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Detectability of the Psychotropic Substance Cannabis in Head or Body Hair: Update of Forensic Criminalistics

Thorsten Floren M.A.

Abstract

Cannabis is a substance known and used by humans for thousands of years. Both from China and India, very old written traditions are known, which prove the use of cannabis in medicine. From the USA, there are opinions of scientists, who attribute a much higher risk for a lethal overdose to prescription drugs than is possible at all by the consumption of cannabis. Estimates for the area of the Federal Republic of Germany assume approximately 85,000 deaths per year due to the use of drugs and their undesirable side effects. The legal view of cannabis use is, with a few exceptions, a worldwide ban. In order to be able to implement these legal norms, investigators make use of a wide variety of procedures to prove the use of psychotropic substances in a court of law. In addition to the classical methods of taking blood samples and/or urine samples, it has also been possible for some time to prove the use of cannabis by examining hair samples. Only for about 40 years have various methods for retrospective forensic protection been available to criminalistics. Investigators use the special characteristics of hair, as opposed to blood, sperm or saliva. The hair grows more or less continuously from the root and stores substances from the metabolism of the body. This makes it possible for investigators to investigate the use of cannabis depending on the length and condition of the hair. In addition, the analytical methods for hair matrix analysis are continuously being developed. Studies have also shown various possibilities for the incorporation and accumulation of THC and its metabolites, the main active substances of cannabis, in hair. In addition to the classical substances for the preservation of evidence, further approaches result from scientific findings regarding the forensic analysis of hair. The securing and examination of head hair has become a standard procedure in investigations. It represents only a minor intervention for the test person. In addition, the storage of hair does not make any special demands on the temperature as an example. This makes hair a good examination tool for many parties involved in the procedure. However, scientific findings show the possibilities, risks and dangers of focusing exclusively on hair. In addition to the use of body hair as an object of investigation for the reliable collection of data, body hair can open up new possibilities. However, scientific findings must not be disregarded here. Every investigator must be aware at all times that he may only carry out interventions on accused persons on the basis of the respective state standards. The courts, too, can only give fair judgements if the investigating authorities have secured evidence that is also based on current scientific findings. In addition to the biological processes involved

in the storage of foreign substances in the hair matrix, it is also necessary to describe in detail the various variants of analysis and evaluation on the various hair samples. All investigators must be aware at all times that they may only intervene against accused persons on the basis of the relevant state standards. The courts, too, can only pass just sentences if the investigating authorities have secured evidence based on the latest scientific findings. In addition to the biological processes involved in the storage of foreign substances in the hair matrix, it is also necessary to describe in detail the various variants of analysis and evaluation on the various hair samples.

Keywords: cannabinoid, THC, forensic head/body hair analysis, scientific findings

1. Introduction

The current relevance of an ever-increasing drug problem is illustrated here using the example of the Federal Republic of Germany. These data are of course not transferable one to one to every country. However, the numbers of trade and consumption of cannabis, for example, continue to rise throughout Europe [1].

According to police crime statistics, the number of trade offences involving cannabis in the Federal Republic of Germany increased by 18% between 2013 and 2017 [2]. The share of cannabis in comparison to other illegal drugs amounts to 64% and thus represents by far the largest share [3]. It should be mentioned here that crime statistics can only ever represent the so-called bright field. These are therefore only criminal acts that have become known to the police. This can be done by own investigations or by statements of witnesses. A frequently much larger proportion of criminal offences are in the dark field, are not known to the investigating authorities and are therefore not included in the statistical surveys.

The investigating authorities rely almost exclusively on the protection of head hair when securing evidence for the use of cannabis. This behaviour, which is partly voluntarily imposed or simply spread away by ignorance, disregards a large part of the securing material. In addition to the obvious hair on the head, body hair can also be secured on the arms, legs, armpits or skinned hair and used for evaluation.

However, it is also questionable to what extent hair from evidence is basically suitable for actual cannabis use?

2. Current status

2.1 Chemical structure of cannabis

Cannabis sativa L. is the Latin name for hemp [4]. In the chemical analysis of cannabis, more than 600 ingredients are already known. There are 100 cannabinoids and 50 hydrocarbons alone [5]. The dried leaves and flowers of the THC-rich cannabis varieties are called marijuana. The drug-typical THC content, which also contains psychoactivity, is between 1 and 20%. The leading cannabinoid responsible for this is the Δ^9 -THC [4]. The exact name of the Δ^9 -THC is Δ^9 -tetrahydrocannabinol. Due to the different numbering systems, the term Δ^1 -tetrahydrocannabinol is also used in part, but it names the same molecule. It is chemically $C_{21}H_{30}O_2$ and has a molecular weight of 314.47 Da [6] (**Figure 1**).

Recent research methods from the Δ^9 -THC have also analysed the main metabolites 11-Nor-9-carboxy-delta-9-terahydrocannabinol (CTHC)/(THC-COOH) and its glucuronide (CTHC-Glu). After cannabis use, CTHC-Glu is the main excretion product that can be detected in urine. However, studies on the detection of cannabis

use in urine or blood have not provided comprehensive, reliable results of actual use [7]. The metabolite of the THC, 11-Nor-9-carboxy-delta-9-tetrahydrocannabinol (THC-COOH), can be stored in, among other things, by the supply in the hair bulb in the hair. THC-COOH is the most important main metabolite (**Figure 2**).

Another relevant stock is THCA-A (Δ^9 -tetrahydrocannabinolic acid A). This cannabinoid is the non-psychotoxic, biosynthetic precursor of THC and is present in fresh plant material of the cannabis plant [8] (**Figure 3**).

Furthermore, the cannabinoids cannabitol (CBN) and cannabidiol (CBD) are also analysed in hair analysis [9]. These substances are not psychoactive and are THC oxidation products.

2.2 Course of hair growth

The forensic preservation of evidence on hair is done by an individualising examination using molecular biological methods. In this way, incorporated foreign substances can be found and secured in the hair. In large parts of jurisprudence the view is taken that in principle a consumption, but also an existing abstinence of the consumption of cannabis can be determined. Here the possibility of retrospective analysis of cannabis use is advantageous. This can also be done for the past weeks up to months [10]. This is possible by a more or less continuous growth of the hair. The human hair grows about 1 cm per month. It allows an appropriate review (depending on the length of the hair) of a possibly long period of time by storing substances absorbed by the body in the hair [11]. This area of hair growth, known as the anagen

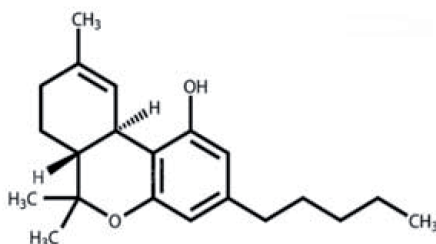


Figure 1.
Chemical formula of the THC.

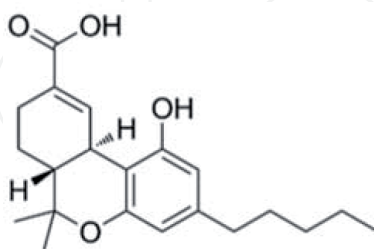


Figure 2.
Chemical formula of 11-Nor-9-carboxy-delta-9-tetrahydrocannabinol (THC-COOH).

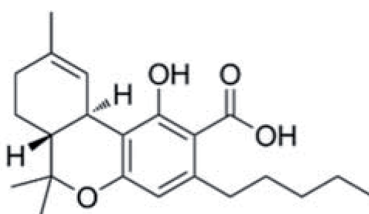


Figure 3.
Chemical formula of THCA-A.

phase, lasts about 4–6 years. About 80–95% of the hair in a healthy person is in this phase. In the second phase, the catagenic phase, cell division is stopped to form the hair. Hornification occurs. The second phase takes place over a period of 2 weeks. Only a few percent of the hair is in this stage of development at the same time. In the last, telogenic phase, the hair is already dead and is pushed out by a new hair forming in the hair root [12]. The diagram provides an overview of the structure and position of the hair root in the skin (**Figure 4**).

In the case of body hair, growth is significantly slower in a period between several months and a maximum of 1 year. The percentage of anagenic hair is only between 20 and 50% [14].

The storage of various substances, such as psychogenic substances in connection with hair growth and the associated pushing out of the hair, creates a temporal record of substance consumption in the hair in the manner of a tachograph, such as an example in a truck.

2.3 Storage of foreign substances

The hair absorbs foreign substances such as psychogenic substances in various ways. On the one hand, this occurs through contact with foreign substances in the body's bloodstream, which supplies the anagen hair with nutrients during growth. Through the metabolism and structure of the hair, the drug substances enter the resulting hair and are stored there [15].

The substances THC and THC-COOH can be stored in the hair in three ways. On the one hand a passive diffusion from blood capillaries directly into the hair matrix takes place. This takes place at the basement membrane of the hair follicle. The second way is the diffusion of sweat or sebum directly into the finished hair. The last possibility is contamination from the surrounding area [16]. The decisive factor is that THC-COOH is only formed in the body [17]. This also means that only THC-COOH can be actively incorporated into the hair matrix, which can be regarded as safe proof of cannabis use. However, the exact process of incorporating THC-COOH from the body into the hair matrix has not yet been fully researched scientifically [16].

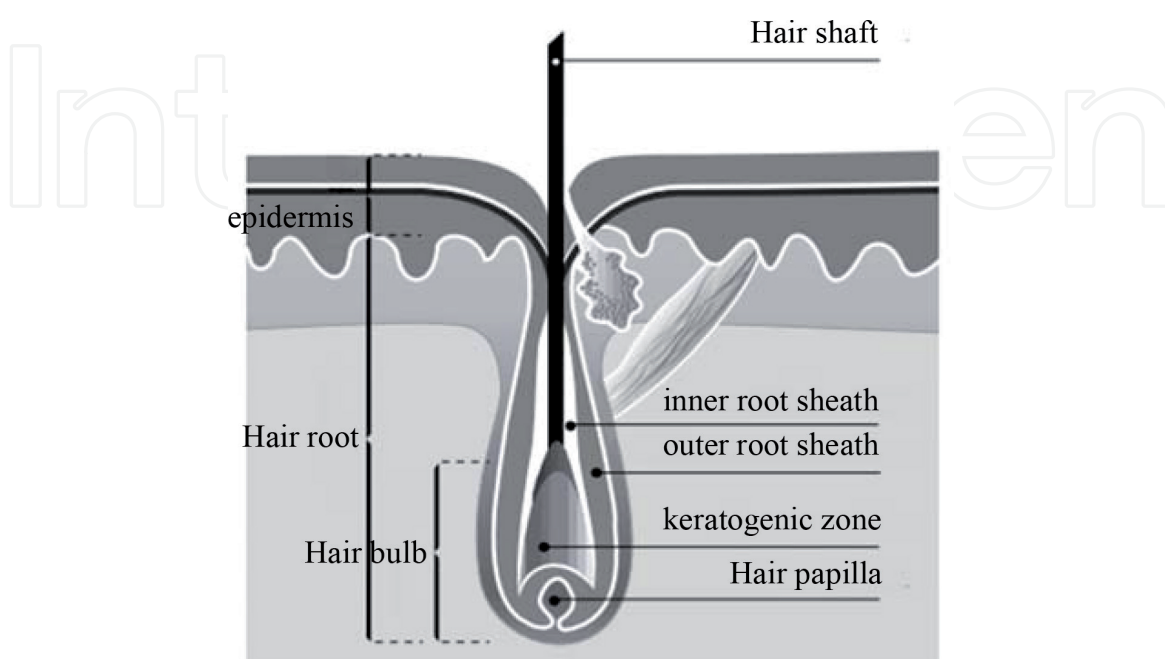


Figure 4.
Structure of the hair root in the skin [13].

In addition to the storage of substances, hair also absorbs them into the hair through external contact with substances and stores them there. The keratinized hair absorbs these foreign substances/substances, for example through drug-containing sweat, gases or dusts. The problem here is that in common laboratory practice, THC is still very often the only substance sought in the hair sample material. THC is found in a very high concentration in cannabis smoke and can lead to a strong contamination of the hair by an external build-up. The detection of THC-COOH in the laboratory is difficult and very time-consuming due to the very low dose [16].

In addition to this problem, very high concentrations of THCA-A (Δ^9 -tetrahydrocannabinolic acid A) also occur in chemical examinations of forensic hair samples [18]. THCA-A is the most important cannabinoid in fresh plant material. This substance is released, for example, by heating (smoking, baking). An uptake of THCA-A into the bloodstream could not be confirmed in earlier studies [8].

The concentration of the stored substances can, however, be drastically changed by environmental influences. The concentration is significantly reduced by the cosmetic treatment of the hair by bleaching, tinting or the form of a permanent wave [15]. The problem here is that there is no reliable data on how much the concentration decreases depending on external environmental influences. The degree of degradation can range from about 10% to almost 100% of the foreign substance [19]. Therefore, no scientifically reliable statement can currently be made as to which environmental influence causes which concentration change. These changes of the substance concentration can lead to a complete destruction of the hair substance and the foreign substances stored with it by a thermal treatment/thermal stretching of the hair [20]. Basically it can be stated that foreign substances are stored in the hair during the formation of new hair and thus in the anagen phase and can additionally be stored in the keratinized hair through external contact.

The difference, however, is that substances stored in the hair through growth fix themselves firmly in the hair matrix and then grow outwards from the hair root [14]. It takes about 10–14 days until the newly formed hair is outside the scalp [21].

3. Legal regulations

3.1 Police preservation of evidence of hair for the detection of cannabis

The example of the Federal Republic of Germany shows that the investigators there use hair on the head as evidence in addition to blood or urine in accordance with the current legal situation. These should be removed in the area “above the occipital protuberance.” In accordance with the national requirements, corresponding documentation obligations are prescribed for the extraction in order to be able to bring the evidence into the criminal proceedings in a legally secure manner and ultimately present it as evidence in court.

Here again a central problem of the investigating authorities becomes apparent. Scientific findings are often only implemented or amended after a very long period of time. As a result, case law and police investigations lag behind scientific progress. This leads in large parts to a frequently delayed, fairer jurisdiction, since evidence is used in court which already no longer corresponds to the current scientific standard.

Closer cooperation between legislators, investigating authorities and researchers is urgently needed to improve the law.

4. Scientific status of the preservation of evidence on hair in cannabis use

Hair analysis is still a very young scientifically researched form of analysis. Forensic detection of drug use in hair has only been possible since 1979 [22]. The current state of science is a coupled analysis method. This starts with a separation of the substance mixture by liquid chromatography. This is also known as gas chromatography, which is used, for example, to determine the age of objects. This is followed by mass spectrometry. It is already possible to divide individual hairs into very short segments and examine them [23]. For this purpose, the hair must be washed before the examination in order to remove adhesions from the hair. It is precisely these adhesions that should not be included in the examination process, since only the substances stored in the hair are to be represented. The hair is then dried. They are then crushed and extracted. This extraction is necessary in order to break down the hair matrix with the stored substances. The final step is the analysis of the extracted material [24]. Here a high-quality measuring technique is needed. The sought-after substances are often only available in the nanogram or even in the picogram range [25].

The result obtained in this way is graphically processed and made available to the investigating authorities.

A major problem in the analysis and preparation of the sample material is the adhesion of substances to the hair. Especially the consumption of cannabis shows a significant problem due to its form of consumption. The active substance THC, which is present in cannabis, is most frequently consumed by smoking.

In addition, the state of scientific research in the field of hair analysis is very low. In 1995 a study was published which proved the storage of the THC metabolite THC-COOH via the blood circulation in the hair. However, this study was carried out on rats [26].

An exclusion, whether a contamination of the hair by sweat, saliva (coat care) etc. resulted, could not be produced. Despite this uncertainty, the detection of THC-COOH in the hair has been regarded as proof of cannabis use since that time [27].

In the forensic medicine department of the University Hospital Freiburg (Germany), a comprehensive study was conducted on the uptake and deposition of THC. In the first test set-up, subjects were exposed to passive smoke of cannabis for a period of 5 days in 3 weeks. The amount was a joint each time. A second experimental group took the active substance THC orally for 30 days (daily dose 7.5 mg). The third trial group only had to handle joints on 5 consecutive days. The study was designed in such a way that the hair of one experimental group only came into contact through cannabis smoke. The second group absorbed THC into their body and this opened up the possibility that THC could be incorporated into the hair matrix through hair growth. In this test group, body hair as well as head hair was examined. In the last test group, the hairs of the test subjects were apparently exposed to significantly less strain when handling cannabis joints, as they only emit a small amount of gas in a non-burning state.

In all three test groups hair samples were taken from the head after the end of the test series. The experimental group exposed to cannabis smoke showed a clearly detectable THC content of the hair. This value was particularly high in the area of the occipital protuberance. Thus exactly in the range, which is intended by the national police in the Federal Republic of Germany also for the removal. Other areas of the head hair showed significantly lower THC loads. The distribution of the THC deposition on the head was altogether very inhomogeneous. THCA-A was only detected in a very small amount in the hair.

In the second group of subjects who had taken the THC orally, no THC was detectable in the hair samples. This was not detectable both in the head and in body hair. However, THC-COOH could be detected in the hair samples. This was positively detectable both in the hairs of the test subjects. Also relatives of these test participants were analysed for THC-COOH. The hair of the relatives was also contaminated. It could be concluded that the oral intake of THC does not lead to storage of THC in the hair. However, THC-COOH was found in the hair. It was unusual that the area of the hair was contaminated with THC-COOH, which was proven to originate from a time before the study and therefore could not be caused by the orally ingested THC. The THC-COOH probably adhered to the hair via sweat and thus led to a positive result [28].

In the third group, which had only handled the joints, both THC exposure and THCA-A storage were observed. However, this was well below the levels of the group exposed to cannabis smoke. It is very problematic that even 1 month after the handling of the joints a positive result was still found in the analyses. Furthermore, the THCA-A value was higher than the THC value. In addition, the value was as high as for actual cannabis users. With the help of this study, the main route of THCA-A transmission into the hair could be shown, although actual use had not taken place [8].

In another study, the hair of children whose parents had been shown to use cannabis was analysed. Approximately 80 hair samples were examined, almost all of which were positive. The researchers found that the detected THCA-A and THC in the hair samples of children's hair was caused by contamination by hands or surfaces to which cannabis had previously been attached [29].

Another problem identified by a study is that the common analysis of hair by gas chromatography mass spectrometry followed by liquid-liquid extraction leads to THCA-A instability. This can lead to a partial conversion of THCA-A to THC, which leads to a wrong result in the evaluation [29].

Further comparative studies show a relatively high number of hairs tested negative, despite a positive urine test for cannabinoids [30].

The current methods of investigation used to provide evidence in court refer only to the analysis of THC. An examination according to THC-COOH, for example, is not carried out because the examination methods are very complex [28].

In addition to the problem of the correct choice of the examination material, there are further problems, especially in the area of hair analysis, such as the aging of the hair. External environmental influences such as solar radiation, cosmetic treatments, heat or heat influence further change the hair substance. The older the hair gets, the worse its evaluability becomes. Since hair is "youngest" at the root, it is generally not useful to analyse hair from a length of about 12 cm. The goal of an investigator with as long a hair as possible to be able to examine at the same time a long period of a test person's life is therefore not possible. At a distance of over 12 cm, the hair has been exposed to an average of so many external environmental influences that no more evaluable test results are to be expected [31].

In the comparison between head hair and body hair, the body hairs frequently show only a rather small length. This limits the evaluable period considerably more. But the lower influence of environmental influences clearly outweighs this disadvantage. Body hair is not treated so comprehensively with cosmetic products. But especially the area of thermal treatment (hairdryer, straightening iron, etc.) is almost completely omitted for body hair. The effect of heat has the greatest effect on the hair matrix and the foreign substances stored in it.

However, an area of the body hair should not be used for hair analysis. The area of the charm hair is often not to be used or used only very limitedly for analysis purposes. The contact with urine represents a very large impairment of the hair

matrix. Due to the chemical composition and the properties of the urine, the evaluability of the hair decreases significantly. Also only very limited are axillary hairs suitable for a hair analysis. Contact with body sweat is not the biggest obstacle. The sometimes very frequent use of cosmetic products in the armpits puts so much strain on the hair that an analysis of the hair matrix often cannot provide meaningful results here either.

In principle, body hairs have a significantly shorter period of investigation or period of life due to their shorter length, but due to their position on the human body, which is partly protected against environmental influences, they represent a very valuable sample material.

It is currently problematic that there is only a very small number of available comparative studies with regard to the examination and analysis of body hair, especially in the area of growth rates and life cycle phases [32].

The presented studies clearly show how cautious a supposed positive THC, THC-COOH, or THCA-A content in a hair sample should be. If body hair had been examined in addition to head hair in this study, the result could have raised further questions. Many areas of the human body are covered with hair, even if most people are not always so aware of it. The only reason is that the hair is very thin, short and often so light that it does not stand out at first glance. A large part of this hair is covered by clothing most of the day and also at night. The area of swarm hair, armpit hair or hair on the stomach or back is exemplary. By covering these hairs with clothing, they are often strongly shielded from external environmental influences. A contamination for example by cannabis smoke or contact with cannabis products can either not take place at all or only very limitedly. The selection of the test material alone can have a considerable effect on the result. A sample of head hair exposed to cannabis smoke in the first experimental group showed a THC and clear THCA-A content.

A hair sample from the same person's back would probably have shown significantly lower or possibly no THC contamination.

The manifold possibilities for testing for THC, THCA-A or THC-COOH alone do not improve the situation. It is assumed that THC-COOH is incorporated into the hair matrix through the bloodstream. A positive test result would then also be a reliable result of actual cannabis use. Unfortunately, the scientific research situation is very low. This means that this storage route cannot be assumed with absolute certainty. In addition there is the difficulty of the complex analysis of hair according to THC-COOH. This is currently possible. However, due to the high costs and the costly examination method, it is not carried out area-wide. Rather, only THC is sought. However, the available studies clearly show that this research method does not stand up to any scientific evaluation. The oral intake of cannabis showed a negative THC result in the hair sample. When handling joints, the contamination with cannabis smoke and the examination of children's hair of cannabis users, positive results were obtained in the hair analysis, although there had actually been no consumption.

The investigation of THCA-A also did not give consistently correct results in hair analysis. The results are comparable to those of the THC study. False positive analyses were found even though no cannabis use was given.

5. Future perspectives

Current research clearly shows that it is precisely when cannabis is consumed, which normally occurs through inhalation, that by far the largest proportion of the THC content is deposited on the hair from the outside. There are now methods that can almost completely remove external adhesions from the hair. However, these

methods are still very costly according to today's state of the art. The hair must be washed intensively and then the cleaned material must be examined for the detection of metabolically produced analytes. Due to the fact that the consumption of illegal drugs is on the rise and the proportion of cannabis is by far the highest, investigation procedures must be available for the investigating authorities, who can safely analyze mass crimes. The choice of sample material could lead to a significant increase in the quantitative and qualitative analysis of hair. The examination of body hair on head hair can significantly defuse the area of contamination with cannabis smoke. For this purpose, specific body hair must be taken, which is not exposed to direct contact with cannabis smoke due to its position, e.g., covered by clothing. In the field of hair analysis, however, it can be said that modern examination methods and the right selection of sample material can be used to make a statement on the consumption of, for example, cannabis drugs. However, the interpretation of the toxicological dose-concentration relationship determined is still difficult due to the different hair growth rate, external influences (age, colouring, heat, etc.), differences in metabolism and hair anatomy. They often do not allow a conclusive statement to be made about the amount of active ingredient actually absorbed. The low scientific knowledge regarding the substance to be investigated remains very problematic. Current hair samples are tested for THC on the basis of economic considerations. The studies clearly show that this way often does not lead to correct results. An examination method which would test for THC-COOH would presumably result in significantly better results.

6. Recommendations

Basically, however, it must be summarized that if a hair analysis is to be carried out according to scientific standards, extensive studies and test procedures are necessary beforehand. This is particularly important if you consider the subject of hair analysis from a legal point of view. The currently valid investigation according to the THC metabolite THC-COOH is from a scientific point of view not tenable as safe proof. Further studies must be carried out to prove the actual way of storing THC or its metabolites in the hair matrix. Here, the difference between the deposition by incorporation from the bloodstream of the THC and an attachment to the hair by smoke exposure, sweat, sebum, etc. must be shown. The difference between body hair and head hair must also be dealt with in the examinations. According to the current state of research, it is still not clear how THC is integrated into the hair matrix. In addition to the already investigated metabolites THC-COOH, the studies should also deal with other substances. In the end all approx. 600 ingredients of THC are known and a multitude of degradation products are added.

The problem of a false, positive THC result in a hair analysis has considerable consequences for the accused and also for the rule of law. It is therefore currently possible that a person who has only been exposed to passive cannabis smoke, which is not a criminal offence under national law, can face prosecution if only his hair is examined as evidence. Standing next to a person smoking a joint is not a criminal offence. However, if a positive result in a hair sample also suggests to the investigator that this person has used cannabis in the past although he did not do so at all, the innocent will be prosecuted.

7. Summary

Hair analysis has been available to investigating authorities since 1979 as a possible way of preserving evidence and evaluating evidence of cannabis use in

criminal proceedings. The investigating authorities, using the example of the Federal Republic of Germany, have regulated the preservation of evidence for hair samples by means of ordinances. The occipital protuberance is explicitly named as the sampling point. This restriction of the sample location represents a clear restriction for an optimal preservation of evidence for the proof of cannabis use. The latest research results have shown that it is possible in a very complex laboratory procedure to extract and analyse only the THC-COOH content from the hair sample material, which was also incorporated into the hair matrix via the hair root and thus by the test person's body. Unfortunately, the research situation is still very low. There are still justified doubts whether the THC-COOH is incorporated into the hair matrix exclusively via the blood circulation or whether another way of contamination with THC or its metabolites is possible. The use of cannabis is only recorded in brightfield by police crime statistics. It is increasing successively and has become a mass crime. The possibility of an efficient investigation should therefore be used. THC accumulates on the hair, especially during inhaled consumption, due to the development of smoke. Studies have shown that, in addition to the adhesion by cannabis smoke, the inhalation into the hair can also occur through contact with sweat, fresh plant material and other surfaces. Both head hair and body hair are affected. The contamination pathways of THC, THC-COOH and THCA-A have been shown in various studies. This is illustrated again in the following diagram. Also the ways are represented, which are not yet finally clarified due to the current research situation (**Figure 5**).

In order to continue to use hair analysis as safe evidence in criminal proceedings, extensive studies should first be carried out to gain more insight into the actual route of enrichment and contamination of cannabis and its metabolites. The current state of scientific knowledge raises more questions than it can answer in relation to hair analysis. If, as an example, it continues to be confirmed that THC-COOH integrates into the hair matrix via the bloodstream after consumption, this would be a way of obtaining legally certain evidence.

Investigation authorities have a neutral legal mandate to secure, evaluate and analyse all incriminating and, in particular, exculpatory evidence. The current findings with regard to the analysis of head hair or body hair do not currently

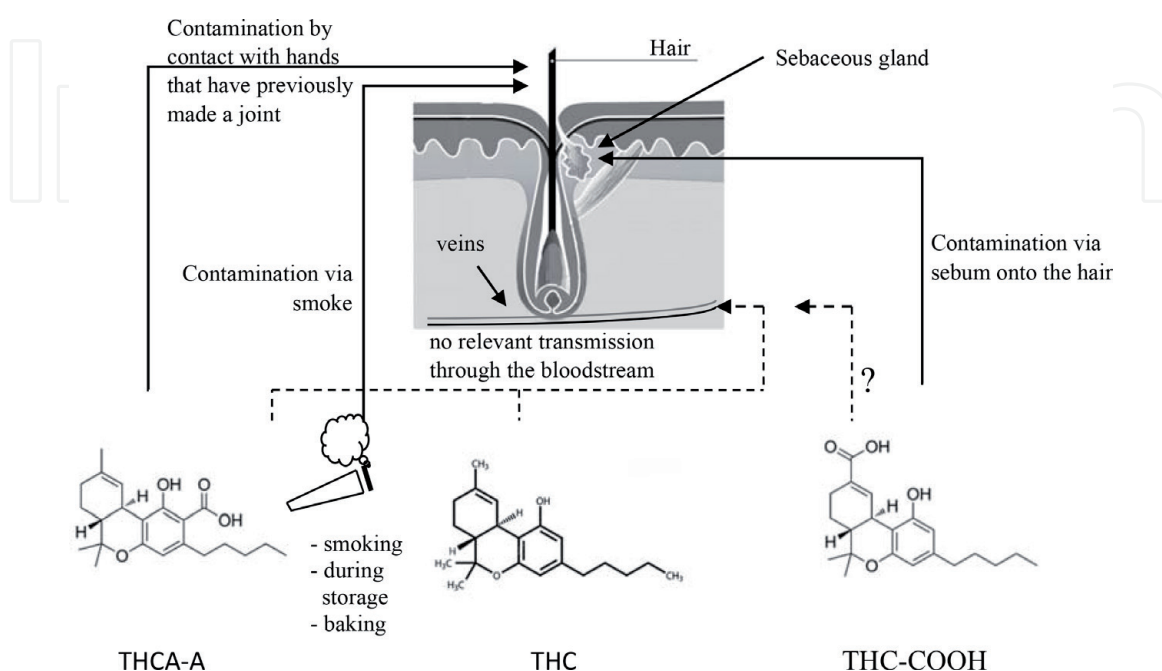


Figure 5.
Incorporation of THC, THCA-A and THC-COOH into the hair.

represent a reliable, scientifically sound basis for the presentation of evidence. In addition to the hair sample analysis, the investigating authorities have the urine sample and the blood sample at their disposal as legally binding evidence. These should primarily be used for the analysis of cannabis use. This serves not only the accused, but also the rule of law and thus society.

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Author details

Thorsten Floren M.A.

University of Police and Public Administration (HSPV NRW), Germany

*Address all correspondence to: thorsten.floren@web.de

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