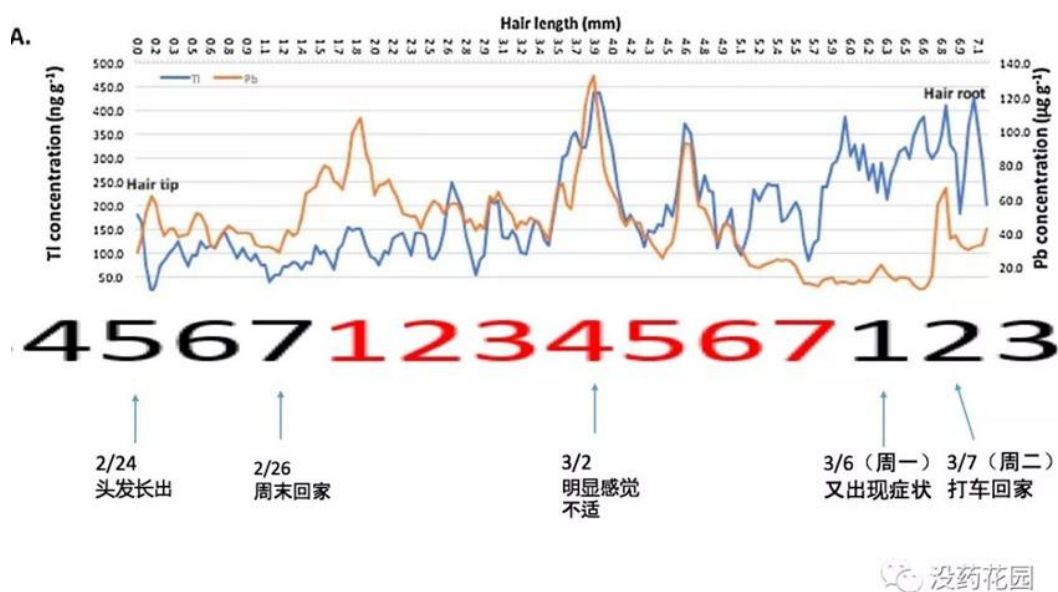
By December 8, 1994, Zhu Ling has not only experienced "persistent dull pain and paroxysmal colicky pain" stomachache and inability to eat, her abdomen, lower back and joints were all in pain, while also having significant hair loss (Xinmin Evening News). The sense of responsibility and determination kept Zhu Ling going. The battle between Zhu Ling and the illness seemed, for the murderer, more like the battle between Zhu Ling and the murderer. Zhu Ling persisted until the end of the performance and returned home on December 12, 1994. By this time, she exhibited typical symptoms of acute thallium poisoning, including stomach pain, tingling in the hands and feet, and hair loss. On December 23, 1994, Zhu Ling was admitted to the

Gastroenterology department of Beijing Tong Ren Hospital for “abdominal pain, hair loss, joint pain to be investigated”, and by then, she had already lost all of her long hair. (China Newsweek, 18/01/2006).

iv. Source of poison revealed by an exceeding-standard level of lead

Overall, because of Zhu Ling's vitality, her first encounter with a combination of chronic and acute poisoning wasn't fatal. She displayed severe symptoms on December 5, 1994, and managed to study and rehearse as normal for a week at Tsinghua University till December 11, 1994. Although she didn't receive effective treatment, her hair grew for an inch by the time she returned to school...

[Insert picture: concentration of thallium and lead in Zhu Ling's hair, annotated with potential poisoning instances]



On the second time of acute poisoning, the frequency was increased to one to two times a day, together with the dose shown in hair which increased to 50-180 times the baseline. (Previously mentioned as 50-80 times).

This frequency of poisoning reflects the increasing audacity and urgency of the murderer, perhaps also the disappointment and anger seeing Zhu Ling's return. The murderer's determination to “eliminate” Zhu Ling made the murderer disregard the potential deadly consequences.

What's more surprising is that the amount of lead in Zhu Ling's hair during that period was higher than the amount of thallium. The author of the paper wrote that, the

overlap of peaks of lead and thallium suggests the absorption of both at the same time.

Did the murderer poison her with two types of toxins out of the concern that thallium wouldn't be enough to be effective? Let's examine the features of this curve: 1), the peaks of lead and thallium are essentially overlapping, indicating simultaneous ingestion; 2), the intervals between each poisoning were mostly 6-18 hours; 3), thallium shows an upward trend in the later stages, while lead decreases significantly.

I believe there are several possible scenarios: 1) the thallium salt itself is contaminated with lead, which I didn't find relevant information for, and how could it be for experimental-level thallium? 2) the container itself used for thallium poisoning (such as a metal cup) contains an unsafe level of lead, and some sort of chemical reaction occurred after thallium nitrate was added, resulting in the lead being released into the drink and ingested...(I've read that pouring acidic juice into lead-containing ceramic cups will dissolve the lead, which then ingested); **3) *The food used for poisoning itself contains lead, and this food is regularly consumed by Zhu Ling twice a day.***

For the last one, I vaguely recall seeing cases about the unsafe concentration of lead in traditional Chinese herbal medicine that lead to lead poisoning. Turns out there are plenty of papers on this.

[Insert 3 pictures: key information of three papers on Chinese herbal medicine causing lead poisoning]

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内服中药引起铅中毒24例

《中国乡村医药》1994年 第4期 | 臧仁迅 谭业雪 山东省莱阳市中心医院内科 莱阳市中医医院内科 265200

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服用中药制剂引发铅中毒2例报告

《中国工业医学杂志》2010年 第1期 | 康明 高天超 聂颖 抚顺市职业病防治院 辽宁抚顺113001

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中药偏方致铅中毒1例

《现代中西医结合杂志》2004年 第8期 | 董秋 封苏新 江苏省南京市疾病预防控制中心金山医院, 江苏南京210042

I then looked up bone strengthening powder and saw some news about the unsafe level of lead. But because there were not many people who use bone strengthening powder, no research papers were found.

[Insert picture: a news report on the high level of lead in bone strengthening powder]

1993年，有研究人员就美国和加拿大市场上70种品牌的钙剂，进行分析、计算每摄入800毫克钙时铅的摄入量。结果，以骨粉中含铅量最高，在统计的6种骨粉中，当其含钙量相当于800毫克的钙时，其中的平均含铅量达11.3微克。25种来源于牡蛎壳等的天然非精制碳酸钙，相应的含铅量平均为6微克。而我国卫生部对钙保健品中含铅量的严格规定是，每公斤钙片含铅量不得超过0.5毫克，如以碳酸钙为例，也就是相当于800毫克钙中的铅，不能超过1微克。

食品与营养安全所的某专家也强调，“骨粉里面的铅含量特别多，其中的铅、砷很容易超标。”人们大概不会忘记2000年和2003年卫生部曾两次抽检、公布的不合格补钙类保健食品中，其中有的钙剂中砷含量超过国家标准2.2倍，铅含量超过国家标准1.2倍。众所周知，仅菌落总数一项微生物指标就超过国家标准

Assuming that herbal medicine wasn't properly regulated in the 1990s, and had the potential to contain a significantly high level of lead, then for the second time, the murderer might have put the poison in Zhu Ling's herbal medicine bottle.

The reason being that, there are regular intervals for taking medicine, perhaps once or twice a day, and there is a longer gap at night because of sleeping. Each time she took the medicine, the high amount of lead within the medicine and the thallium added by the murderer were consumed together.

It's known that the herbal medicine was gathered from Tong Ren Tang and taken to Tsinghua university along with bread by Zhu Ling's mother after work every day. Zhu Ling would reheat it outside the next day after leaving it in the dormitory overnight. Many may question: if a dormitory roommate could poison her in the herbal medicine bottle, would someone be able to do the same at the place where she reheats her medicine? From what I've seen in multiple news reports, Zhu Ling **reheats her medicine at the Youth League** everyday (see the first article). But what Sun Wei said in her statement was, "Zhu Ling has a lot of friends and many club events, while being an active member of the university's arts club, and she spends more time at the club than in the dormitory; even after she returned to university following the first time she fell sick, she continues to reheat **her medicine at the dormitory building of the arts club**". The Youth League and the arts club are entirely different places, and the processes of cooking and reheating medicine are nothing similar.

[Insert picture: a map of the distance between the dormitory building and the Youth League office]



Place 1, the Youth League, where Zhu Ling heated the herbal medicine was introduced to Zhu Ling by her boyfriend Mr. Huang, not only because one of a member of the folk orchestra worked there, but also because it was near to her dormitory.

Zhang Jie, the lawyer for Zhu Ling, said in his investigation report: "After the spring semester , Zhu Ling never went to the folk orchestra, so the conclusion is that: The second poisoning place could not be there. ***It took her 3 minutes from her dormitory to place 1***, where she heated the herbal medicine which had been boiled at home. At place 1, ***she put the medicine bottle directly into the hot water without opening the lid. During this process, she was standing there and watching.*** Therefore, this process was totally under her control. Nobody could do anything wrong. "

Place 1 was mainly used as a place for the activities of the Youth League, so only a few relevant teachers and students worked there, which means it was probably not a public place for strangers. So it is almost impossible for the murderer to go there and put poison in the bottle every day in such a short time in their presence.

It seemed Sun Wei unintentionally mentioned ***the details when Zhu Ling was heating medicine***, which made us doubt the reason why the murderer put poison in the medicine bottle. His or her mindset was: Zhu Ling took the medicine

bottle out every day, so it would be difficult to confirm the place for poisoning even though the poison was found in the bottle later.

The possibility of poisoning in the bone strengthening powder was little. If the brewed bone strengthening powder had been poisoned, the murderer would have chosen the interval before Zhu Ling drank it and after she prepared it every day. Such behavior was very hard to control.

If the murderer had poisoned the solid bone strengthening powder, the poison should have been the solid thallium and the powder should have been in a big canister and eaten up by Zhu Ling or thrown away. Otherwise, the police would have found the thallium there easily after testing. Moreover, Longmu Zhuanggu Keli drunk by Zhu Ling was all in small packages.

If the murderer put the thallium in the medicine bottle, it would match the report by *The Lawyer of China* on page 16 in June, 1998: "Confusingly, Zhuling's water bottle and medicine bottle were lost."

Zhu Ling's aunt said in an interview: "the police officer gave us a list about Zhu Ling's personal belongings. **But there was nothing for oral use**, like any lunch box, cup, chopsticks, spoon, food, etc. I felt strange and asked Xue Fangyu. So did he and he asked others to find out why. After a long time, he called me and asked me if her bottle was made of stainless steel, because Sun Wei said she found it under her bed."

I have given all my reasons for the judgement above. According to the reference, lead content in normal human hair is 0-30ug/g.

Reference: Pirsaraei SR. Lead exposure and hair lead level of workers in a lead refinery industry in Iran. *Indian J Occup Environ Med.* 2007;11(1):6–8. doi:10.4103/0019-5278.32457

The lead content in Zhu Ling's normal hair is around 1ug/g. But in her 0.7cm hair, the average lead content is 43ug/g.

Is it possible that such high lead content was caused by the lead excess in herbal medicine in 1990s? I did not find relevant data (Usually, people only test lead content of their blood). And now the herbal medicine industry is much better controlled so it is meaningless to compare the hair lead data of a person taking the same medicine with Zhu Ling's.

v. Greater probabilities of poisonings by the roommate

Before the paper was published, Sun Wei's supporters such as Fang Zhouzi insisted that it was impossible to poison the shampoo and the contact lens solution. They held that Zhu Ling was poisoned by one or two big doses in water or food, so everybody who knew Zhu Ling might be the murderer. They even said Bei Zhicheng was the suspect.

But the paper confirms that Zhu Ling was not poisoned just for one or two times. On the contrary, she was poisoned dozens of times in 4 months after the late August and got poisoned once or twice per day after she came back to school following the end of winter holiday in 1995.

Even though many times of poisoning was because she contacted the same poison source, we can conclude that the murderer did not finish poisoning just in a single time. From the curve we can see, the murderer was watching Zhu Ling and adjusted the type of carriers as well as the content of Thallium.

By the way, the poison was absorbed not only by skin in small doses, but also with frequent food intake in big doses.

Due to the very few ways for skin to absorb the poison and the details of the dormitory theft, the carriers of poison were the toiletries. Zhu Ling's toiletries were either in the dormitory or in the public bathroom for girls. So how could a male catch the chance to poison? Not to mention that the contact lens solution would not leave her dormitory.

The conclusions:

1. The murderer could recognize Zhu Ling's toiletries and ***had enough time to touch these things separately for many times***. It is the most convenient and safest for the roommates compared with others to do that.
2. During the second time of poisoning, Zhu Ling took the poison orally at least once a day, which also confirmed that the murderer needed to wait for Zhu Ling to stay out from her food(and maybe her medicine bottle). This conclusion also points to the roommate.
3. After Zhu Ling came back from school on February 19, 1995, she never went back to the folk orchestra. Instead, she just walked to place 1, 300 meters away from her dormitory. The medicine bottle stayed much longer in the dormitory than in place 1. (Source: *the truth investigation*) Meanwhile, during heating, the medicine bottle was always within her sight. But the murderer could wait for the opportunity to poison when Zhu Ling was asleep, at toilet, washing and going to canteen.

Concerning the reasons above, it's clear that the poisoning activities were happened within the dormitory. To say the least, they were happened inside the sixth girls' dormitory building. So if someone sticks that the murderer is a friend of the folk

orchestra who had meals with Zhu Ling in the canteen or an admirer from Peking University, his or her motive would be very suspicious.