Medical age assessment

Petter Mostad

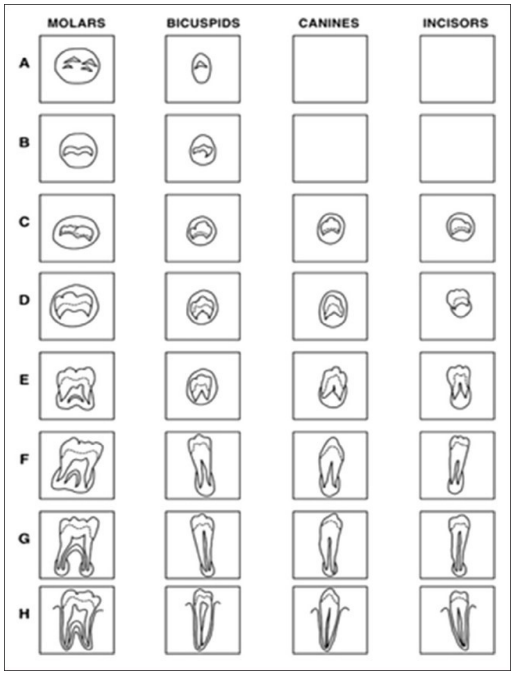
Chalmers

October 18, 2018

Medical age assessment

- Observation of medical/biological characteristics ("indicators") changing at fairly specific ages.
- Examples:
  - Teeth
  - Parts of the skeleton
  - Puberty indicators, weight, length, ...
  - Pschychological maturity
  - DNA-data, for example telomeres
- A number of different purposes
- Choose indicators with most change at the age relevant for the purpose.
- Our purpose: Decide if over/under 18 years. Much used indicators: Teeth, wrists, collar bones, ...

Example: Teeth (third molars)



- Use x-ray images to investigate roots of teeth
- Common classifying scheme: Demirjian (there are alternatives).
- Development stage of third molar often reaches "mature" (H) in late teens.
- Age of maturity varies between persons with a couple of years.
- Dependency on gender. Dependency on genetic background and socioeconomic background is discussed.

Example: Knees

- Usage of NMR, not x-rays.
- Investigate the distal femur and its growth zone. Varying methods.
- Age of maturity often in late teens.
- Considerable variation. Depends on gender. Possible covariates like genetic background and socioeconomic background not much investigated.

Age determination of asylum seekers in Sweden

- During 2014-15, 244.178 people applied for asylum in Sweden. Among these: 42.418 "unaccompanied minors".
- For 2016-17, the numbers decreased to 52.667 and 3435, respectively.
- Chances for asylum depend on whether the asylum seeker is above or below 18.
- The asylum seeker has the legal responsibility to document his or her "identity", including age.
- Documentation from Afghanistan/Somalia/... not trusted by the Migratory board, or not available.
- Some asylum seekers took the initiative to undergo medical age assessment.

Standardized age assessment via Rättsmedicinalverket (RMV)

- Starting spring 2017, asylum seekers are offered a standardized age assessment organized by Rättsmedicinalverket (RMV), as an alternative to their age being fixed by the Migratory board.
- RMV outsources data collection to different laboratories: X-rays of third molars and NMR of knees.
- Experts, two for each data type, determines if the age indicator is **mature**, **not mature**, or **not possible to determine**.
- Both experts need to make the judgement mature for the body part to be regarded as mature.
- On the other hand, the person is judged as over 18 if at least one of the indicators is mature.
- NOTE: RMV output consists of texts of various types, indicating some uncertainty. However, the migratory board generally makes it's decision in a way that corresponds to the rule above.

Problems with this decision rule

- Generally all uncertainty is disregarded: The decision about age is based only on the conclusion from RMV, and no other case information is taken into account.
- The properties of this decision rule are not well known: **No validation study, where the method is applied to persons with known chronological ages, has been published**.
- A number of times, new information has appeared casting doubt on RMVs own description of the properties of its method:
  - Assessment of females.
  - Second-opinion of knee data changed the result in 55% of 137 investigated cases.
  - The number of males with mature knee and immature tooth is 4-5 times as high as the number with immature knee and mature tooth. Hard to explain if, as RMV claims, teeth generally mature before knees.

Can statistical methods reveal more about the properties of the RMV method?

- Investigate how much one can say about the properties of the method, *and* about the ages of the assessed asylum seekers, given available information.
- Available data for males, 2017:

	Knees mature	Knees immature	No data knees	SUM
Teeth mature	4176	348	187	4711
Teeth immature	1735	1087	83	2905
No data teeth	1364	237	63	1664
SUM	7275	1672	333	9280

  Additionally, there is information about the age indicators in published literature.
- I applied in June 2017 for more specific data from RMV. I have still not received such data.
- **Mostad, Tamsen: Error Rates for Unvalidated Medical Age Assessment Procedures** published in **International Journal of Legal Medicine**. ▸ Link

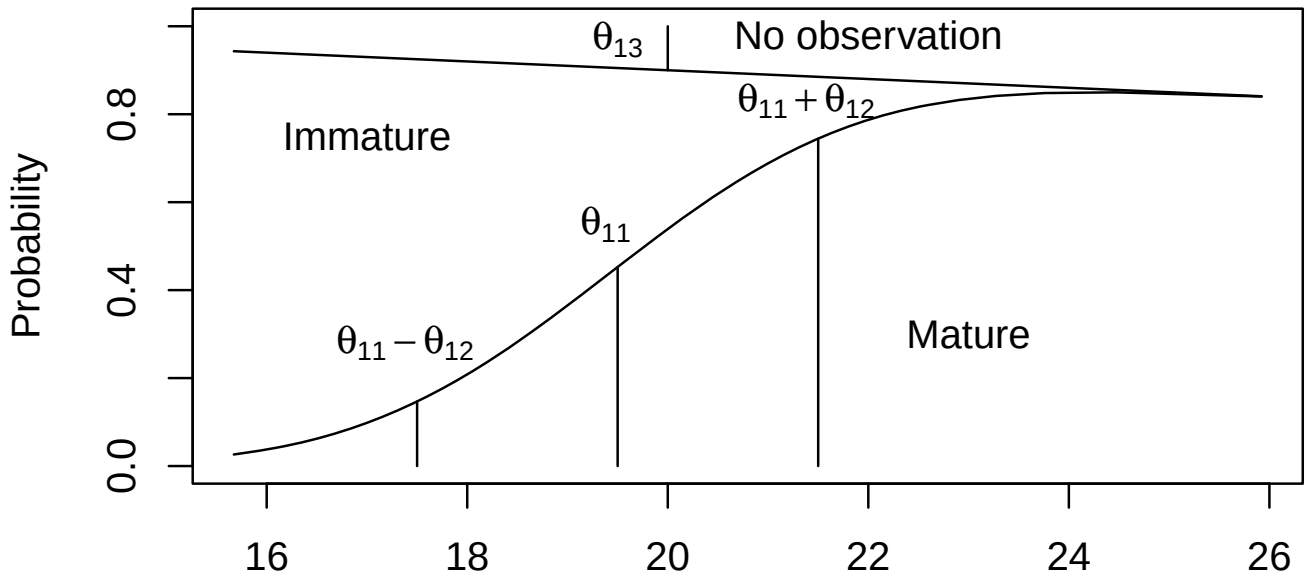
Modelling age indicator maturity as function of age

Parameters $\theta_k = (\theta_{k1}, \theta_{k2}, \theta_{k3}, \theta_{k4})$ describing relationship between chronological age x and age indicator k ($k = 1$: teeth, $k = 2$: knees).

$$
\begin{aligned}
p_{k1}(x) &= (1 - p_{k3}(x))\, \Phi\left(\frac{x-\theta_{k1}}{\theta_{k2}}\right) && \text{P(mature)} \\
p_{k2}(x) &= (1 - p_{k3}(x)) \left(1 - \Phi\left(\frac{x-\theta_{k1}}{\theta_{k2}}\right)\right) && \text{P(immature)} \\
p_{k3}(x) &= \theta_{k3} + \theta_{k4}(x - 20) && \text{P(no observation)}
\end{aligned}
$$

Below: $\theta_{11} = 19.5$, $\theta_{12} = 2$, $\theta_{13} = 0.1$, and $\theta_{14} = 0.01$.

An age indicator model:



Model variables

- $\theta = (\theta_1, \theta_2) = ((\theta_{11}, \ldots, \theta_{14}), (\theta_{21}, \ldots, \theta_{24}))$: Age indicator model parameters.
- $\psi = (\psi_1, \ldots, \psi_{100})$: Probability vector for probability of tested persons having specific ages $x_1, \ldots, x_{100}$. ($x_i \in [15, 30]$).
- $\tau = \{\tau_{ij}\}$, $i = 1, \ldots, 100$; $j = 1, \ldots, 9$: Counts of the number of persons of age x_i classified by RMV into category j: (mature/mature, mature/immature, ..., no data/no data).
- $y = (y_1, \ldots, y_9)$: The data, i.e., the total counts of persons classified by RMV into the categories 1,...,9.

Stochastic model

$$\pi(y, \tau, \psi, \theta) = \pi(y \mid \tau)\pi(\tau \mid \psi, \theta)\pi(\psi)\pi(\theta)$$

- $\pi(y \mid \tau)$ is determinstic, summing over ages.
- $\pi(\tau \mid \psi, \theta)$ is Multinomial as ψ and θ together specify the probability of each category.
- $\pi(\theta)$ is truncated multivariate normal, fitted using data from a range of publications.
- $\pi(\psi)$ is Dirichlet-distributed. We use an *uneven* spread of ages $x_1, \ldots, x_{100}$, in such a way that the most probable age distribution is a Gamma$(4, 1)$ density translated to start at 15 years and truncated at 30 years. Much variance around this maximum is used.

Parameter estimates based on published papers

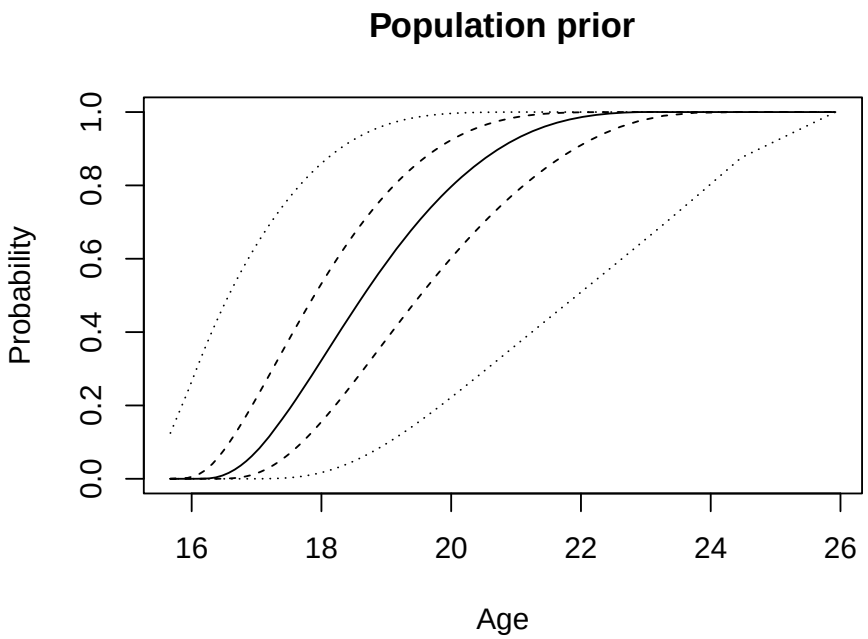
- Teeth parameters estimated from the following papers / data base:
  - DARL: https://www.dentalage.co.uk/rds-uk-caucasian
  - Lucas et al (2016) "Dental age estimation: ..."
  - Mincer et al (1993) "The ABFO study..."
  - Haglund et al (2018) "A systematic review and meta-analysis..."

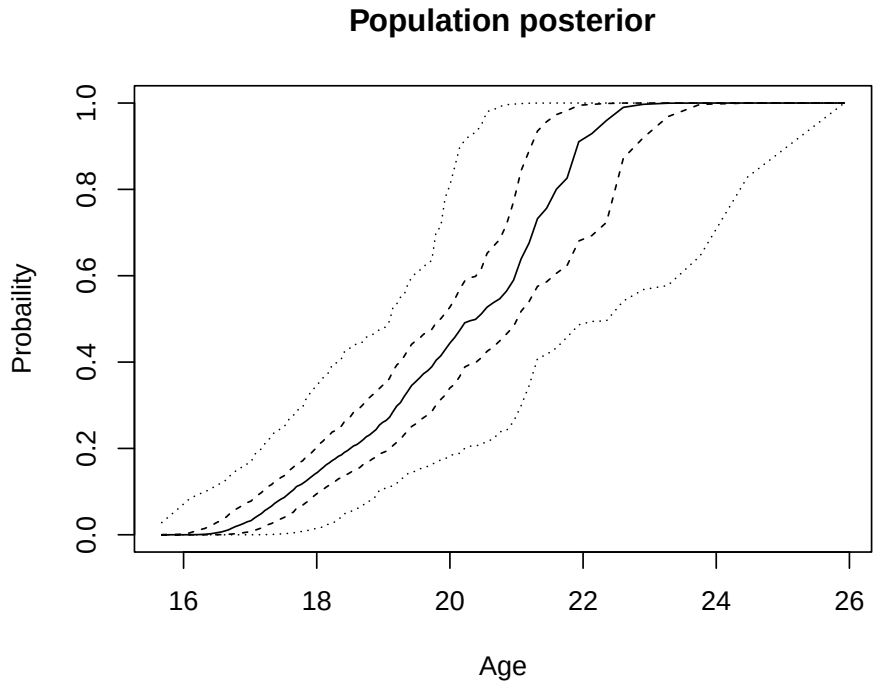
	DARL	Lucas	Mincer	Haglund	Prior
θ_{11}	19.5	18.6	19.9	20.9	19.5
θ_{12}	1.6	0.8	2.2	2.5	1.6

- Knee parameters estimated from papers:
  - Soc.s.:Socialstyrelsen (2018) Om magnetkamera vid bedömning av ålder.
  - Ottow et al (2017) "Forensic age estimation by magnetic resonance imaging of the knee..."
  - Adj. Ott.: Using adjusted data from Ottow et al.

	Soc.s.	Ottow	Adj. Ott.	Prior
θ_{21}	18.5	18.5	17.7	18.5
θ_{22}	1.3	1.5	1.4	1.4

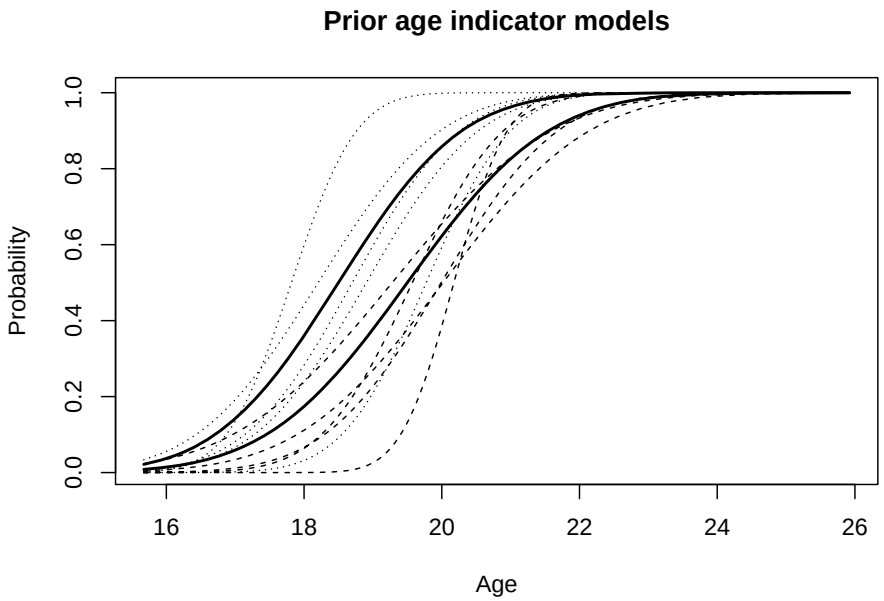
Prior and posterior age distribution: ψ

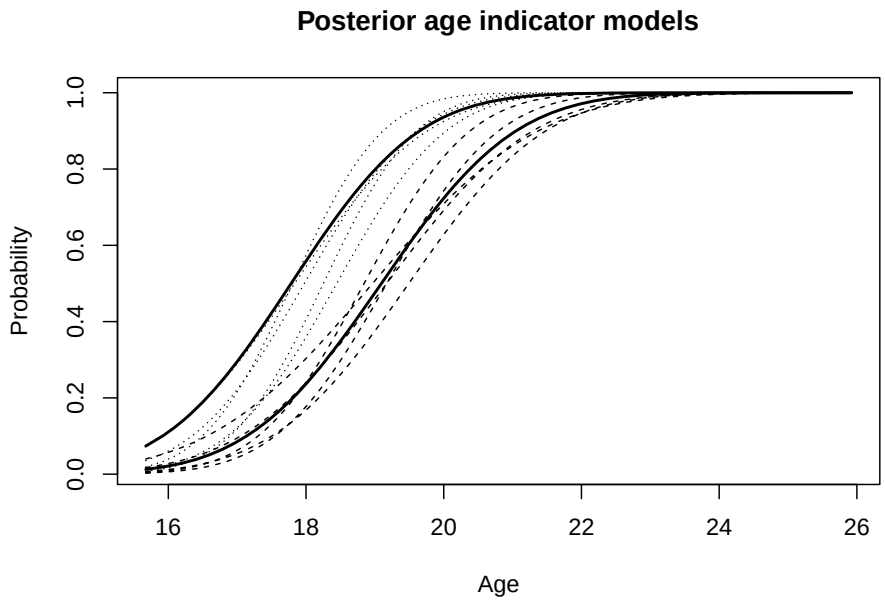




Figures show the cumulative age distribution under the prior and the posterior. The innermost band shows a 50% credibility interval. The outermost band shows a 95% credibility interval.

Prior and posterior age indicator parameters θ





Figures show the prior and posterior for the age indicator models. In each plot, the right bold line represents teeth and the left bold line represents knees. The dashed and dotted lines represent simulated possible models under each distribution.

Estimated results for males tested during 2017

	Class. as adults	Class. as children	Not class.	SUM
Adults	7260 (5908 – 7794)	581 (116 –1305)	59 (49 –63)	7900 (6102–8570)
Children	550 (16 – 1902)	826 (102 –1291)	4 (0 – 14)	1380 (133 –3379)
SUM	7810	1407	63	9280

The table shows the most likely number of people within each group. The parentheses show 95% credibility intervals.

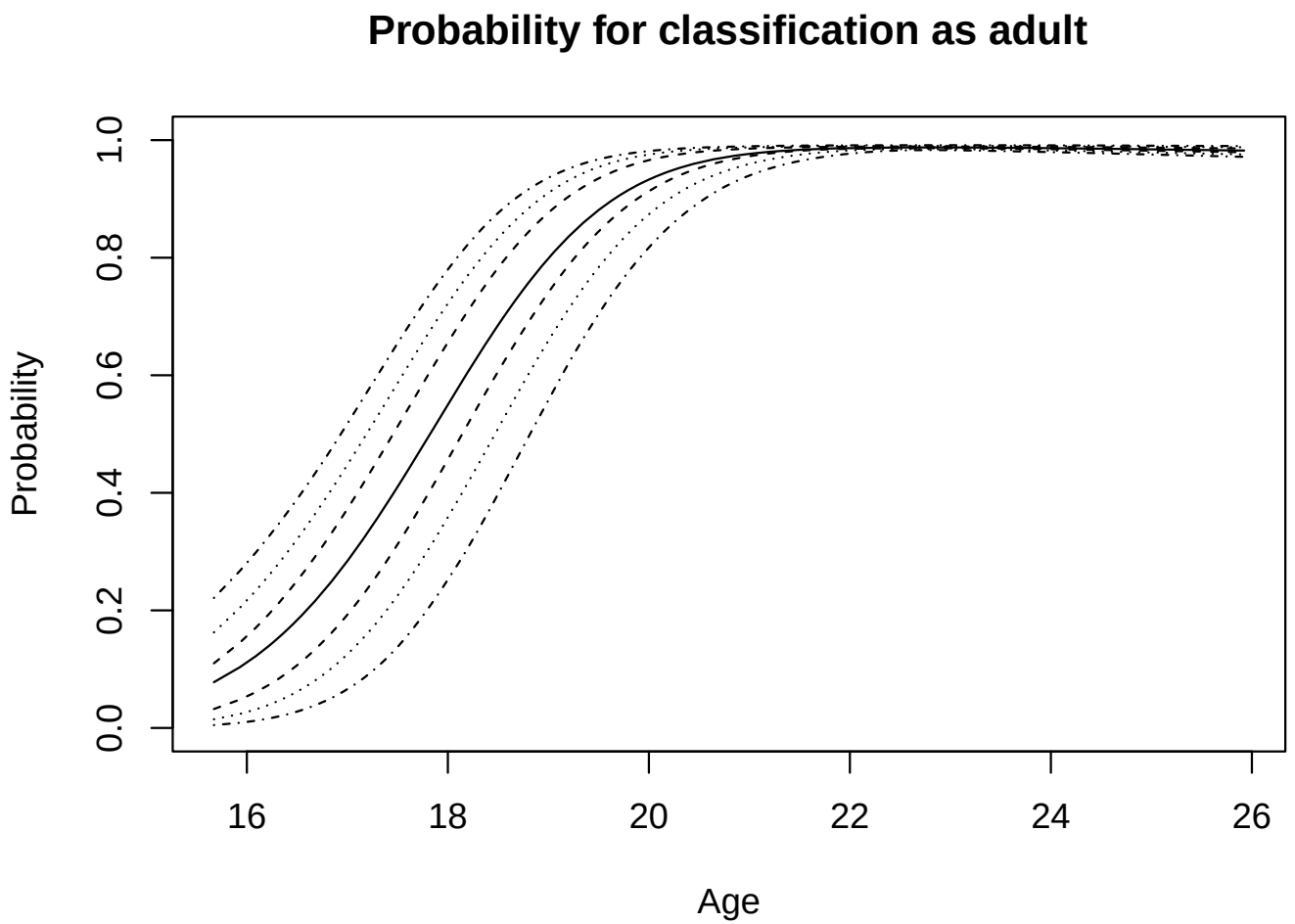
Sensitivity 93% (CI: 86-98), specificity 67% (CI: 39-94), Positive predictive value 93% (CI: 76-100), Negative predictive value 59% (CI: 7-92).

Proportion children in the classification groups

	Knees mature	Knees immature	No data knees	SUM
Teeth mature	1 (0–8)	24 (8–78)	2 (0–9)	3 (0–12)
Teeth immature	19 (1–64)	63 (8–95)	28 (2–70)	36 (4-74)
No data teeth	5 (0–17)	48 (4 –88)	7 (0–22)	11 (1–27)
SUM	6 (0–23)	53 (6–90)	9 (1–26)	15 (1–34)

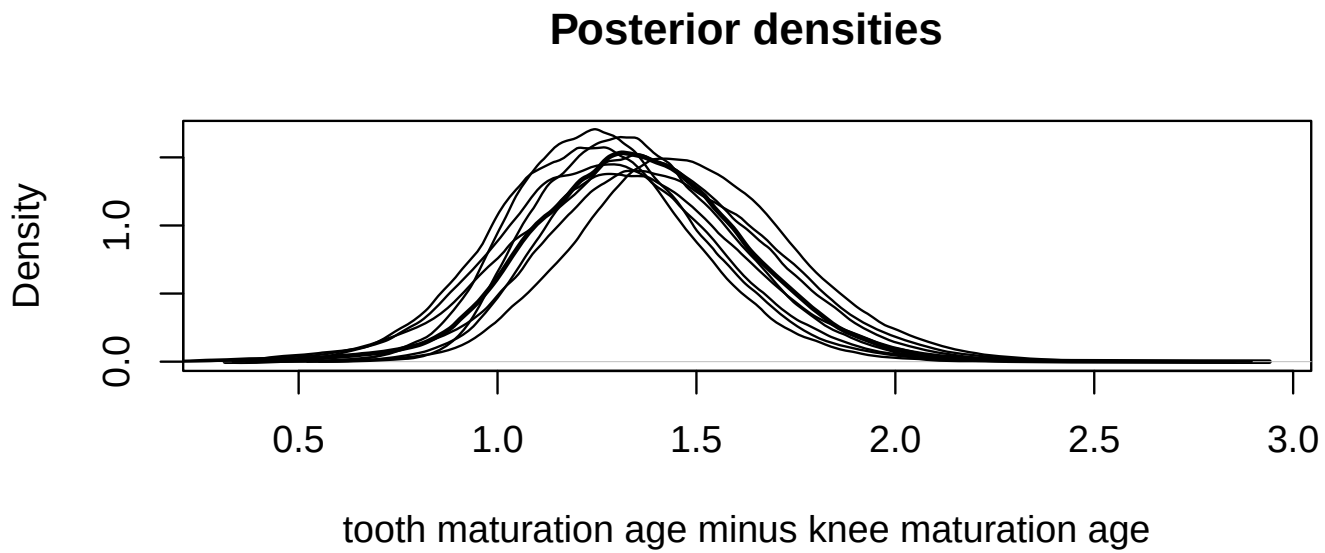
Percentage children in each category (95% credibility intervals in parentheses). The cells with gray background represent those where the RMV procedure classifies males as adults.

Consequences of the posterior for θ



For those with exact age somewhere between 17 and 18, the probability to be classified as an adult is 41%. The 95% credibility interval for this number is 12%-70%.

Knees mature before teeth



- RMV has claimed that knees generally mature after teeth.
- The bold line above shows the posterior distribution for the age at which 50% of boys have attained mature teeth minus the age at which 50% of boys have attained mature knees.
- The other lines represent results under alternative priors: We have done extensive calculations to investigate robustness.

Computational issues

- An MCMC algorithm was used to simulate from the posterior.
- Specifically, Gibbs sampling was used over the three parameters θ, ψ, and τ, with a random-walk proposal function for θ and direct simulation from conditional distributions for ψ and τ.
- Mixing was quite slow, but overcome using large samples.
- A burn-in of 20.000 samples and a total of 1.000.000 sampled iterations was used for computing results.
- Extensive checking was done to investigate robustness with respect to changes in the prior.

Central conclusions regarding RMVs age assessment procedure

- Stochastic modelling makes it possible to extract some information about how the procedure works along with some information about the ages of those tested.
- Some selected results:
  - 85% (66-92) of males age-assessed during 2017 were above 18.
  - Among those classified as adults based on mature teeth and immature knees, 24% (8-78) were children.
  - Among 17-year-olds, the probability to be classified as an adult was 41% (12-70).
  - Knees generally mature about 1 - 1.5 years before teeth.
- Interpretation and use of results from RMVs assessments has been based on information from RMV about their procedure that has now been proven wrong. Thus, scientific incompetence at parts of RMV, including its management, has endangered due process for age assessment of of asylum seekers in Sweden.

How should forensic age assessment be done?

- It must be possible to weigh together information about age coming from different sources.
- This points towards a Bayesian framework, as used in many other parts of forensic statistics.
- For example, the results from medical age assessments could be reported as a likelihood curve.
- A challenge to get case workers to correctly weigh probabilities against each other, but:
  - This is in a way what they do today (with limited success).
  - Procedural support for computations in type cases could be used.
- A connection with Bayesian decision theory (using costs of errors) should be made.

Challenges in likelihood computations for medical age assessments

- Available publications do not give consistent results on age indicators. Reasons?
- More complex models for maturity proportions.
- Conditional dependencies between indicators.
- Better models using covariates such as gender, genetic background, and socio-economic background.