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Development of an Automated Shape and Textural Software Model of the Paediatric Knee for Estimation of Skeletal Age.

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Synopsis:
There are multiple methods available for skeletal age determination in the paediatric endocrine population. Only two methods, using left hand and wrist x-rays are in frequent clinical use, however Greulich & Pyle is based on data collated between 1931 and 1942 and Tanner Whitehouse uses data from as far back as 1949. We present the initial results of an automated software model of shape and textural analysis of the epiphyses of the knee.

Introduction

Disorders of growth and metabolism are a significant public health problem, responsible for the majority of paediatric endocrinology referrals and a significant number of consultations with general practitioners. Correlation of skeletal age (SA) and chronological age (CA) alongside other clinical findings is key to the diagnosis and management of many endocrine conditions, including puberty disorders and short stature. These children often undergo serial x-rays during their period of treatment to assess bone age. Recent studies of Japanese [1] and Italian [2] children examined the potential of magnetic resonance images (MRI) of the left wrist for skeletal age estimation, demonstrating correlation (R^2 >0.9) between CA and SA.

Other methods of SA determination include evaluation of knee x-rays [3], digital atlases of the wrist [4] and automated software models of wrist x-rays[5], however to our knowledge there has not been any evaluation of the textural and shape change at the epiphysis on MRI.

During the earlier stages of growth when corrective procedures are under consideration, the epiphysis is not fully ossified and therefore a wealth of information is missing from an x-ray. The shape and textural features of an epiphysis on MRI should generate more information, potentially allowing for more accurate age estimation.

Purpose

1) To train and test a software model of MRI knee physis shape and texture for estimation of SA.
2) To compare the model's SA estimation with CA.

Methods:
A retrospective review of all paediatric MRIs of the knee performed at University Hospital Coventry & Warwickshire identified 143 patients on the radiology information system between 18/08/2010 and 10/08/2015. 4 cases were excluded due to synovial abnormality or arthropathy and 6 were excluded due to movement artefact or inadequate sequences.
The image analysis consisted of three stages: (1) expert mark-up of training images to build the shape and appearance models of variation [6]; (2) validation of the accuracy of the models using leave-one-out testing on the training samples; (3) regression of shape and texture co-factors from training samples to CA.
During stage (1) we used proton-density and fat saturation sequences to produce accurate surface delineations of the epiphyses. The point data were converted to a surface mesh, co-registered and the surfaces re-sampled with a smaller sub-set of corresponding points at which appearance data was extracted. At stage (2), we partitioned the training data and used cross-validation testing to verify the accuracy of the shape and appearance model fitting. In addition, the model characterised the textural changes across the epiphyseal plate and this was used to produce an model of normal age-related change by using multivariate, non-linear regression to CA. This was carried out by means of a neural network classifier [7].

Results:
Chronological age ranged between 4.99 and 18.4 years, of which 43.4% were male. Overall root-mean-square error (RMSE) was 592 days (1.62 years) and the average absolute age prediction error was 457 days (1.25 years). Regression of the appearance and shape factors to CA showed moderate correlation (R^2 = 0.634) (fig 2). Analysis of the degree of error by age group demonstrated a higher mean error in the groups with smaller samples (fig 3).

Discussion:
SA determination is an important tool in paediatric endocrinology, but assessment still relies on out-dated atlases [8, 9] and the reader reliability of the interpreter, with intra-observer differences of up to 0.96 years [10]. There are differences in SA versus CA that exist within different populations such as ethnic background [11] and obesity [12].

This work represents a first step in the development of an automated software model for SA determination using knee MRI. Despite the small sample size, the average age prediction error of 1.25 years lies within the 95% confidence intervals of reported intra-observer error based on both the TW2 and GP atlases [10], however relatively high age prediction errors occurred where there were smaller numbers within an age group.

Conclusion:
We present the initial results of an automated software model of shape and textural analysis of the epiphyses on knee MRI with a mean age prediction of 1.25 years. Further normative data is needed to refine the software model., so that it can be used for prediction of epiphyseal fusion and skeletal age determination.

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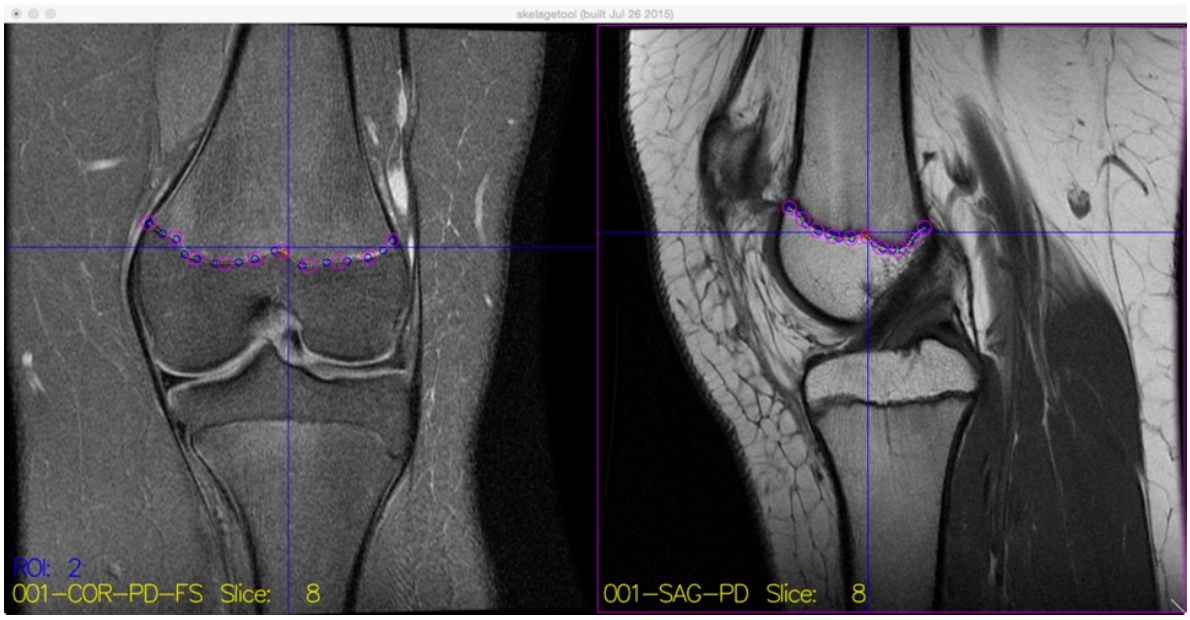
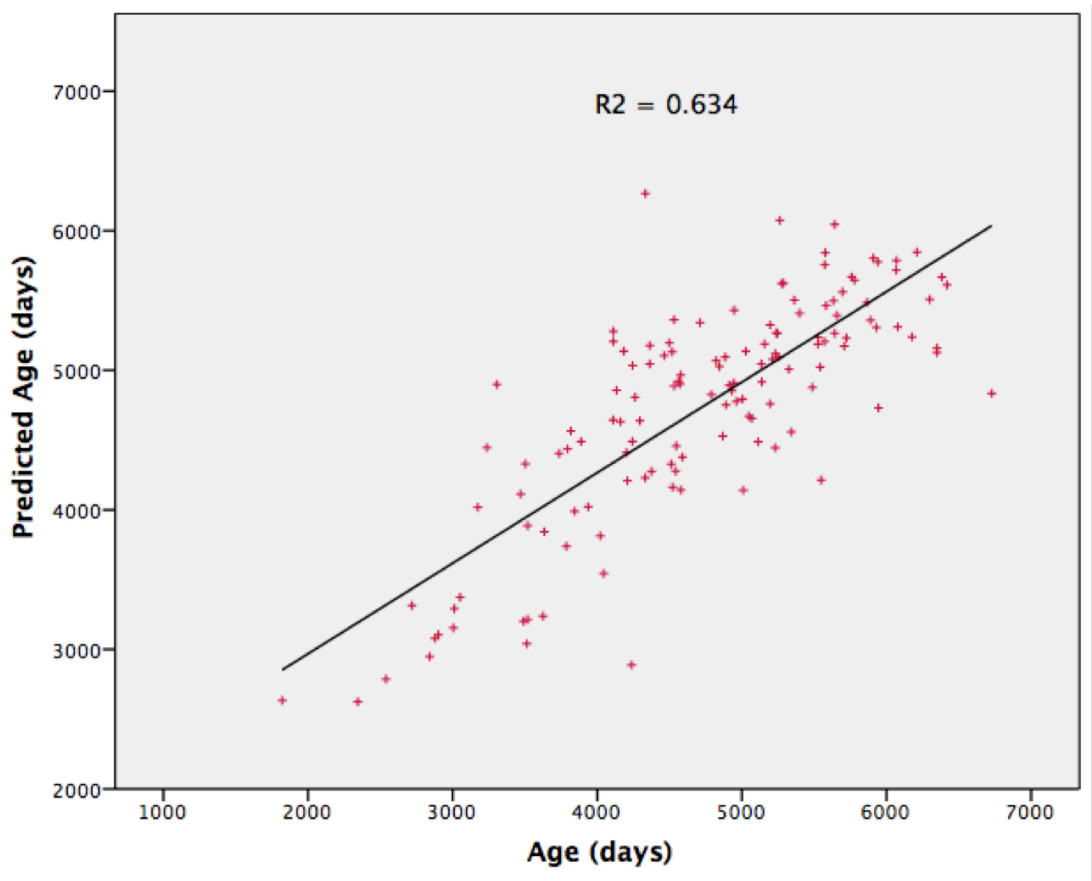
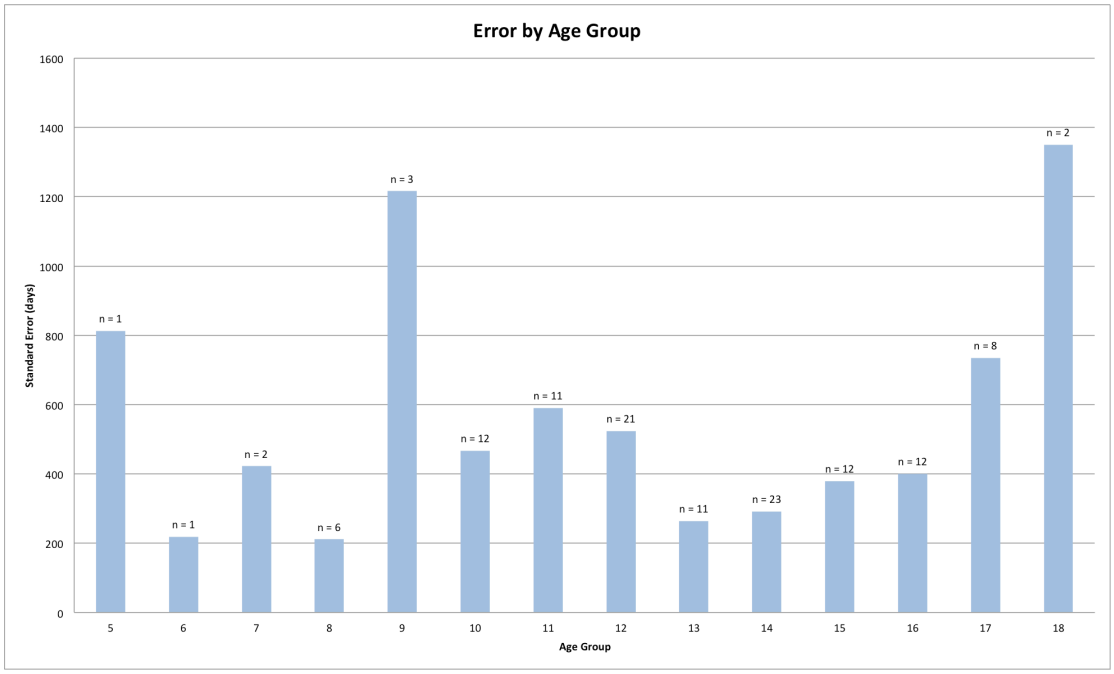

skelagetool (built Jul 26 2015)
ROI: 2
001-COR-PD-FS Slice: 8
001-SAG-PD Slice: 8


R2 = 0.634
Predicted Age (days)
Age (days)
7000
6000
5000
4000
3000
2000
1000
2000
3000
4000
5000
6000
7000


Error by Age Group
Standard Error (days)
1600
1400
1200
1000
800
600
400
200
0
n = 1
n = 1
n = 2
n = 6
n = 3
n = 12
n = 11
n = 21
n = 11
n = 23
n = 12
n = 12
n = 8
n = 2
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Age Group