**University Hospital Acibadem City Clinic**
**Sofia, Bulgaria**

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# Thermography AI saving limbs and lives

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Potential conflicts of interest:

**Speaker's name : Ivo Petrov**

- ☑ Minor shareholder
  - Kelvin Health
- Investigator honoraria
  - Medtronic
  - Contego
  - Cardiatis
  - Novonordisk
  - Amgen
- Speaking/proctoring Honoraria:
  - Medtronic
  - Contego
  - Cardiatis
  - Amgen
  - Astra Zeneca

EAPCI

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## CAD/PAD/COD relation

ESC
European Society of Cardiology



**Figure 1.** Multisite artery disease and ranges of other localization of atherosclerosis in patients with a specific arterial disease  LE-PAD = lower extremity peripheral arterial disease, CAD = coronary artery disease; COD = carotid occlusive disease (severe carotid artery stenosis ≥ 70%).

- PAD is a manifestation of systemic atherosclerosis disease.
- PAD patients have a poor prognosis with an increased risk of cardiovascular (CV) events including myocardial infarction (MI), stroke, limb ischemia and CV death
- PAD and coronary artery disease (CAD) share a common pathogenesis and risk factors for development;
- PAD and CAD also share some treatment goals, including an aggressive modification of risk factors to reduce the risk of CV events

https://doi.org/10.3390/jcm12134338

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**Under-recognition of PAD – WHY?**
**Pulse Palpation:**
**human (operator) dependent**

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Viborg Vascular Screening Trial

Population-based (18,681, 65-74 years)

Sensitivity 71.7%  specificity 72.3%

Exclusion of severe LEAD

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**Peripheral artery disease- global noninfectional pandemic**

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JAMA | US Preventive Services Task Force | RECOMMENDATION STATEMENT
Screening for Peripheral Artery Disease and Cardiovascular Disease Risk Assessment With the Ankle-Brachial Index
US Preventive Services Task Force Recommendation Statement

– The first-line method to diagnose PAD - ankle-brachial index (ABI), is not readily available in most clinics.

– Inaccurate in diabetics because medio-calcinosis

25% of patients with CAD had disease in other vascular beds

2- to 3-fold increase in risk of stroke

61% of patients with LEAD had disease in other vascular beds

4-fold increase in risk of fatal MI

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**What do we need to early recognize pts with PAD?**

A diagnostic/screening method, which is:

I.  Noninvasive, safe (No radiation, no contrast)

II. Quick and reliable

III. Non-operator dependent, no physical contact

IV. Cheap

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**What do we need to early recognize pts with PAD?**

(AI Thermography)

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Spotted Thrombophlebitis

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**Hippocrates (460-375 BCE) is quoted as saying:**

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*"...should one part of the body be colder or hotter than the other, disease is present in that part."*

➢ First data, about the implementation of infrared thermography (IRT) in the field of medicine goes back to 1940's.
➢ There was a decrease in interest, because of the unsatisfactory image quality, artefacts and non-developed softwares.
➢ In the last decade and especially with the emerging COVID-19 pandemic, IRT gained back its place.

**IRT imaging evaluates the surface temperature** (by detecting the amounts of radiation it produces), **internal and surface temperature correlates with the blood flow in the arterial system.**

Typical thermal images of a subject talking on a hand-held mobile phone – (b) after 15-min phone talk:



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**Brief History**

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Sir William Herschel (1738-1822)

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**Infrared Thermography (IRT)**

Both in iliofemoral and femoropopliteal segment , an IRT camera provided a **real time screening information** of the tissue perfusion, based on the skin surface temperature.

**Table I.** Clinical variables of eight patients undergoing endovascular or surgical revascularization

| Patient No. | Age, years | Rest pain | Foot ulcer | Interventions | Preoperative | Postoperative | IT postoperative improvement |
|---|---|---|---|---|---|---|---|
| 1 | 68 | + | – | SFA stenting and atherectomy | 0.34 | 0.5x | + |
| 2 | 72 | + | + | Femorotibial bypass | 0.25 | 0.64 | + |
| 3 | 59 | + | – | Femoropopliteal bypass | 0.34 | 0.64 | + |
| 4 | 61 | + | + | SFA stenting and atherectomy | 0.41 | 0.53 | + |
| 5 | 73 | + | + | Iliac and SFA stenting | 0.37 | 0.65 | + |
| 6 | 74 | + | + | Femoropopliteal bypass | 0.45 | 0.67 | + |
| 7 | 68 | + | + | SFA stenting and atherectomy | 0.35 | 0.76 | + |
| 8 | 82 | + | + | Iliac and SFA stenting | 0.27 | 0.56 | + |

*IT, Infrared thermography. SFA, superficial femoral artery.*
*All patients showed improvement of ankle-brachial index and infrared thermographic tissue perfusion after interventions*

Corresponding improvement in ankle-brachial indices and thermal imaging after interventions up to the 7th month post procedurally.

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Lin PH, Saines M. Assessment of lower extremity ischemia using smartphone thermographic imaging. J Vasc Surg Cases Innov Tech. 2017;3(4):205-208. Published 2017 Oct 14. doi:10.1016/j.jvscit.2016.10.012

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**IRT as a screening method in patients with Diabetes**

•  Patients with DM (n = 118) and healthy controls (n = 93)
•  **ABI** and **IRT** at five foot areas

Cold (blue) to hot (red) temperatures

(a) The five areas measured are shown (circles) on the (left) plantar and (right) dorsal sides of foot (patient in the healthy control group).

(b) Patient with diabetes with bilateral neuropathy and mottled colorations, showing critically ischemia in the first toe on the right side (white arrows).

(c) Patient with diabetes with acute inflammation of Charcot neuroarthropathy on the right side (black arrows).

(d) Patient with diabetes with bilateral peripheral angiopathy, which is worse on the left side (red arrows) **ABI: 0.93 right/0.79 left**



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. Infrared Thermography and Vascular Disorders in ...s Sci Technol. 2020 Jan;14(1):28-36

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Diagnostics as simple as taking a thermal image

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1  Mobile Thermocamera

2  Thermal Segmentation

3  Automated AI Analysis

4  Notifying The specialist

## AI analysis via Deep Neural Networks

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**Input**
Thermal Images

**Processing via Deep Neural Networks**
Trained on medically annotated samples

**Output**
"ABI" Thermal Index

Novel Convolutional Neural Network for Thermal Images

Novel Convolutional Neural Network for Thermal Images

Aggregation Layer

Spatio-Temporal Prediction

| AT | PT | PER |
|----|----|-----|
| 0.6 | 0.5 | 0.7 |

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## Renowned (vascular) specialists around the world are excited

"I would 100% use this over ABIs any day of the week if it's that more sensitive and it seems just pretty simple."
— Emergency physician, California
20+ years experience;
2+ years as an ER Chief, EMS fellow

"Every podiatrist should have one of these, and ideally primary care."
— Interventional Cardiologist, California
40+ years experience;
10+ years as a Cardiac Cath Lab Director

"... quick and objective tool for immediate diagnosis and repeatable post-interventional follow-up..."
— Dr. Amar Pattani
Medical Doctor & Researcher, Nottingham University Hospital NHS Trust

"... one of the most important tools for a vascular specialist..."
— Prof. Ivo Petrov
Head of Cardiology & Angiology

"... very useful to assist the rapid diagnosis of our peripheral patients and the evaluation of stroke and carotid interventions..."
— Dr. Alejandro Alvarez
Interventional Cardiology
Hemodinamia del Sur

"... very promising in the field of PAD and especially in the perioperative evaluation of a revascularization procedure..."
— Prof. Theodosios Bisdas
Head, Clinic of Advanced Endovascular Services, Athens Medical Center

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## Kelvin Health's comparison to the gold standard of PAD & CLI diagnostics

BLOOD FLOW BLOCKED AT THE KNEE LINE

"Kelvin Health reflects very well the CLI condition of the patient and its localities, confirmed with angiography."

— Prof. Ivo Petrov
Head of Cardiology & Angiology
Acibadem "City Clinic" Cardio

- ✓ 2 600+ patients
- ✓ 12 000+ thermograms
- ✓ 100% sensitivity
- ✓ 96% specificity

X-RAY ANGIOGRAPHY
3 HOURS / $4,000+
INVASIVE / RADIATION

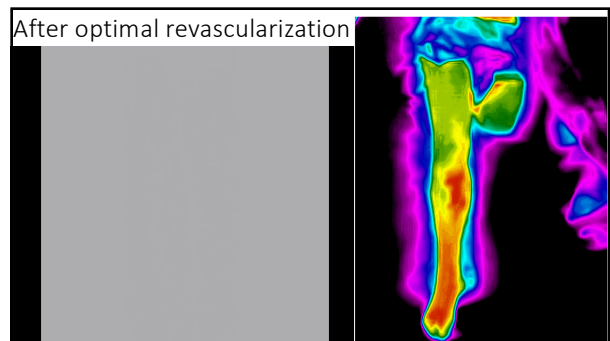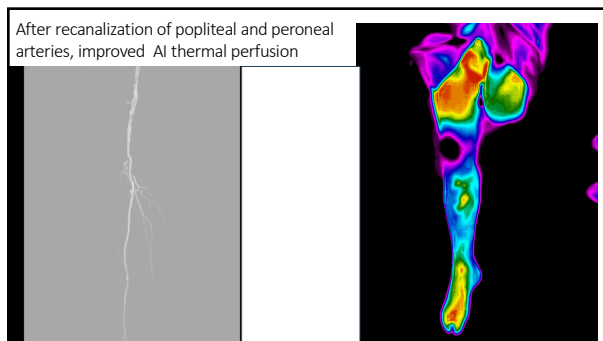3 MINUTES / $50
NON-INVASIVE / NO RADIATION

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* based on a ML model trained on a dataset of 253 medically and technically annotated angiograms of 42 patients

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## Our experience (n=442)

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**Baseline Characteristics:**

| Variable | | N | % |
|----------|------|----|-----|
| Sex | Male | 33 | 78,6 |
| | Female | 9 | 21,4 |
| Type 2 Diabetes | No | 19 | 45,2 |
| | Yes | 23 | 54,8 |
| Arterial Hypertension | No | 1 | 2,4 |
| | Yes | 41 | 97,6 |
| Smoker | No | 10 | 23,8 |
| | Yes | 29 | 69,0 |
| | Prior | 3 | 7,1 |
| IHD | No | 13 | 31,0 |
| | Yes | 29 | 69,0 |
| Prior intervention | No | 15 | 35,7 |
| | Yes | 27 | 64,3 |
| CKD | No | 30 | 71,4 |
| | Yes | 12 | 28,6 |
| PAD | Stenosis | 7 | 16,7 |
| | Thrombosis | 10 | 23,8 |
| | Both | 25 | 59,5 |
| | II-a | 20 | 47,6 |
| | II | 17 | 40,5 |
| | IV | 5 | 11,9 |

**Doppler:**

| Doppler | | Doppler-1 | | Doppler-2 | |
|---------|-----|----|-----|----|-----|
| | | N | % | N | % |
| CIA | Не | 26 | 61,9 | 0 | 0,0 |
| | Да | 16 | 38,1 | 42 | 100,0 |
| AIE | Не | 30 | 71,4 | 0 | 0,0 |
| | Да | 12 | 28,6 | 42 | 100,0 |
| AFC | Не | 35 | 83,3 | 0 | 0,0 |
| | Да | 7 | 16,7 | 42 | 100,0 |
| AFS | Не | 7 | 16,7 | 1 | 2,4 |
| | Да | 35 | 83,3 | 41 | 97,6 |
| AP | Не | 28 | 66,7 | 3 | 7,1 |
| | Да | 14 | 33,3 | 39 | 92,9 |
| ATA | Не | 18 | 42,9 | 20 | 47,6 |
| | Да | 24 | 57,1 | 22 | 52,4 |
| A. Peronea | Не | 24 | 57,1 | 12 | 28,6 |
| | Да | 18 | 42,9 | 30 | 71,4 |
| ATP | Не | 19 | 45,2 | 16 | |
| | Да | | | | |

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## Sensitivity and specificity

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**Thermography vs Doppler**

| | Statistic | Value | 95% CI |
|------|-----------|-------|--------|
| AFS | Sensitivity | 88.24% | 63.56% to 98.54% |
| | Specificity | 33.33% | 84% to 90.57% |
| AP | Sensitivity | 72.73% | 39.03% to 93.98% |
| | Specificity | 36.84% | 16.29% to 61.64% |
| ATP | Sensitivity | 81.25% | 54.35% to 95.95% |
| | Specificity | 83.3% | 0.21% to 38.48% |
| ATA | Sensitivity | 80.95% | 58.09% to 94.55% |
| | Specificity | 71.4% | 0.18% to 33.87% |

**Thermography vs Angio**

| | Statistic | Value | 95% CI |
|------|-----------|-------|--------|
| AFS | Sensitivity | 85.71% | 42.13% to 99.64% |
| | Specificity | 75.38% | 1.92% to 45.45% |
| AP | Sensitivity | 66.67% | 34.89% to 90.08% |
| | Specificity | 65.29% | 14.21% to 61.67% |
| ATP | Sensitivity | 100.00% | 73.54% to 100.00% |
| | Specificity | 85.00% | 7.27% to 52.38% |
| ATA | Sensitivity | 89.47% | 66.86% to 98.70% |
| | Specificity | 88.75% | 4.05% to 45.65% |

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## Our scientific publications & scientific conferences presentations

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## What is the underlying condition?



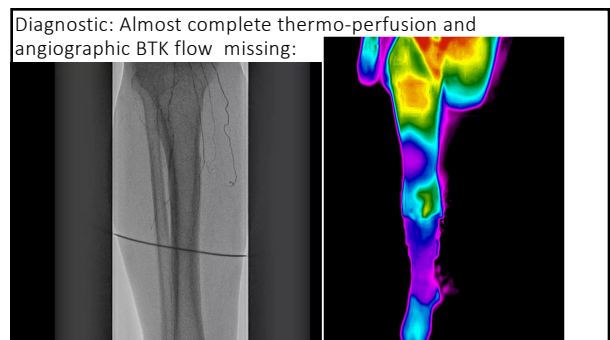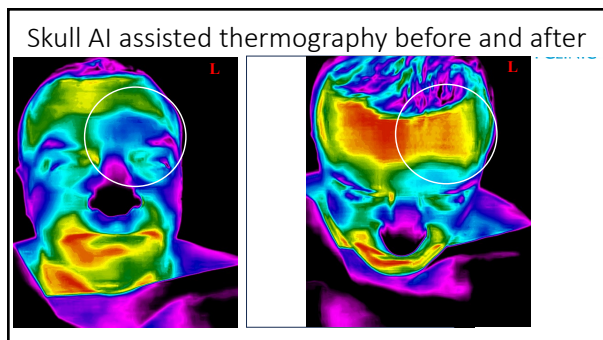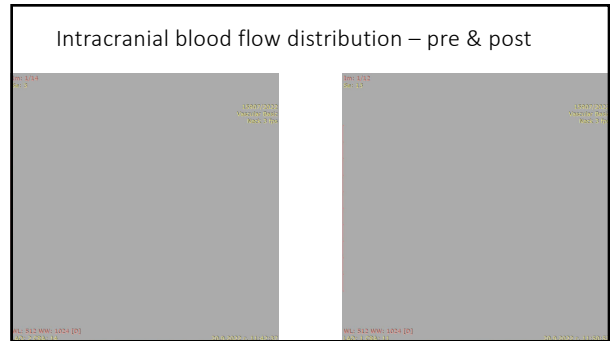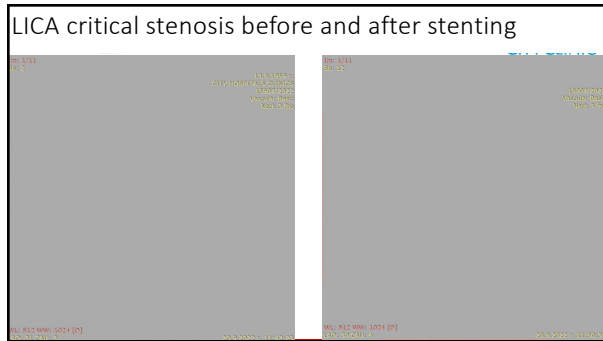### Leriche syndrome detected by IRT



## Case presentation

- Male patient, 75-year-old with complex risk profile
  smoking, dyslipidemia, diabetes and family history.
- After TEA of left CFM, and amputation of left lower extremity.
- Presenting in IV stage (Rutherford) extreme right lower leg ischemia (pain at rest)

### Diagnostic: Almost complete thermo-perfusion and angiographic BTK flow missing:



After recanalization of popliteal and peroneal arteries, improved AI thermal perfusion



## After optimal revascularization

## LICA critical stenosis before and after stenting



## Intracranial blood flow distribution – pre & post



## Skull AI assisted thermography before and after



## AI assisted infrared thermography.
## Take home messages

- Thermal imaging for vascular disease screening carries numerous benefits:
1. **Non-Invasive**:
2. **Radiation-Free**. Given the fact no harmful energy is used, this method is suitable for repeated monitoring over time.
3. **Time-saving**: Thermal images can be produced and interpreted almost immediately. It saves precious time for both specialists and patients.
4. **Detecting Early Changes**, enabling early detection, intervention and follow-up.