HKU Med LKS Faculty of Medicine
Department of Orthopaedics & Traumatology
香港大學矯形及創傷外科學系

Introduction to Digital Health

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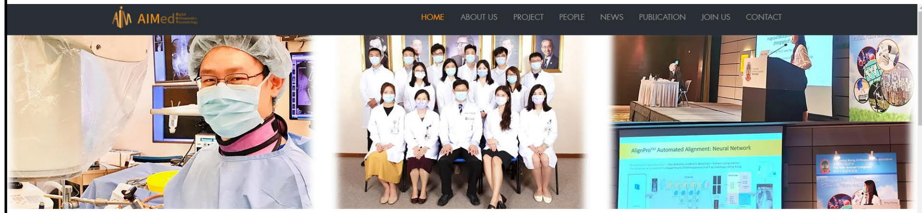
http://aimed.hku.hk



Objectives

Founded by surgeons, scientists and engineers from Queen Mary Hospital, HKU, Cambridge and Silicon Valley, Digital Health Laboratory commits to investigate the cutting-edge AI techniques for clinical applications, including:

- Enable AI integrated modelling with applications in fields including optimised surgical planning, 3D printing of personalized implants and robotic surgery navigation.
- Launch standardized and secured clinical big data center for disease progression prediction, automated patient follow-ups and subjects recruitment for clinical research.

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Historical Milestones

1990s electronic medical records (eMR/eHR) → 2007 1st E-patient white paper (Dr Tom Ferguson) → 2017 FDA Launched Digital Health Unit → 2018 ITU-WHO Focus Group on Artificial Intelligence for Health (FG-AI4H)

AI for Health
An ITU Focus Group
In collaboration with WHO

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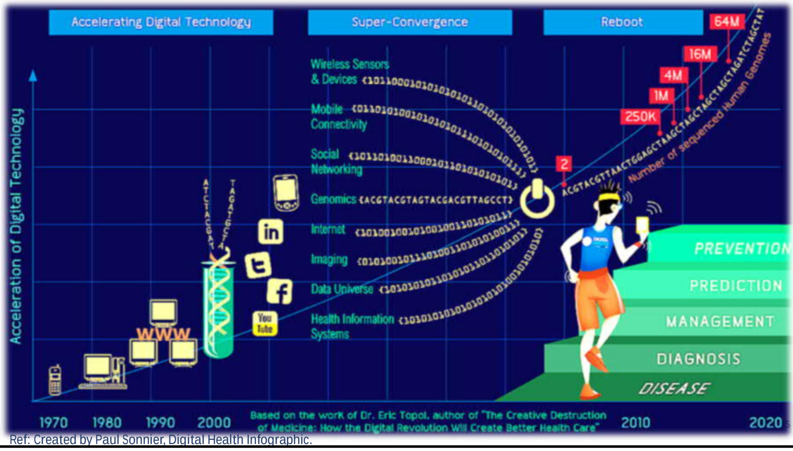

Ref: Created by Paul Sonnier, Digital Health Infographic.

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Current technologies and industries

Current technologies

1) Telemedicine
   - e-medical records, remote care, e-appointment booking, self-symptom checkers, patient outcome reporting, etc.
   - Teledoc (1st), MeMD, iCliniq, etc. (mostly internal medicine)
2) Wearable devices
   - smartwatches and on-body sensors for detecting health-related data etc.
   - AliveCor (mobile ECG), BioTelemetry (health management in clinical setting), Gentag (diagnostic sensors)
3) Augmented reality
   - technology enhances real-world experiences with computerised sensory information and is used to build smart devices for healthcare professionals
   - FundamentalVR (surgical training), Karuna Labs (chronic pain management), OxfordVR (Mental Health)
4) Others
   - Assistive technologies, rehabilitation robotics, unobtrusive monitoring sensors, etc.

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Future Potentials

What AI/ML/DL can do

1) Better decision making
   - standardised data aquisition
   - consistent results generation
2) Early/auto-diagnosis
   - subtle feature detections
3) Continuous/out of hospital management
   - home care with continuous feedback
4) Benefits
   - to reduce inefficiencies, to improve access, to control costs, to increase quality, and to enable personalised medicine

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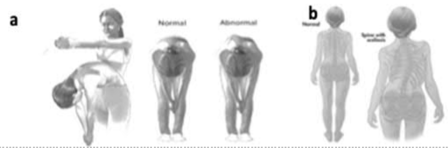
Real Case scenario: spine malalignments

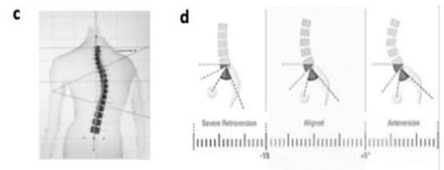
- Physical Examinations for Screening
  - a: Adam Bending
  - b: Posteriorly observations

Disadvantages
- Subjective, Inaccurate, Not repeatable



- X-Ray Examinations for Diagnosis
  - c: Deformity -Cobb angle as the gold standard
  - d: Low back pain - Sagittal alignments for surgical planning

Disadvantages
- Manually assessed within the stationary PACS
- Time consuming and inconsistent with human errors
- No real-time feedbacks to the patients
- Inter-rater difference between different surgeons



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Other disadvantages

Harmful Radiation

- For adolescence, X-rays needs to be repeated in every 3-6 months. Repetitive radiation can harm the health;
- New England Journal reported，0.4% cancer patients are associated with medical radiations and this number can be as high as 1.5-2%.

Time Consuming

- Long waiting time to have an appointment with the specialists;
- Long waiting and travel time for attending the consultations;
- Need to wait repeatitively to see specialist repetitively.

NO Real-time feedbacks

- No high throughput tests exist;
- No immediate feedbacks of the test results;
- Increased anxiety during waiting;
- No compliance tracking of the prescript treatments.

Expensive

- Travel fee $
- Screening fee $$
- Diagnosis fee $$$
- Consultation fee $$$
- Treatment fee $$$
- Surgery fee $$$$$$$$$

Analysis: Current digital alignment assessment tools

Manual alignment analysis product

- Surgimap, X-Align, Integrated Global Alignment, etc.

Automated alignment analysis tools

(no product available)

- Conventional imaging process-based methods and disadvantages
  - Heterogeneous patterns of deformities
  - X-rays having high variance
  - Limited accuracy[1,2] with original high-resolution images
- AI integrated methods and disadvantages
  - Semi-automated[3]
  - Automated (CV convenient but not mimic clinicians)
    - Direct regress CA[4] cannot guarantee what has been learnt
    - Indirect regress CA[5] still without intermediate supervision
    - CNN alignment detections[6, 7]
    - All used original high-resolution X-rays but often generated low accuracies (>10° errors)

References:
1. R. Kundu, et al, "Cobb angle measurement of scoliosis with reduced variability"
2. J. Zhang, et al, "Automatic Cobb measurement of scoliosis based on fuzzy Hough Transform with vertebral shape prior"
3. J. H. Zhang, et al, "Computer-Aided Cobb Measurement Based on Automatic Detection of Vertebral Slopes Using Deep Neural Network"
4. H. L. Sun, et al, "Direct Estimation of Spinal Cobb Angles by Structured Multi-output Regression"
5. H. Wu, et al, "Automatic landmark estimation for adolescent idiopathic scoliosis assessment using boostnet"
6. F. Galbusera et al., "Fully automated radiological analysis of spinal disorders and deformities: a deep learning approach"
7. M.-H. Horng, et al, "Cobb angle measurement of spine from x-ray images using convolutional neural network"

Our aim and objectives

Aim

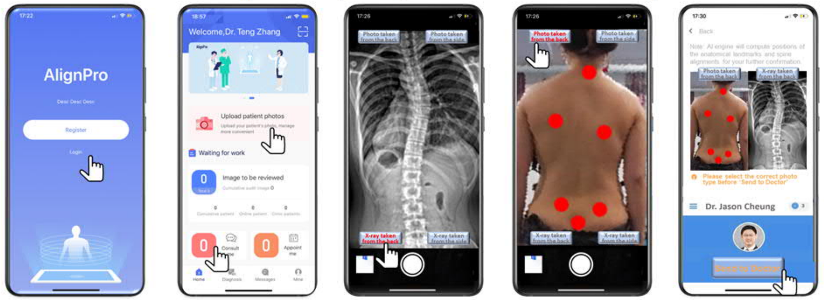
- Provide reliable and easily accessible automated vertebral landmark detection irrespective of image quality.

Objectives

1. Establish a reliable deep learning-based method to accurately detect vertebral landmarks, including endplates and end vertebrae
2. Eliminate previous restrictions of automatic coronal alignment on curve patterns or imaging quality by training the model using non-original X-rays of various image quality and different curve patterns.

AlignPro™ Automated Alignment: Mobile app

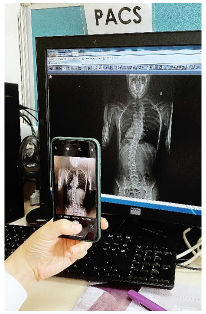
Standardised data acquisition – Key anatomy landmark detection – Pattern computation



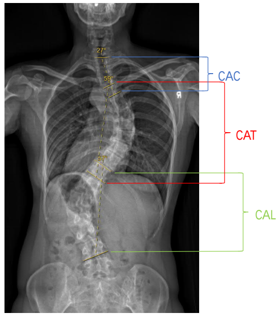
1. Log in AlignPro™ 2. Click on Upload Photo 3.1 Take a photo of X-ray 3.2 Take a photo of patient 4. Send to AI server

AlignPro™ Automated Alignment: Mobile app

A: Image acquisition



B: Cobb angles and landmarks



C: Clinical relevance of Cobb angles

CAs range	Severity and clinical managements
0°-20°	Normal - Mild
	No specific interventions required, but for cases with a curve between 10°-20°, follow-ups may be required for every two years.
21°-40°	Moderate
	Conservative management would be suggested, with no invasive procedures, including brace wearing and scoliosis specific exercises.
>41°	Severe
	Surgeries maybe required to correct the spine deformity

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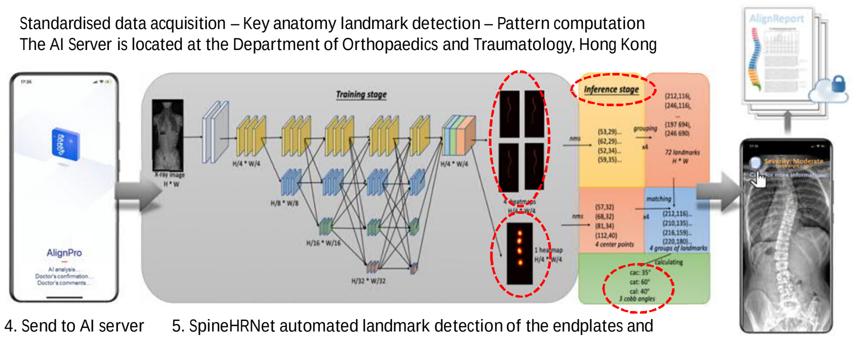
AlignPro™ Automated Alignment: Neural Network

Standardised data acquisition – Key anatomy landmark detection – Pattern computation
The AI Server is located at the Department of Orthopaedics and Traumatology, Hong Kong



4. Send to AI server for Auto-analysis

5. SpineHRNet automated landmark detection of the endplates and detection of the end vertebrae with the angles calculated during the inference stage

AlignPro™ Automated Alignment: training dataset

Figure 1: Frequency of each vertebra to be chosen as an end vertebra

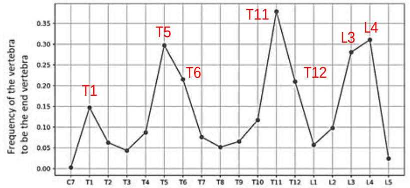


Figure 2: Number of curves as CAC, CAT or CAL

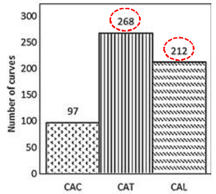
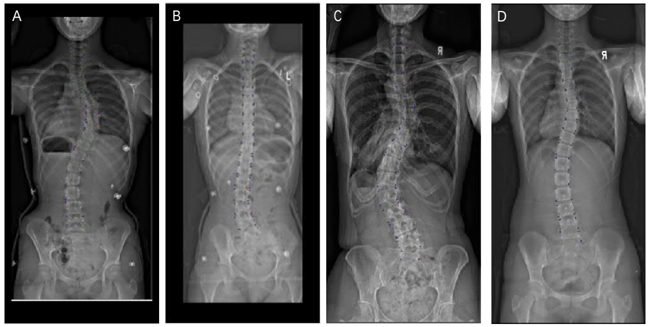


Table 1: Summary of the ground truth CAs

Curves	Number of curves	Min	Max	Average	Standard deviation
CAC	97	12.95°	67.77°	28.98°	12.78°
CAT	268	10.73°	82.48°	29.35°	14.45°
CAL	212	10.08°	75.16°	24.7°	11.66°
CA total	577	10.08°	82.48°	27.55°	13.41°

AlignPro™ Automated Alignment: landmarks detections

Green points = the ground truth (GT) landmarks   Blue points = the predicted landmarks
Red lines connecting predicted landmark and corresponding GT landmark



Retrieval rate
99± 0.9 %
L2 error
2.8 pixels

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AlignPro™ Automated Alignment: end vertebrae detections

Figure 1. Examples of end vertebrae detection

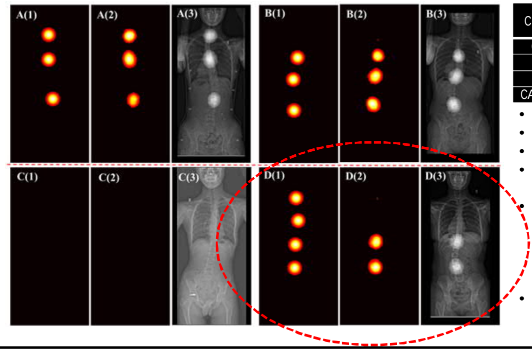

Table 1. Evaluation metrics on CA prediction

Curves	Recall	Precision	F1-score	Angle error	Standard deviation
CAC	0.62	0.78	0.69	4.09°	3.35°
CAT	0.88	0.88	0.88	4.48°	3.32°
CAL	0.83	0.80	0.82	3.73°	3.64°
CA total	0.82	0.83	0.83	4.15°	3.11°

- A: CAC and CAT
- B: CAT and CAL angle
- C: normal with no curves;
- D: CAC and CAT and CAL angle.

- For each part
  - (1) the ground truth heatmap
  - (2) predicted heatmap
  - (3) original image merged with predicted heatmap
- An interesting false negative in the cervicothoracic region was shown in D.

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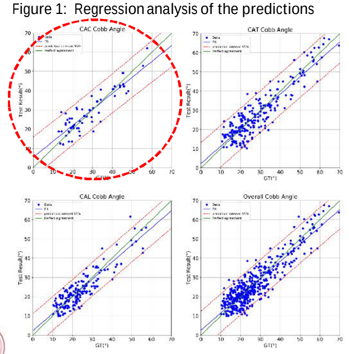
AlignPro™ Automated Alignment: reliability assessment

Figure 1: Regression analysis of the predictions



Curves	R²	p value	Slope of the regression line	Standard error of the measurement (S)
CAC	0.787	<0.01	38°	1.742°
CAT	0.832	<0.01	42°	0.856°
CAL	0.839	<0.01	42°	0.802°
CA total	0.833	<0.001	42°	0.558°

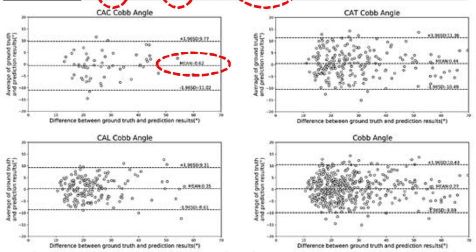


Figure 2: Bland-Altman comparing the agreement of CAs between the predictions & GT

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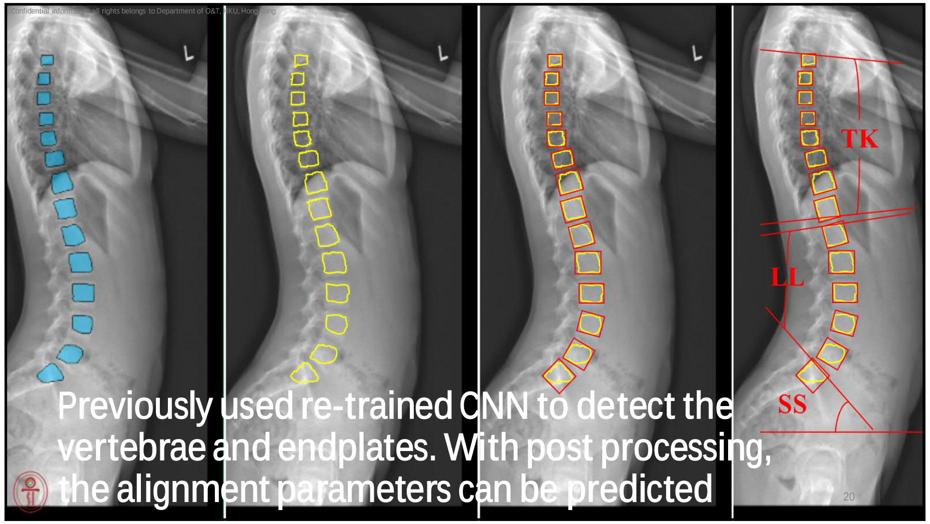

Previously used re-trained CNN to detect the vertebrae and endplates. With post processing, the alignment parameters can be predicted

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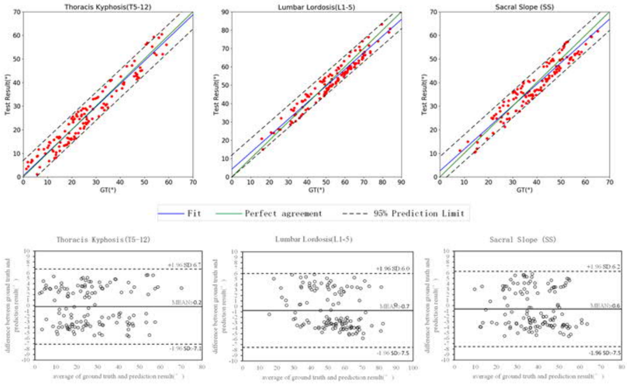
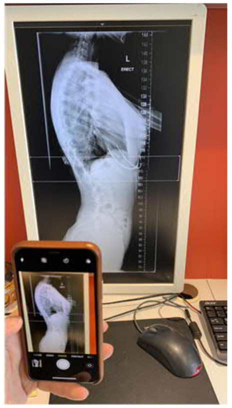
A

B





Results

1. Vertebrae segmentation accuracy
   i. Dice similarity coefficient (DSC)
   84.6 ± 3.8%
   ii. Mean intersection over union (mIoU)
   72.1 ± 4.8%

2. Alignment prediction accuracy
   i. Regression analysis - Figure A
   ii. Bland-Altman plots - Figure B

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doi: 10.1007/s00586-019-06264-y.

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Take home messages

Clinical relevance key points

1) AI powered Digital Health will be the future of healthcare

2) AlignPro^{TM} using our SpineHRNet enables fully automated alignment analysis with no limitations of the curve patterns using smartphones, providing consistent and fast alignment analysis results for large clinical trials and may facilitate out of hospital consultation.

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