



# Chronological age and crime: A review of how Swedish Courts evaluate age evidence

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## ABSTRACT

In criminal cases, age estimations are not only commonly occurring but also tremendously influential e.g. for determining whether an individual is old enough to be held responsible as well as the appropriate sentencing. In this research we review 61 Swedish cases focusing on the 15, 18 and 21 years thresholds, which entailed varying forensic, oral and documentary age evidence. The findings suggest e.g. that age estimations are most commonly used for sentencing issues (18/21 years) and that forensic age evidence is more influential than other types of age evidence. When the case concerned a violent crime, the odds that the Courts concluded that an individual was 18 years or older were 38 times higher when there was supporting forensic evidence supporting, while no corresponding trends were seen for oral and documentary age evidence. The research highlights both methodological and human sources of error to be addressed in research and legal practice.

## 1. Introduction

It is today well known that estimating the chronological age of individuals presents significant scientific challenges [1,2], while these estimations undoubtedly have considerable legal implications [2]. The scientific challenges stem from the fact that chronological age is typically estimated using another type of age, namely biological age, and the exact relationship between the two cannot be generally stated [3]. Chronological age measures the number of days or years since birth, determined by calendar dating, while biological age is a medical measure that estimates different levels of functional ability or impairment [4]. Traditionally, biological age estimations have been performed using X-ray imaging and evaluating the maturity of teeth or skeletal parts. Importantly, there are individual differences in the pace of biological ageing e.g. when it comes to bone and tooth maturity/mineralization [5]. When determining biological age, and more specifically when assessing ossification and/or mineralisation stages of wrists or teeth, etc., forensic providers across the globe use scales such as Greulich and Pyle for hands/wrists [6] or Demirjian et al for teeth development [7]. Such probabilistic scales are not typically part of legal actors' education and training, and research also suggests that, more widely within the forensic field, there is significant variation in how experts present

forensic evidence to or at Court [1].

Because chronological/legal and biological age are distinct age concepts, but the legal context still places great trust in that chronological/legal age can be reliably estimated using biological age, the scientific community, as well as organizations such as the European Asylum Support Office (EASO), the United Nation's Children's Fund (UNFC), the Forensic Anthropology Society of Europe (FASE) and the Study Group on Forensic Age Diagnostics (AGFAD), agree that there is a need for combined forensic approaches to age estimations [8–10]. It also deserves to be emphasized that biological age is a composite construct because e.g. skeletal age, dental age and sexual age are not necessarily the same in a given individual. However, a recent survey suggests that these guidelines and recommendations are only partially implemented across Europe [11]. In Sweden, The National Board of Forensic Medicine (RMV) is the expert authority responsible for performing forensic age assessments upon request by the Police Authority in criminal cases or by the Migration Agency in asylum cases. RMV has various methods that may be utilised, depending on the specific questions posed by the requesting authority, including X-ray examination of the hand/wrist, computed tomography scan (CT) of the clavicle and/or magnetic resonance imaging (MRI) examination of the knee. These assessments are based on a probability model that uses scientific studies to compare the

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degree of maturity with, and statistical calculations to estimate the likelihood of the individual being below or above the age thresholds of 15, 18, or 21 years old. In addition, the skeletal examination is complemented by an X-ray examination of the wisdom teeth. After examination, the obtained images are reviewed by qualified specialists in the relevant medical field. While the more specific methods used may thus vary, the most common practice in criminal cases is to examine knees and teeth. Subsequently, a forensic medical doctor establishes an overall assessment of the examined individual's age in a forensic report [12].

Hence, the standard procedure in Sweden is to use combined forensic age estimation methods, but it is unknown whether such combined forensic age evidence is always requested by law enforcement and/or presented in Court. Moreover, criminal cases also typically vary in terms of the availability of other age evidence, e.g. oral and/or documentary evidence, and whether it contradicts or supports the forensic findings. This is highlighted by a recent Swedish case concerning gang-related murder and attempted murder in which convincing evidence identified AA as the shooter, but questions arose as to whether AA was old enough to be sentenced to life imprisonment [13]. On the basis of forensic age evidence, including radiological examinations of AA's teeth, knee and wrist, the prosecutor argued that AA had been over 18 years at the time of the crimes. However, AA himself argued that he was 15 years old at the time in question. Oral statements from family members supported AA's contention, and AA had himself used a birth date for his social media accounts, suggesting he was 15 years old. Other documentary evidence was more ambiguous, as AA had indicated a birthdate to the Swedish authorities implying that he had in fact been 18 years at the relevant time. AA claimed he had done so to avoid involvement with the social services. The Court noted that "it is more probable that AA had turned 18 years old at the time of the crime than that he had not" [13]. However, the Court did not consider this sufficient for life time prison and sentenced him to 14 years in prison, a verdict that was not appealed. The case highlights that there is much to learn about how Courts incorporate, combine and interpret such complex and/or ambiguous age evidence into their decision-making. Hence, the purpose of this research is to examine how Swedish Courts evaluate age evidence. To this end, we have reviewed 61 Swedish criminal cases that were addressed by both a District Court and a Court of Appeal.

Specifically, in this research, we focus on the age thresholds of 15, 18 and 21 years. This focus is a result of Swedish law, which holds that individuals under 15 years have not reached the age of criminal responsibility and therefore cannot be convicted of a crime (The Criminal Code 1 ch. 6 §). If an individual commits a crime under the age of 18 or 21 years, the young age should be considered a mitigating circumstance, and the younger the offender is, the more reduced the sentence should be. Furthermore, imprisonment may only be imposed if there are extraordinary reasons for a crime committed by an individual under the age of 18. The Court should instead primarily consider imposing institutional care as a penalty (The Criminal Code 30 ch. 5 § and 32 ch. 5 §). When someone is reasonably suspected of a crime that may lead to a prison sentence, the Swedish Police Authority can request a forensic age assessment to be conducted by the National Board of Forensic Medicine (Rättsmedicinalverket, RMV) (The Code of Judicial Procedure 28 ch. 12 §). The focus on the 15, 18 and 21 year thresholds means that both questions pertaining to criminal responsibility ( $\geq 15$  years) and sentencing issues ( $< 18$  or 21 years) are addressed. Sentencing issues refers to whether the young individual can, legally speaking, be sentenced to e.g. prison and closed psychiatric care like adults, or if only sentences adjusted for minors are applicable. In Sweden, individuals are considered adult when they are 21 years old, although the available sentencing options start to look more like those available for adults already when an individual is 18 years.

## 2. Method

### 2.1. Study design and setting

This archival study focused on criminal case verdicts from Swedish District Courts and Court of Appeal which entailed age estimations of either of the parties, i.e. the plaintiff or the defendant. These age estimations had either been conducted to establish i.e. whether the defendant was old enough to take on criminal responsibility ( $\geq 15$  years), sentencing issues ( $< 18$  or 21 years) or whether the plaintiff's age would impact on the labelling of the criminal charges, e.g. whether a crime against a child ( $< 15$  years) had been committed or not.

### 2.2. Data

A total of 61 verdicts from Swedish District Courts and Courts of Appeal in 2010–2024 were obtained from the online legal database JUNO. The database is widely used in Sweden because it provides access to judgments from all three Court instances, i.e. District Courts ( $N = 48$ ), Courts of Appeal ( $N = 6$ ) and the Supreme Court ( $N = 7$ ). The search term "age estimation" was used.

### 2.3. Inclusion and exclusion criteria

Only criminal case verdicts from the years 2010–2024 that were available through JUNO were included. This constituted all cases available online. Additional cases that have not been published online but are available at the Courts were not requested because they could be expected to concern sensitive enough issues that the Courts would be reluctant to share them with us. It is possible that different trends would be seen in those sensitive cases.

### 2.4. Variables

All verdicts were reviewed and coded using the following variables: Court, Case No, type of crime(s), relevant age threshold (15, 18, 21), legal relevance (e.g. criminal responsibility/sentencing), outcome (convict/acquit/fully/partially), forensic age evidence available (yes/no), type of forensic age evidence available, implications of forensic age evidence (e.g. under/over 18), oral age evidence available (yes/no) and type of oral age evidence available.

### 2.5. Raters

Two raters conducted the full review including all variables in relation to all cases. After the first rater had completed her review, the second rater started hers, and cross checked the results of the first rater. This resulted in one brief addition to the data in the review protocol, namely an additional age estimation in one of the cases that had been left out at first.

### 2.6. Data analyses

The collected data enabled both quantitative and qualitative analyses of trends in the data. Because the available data was only sufficient for inferential quantitative analyses pertaining to sentencing issues, questions on criminal responsibility and whether crimes against children had been committed were instead subjected to descriptive quantitative analyses and qualitative analyses.

### 2.7. Quantitative analyses and statistical software

For the quantitative analysis, the software IBM SPSS Statistics version 30.0.0.0 (172) was used.

Given the categorical nature of the relevant data, the inferential statistics used comprised chi-square and odds ratios for measures of

effect size [14]. When it comes to interpreting Odds Ratios (ORs), there is no specific value at which they are deemed to be small, medium or large, but the further away the OR is from 1, the higher the likelihood that a variable has an actual effect [15,16]. Hence, contextualised interpretations will be provided for any reported OR.

## 2.8. Qualitative analyses

The qualitative analyses entailed thematical analyses, i.e. the cases were analysed to look for common denominators and characteristics.

## 3. Results

Table 1 illustrates the distribution of legal outcomes and the seriousness of crimes in relation to legal relevance in the reviewed verdicts involving age assessments from Swedish courts.

As illustrated in Table 1, among the 61 cases, many concerned multiple individuals, resulting in a number of 75 individual age estimations in total. In most cases, 82.67 % (62 out of 75), of the age estimations conducted pertained to the age thresholds 18 and/or 21 and were therefore relevant for sentencing only. The second largest category, 10.67 % (8 out of 75) was age estimations pertaining to criminal responsibility and sentencing i.e. the age thresholds 15 and 18 and/or 21 and the least common category 0.67 % (5 out of 75) was age estimations pertaining to criminal responsibility only, i.e. the 15-year threshold.

For cases concerning sentencing (N = 62), convictions on all charges represented the largest share with 43 cases, followed by 17 cases of partial acquittals and partial convictions, and the smallest share of acquittals on all charges with 2 cases.

In cases involving both criminal responsibility and sentencing (N = 8), convictions accounted for 6 cases and partial acquittals and partial convictions accounted for 2 cases. There was no case involving both criminal responsibility and sentencing that resulted in an acquittal on all charges.

Among the cases where criminal responsibility (N = 5) was the primary legal issue, 2 cases resulted in acquittals, 2 in convictions and 1 resulted in a partial acquittal and a partial conviction.

In addition, of the reviewed 75 cases of age assessments, 60 cases concerned serious crimes, defined as crimes against persons, while 15 cases were considered as non-serious crimes. Across all categories of legal relevance, cases considered as serious crimes consistently dominated, corresponding to criminal responsibility (N = 4), sentencing (N = 49), and criminal responsibility and sentencing (N = 7).

### 3.1. Age evidence and its relation to the Courts' conclusions

#### 3.1.1. 18-year threshold (sentencing)

Table 2 outlines the District Court and the Court of Appeal's conclusions on age in situations where the prosecution and defense's claims contradicted each other, and the implications of the different types of age evidence (forensic, oral, documentary) varied.

As illustrated in Table 2 (first row), when the prosecutor claimed that the defendant was 18 years or older and there was forensic evidence to

support this conclusion, in most cases it did not seem to matter that the defense claimed the defendant was younger than 18 years and there was oral and documentary evidence to support the defence's claim. Specifically, in these cases, the District Court concluded in 79.20 % of the cases that the defendant was 18 years or older. However, the Court of Appeal only concluded that the defendant was 18 years or older in 54.20 % of these cases. This is essential as the defense's age claim often would not deviate too much from 18 years old. Specifically, in 56.20 % of the cases, the defense claimed the defendant had been 16 or 17 years old at the time of the crime. It is not scientifically possible to reliably distinguish a 16 or 17 year old from an 18 year old based on the forensic evidence presented in these trials. When the forensic age evidence was based on teeth and knee X-ray examinations, the uncertainty was expressed in the following way, suggesting a known risk to overestimate the age of 16 and 17 year olds:

"Approximately 10 percent of children with a chronological age close to 18 years who have a fully matured growth zone in the lower thighbone and wisdom tooth may be wrongfully assessed as being over 18 years based on the currently available data [17]"

### 3.2. The role of different types of age evidence for the Courts' conclusions

Neither type of age evidence was on its own significantly associated with the District Court's conclusions,  $X^2(1) = 2.009$ ,  $p = 0.156$  (forensic),  $X^2(2) = 2.136$ ,  $p = 0.344$  (oral),  $X^2(1) = 0.241$ ,  $p = 0.623$  (documentary), or the Appellate Court's conclusions regarding age,  $X^2(1) = 2.949$ ,  $p = 0.086$  (forensic),  $X^2(1) = 0.365$ ,  $p = 0.833$  (oral),  $X^2(1) = 2.783$ ,  $p = 0.095$  (documentary).

### 3.3. Forensic age evidence and type of crime

When the case concerned a violent crime against a person, forensic evidence supporting the conclusion that a defendant was 18 years or older was significantly associated with the District Court,  $X^2(1) = 4.909$ ,  $p = 0.027$ , and the Appellate Court,  $X^2(1) = 5.318$ ,  $p = 0.021$ , concluding that the defendant was 18 years or older. The odds of an 18 or older conclusion were 38 times higher when the forensic evidence suggested that the defendant was 18 years or older compared to when it suggested the defendant was younger than 18 years. This suggests that the forensic evidence was greatly influential, as even 2 times higher odds would be relevant not the least from the defendant's perspective.

However, when the case concerned a non-violent crime, not directed against a person, forensic evidence supporting the conclusion that a defendant was 18 years or older was not significantly associated with the District Court's conclusion,  $X^2(1) = 1.389$ ,  $p = 0.239$ , or the Appellate Court's conclusions,  $X^2(1) = 0.174$ ,  $p = 0.676$ .

No corresponding interactions were found for the oral or documentary evidence, in any of the Courts,  $X^2(1) = 0.090$ ,  $p = 0.764$  (oral, District Court),  $X^2(1) = 0.481$ ,  $p = 0.488$  (oral, Appellate Court),  $X^2(1) = 1.264$ ,  $p = 0.261$  (documentary, District Court),  $X^2(1) = 0.034$ ,  $p = 0.853$  (documentary, Appellate Court).

**Table 1**

Distribution of legal outcomes and the seriousness of crimes in relation to their legal relevance in Swedish courts during the years 2010–2024.

Legal relevance (age thresholds)	Acquitted on all charges	Convicted on all charges	Partially acquitted charges/Partially convicted charges	Total	Serious crime	Non-serious crime
Criminal responsibility <sup>a</sup>	2	2	1	5	4	1
Sentencing <sup>b</sup>	2	43	17	62	49	13
Criminal responsibility and sentencing <sup>c</sup>	0	6	2	8	7	1
Total	4	51	20	75	60	15

<sup>a</sup> Age threshold 15.

<sup>b</sup> Age threshold 18 and/or 21.

<sup>c</sup> Age threshold 15 and 18 and/or 21.

**Table 2**

The Courts' conclusions (%) regarding age divided by claims by the prosecution, defense and the implications of the forensic, oral and documentary evidence.

Prosecution's claim	Defense's claim	Implications of evidence			District Court		Court of Appeal	
		Forensic	Oral	Documentary	18 +	18 -	18 +	18 -
18 +	18 -	18 +	18 -	18 -	79.20	20.80	54.20	45.80
18 +	18 -	18 -	18 -	18 -	100	0	0	100
18 +	18 -	18 -	18 -	18 +	100	0	100	0
18 +	18 -	18 +	18 +	18 +	50	50	50	50

Note. In the table 18 + means 18 years or older, 18 - means younger than 18 years.

**3.3.1. 15-year threshold (criminal responsibility)**

Because only 5 cases concerned solely criminal responsibility, and the 15-year threshold, no inferential statistics have been carried out for this category. Table 3 outlines the age evidence and Court outcomes in the five cases in which the prosecution and defence made opposing claims about whether the defendant or plaintiff had or had not turned 15 years at the time of the alleged crime(s).

Cases 1 and 2 concerned age estimations of female plaintiffs in cases of alleged rape against a child. In both cases, the prosecution claimed the plaintiff had been younger than 15 years at the relevant time, while the defense claimed the plaintiff was 15 years or older. In both cases, it appears that the final age determination was made based on evidence other than forensic evidence. In Case 1, no forensic examination had been conducted; however, both the plaintiff herself, witnesses and documents suggested she was younger than 15 years at the relevant time, which was enough to convince both Court instances [18]. In Case 2, the presented forensic evidence was ambiguous as two medical external examinations suggested the plaintiff was younger than 15 years at the relevant time, but the wrist X-ray resulted in an age span, which meant she could be either under or over the 15-year threshold [19]. Multiple witnesses testified that she was younger than 15 years, and both the District Court and the Court of Appeal determined her age to be younger than 15 years, and convicted the defendant for e.g. rape against a child and attempt at rape against a child. However, the Supreme Court did not consider it proven beyond reasonable doubt that the plaintiff was younger than 15 years, and therefore acquitted the suspect of the charges concerning rape against a child, attempt at rape against a child, etc. [19,20]. In its acquittal, the Supreme Court noted that the age registered for the plaintiff when she arrived in Sweden after being adopted could not be taken for granted; instead, an examination of the basis for the registered age was required.

Cases 3 to 5 concerned age estimations of male defendants accused of crimes of varying seriousness [21,22]. In Case 3, the defendant was accused of inflicting damage and theft, and only after having been convicted in the District Court, did he object in the Court of Appeal that he was younger than 15 years old at the relevant time and therefore should be acquitted. The forensic age evidence presented consisted of a medical external examination of length, weight and puberty stage as well as a wrist X-ray. The documentary evidence was references from a school counsellor and a lay probation officer, both suggesting that the

**Table 3**

Age evidence and outcomes in the five cases pertaining to the 15-year threshold.

Case	Implications of evidence			District Court	Court of Appeal	The Supreme Court
	Forensic	Oral	Documentary			
1	NA	15-	15-	15-	15-	NA
2	15+/-	15-	NA	15-	15-	15+
3	15-	15-	15-	15+	15-	NA
4	15+	15-	15+	15+	15+	NA
5	15+	15-	15+	15+	15-	NA

Note. In the table, 15- = the evidence suggests the examined individual was younger than 15 years, 15+ = the evidence suggests that the examined individual was 15 years or older, 15+/- = the evidence was ambiguous as to whether the examined individual had reached 15 years old or not, NA = Not available.

defendant did not possess the level of maturity expected from someone older than 15 years. Furthermore, the defendant testified that he had provided the Migration Agency with incorrect information about his birth date because he believed that would speed up the visa process. The Court of Appeal noted that: "The evidence shows that there is considerable uncertainty regarding the defendants' real age. It is troublesome for the accused that he did not state in previous prosecutions that he was under 15 years of age. However, the evidence in this case does not prove that he had reached the age of criminal responsibility at the time of the relevant acts. The plaintiff shall therefore be acquitted." [21].

In Case 4-5, stemming from the same trial, two defendants were accused of gross rape and narcotic drug offences [22]. The first defendant, BB, had been examined using dental and wrist radiographs, and the second defendant, CC, had been examined externally by a medical doctor. The forensic examination of BB suggested he was between 16 and 18 years old, while the examination of CC implied he was 18 years old. In relation to BB, there were documents from Interpol suggesting that BB had been convicted of other crimes, using other names, in Germany and Norway, alongside information suggesting he was 18 years old at the time of the crime committed in Sweden. In relation to CC, documents from the Swedish Migration Agency suggested that CC himself had reported a date of birth that would have made him older than 15 years at the relevant time. Both defendants claimed they were younger than 15 years and, therefore, could not be convicted of a crime.

Interestingly, the Court of Appeal made opposite determinations in relation to BB and CC's ages. In relation to BB, the Court of Appeal noted that: "Taken together, and especially considering the age investigation conducted in Germany that has been examined by a German Court, the Court of Appeal considers BB's submission that he today is only 13 years old, and therefore would have been only 12 years old when he was convicted in Germany, is so unlikely that it comes across as groundless. The Court of Appeal therefore determines that the prosecution has proven that BB had turned 15 years at the time of the crime. He shall therefore be sentenced." [22] Regarding CC, the Court of Appeal noted limitations in the medical examination. It provided the following explanation for trusting CCs own claim that he was younger than 15 years old at the time of the crime: "The medical examination is based only on a visual inspection and does not have any real probative value. Taken together with the other evidence, CCs own submission that he was younger than 15 years at the time of the crime does not come across as groundless. Therefore, he cannot be convicted or sentenced." [22].

**3.4. Occurrence of forensic age evidence over time**

As illustrated in Fig. 1, the occurrence of forensic age evidence has varied over time. During the time period 2010-2024, 61 out of 75 age estimations included forensic age evidence, whereas 14 cases relied solely on oral and/or documentary evidence. The highest numbers of forensic age evidence were seen in 2017-2018, which were also the two years with the highest number of age estimations conducted. For the years 2015, 2017, 2020 and 2022, all age estimations included forensic age evidence.

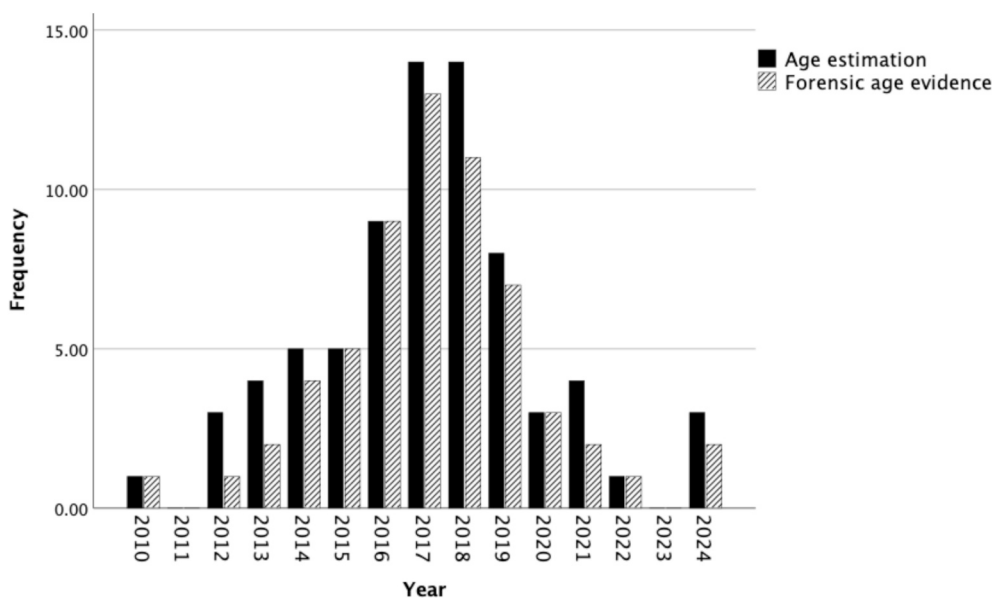


Fig. 1. Number of age estimations (n = 75) and forensic age evidence (n = 61) in Swedish Courts during the years 2010–2024.

### 3.5. Types of forensic age evidence

The frequency and distribution of medical methods used for forensic age estimation in the reviewed verdicts from Swedish courts is summarized in Table 4. A total of 110 single medical age estimations were performed, with two or more different methods often being applied and combined within the same case of forensic age estimation. Consequently, the total number of age estimations made (n = 110) exceeds the total number of forensic age estimation cases (n = 61).

As illustrated in Table 4, the most frequently used method, by far, was dental examination, 41.80 %, followed by knee joint, 16.40 %, hand/wrist examinations, 14.50 %, and skeletal examinations, 8.20 %. Meanwhile, physical examination (n = 7) and clavicle examination (n = 4) were used less frequently and constituted 6,4 % respectively 3,6 % of the total number of estimations. The emphasis on dental and knee joint examinations is likely due to the fact that these are the two most commonly used methods by RMV in the criminal case context.

The type of forensic age evidence presented in a case was significantly associated with the District Court’s conclusions regarding age,  $X^2(11) = 23.276, p = 0.016$ . For example, the odds of the District Courts’ concluding that a defendant was 18 years or older were 6.5 times higher when the presented age evidence consisted of radiographs of teeth and an MRI of the knee joint compared to a foreign doctor’s examination. It

Table 4

Frequency of forensic age estimation methods used in Swedish courts during the years 2010–2024.

Method	Number of age estimations	Percentage of total age estimations (%)
Dental examinations <sup>a</sup>	46	41.80
Physical examinations <sup>b</sup>	7	6.40
Skeletal examinations	47	42.70
Knee joint	18	16.40
Hand/Wrist <sup>a</sup>	16	14.50
Clavicle	4	3.60
Unspecified	9	8.20
Unspecified examination <sup>c</sup>	10	9.10
Total	110	100

<sup>a</sup> Radiographic examination of maturity.

<sup>b</sup> Physical examination by a medical doctor.

<sup>c</sup> Specific methods used was not stated in the verdict.

thus seems like the lower Courts had a clear preference for forensic evidence consisting of teeth and knee examinations, which is somewhat unsurprising as this is the most common forensic evidence used in the Swedish setting, given the established practice of the National Board of Forensic Medicine. In contrast, the type of forensic age evidence was not significantly associated with the Appellate Court’s conclusions,  $X^2(11) = 13.275, p = 0.276$ .

### 4. Discussion

The results in this study raise three primary questions, namely (i) the difficulties the Courts seem to have in distinguishing age claims by the prosecution and defense when the claims are very close to one another, e.g. 18 and 17 or 16 years old, (ii) the importance of crime type and (iii) the relative importance of forensic evidence vis á vis documentary and oral age evidence.

As illustrated in the Results section, fairly commonly, the defense made an age claim that was not too far off from the age claimed by the prosecution (i). For example, the defense often claimed 16 or 17 years when the prosecution claimed 18 years or over. Because determining whether and individual falls on either side of the 18-year thresholds has huge implications for the possible sentences, there is a pronounced need for more refined forensic methods. Age estimations based on DNA methylation levels have emerged as a powerful tool in forensic science, offering a novel method for estimating chronological age from biological samples, including blood, saliva, bone and teeth. This epigenetic approach analyses age-dependent changes in the methylation patterns of specific genes. By examining DNA at epigenetic “clock” sites in samples from a crime scene or an individual, forensic scientists can build a statistical model to estimate the donor’s age [23]. Current models can predict age with a Mean Absolute Deviation (MAD) of approximately 3 to 4 years in adults, but further research on machine learning models may improve the prediction accuracy to 1 to 2 years [24]. While this precision is not sufficient to determine whether someone is exactly 17 or 18, it can provide crucial probabilistic information. Therefore, while not a standalone definitive test for precise legal age estimations, DNA-methylation analysis offers an additional evidence-based biological estimate that complements medical age estimations, visual assessments or documentary evidence in disputed cases, providing a valuable tool for informed decision-making.

Furthermore, the results in this study point to (ii) the potential

importance of crime type for how courts perceive of forensic age evidence. Because the results of forensic age estimations are regularly expressed with a certain degree of uncertainty, and there is no guarantee that all judges understand that uncertainty in the same way, there is considerable discretion for judges to determine the legal significance of age evidence in a given case. This data suggests that when the case concerned a violent crime against a person, forensic evidence supporting the conclusion that a defendant was 18 years or older was significantly associated with both the District Court and the Appellate Courts conclusions. Specifically, the odds of an 18 or older conclusion were 38 times higher when the forensic evidence suggested that the defendant was 18 years or older compared to when it suggested the defendant was young than 18 years. It is therefore clear that such forensic evidence has an important impact on the Courts' age determinations. However, when the case concerned a non-violent crime, not directed against a person, forensic evidence supporting the conclusion that a defendant was 18 years or older was not significantly associated with the District Court's conclusions. This indicates that the strength of the forensic evidence may be evaluated in a contextual manner, i.e. the crime for which the defendant is accused may be important, even though logically it has no relevance whatsoever for the reliability or the implications of the forensic age evidence whatsoever. However, this possibility needs to be further evaluated as the data presented here are archival and correlational and therefore not informative about causality. It is also noteworthy that the emphasis in Swedish practice is on dental and knee examinations, whereas international recommendations entail physical, dental and skeletal examinations.

Although only five cases concerned criminal responsibility solely, these cases do illustrate the relative importance that the Court's put on forensic evidence vis á vis documentary and oral age evidence (iii). In fact, in both Cases 1 and 2, other than forensic evidence was decisive, because the provided forensic evidence was considered too ambiguous (Case 2) or no forensic evidence at all was presented (Case 1). This highlights, again, the need for refined forensic methods, and, additionally, that the prosecution presents such evidence in Court. There are no systematic studies comparing the relative accuracy of oral age evidence, often based on visual age assessments, and forensic age evidence, but the studies that do exist suggest that the error margin is wider for visual age assessments [2]. As illustrated in Fig. 1, there was a peak in both the number of age estimations conducted and the forensic evidence presented. This can be explained by multiple factors such as the effectiveness of police investigations, prosecutorial charging trends and migration trends. However, it is clear that still today, cases are taken to Court without any forensic evidence at all. Although the exact reasons are unknown, this may be due to the prosecutors' discretion and/or a lack of consent to invasive forensic methods. Furthermore, it seems to differ how much weight the Courts put on the age estimated individuals' own accounts of their ages, especially in cases of contradicting accounts over time, as illustrated by Cases 4 and 5.

## 5. Conclusion

This research suggests that age estimations in the Swedish Court context are primarily relevant for sentencing issues, even though there are a few cases concerning both sentencing and criminal responsibility or only criminal responsibility. These are all examples of questions that have very significant impacts on private, and young, individuals' lives. Yet, this research highlights potential methodological and human sources of errors when estimating chronological age for legal purposes.

Researchers have yet to overcome the methodological limitations associated with forensic age estimation methods that measure biological rather than chronological age. This is particularly important in the legal context that is exclusively interested in chronological age. Even though contemporary research highlights the promise of combined methods based on DNA and/or AI, there is still more work to be done before such evidence is ready for the Court. As suggested in this study, the primary

forensic age evidence presented in the Swedish context remains dental, knee, and hand radiographs.

Consequently, the uncertainty associated with forensic age evidence needs to be effectively communicated to judges. It is today unknown to what extent the judges' understanding of forensic age evidence in fact reflects its actual meaning. Also, it is unknown whether forensic experts who are to communicate the uncertainty use the terminology consistently among themselves. The importance of such human variation for the final outcome of the case should not be underestimated and deserves further attention in research.

Overall, age estimations are complex procedures which need to rely on evidence-based research, and the best interest of the child is often emphasized [25]. In asylum and family cases it may however be more straightforward than in criminal cases to protect the best interest of the child. This is because criminal case procedures prioritize interests pertaining to the suspect, e.g. the right to be presumed innocent, in *dubio pro reo* ("when in doubt for the accused") and so on. These priorities in criminal case procedures may be aligned with protecting the best interest of the child, but it is not always the case. For example, if doubt regarding a suspect's age is counted to his/her advantage this may prevent that children are wrongfully imprisoned or detained in adult facilities [26]. However, if one is instead estimating the age of an alleged child soldier or a rape victim (< 15 years) and counts uncertainty to the advantage of the young individual examined, this also means that the defendant more often would be convicted of e.g. having recruited a child soldier or having raped a child. Such an order would be inconsistent with giving the benefit of doubt to the accused. This additional dimension to criminal cases further emphasizes the crucial importance of optimizing the methods used, as well as the human interpretations of age estimation data. Even though there are today no exact methods able to estimate age with 100 % accuracy [9] dental and radiological methods show error ranges that are better known, tested and quantifiable than those of other non-medical methods [27]. This highlights the importance of using forensic age evidence in all criminal cases, and the Swedish Court data suggests that this is not always the case.

## Ethical approval

The study was approved by the Swedish Ethics Authority 2023-06788-01 prior to commencement of data collection.

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## CRedit authorship contribution statement

**Moa Lidén:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Marie Allen:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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