Institution: Queen Mary University of London (QMUL)

Unit of Assessment: A3 (Allied Health Professions, Dentistry, Nursing and Pharmacy)

Title of case study:

The London atlas of dental development and eruption

1. Summary of the impact

Dr Helen Liversidge's research from 1995 to 2013 has focused on age variation in tooth formation and the use of indices of dental development to estimate a person's age. The London Atlas of Dental Development and Eruption is an original and accurate diagnostic tool for dental age estimation in individuals up to 22 years. It has proved an invaluable resource for a number of groups, notably disaster recovery workers (to identify the ages of tsunami, war and earthquake victims) and to archaeologists (who seek to learn more about archaeological remains). It has also been called on as courtroom evidence in the cases of asylum-seeking minors. The Atlas has global reach as it is freely available as a web download.

2. Underpinning research

The research team is led by Dr Liversidge, who joined the Institute of Dentistry as a Lecturer in Paediatric Dentistry in 1995. Building on previous PhD work elsewhere, she began systematically to collect data from dental radiographs of London children. This involved large samples and the beginning of a unique worldwide collaboration investigating ethnic differences in tooth formation.

Dental charts are used by disaster victim identification teams to estimate age and thereby help identify children (see a review of this topic Hill et al Forensic Science International 2011; 205, 44–47). The 2004 Tsunami highlighted the need for an evidence-based atlas as well as testing which of the many methods of age estimation was most accurate. The London Atlas began as a PhD project of Dr Sakher AlQahtani and consists of a series of drawings of dental development for 31 age categories from before birth to 23 years of age. It is based on tooth data from foetal and skeletal remains of individuals with known age-at-death as well as dental radiographs, from Maurice Stack's Collection at the Royal College of Surgeons of England and Spitalfields Collection at the Natural History Museum in London. The London Atlas was published in a peer-reviewed journal in 2010 (see references 1-9). Dr AlQahtani has world copyright for the image and it is freely available online in sixteen languages and as free software in English.

Dr Liversidge and her team have designed an atlas specifically to estimate age, to overcome the major flaws of the previous dental atlas. Improvements include detailed tooth stage descriptions, clear illustration with internal and external features of each tooth, adequate and representative sample size, age variation for each tooth stage and consecutive age categories.

To underpin the development of the London Atlas, Dr Liversidge has tested the accuracy of more than 50 methods of dental age estimation. This has improved the way we assess ageing methods and highlighted the importance of the age range and the structure and features of reference data, clearly defined tooth stages and expression of uncertainty in estimated age.

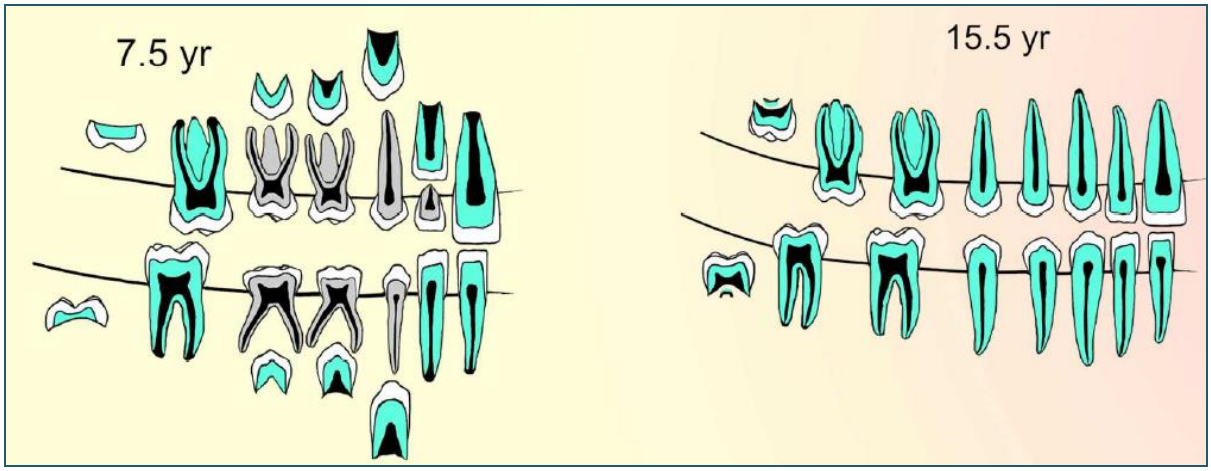
Dr AlQahtani validated the London Atlas on skeletal remains and dental radiographs of known age individuals and showed it to be the most accurate method to estimate age from developing teeth. When piloted, the Atlas was also found to be easier and clearer than previously used dental charts.

Dr Liversidge has collaborated with colleagues around the world since 2001 to investigate ethnic differences in tooth formation by comparing average age of tooth formation stages for each geographic group. She and her collaborators have compared more than 10 000 dental radiographs (from United Kingdom, South Africa, West and East Africa, Malaysia, Japan, Australian Aborigine, Maori, Pacific Islanders, Inuit and Native Americans) and shown that the timing of tooth development is similar between ethnic groups and remarkably unaffected by environmental influences. This underscores the importance of the London Atlas as being suitable to estimate age

worldwide.

The work was part-funded by The Ministry of Education, Saudi Arabia. Six years £168,000. Dr Liversidge received travel funds from Central University Fund (University of London) and Daiwa Anglo-Japanese Foundation

An example diagram from the atlas is reproduced below: Each tooth and eruption level represents the median tooth stage from children aged 7 and 15 respectively.



3. References to the research

1. Maber M, Liversidge HM, Hector MP. Accuracy of age estimation of radiographic methods using developing teeth. Forensic Science International 2006; 159, S68. http://europepmc.org/abstract/MED/16533584
2. AlQahtani SJ, Hector MP, Liversidge HM. The London atlas of human tooth development and eruption. American Journal of Physical Anthropology 2010; 142:481-490. http://www.ncbi.nlm.nih.gov/pubmed/20310064
3. Liversidge HM, Smith BH, Maber M. Bias and accuracy of age estimation using developing teeth in 946 children. American Journal of Physical Anthropology 2010; 143: 545-554. http://www.ncbi.nlm.nih.gov/pubmed/20623675
4. AlQahtani S.J., Hector M.P., Liversidge H.M. Testing the performance and quality of three dental age estimation charts: Schour and Massler, Ubelaker and the London Atlas. American Journal of Physical Anthropology (response to reviewers' comments submitted).
5. Liversidge HM, Marsden PH. Estimating age and the likelihood of having attained 18 years of age using mandibular third molars. British Dental Journal 2010; 209 (8): E13 http://www.ncbi.nlm.nih.gov/pubmed/20953166
6. Liversidge HM. Similarity in dental maturation in two ethnic groups of London children. Annals of Human Biology 2011; 38: 702-715. http://informahealthcare.com/doi/abs/10.3109/03014460.2011.609565
7. Liversidge HM. The assessment and interpretation of Demirjian, Goldstein and Tanner's Dental Maturity. Annals of Human Biology 2012, 39: 412-431.
8. Liversidge HM. Timing of human third molar formation. Annals of Human Biology. 2008, 35: 294–321. http://www.informaworld.com/smpp/title~content=t713723502~db=all~tab=issueslist~branches=35 - v35
9. Elamin F, Liversidge HM. Malnutrition has no effect on the timing of human tooth formation. PLoS ONE 8(8): e72274. doi:10.1371/journal.pone.0072274.
10. Liversidge HM.2004. Chapter: The Dentition. In: *The Juvenile Skeleton*. Scheuer L and S Black. London: Elsevier Academic Press, pages 149-180.

4. Details of the impact

The inspiration for the research described above was the 2004 Tsunami, which highlighted the need for an evidence-based tool, presented in an accessible format, to accurately estimate the ages of victims to help identification. It is accessible in various web formats including a training video [11]. It has been widely covered in the scientific [12] and lay press [13] and listed as a key source in textbooks [14].

The London Atlas was subsequently used to estimate the ages of victims in the air crash in Libya in May 2010 and the earthquake in New Zealand in February 2011. Professor Jules Kieser, Director, Sir John Walsh Research Institute, University of Otago, Dunedin, New Zealand commented: *"…as a forensic dentist I, together with my team, used your atlas when we did the identification of the victims of the tragic Christchurch Earthquake. The atlas enabled even inexperienced volunteers to understand dental ageing, and possibly most importantly, it was hugely useful when presentations were made to the Coroner's Board. They were able to get a visual appreciation of what we were telling them. In summary, thank you again for providing us with a landmark in the field of dental ageing."*

The London Atlas has now been adopted by the New Zealand Society of Forensic Dentistry.

The London Atlas is now an accepted method of age estimation around the world, and is used in training workshops run by the American Academy of Forensic Sciences, the International Organisation of Forensic Odontology, and the Biological Anthropology Research Centre and Bio-archaeology, Warsaw. Professor Bob Wood, Forensic Dentist and Disaster Victim Identification (DVI) trainer, Toronto University, says the Atlas is part of the standard information pack given to the Canadian DVI team [16].

In November 2010 Dr Liversidge was invited to present at the 'International Workshop on methods for age estimation in teenagers and young adults' held by the Norwegian Directorate of Immigration and the Baltic Medico-Legal conference. This resulted in a policy change of practice dealing with estimating age of age disputed asylum seekers in Norway. Dr Liversidge's paper on third molars in different ethnic groups is used to estimate age of asylum seekers from Afghanistan.

The London Atlas is used in teaching of forensic anthropology (UK, Canada, USA, Israel, Italy), disaster victim identification (UK, Australia, Canada, Pakistan), forensic dentistry (UK, Belgium, Canada, American Board Forensic Odontology, USA) and archaeology (Bradford, Liverpool John Moore, University College London UK, New Mexico, USA). The Atlas has been used to estimate age of forensic cases in UK, Switzerland, Israel, Australia, New Zealand, Libya, Canada, New Mexico, Texas and Washington State USA.

The teaching of dental anatomy and development of the dentitions also relies heavily on the London Atlas: it is currently used in most dental schools in the UK, as well as those in Belgium, Croatia, China, Finland, Germany, Greece, Israel, Iceland, Norway, Switzerland, USA, Canada, Japan, Malaysia, Middle East, Australia, New Zealand and Venezuala.

The London Atlas has also been used by archaeologists for ageing skeletal remains in USA, Greece and Peru. Finnish forensic archaeologist Dr Jana Hurnane and her team consulted the atlas to learn more about child mummies found in Peru.

A well-executed dissemination strategy has been key to the widespread use and success of the London Atlas. Worldwide copyright was taken out in 2009 to allow free access on the internet [11]. Since the launch in April 2012 to August 2013 there were 56150 hits from 73 countries, and the website gets on average 130 hits a day. The Atlas has been translated into 16 languages including Chinese, Arabic and Japanese. The app has been downloaded many thousands of times. A training video has been developed and is freely available on the internet.

The project was shortlisted for Research Project of the year by Times Higher Education Supplement in 2012 [15]. The London Atlas was shown in 'History Cold Case' documentary on BBC2 in May 2010.

5. Sources to corroborate the impact

11. Internet links
    - Webpage www.atlas.dentistry.qmul.ac.uk
    - Downloadable app www.qappsonline.com/apps/atlas/
    - Training video www.youtube.com/watch?v=FSyQvZaiXGo&feature=c4-overview&list=UU7JSE8G0aOmtL1oYWGueSVg

12. Articles in the scientific media:
    - Dentistry www.dentistry.co.uk/news/5335-New-dental-software-will-qaposrevolutionisegapos-forensics
    - Nature www.nature.com/bdj/journal/v213/n1/full/sj.bdj.2012.582.html

13. Articles in the lay press:
    www.dentistry.co.uk/news/5335-New-dental-software-will-qaposrevolutionisegapos-forensics
    http://www.nature.com/bdj/journal/v213/n1/full/sj.bdj.2012.582.html

14. Books: The London Atlas has been included in the 3rd editions of "The Human Skeleton in Forensic Medicine" (Iscan and Steyn) and " Manual of Forensic Odontology " (Senn and Weems).

15. Prize: Times Higher Education Supplement Research Project of the Year Award shortlist 2012: http://www.timeshighereducation.co.uk/421042.article

16. Feedback comments by email (available on request):

    - Director, Sir John Walsh Research Institute, University of Otago, Dunedin, New Zealand
    - President of the British Association of Forensic Odontology
    - Forensic Dentist and Disaster Victim Identification (DVI) trainer, Toronto University, says the Atlas is part of the information pack given to the Canadian DVI team.