Hemoglobin A1C Accuracy Report of SDK 5.9.1

Executive Summary

Goal

This document assesses the accuracy of Hba1c evaluations in SDK 5.9 [iOS and Android] rPPG by comparing them with invasive blood test results, using data collected from India and Italy.

Results

- The Hba1c measured by Binah's SDK was found to be **within the accuracy target (±1.1 g/dl) in 73.3%** of the measurements for iOS and Android and the following confounding factors (see appendix):
  - Both female and male
  - All skin tones (Fitzpatrick I to VI)
  - Ages 18 to 81
  - BMI from light to morbid obesity
  - Distances close and far from the face
  - Luminance from dark to brighter surroundings
  - Similar performance on all devices used for recordings
  - Similar performance in several countries with different ethnicities

Conclusions

This report describes the results of accuracy studies conducted in India and Italy. Binah.ai's SDK 5.9 Hba1c evaluations were correlated with regular blood test results for both iOS and Android operating systems. The correlation factor was r=0.462 and 73.3% of the measurements for both operating systems were within the target error range.

Introduction

Glycated hemoglobin (HbA1c) is a biomarker used to assess long-term blood glucose control. It forms when glucose in the bloodstream binds irreversibly to hemoglobin in red blood cells. Since red blood cells have an average lifespan of approximately 120 days, HbA1c reflects the average blood glucose concentration over the preceding two to three months.[1,2]

HbA1c is commonly measured using a blood test and is expressed as a percentage. Normal HbA1c levels are typically below 5.7%, while levels between 5.7% and 6.4% indicate prediabetes, and levels of 6.5% or higher suggest diabetes.[3,4] Elevated HbA1c levels are associated with an increased risk of diabetes-related complications, including cardiovascular disease, neuropathy, nephropathy, and retinopathy.[5,6]

Currently, HbA1c assessment requires an invasive blood test. Replacing this method with a non-invasive, cost-effective, and remote alternative would greatly enhance accessibility, affordability, and usability.

Photoplethysmography (PPG) is a non-invasive, simple, and cost-effective optical technique that detects blood volume changes in the microvascular bed of tissue. The PPG waveform comprises a pulsatile ("AC") component, corresponding to cardiac-synchronous blood volume changes with each heartbeat, superimposed on a slowly varying ("DC") baseline influenced by factors such as respiration, sympathetic nervous system activity, and thermoregulation. PPG technology has been widely implemented in various medical devices to measure oxygen saturation, blood pressure, cardiac output, and autonomic function.[7] Hba1c can also be evaluated by devices using PPG technology.

Camera-based approaches make it possible to derive remote PPG (rPPG) signals, and therefore might enable a remote and non-invasive measurement of blood parameters. Binah.ai's Hba1c algorithm uses the rPPG signal recorded from facial skin tissue. The algorithm extracts face video images, produces an rPPG signal, analyzes the data using AI, and provides the end user with a Hba1c measurement in real-time.

This report describes the results of accuracy studies conducted in Israel, India, South Africa, Nepal, and Italy that compare Binah.ai's Hba1c evaluations with the results of regular, invasive blood tests.

Methods

Binah.ai's Hba1c measurements were compared to the Hba1c values received in regular blood tests of all subjects.

Measurement set-up:

In all sites, each participant was instructed to sit as stable as possible. Recordings were conducted in a testing room, with controlled and fixed artificial ambient light.

For rPPG measurements, a mobile device was placed on a stand in front of the participant. The participant's face filled most of the frame's area (distance of about 20-40 cm) and was positioned in the center of the frame. The camera was set at the forehead's level and perpendicular to the face.
Participants were instructed to look at the screen throughout the recording.
Participants were instructed to take off their glasses and to avoid any movement, including talking, and were required to sit still with their feet flat on the floor. Each recording lasted 60 seconds.

Blood tests were conducted as close as possible to the rPPG measurement to minimize timing discrepancies.

Statistical analysis:

Accuracy was calculated using the following parameters:

$$AE\ (Absolute\ Error) = App_i - Ref_i$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (App_i - Ref_i)^2}{N}}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |App_i - Ref_i|$$

When,
N is the number of data points.
App is the measurement of the Binah.ai's application.
Ref is the reference results.
i is the index number of measurements.

For this report, Binah.ai's **SDK 5.9** was compared to invasive blood test results.
The measurements were recorded in several locations in India and Italy using the mobile device models listed below:

iOS: iPhone 13 Pro, iPhone 13 Pro Max, iPhone 14, iPhone 14 Pro max, iPhone 14 Plus.
Android: Samsung S21 Ultra, Samsung S23 Ultra, Pixel 6 Pro, Google pixel 8a, Xiaomi 14 CIVI.

Results

Measurement disposition

Number of subjects/measurements with reported HbA1c: 296/537

Number of Unique Subjects and Measurements by country and Hba1c distribution

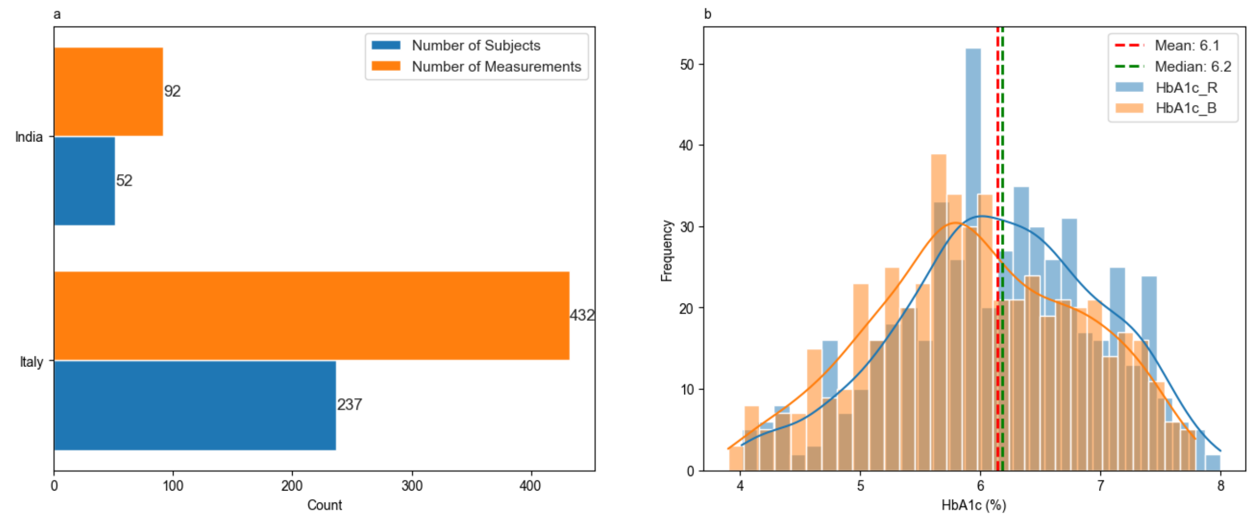

Figure 1:
a. **Number of Unique Subjects and Measurements (with reference values) for each country.**
b. **Distribution of Hba1c measured by reference device and Binah.ai's application.** The mean and median lines are calculated for the reference values.

Demographics Data:

Subjects/Measurements	Age (mean ± std)	BMI (mean ± std)	Sex (F/M)	
289/ 524	59.0 ± 12.8	27.7 ± 5.2	141 / 148	
Fitzpatrick Skin Tone (I/II/III/IV/V/VI)	Beard (No/Yes)	Glasses (No/Yes)	Face cream (No/Yes)	
15 / 159 / 73 / 24 / 14 / 4	213 / 76	205 / 84	234 / 55	
Distance (mean ± std)	Luminance (mean ± std)	Angle yaw (mean ± std)	Angle roll (mean ± std)	Angle pitch (mean ± std)
0.25 ± 0.04	154.5 ± 88.8	5.2 ± 4.0	2.3 ± 1.8	5.7 ± 4.7

Table 1: Demographic data for experiments using Binah.ai application.
* Fitzpatrick skin tone classifications are I- Pale white, II- white, III- Darker white, IV- Light brown, V- Brown, VI- Dark brown or black. ** Skin tone, beard, glasses, and face cream information does not exist for all subjects

Accuracy Data:

OS	Unique Subjects	Measurements	MAE±std	Ref Range
iOS	258	258	0.8 ± 0.5	4.0 - 8.0
Android	265	266	0.7 ± 0.5	4.0 - 8.0

Table 2: Accuracy data (MAE±std) when Binah.ai's and the reference device's measurements are compared in the presented Hba1c range (Ref range).
MAE - Mean Absolute Error, std - Standard Deviation

Correlation and Bland-Altman plots

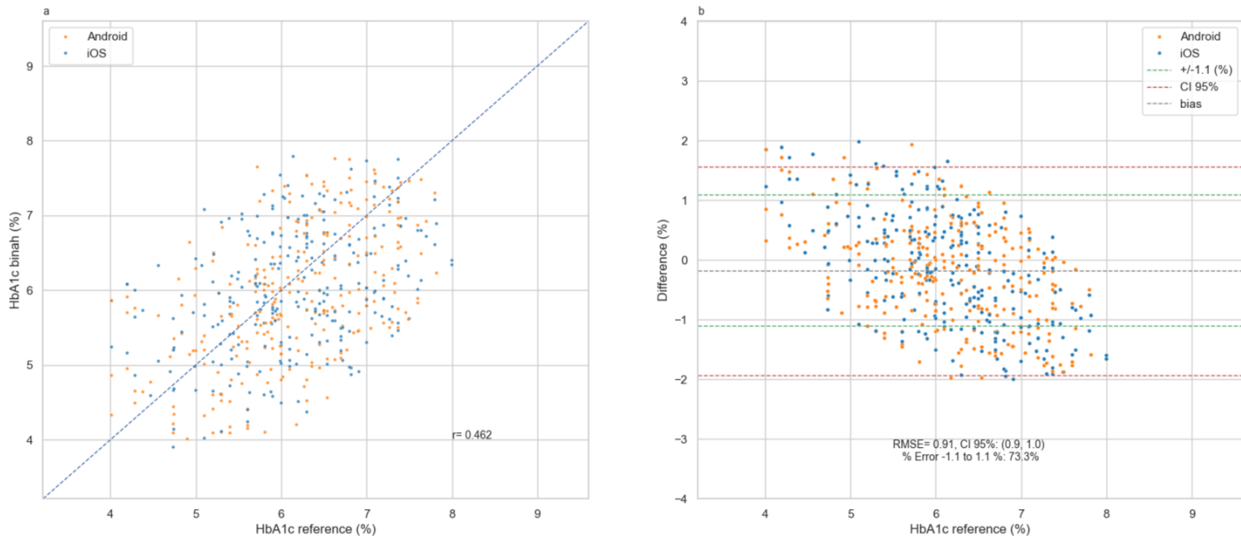

Figure 2:
a. Correlation plot by operating system - Binah.ai’s Hba1c estimations versus invasive blood test results were found to be correlated with an r=0.462 for both operating systems (Android and iOS).
b. **Bland-Altman plot by operating system** - Comparison between Hba1c measurements of the two methods (Binah.ai and the blood test results) in the presented reference range.

The “Bias” gray dashed line stands for the mean difference between measurements of Binah.ai and the blood tests results, the “Error” green dashed lines of ±1.1% represent the value of the accuracy criterion, the “Limits of agreement” red dashed lines mark the limit of 95% of the samples

Conclusions:

This report describes the results of accuracy studies conducted in India and Italy. Binah.ai's Hba1c evaluations were correlated with regular blood test results for both iOS and Android operating systems. The correlation factor was r=0.462 and 73.3% of the measurements for both operating systems are within the target error range.

References:

1. Selvin E, Steffes MW, Zhu H, et al. Glycated hemoglobin, diabetes, and cardiovascular risk in nondiabetic adults. N Engl J Med. 2010;362(9):800-811.
2. Nathan DM, Turgeon H, Regan S. Relationship between glycated hemoglobin levels and mean glucose levels over time. Diabetologia. 2007;50(11):2239-2244.
3. American Diabetes Association. Classification and diagnosis of diabetes: Standards of Medical Care in Diabetes—2023. Diabetes Care. 2023;46(Suppl 1):S19-S40.
4. World Health Organization. Use of glycated hemoglobin (HbA1c) in the diagnosis of diabetes mellitus. Diabetes Res Clin Pract. 2011;93(3):299-309.
5. Stratton IM, Adler AI, Neil HA, et al. Association of glycemia with macrovascular and microvascular complications of diabetes (UKPDS 35). BMJ. 2000;321(7258):405-412.
6. Skyler JS, Bergenstal R, Bonow RO, et al. Intensive glycemic control and the prevention of cardiovascular events: implications of the ACCORD, ADVANCE, and VA diabetes trials. Circulation. 2009;119(2):351-357.
7. Allen J. Photoplethysmography and its application in clinical physiological measurement. *Physiol Meas.* 2007;28(3):R1-R39.

Appendix

Hba1c error by Age and BMI

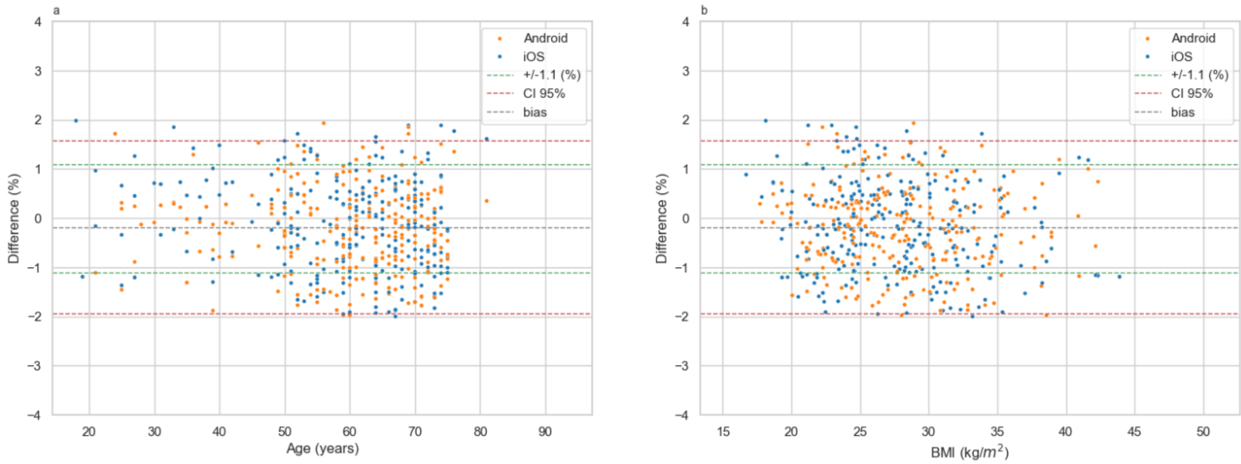

Figure 4:

a. **Bland-Altman plot by age** - Comparison between Hba1c measurements obtained by Binah.ai and the reference device for both operating systems (Android and iOS) within the presented age range.

b**. Bland-Altman plot by BMI -** Comparison between Hba1c measurements obtained by Binah.ai and the reference device for both operating systems (Android and iOS) within the presented BMI range.

The "Bias" gray dashed line stands for the mean difference between measurements of Binah.ai and the blood tests results, the "Error" green dashed lines of ±1.1% represent the value of the accuracy criterion, the "Limits of agreement" red dashed lines mark the limit of 95% of the samples

Hba1c error by skin tone with Gender and OS

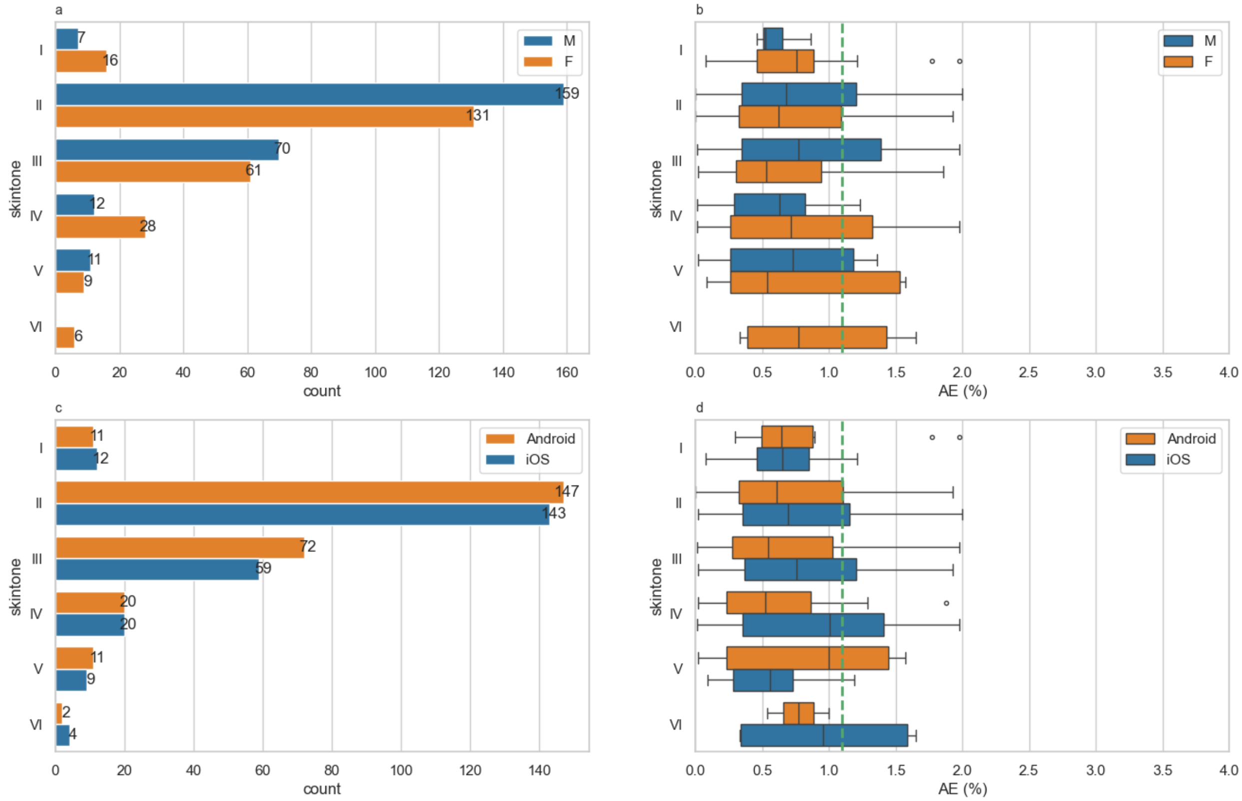

Figure 5:
a. **Number of measurements by Fitzpatrick skin tone and sex** (female and male).
b. **Box plot by Fitzpatrick skin tone and Sex** – Hba1c measurements obtained by Binah.ai versus the reference device for both sexes (female and male) across all presented skin tones.

The green dashed “Error” lines set at 1.1% represents the value of the accuracy criterion’s value.

c. **Number of measurements by Fitzpatrick skin tone and operating system** (Android and iOS).
d. **Box plot by Fitzpatrick skin tone and operating system** - Hba1c measurements obtained by Binah.ai versus the reference device presented by OS (Android and iOS) across all skin tones.

The green dashed “Error” lines set at 1.1% represents the value of the accuracy criterion’s value.

Hba1c error by distance and luminance

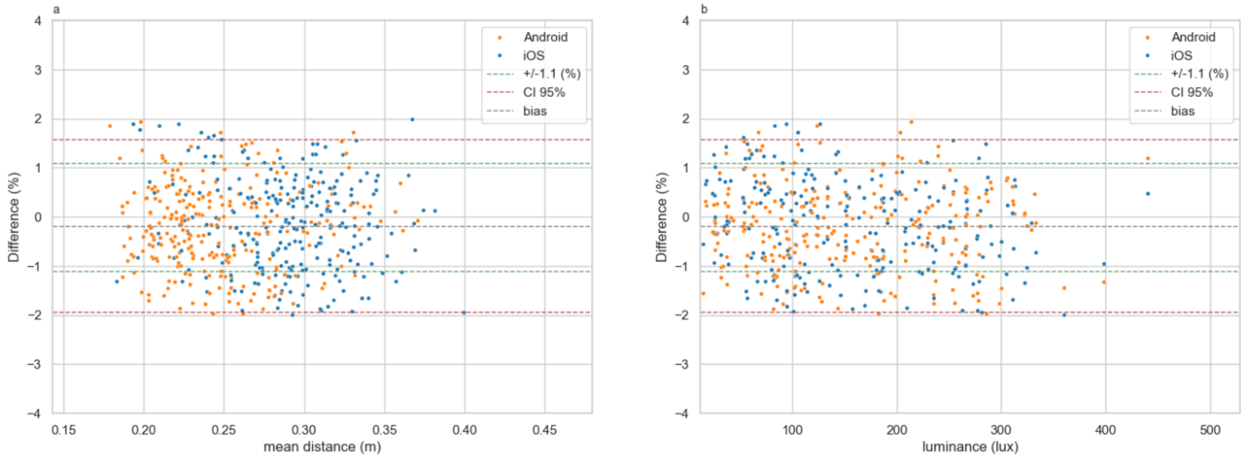

Figure 6:
a. **Bland-Altman plot by distance (m)** - Comparison between Hba1c measurements obtained by Binah.ai and the reference device for both operating systems (Android and iOS) within the presented distance range.
b**. Bland-Altman plot by luminance (lux)** - Comparison between Hba1c measurements obtained by Binah.ai and the reference device for both operating systems (Android and iOS) within the presented luminance range.

The "Bias" gray dashed line stands for the mean difference between measurements of Binah.ai and the blood tests results, the "Error" green dashed lines of ±1.1% represent the value of the accuracy criterion, the "Limits of agreement" red dashed lines mark the limit of 95% of the samples

Hba1c error by face Angles

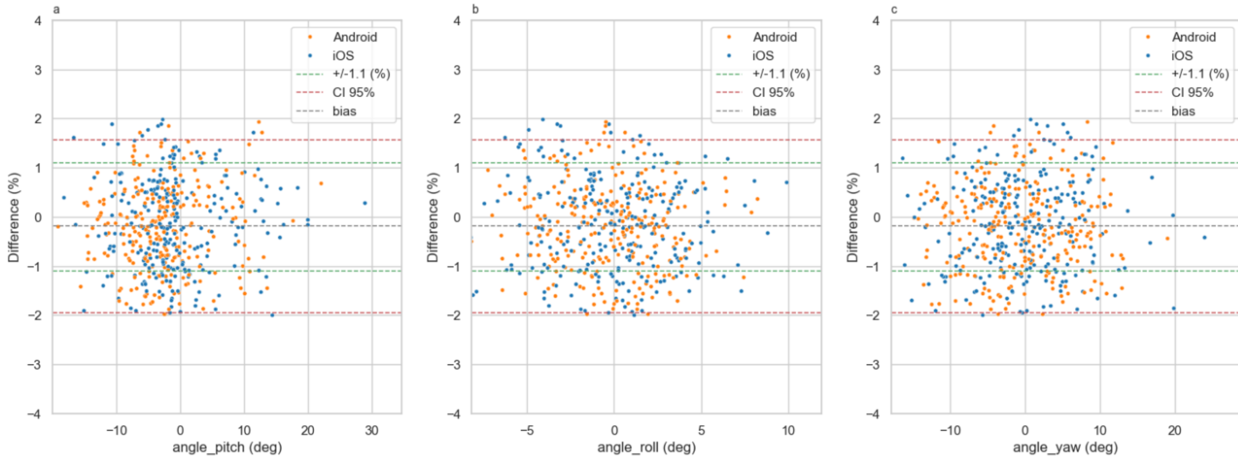

Figure 7:
a. **Bland-Altman plot by pitch angle (deg)** - Comparison between Hba1c measurements obtained by Binah.ai and the reference device for both operating systems (Android and iOS) within the presented pitch angle range.
b. **Bland-Altman plot by roll angle (deg)** - Comparison between Hba1c measurements obtained by Binah.ai and the reference device for both operating systems (Android and iOS) within the presented roll angle range.
c**. Bland-Altman plot by yaw angle (deg)** - Comparison between v measurements obtained by Binah.ai and the reference device for both operating systems (Android and iOS) within the presented yaw angle range.

The "Bias" gray dashed line stands for the mean difference between measurements of Binah.ai and the blood tests results, the "Error" green dashed lines of ±1.1% represent the value of the accuracy criterion, the "Limits of agreement" red dashed lines mark the limit of 95% of the samples

Boxplot of Hba1c error by Mobile device models

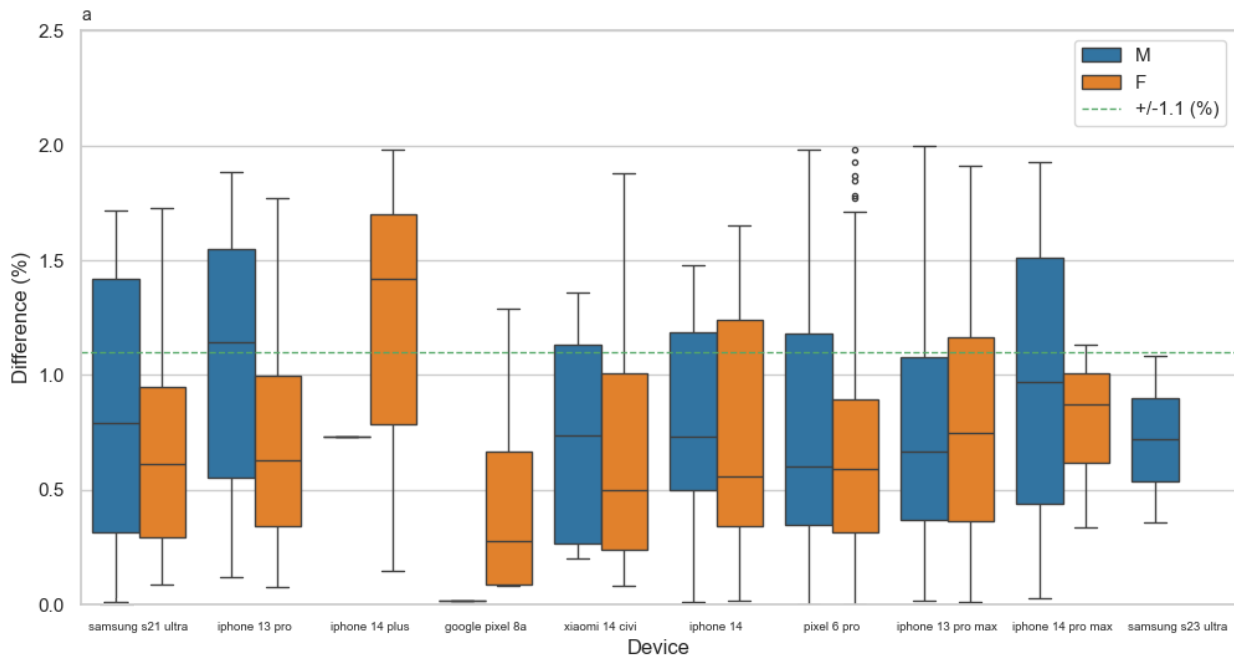

Figure 11:

Error by Mobile device models – Hba1c measurements obtained by Binah.ai versus the reference device for both sexes (female and male) presented by mobile device models.

The green dashed "Error" line set at 1.1%

Boxplot of Hba1c error by Country by OS

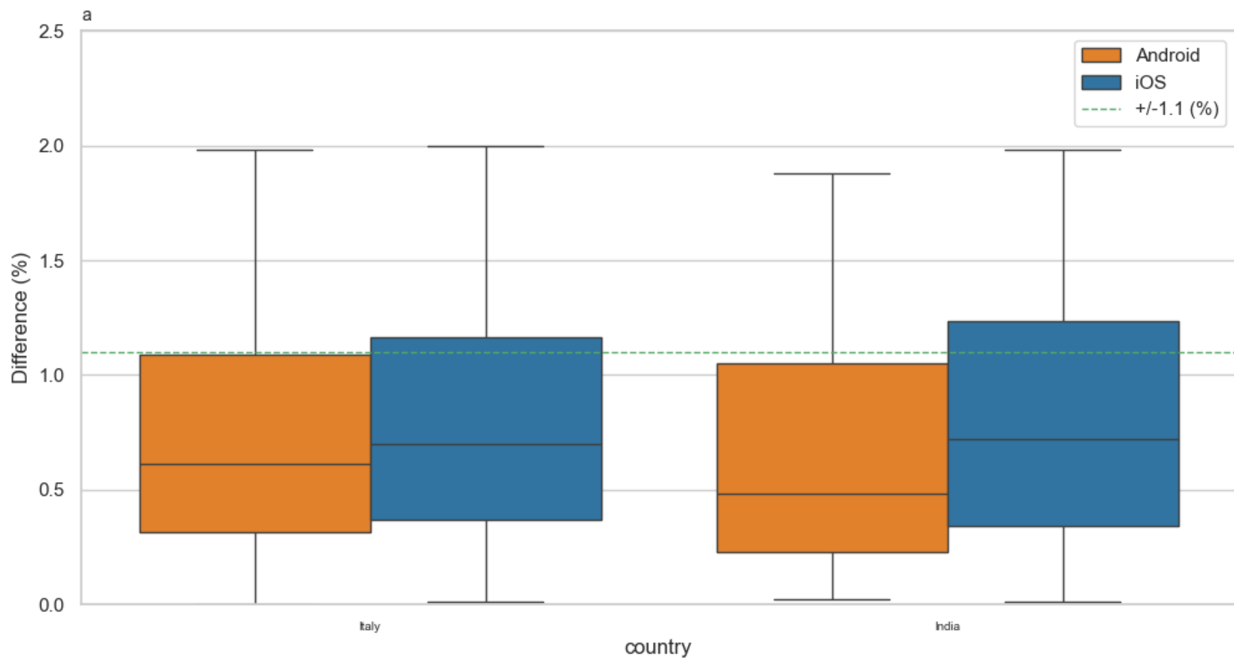

Figure 12:
Error by country – Hba1c measurements obtained by Binah.ai versus the reference device for both operating systems (Android and iOS).
The green dashed “Error” line set at 1.1%