

Estimating age-at-death of humans from tooth-wear

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Age estimation

- key procedure in human osteoarchaeology
- many methods
 - most use a modern *reference population* to estimate ages of archaeological *target population*
 - for juveniles based on growth and development
e.g. fusing of bones, development of teeth
 - for adults based on degeneration
e.g. changes to joint surfaces, tooth-wear

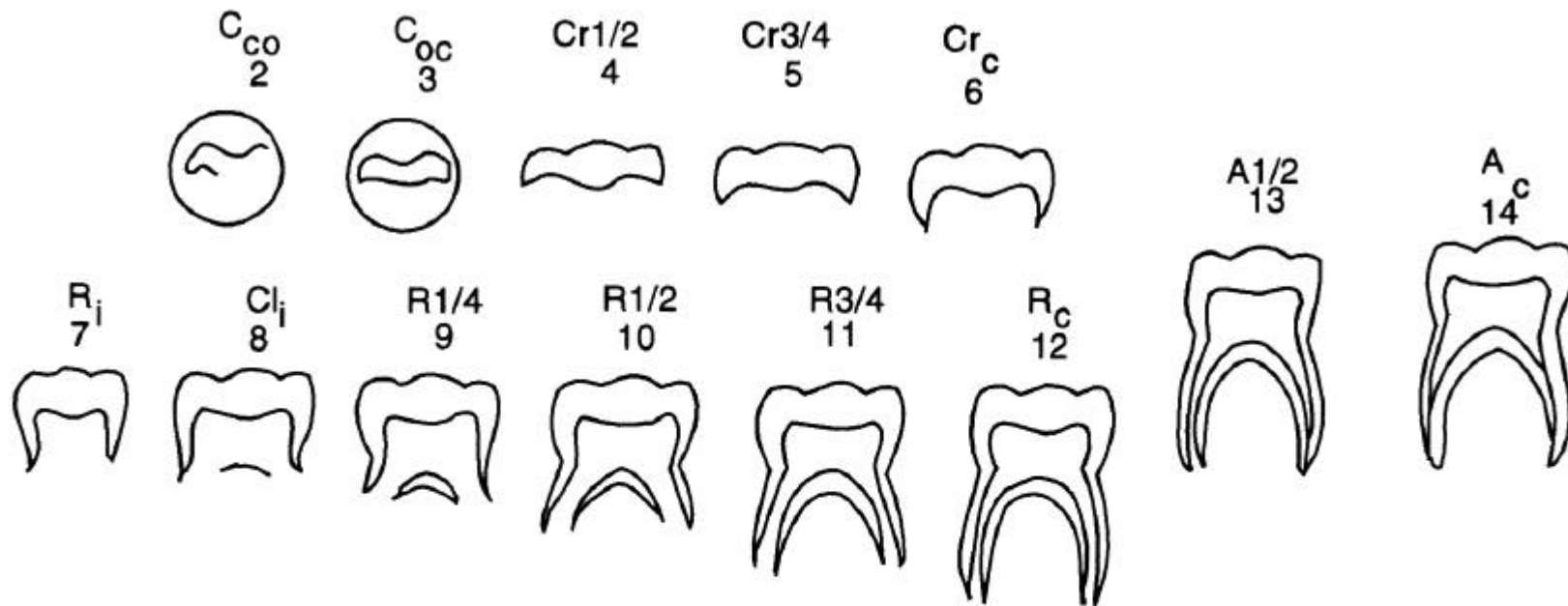
Age estimation

- key procedure in human osteoarchaeology
- many methods

“nearly all methods of ageing in current use do not make proper use of the statistical nature of age estimates ... age estimation is a process of generating the *distribution* of possible chronological ages for a skeleton.”

(Konigsberg & Holman 1999)

Tooth development



Code

Stage

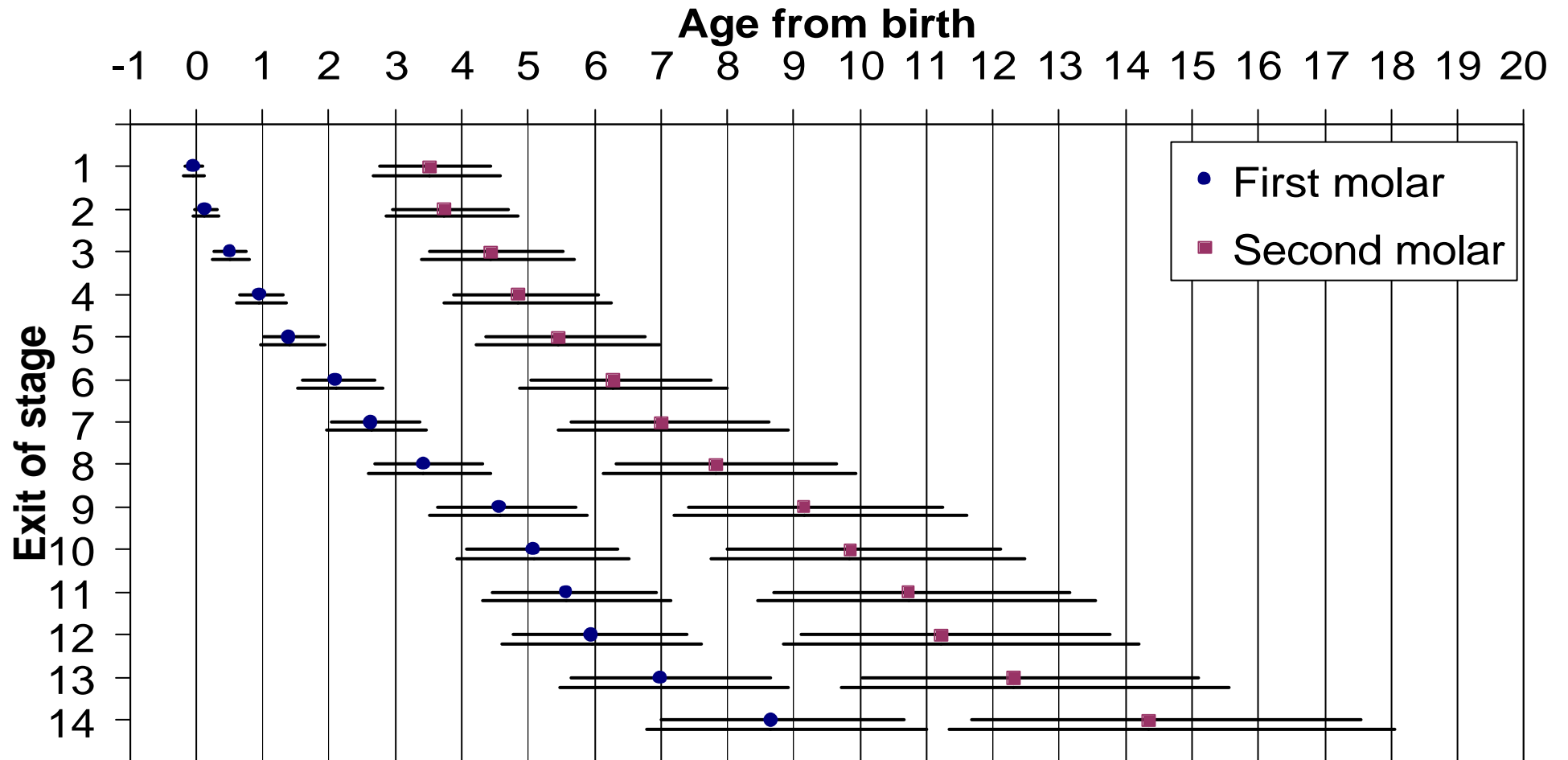
- | | |
|---|------------------------|
| 1 | Initial cusp formation |
| 2 | Coalescence of cusps |
| 3 | Cusp outline complete |
| 4 | Crown 1/2 complete |
| 5 | Crown 3/4 complete |
| 6 | Crown complete |
| 7 | Initial root formation |

Code

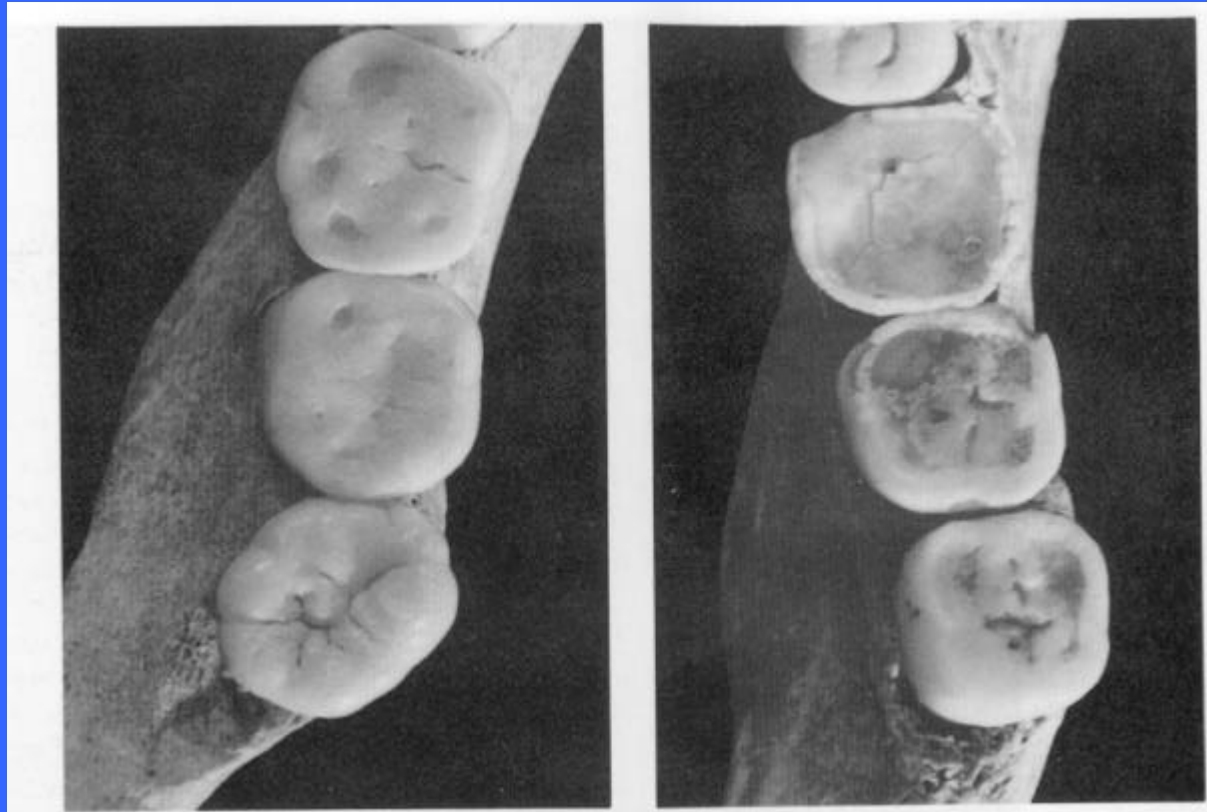
Stage

- | | |
|----|-------------------------|
| 8 | Initial cleft formation |
| 9 | Root length 1/4 |
| 10 | Root length 1/2 |
| 11 | Root length 3/4 |
| 12 | Root length complete |
| 13 | Apex 1/2 closed |
| 14 | Apex closed |

Age thresholds for development



Tooth wear



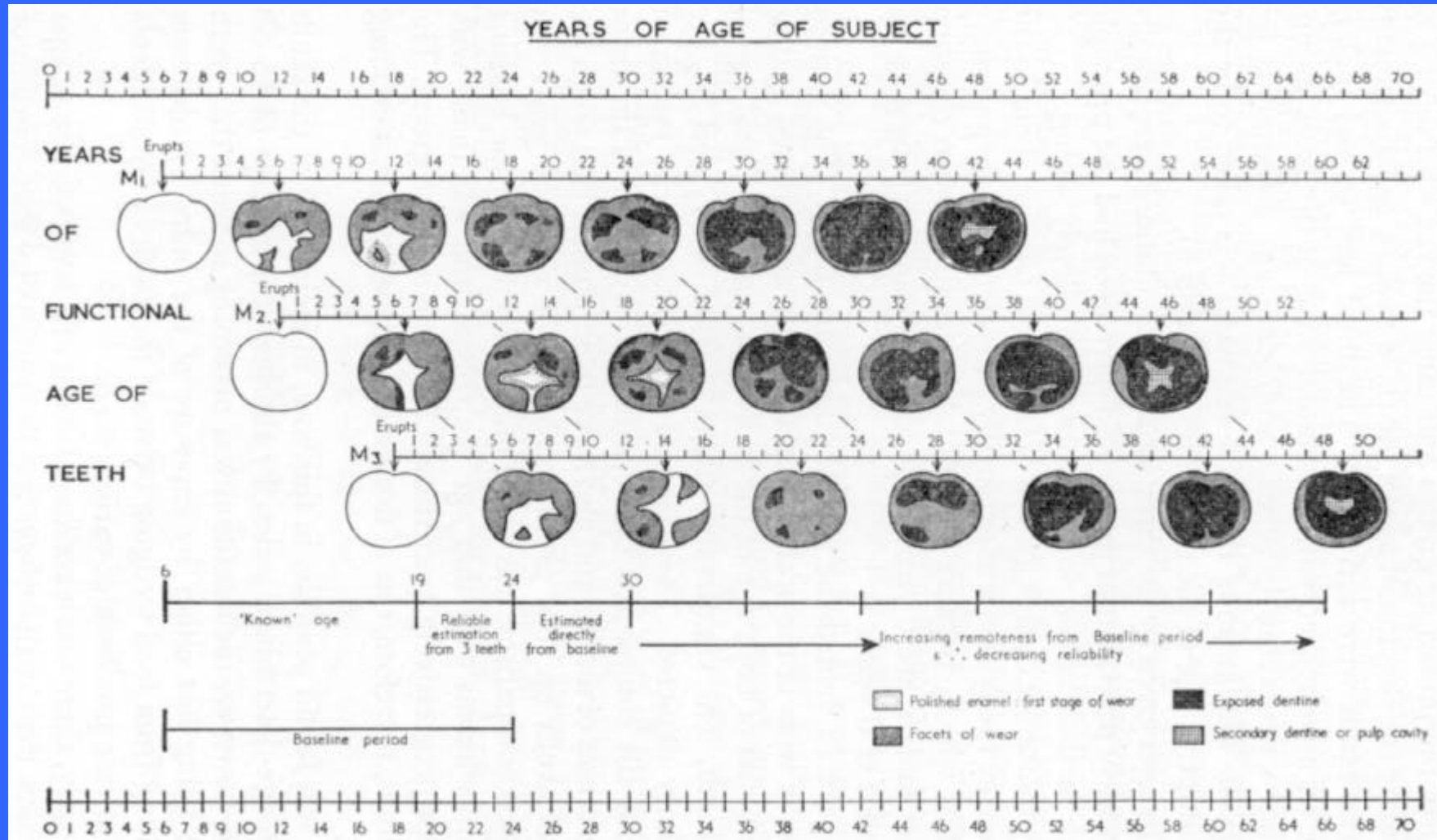
approx. 18 years

approx. 40-50 years

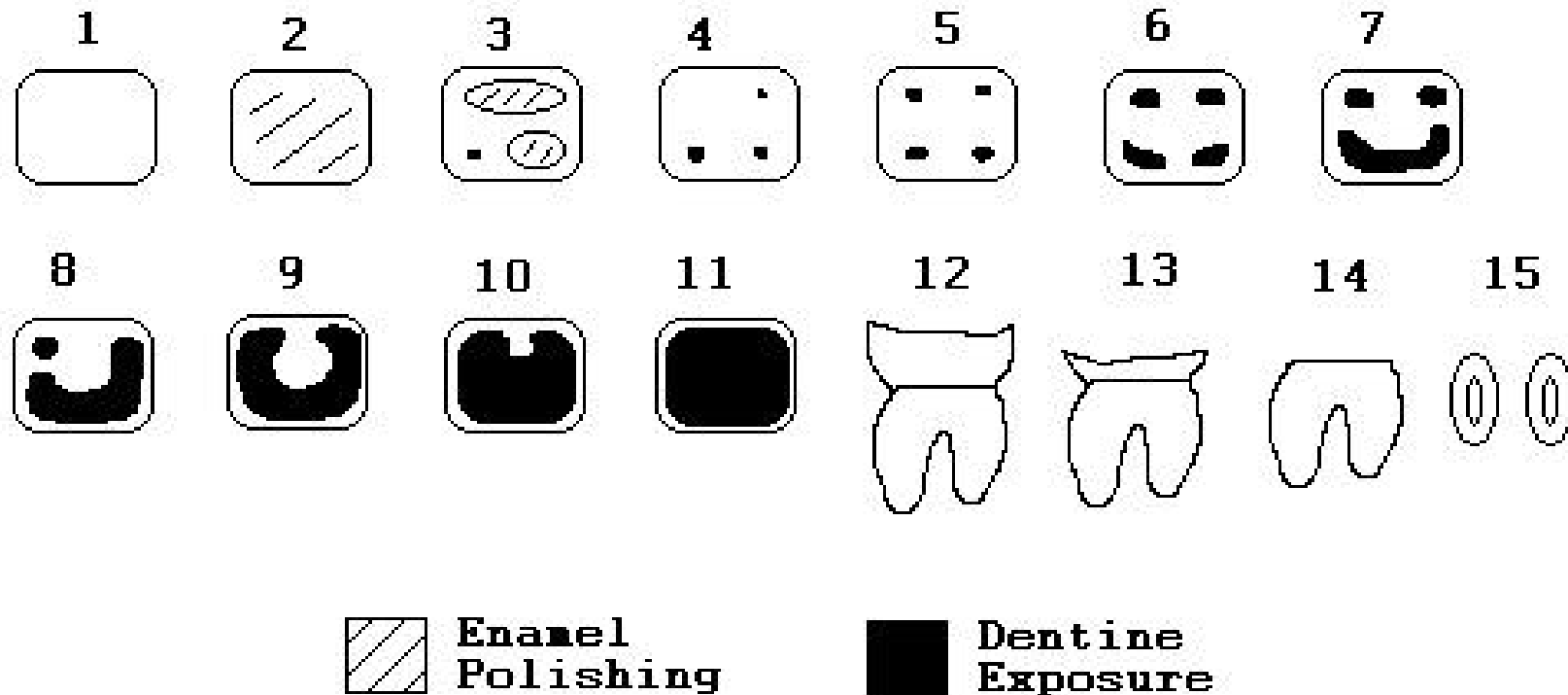
Ageing from tooth wear

- No reference population
- Miles' (1963) method
 - ▶ age younger people from tooth development
 - ▶ M1, M2 and M3 erupt at ~6 year intervals
 - ▶ estimate ages for early wear stages on M1 & M2
 - ▶ assume same wear stage at same functional age
 - ▶ 18-24 and 24-30 year olds can be aged
 - ▶ extrapolate to older and older ages

Miles' method



Tooth wear thresholds



Model for development ages

Generic model for tooth development and wear:

$$\text{logit}(Q_{i,j,k}) = \mathbf{d} \times [\ln(\mathbf{q}_i) - \ln(\mathbf{g}_{j,k})]$$

$$p_{i,j,k} = Q_{i,j,k-1} - Q_{i,j,k}$$

where

\mathbf{q}_i is the age of individual i in years from conception

$\mathbf{g}_{j,k}$ is the mean threshold for tooth j leaving stage k

\mathbf{d} is the discriminability which measures the population variability

The data

- Recorded >1000 individuals from AD 300-500
- 488 suitable individuals (i.e. molars with no significant caries, no ante-mortem loss)
- recorded stage of development of upper permanent dentition and lower incisors
- recorded wear of all molars present
- much tooth loss: 23% of development data missing, 22% of wear data missing

Our Bayesian approach

Priors:

q_i : uniform on (0,100)

model life table prior possible

$g_{j,k}$: known for development

d : approximated from Moorees *et al.* (1963)

missing data has prior implied by prior on q

Results:

posterior confidence ranges for ages from birth

Bayesian version of Miles' method

- model as for development
- regression to estimate thresholds
- relate M1, M2 and M3 thresholds via functional ages:

$$\mathbf{g}_{j,k} = \mathbf{g}_{j,1} + \mathbf{a}_j \times (\mathbf{g}_{M1,k} - \mathbf{g}_{M1,1}), \quad j=M2, M3$$

- prior on $\mathbf{g}_{M1,k}$ is $\mathbf{g}_{M1,k-1} < \mathbf{g}_{M1,k} < \mathbf{g}_{M1,k+1}$ with 0 and 100 as limits on first and last values
- $\mathbf{a}_j = 1$ or from Miles $\mathbf{a}_{M2} = 6/6.5$, $\mathbf{a}_{M3} = 6/7$
- calculate stepwise through ages like Miles

Implementation

Series of WinBUGS models derived from *Bones* example:

0: development alone where incomplete development

1: regression for thresholds 1-5

2: regression for thresholds 6-12 using mean γ from 1

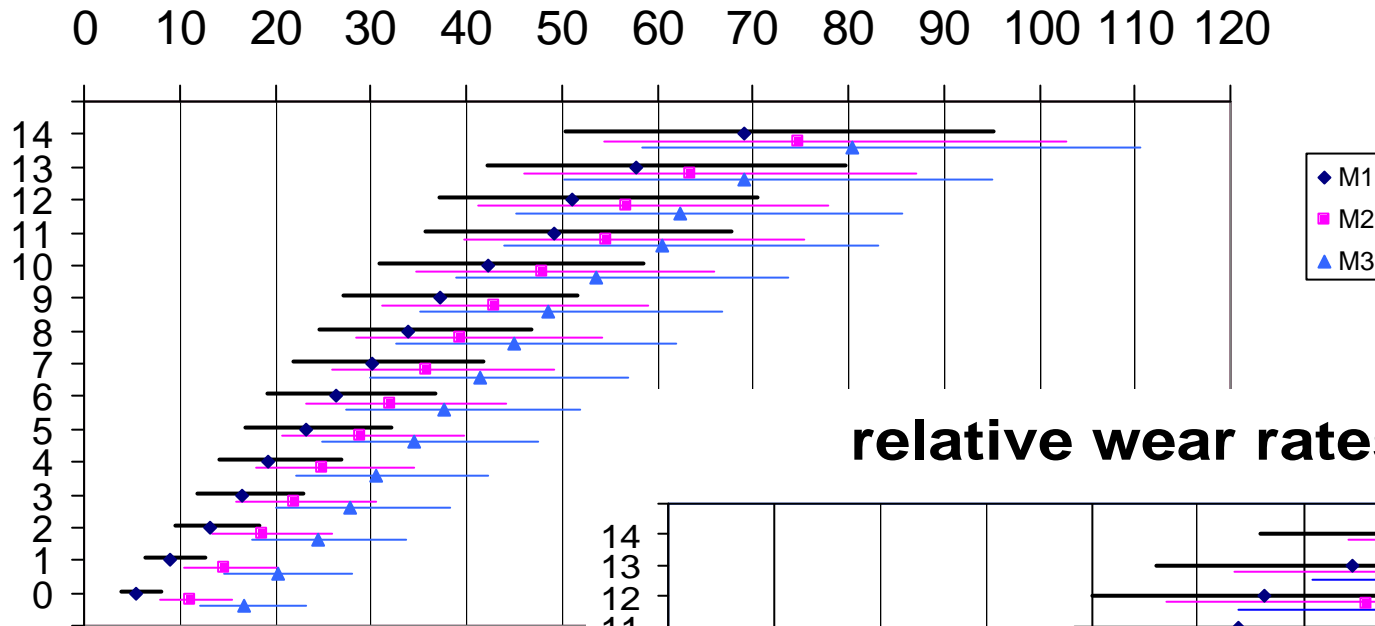
3: regression for thresholds 13-15 using mean γ from 2

Missing values handled easily

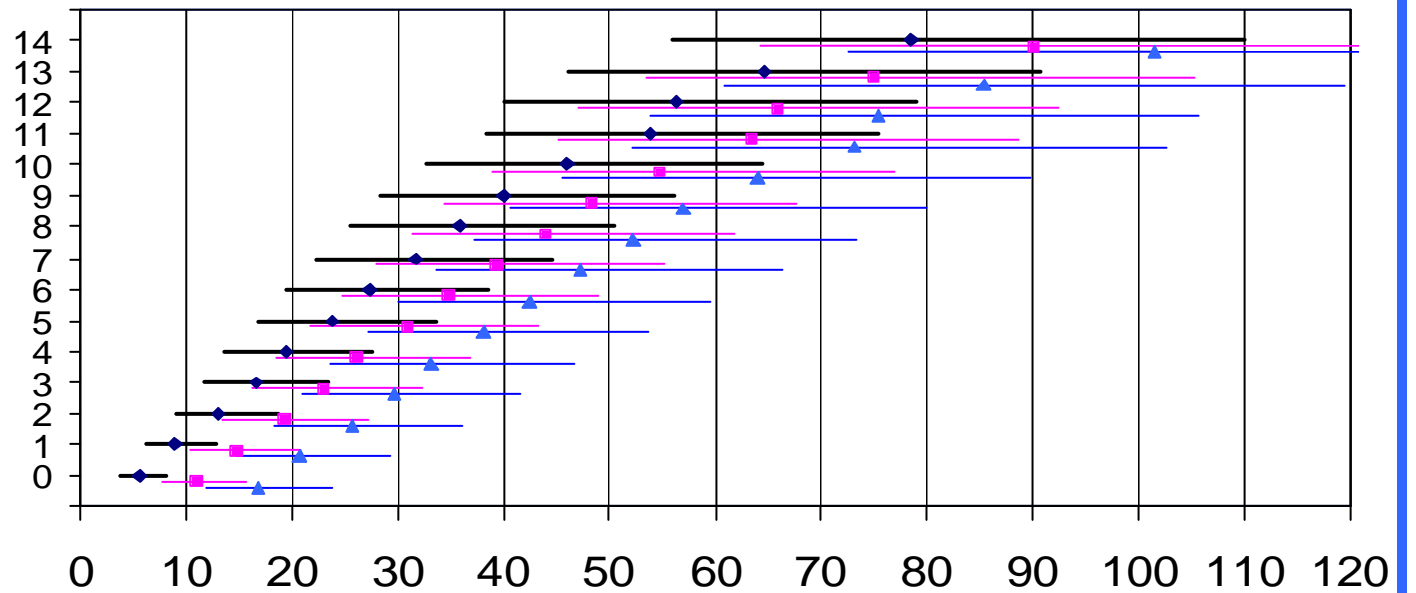
Use age divided by 10 to improve convergence

Toothwear ageing results

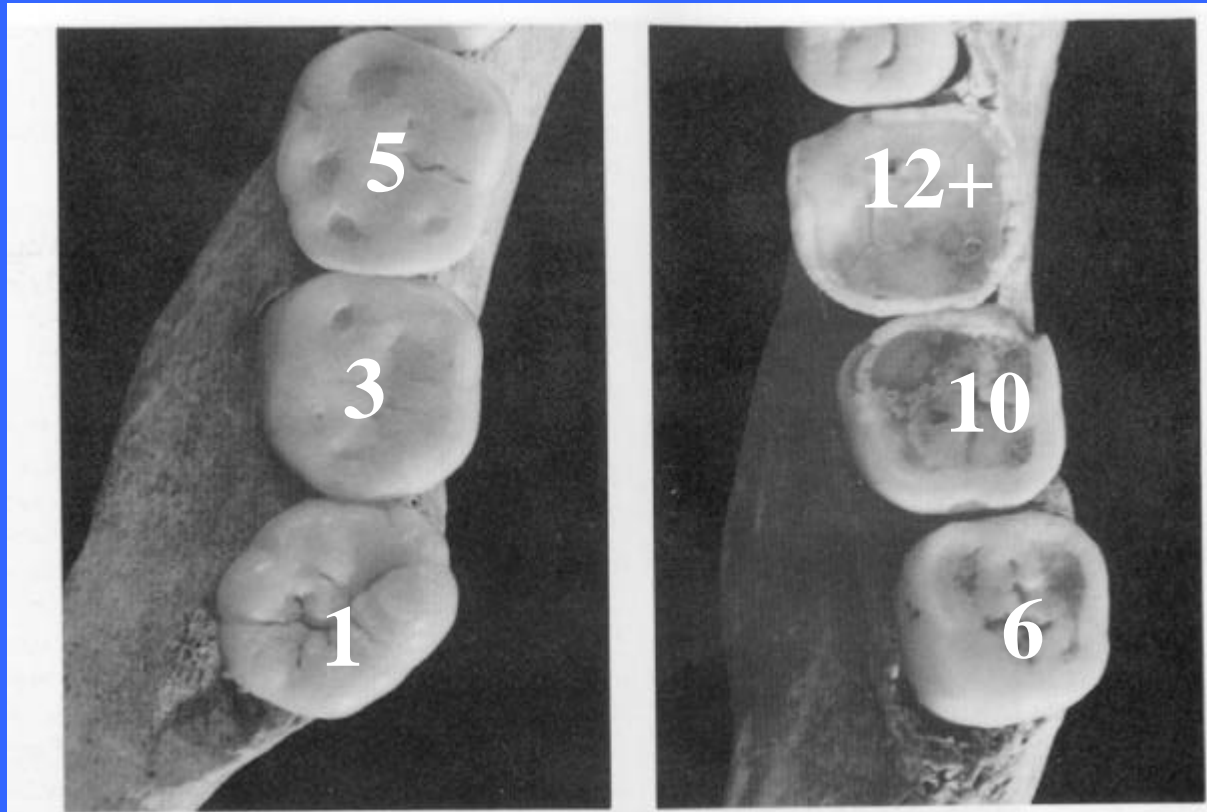
Equal wear rates



relative wear rates from Miles



Tooth wear results



approx. 18 years

approx. 40-50 years

our estimates: 18-22 years
17-21 years

43-54 years (equal rates)
48-61 years (Miles' Rates)

Problems and limitations

- estimating a_j from data produces large values
- discriminability assumed constant for all wear stages and molars
- assume thresholds in different teeth are independent
 - known not to be true for eruption
- use of logit rather than probit

Future development

- Comparisons with other ageing methods
- Combination with other ageing methods
- Hyperpriors on q :
 - current method estimates individual ages
 - palaeodemographers are interested in the population age distribution: put a prior on that
- Extension to other species

Conclusions

- Our Bayesian method gives:
 - ▶ more realistic age estimation, with less underestimation of age
 - ▶ accounts for missing data
 - ▶ improved estimates of uncertainties
 - ▶ ability to estimate other age-dependent population parameters