



Final Report

Evaluating system accuracy of blood glucose monitoring systems for self-testing in managing diabetes mellitus [following ISO 15197]

GlucoCheck Excellent

Project code IDT-1239-AA

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Table of contents

1 Introduction6

2 Material and Methods7

 2.1 Study objective7

 2.2 Inclusion criteria7

 2.3 Exclusion criteria (shortened list)7

 2.4 Study duration per subject7

 2.5 Screening.....7

 2.6 Study devices8

 2.6.1 GlucoCheck Excellent8

 2.6.2 YSI 2300 STAT PLUS10

 2.6.3 Cobas c11110

 2.6.4 OPTI CCA-TS11

 2.6.5 Maintenance, adjustment, control procedures11

 2.7 Control measurements with blood glucose monitoring systems11

 2.8 Determination of hematocrit11

 2.9 Experiment.....12

 2.9.1 Requirements according to EN ISO 15197:200312

 2.9.2 Additional exclusion criteria for samples.....13

 2.9.3 Determination of glucose concentration - sample preparation14

 2.9.4 Determination of glucose concentration - measurement procedure.....14

 2.10 Data analyses15

 2.10.1 Analysis of system accuracy according to EN ISO 15197:2003 [1].....15

 2.10.2 Analysis of system accuracy applying performance criteria defined by ISO 15197:2013 [2]15

3 Results16

 3.1 Time span of experiments16

 3.2 Study subjects16

 3.3 Equipment failures16

 3.4 Adverse Events.....16

 3.5 Samples.....17

 3.6 System accuracy analysis versus YSI 2300 STAT PLUS.....18

 3.6.1 Summary of system accuracy analysis following EN ISO 15197:200318

 3.6.2 Summary of system accuracy analysis applying performance criteria defined by ISO 15197:201319

 3.7 System accuracy analysis versus Cobas c11119



Final Report GlucoCheck Excellent

Dokument 1239-AA_FinalReport_Excellent_1_V_130717.doc
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4	Summary and Conclusions.....	20
	References.....	21
	Signatures.....	22
	Appendix.....	23

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1 Introduction

Main objective of modern diabetes therapy is to achieve near normal blood glucose levels in order to prevent late damages. Self monitoring devices allow for metabolic control by patients and doctors and for a flexible therapy adjustment by the patient himself. As insulin therapy is controlled by the measured values high-quality blood glucose monitoring systems (BGMS) are required.

EN ISO 15197:2003 [1] is an international standard specifying requirements for in vitro glucose monitoring systems for self-testing in managing diabetes mellitus.

The minimum acceptable accuracy for results produced by a glucose monitoring system shall be as follows: Ninety-five percent (95%) of the individual glucose results shall fall within ± 0.83 mmol/l (15 mg/dl) of the results of the manufacturer`s measurement procedure at glucose concentrations < 4.2 mmol/l (< 75 mg/dl) and within $\pm 20\%$ at glucose concentrations ≥ 4.2 mmol/l (≥ 75 mg/dl).

The International Standard ISO 15197:2013 [2] is a revision of EN ISO 15197:2003 [1]. The minimum acceptable accuracy for results produced by a glucose monitoring system shall be as follows: 95% of the measured glucose values shall fall within either ± 0.83 mmol/l (± 15 mg/dl) of the average measured values of the reference measurement procedure at glucose concentrations < 5.55 mmol/l (< 100 mg/dl) and within $\pm 15\%$ at glucose concentrations ≥ 5.55 mmol/l (≥ 100 mg/dl). Moreover at least 99% of individual glucose measured values shall fall within zones A and B of the Consensus Error Grid for type 1 diabetes [3].

In this study system accuracy evaluation according to EN ISO 15197:2003 was performed for the investigated system GlucoCheck Excellent. In addition data were analyzed applying performance criteria defined by ISO 15197:2013.

2 Material and Methods

2.1 Study objective

The aim of this study was to collect measurement data from capillary blood with defined distribution of glucose concentrations in order to perform system accuracy evaluation according to EN ISO 15197:2003 for GlucoCheck Excellent. In addition data were analyzed applying performance criteria defined by ISO 15197:2013. The comparison measurements were performed on YSI 2300 STAT PLUS. Measurements on Cobas c111 were used for an additional evaluation.

2.2 Inclusion criteria

- Male or female subjects with diabetes type 1 or 2 or subjects without diabetes
- For provoked blood glucose excursions: male or female subjects with diabetes type 1 or 2 and intensified conventional insulin therapy or insulin pump
- Written informed consent
- Minimum age of 18 years
- With legal capacity and able to understand nature, meaning and consequences of the clinical trial

2.3 Exclusion criteria (shortened list)

- Pregnancy or lactation period
- Severe acute disease or chronic disease with potential risk during the trial
- Current constitution of the subject which does not allow to take part in the study
- Legal incompetence or accommodated in an institution
- Language barriers precluding adequate compliance with the study procedures
- Dependency from the sponsor or the clinical investigator

2.4 Study duration per subject

- Up to 3 hours

2.5 Screening

- Information about the study (aims, procedures, risks, duration)
- Written informed consent
- Anamnesis, physical examination and urine pregnancy test (if applicable)

2.6 Study devices

2.6.1 GlucoCheck Excellent

Manufacturer: aktivmed GmbH
 Prinzregentenplatz 1
 86150 Augsburg

▪ *Technical specifications*

Blood sample:	Capillary blood
Sample volume:	0.5 µl
Measuring range:	10 - 600 mg/dl (0.6 – 33.3 mmol/l)
Analysis time:	5 sec
Operating temperature:	10 - 40°C
Operating humidity:	10 - 90%
Hematocrit range:	20 - 60%
Measurement technology:	Glucose oxidase
Calibration:	Plasma equivalent
Coding:	Autocoding

▪ *Meters, test strips, control solutions*

GlucoCheck Excellent	
Serial number	Study code
G28C13B1907389	<i>B1</i>
G28C13B1907385	<i>B2</i>
G28C13B1907388	<i>B3 (backup)</i>
G28C13B1907387	<i>not used</i>
G28C13B1907386	<i>not used</i>

GlucoCheck Excellent Blutzuckerteststreifen		
Lot	Lot number	Expiry
1	S5VC13B07	2015/02
2	S5VC13B14	2015/02
3	S4VC13A21	2015/01

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Control solution	Lot number	Expiry	Target range [mg/dl]
GlucoCheck Excellent Kontrolllösung	CL9NB14	2015/02	Lot 1: 19 - 49 Lot 2: 72 - 108 Lot 3: 209 - 283
GlucoCheck Excellent Kontrolllösung	CN9NB25	2015/02	Lot 1: 19 - 49 Lot 2: 72 - 108 Lot 3: 209 - 283
GlucoCheck Excellent Kontrolllösung	CH9NB19	2015/02	Lot 1: 19 - 49 Lot 2: 72 - 108 Lot 3: 209 - 283

2.6.2 YSI 2300 STAT PLUS

- Manufacturer: YSI Incorporated, Yellow Springs, Ohio, USA
- Method / chemistry: Glucose oxidase (GOD-H₂O₂)
- Sample: capillary plasma
- Certificate of interlaboratory comparison is available
- Double test = measurement with 2 electrodes

Trueness and precision

- Trueness was assessed according to CLSI EP15-A2 [4] by assaying Bioanalytical Standards (Glucose), YSI Incorporated, Yellow Springs, OH, USA
- Precision was assessed according to CLSI EP15-A2 [4] by assaying AutoCheck 5+, Radiometer Medical ApS, Brønshøj, Denmark
- Autocheck 5+ control samples were measured on each study day to confirm constant trueness and precision according to the RiliBÄK guideline [5].
- In addition Bioanalytical Standards (Glucose) were measured on each study day to confirm constant trueness and precision.

2.6.3 Cobas c111

- Manufacturer: Roche Instrument Center, Rotkreuz, CH
- Method / chemistry: Hexokinase
- Sample: capillary plasma
- Certificate of interlaboratory comparison is available

Trueness and precision

- Trueness was assessed according to CLSI EP15-A2 [4] by assaying Standard Reference Material (SRM) 965b, National Institute for Standards and Technology (NIST), Gaithersburg MD, USA
- Precision was assessed according to CLSI EP15-A2 [4] by assaying Precipath U / Precinorm U, Roche Diagnostics GmbH, Mannheim, Germany
- Precipath U / Precinorm U control samples were measured on each study day to confirm constant trueness and precision according to the RiliBÄK guideline [5].
- In addition NIST SRM 965b samples were measured on each study day to confirm constant trueness and precision.

2.6.4 OPTI CCA-TS

- Manufacturer: OPTI Medical Systems, Inc., Roswell, GA, USA
- Method / chemistry: Optical fluorescence (for oxygen partial pressure)
- Sample: capillary whole blood
- Certificate of interlaboratory comparison is available

Trueness and precision

- Opti™ Check (OPTI Medical Systems, Inc., Roswell, GA, USA) control samples were measured on study days prior to usage to confirm constant trueness and precision according to the RiliBÄK guideline [5].

2.6.5 Maintenance, adjustment, control procedures

- For all study devices maintenance, adjustment and control procedures were followed in accordance with the manufacturers' instructions.

2.7 Control measurements with blood glucose monitoring systems

- Control solutions / levels see 2.6 Study devices.
- Measurements were performed according to manufacturer's instructions
- Unsuccessful control measurements had to be repeated once.
- If the result was still not within the range, the meter had to be cleaned following the system specific cleaning instructions. If the result was still not within the range, the meter had to be changed and the procedure reiterated.
- Available levels of control solutions were measured daily before measurement of blood samples. In addition control measurements were performed with test strips from each test strip vial using one level of control solution.
- A system passed the qualification when all measurements were inside the target ranges given by the manufacturer.

2.8 Determination of hematocrit

- Centrifugation of capillary whole blood in heparinised capillaries
- Reading of hematocrit level on alignment chart
- Double test (if both measurements were successful the mean value was calculated)
- Determination before or after measurements with BGMS
- Certificate of interlaboratory comparison is available

Trueness and precision

- Liquichek™ Hematology-16 Control (Bio-Rad Laboratories, Irvine, CA, USA) control samples were measured on study days prior to usage to confirm constant accuracy and precision according to the RiliBÄK guideline [5].

2.9 Experiment

2.9.1 Requirements according to EN ISO 15197:2003

2.9.1.1 Samples

- ≥ 100 fresh capillary blood samples collected by skin puncture were prepared, processed and applied according to the manufacturer's instructions
- Only unaltered capillary blood samples were used for glucose concentrations of $\geq 50 - < 400$ mg/dl
- For samples of < 50 mg/dl and ≥ 400 mg/dl glucose concentration could be adjusted
- Exclusion criteria for samples were defined based on the manufacturer's instructions for use (see also additional exclusion criteria for samples)
- Aliquots were removed from each sample immediately before the first and immediately after the last measurement with the blood glucose monitoring system for duplicate measurement with the comparison methods.
- Defined distribution of glucose concentrations was obtained:

Percentage of samples [%]	Glucose concentration [mg/dl]
5	< 50
15	$\geq 50 - < 80$
20	$\geq 80 - < 120$
30	$\geq 120 - < 200.5$
15	$\geq 200.5 - < 300.5$
10	$\geq 300.5 - < 400$
5	≥ 400

Samples were assigned to the respective category according to the glucose concentration measured with YSI 2300 STAT PLUS or Cobas c111, respectively..

- Once a concentration category was filled, no more samples were added to that category

2.9.1.2 Reagent system

- Three lots of reagent system units were examined.
- At least 200 reagent system units from at least 10 packages were used
- Reagent system units were taken from the same package for each sample
- Packages were changed approximately every 10 subjects

2.9.1.3 BG monitoring systems

- Users have received proper training
- Devices were properly maintained
- Required adjustment and control procedures were followed in accordance with the manufacturer's instructions.
- Samples were measured with 2 different devices

2.9.1.4 Environment

- Measurements using the blood glucose monitoring system were performed at $23^{\circ}\text{C} \pm 5^{\circ}\text{C}$

2.9.1.5 Evaluation procedure

- Results from comparison methods were evaluated to verify sample stability
(If change between first and last result $> 4\%$ at glucose > 100 mg/dl or > 4 mg/dl at glucose ≤ 100 mg/dl, results for that sample had to be rejected)

2.9.2 Additional exclusion criteria for samples

- Humidity had to be between 10 - 90%
(based on manufacturer's instructions for use)
- Glucose concentration measured with the comparison methods had to be within the measurement range of 10 - 600 mg/dl
(based on manufacturer's instructions for use)
- Hematocrit had to be between 20 and 60%
(based on manufacturer's instructions for use)
- Exclusion of samples possibly containing endogenous and exogenous interferents:
subjects' anamnesis and medication was reviewed by a physician in comparison to the interferents given in the manufacturers' instructions for use or as specified by the customer
- Acceptance criterion for double measurements (comparison methods):
If values of a double measurement had a coefficient of variation (CV) $\geq 5\%$, then the results for that sample had to be rejected.

2.9.3 Determination of glucose concentration - sample preparation

- Native samples: capillary whole blood from finger prick
 - for measurements with BG meters: sample taken directly from finger prick
- Samples designated to be adjusted to < 50 mg/dL or ≥ 400 mg/dL:
 - capillary whole blood collected in lithium-heparin Multivettes (Sarstedt AG & Co., Nümbrecht, D).
 - Adjustment was performed according to EN ISO 15197:2003 by either
 - incubation
 - supplementation with glucose (stock solution: 40% in 0.9% NaCl)
- For measurements with comparison methods: capillary plasma
 - obtained from capillary whole blood from finger prick collected in lithium heparin Monovettes, Multivettes (Sarstedt AG & Co., Nümbrecht, D)

2.9.4 Determination of glucose concentration - measurement procedure

- Screening measurement with Accu-Chek® Aviva Nano, Roche Diagnostics (optional)
- Determination of hematocrit (before or after measurements with test systems)
- Taking of 1st sample for comparison methods
- Measurement with devices:
 - GlucoCheck Excellent – A1 Lot 1: S5VC13B07
 - GlucoCheck Excellent – A2 Lot 1: S5VC13B07
- Taking of 2nd sample for comparison methods (native samples only)
- Measurement with devices:
 - GlucoCheck Excellent – A1 Lot 2: S5VC13B14
 - GlucoCheck Excellent – A2 Lot 2: S5VC13B14
- Taking of 3rd sample for comparison methods (native samples only)
- Measurement with devices:
 - GlucoCheck Excellent – A1 Lot 3: S4VC13A21
 - GlucoCheck Excellent – A2 Lot 3: S4VC13A21
- Taking of 4th sample for comparison methods
- Plasma separation and comparison measurements
- Determination of oxygen partial pressure (OPTI CCA-TS) to exclude elevated levels >100 mmHg (adjusted samples only)

2.10 Data analyses

2.10.1 Analysis of system accuracy according to EN ISO 15197:2003 [1]

- performed vs. YSI 2300 STAT PLUS, Cobas c111
- including:
 - Bias analysis according to Bland and Altman [6]
Analysis done with Analyse-it for Microsoft Excel (version 2.30) [7]
 - Regression analysis according to Passing and Bablok [8]
Analysis done with Analyse-it for Microsoft Excel (version 2.30) [7]

2.10.2 Analysis of system accuracy applying performance criteria defined by ISO 15197:2013 [2]

- performed vs. YSI 2300 STAT PLUS, Cobas c111
- using the data generated according to EN ISO 15197:2003
- including:
 - Consensus Error Grid analysis according to Parkes [36 \r \h * MERGEFORMAT [3]]

3 Results

3.1 Time span of experiments

- 29.04.2013 – 16.05.2013

3.2 Study subjects

- Total number of subjects screened: 108
- Total number of subjects completed: 108
- 100 → analysis according to ISO 15197

3.3 Equipment failures

- No equipment failures

3.4 Adverse Events

- No adverse events

3.5 Samples

	Lot 1	Lot 2	Lot 3
Samples taken from 108 different subjects	120	119	117
Samples rejected because of			
- comparison method control measurement not in range	1	1	1
- missed stability criterion	7	2	1
- concentration category different between lots and/or comparison methods	6	7	7
- concentration category was already filled	6	6	6
- incomplete measurement series	0	1	1
- subject already provided valid measurement	0	2	1
Minimum and maximum of glucose concentrations (samples included in evaluation)			
- minimum [mg/dl]	37.475	37.475	37.475
- maximum [mg/dl]	487.5	487.5	487.5
Environmental conditions during measurements (samples included in evaluation)			
- temperature [°C] target range: 23 ± 5 °C	20.3 – 23.9	20.3 – 24.0	20.3 – 24.0
- humidity [%] target range: 10 – 90%	32.0 – 56.5	32.0 – 56.5	32.0 – 56.5
Hematocrit (samples included in evaluation)			
- hematocrit [%] target range: 20 – 60%	35.0 – 55.0	35.0 – 55.0	35.0 – 55.0

3.6 System accuracy analysis versus YSI 2300 STAT PLUS

3.6.1 Summary of system accuracy analysis following EN ISO 15197:2003

3.6.1.1 Summary of combined system accuracy

<i>n</i> = 200	Combined system accuracy	Criteria of EN ISO 15197:2003 met?
Lot 1: S5VC13B07	198 / 200 (99.0%)	YES
Lot 2: S5VC13B14	197 / 200 (98.5%)	YES
Lot 3: S4VC13A21	198 / 200 (99.0%)	YES

3.6.1.2 Summary of bias analysis

<i>n</i> = 200	Bias [mg/dl]	95% Limits of agreement [mg/dl]	Bias [%]	95% Limits of agreement [%]
Lot 1: S5VC13B07	4.522	-18.333 – 27.377	4.2	-8.9 – 17.4
Lot 2: S5VC13B14	3.236	-23.645 – 30.118	3.7	-10.6 – 17.9
Lot 3: S4VC13A21	5.438	-19.040 – 29.916	4.6	-8.9 – 18.1

3.6.1.3 Summary of regression analysis

<i>n</i> = 200	Regression
Lot 1: S5VC13B07	$y = 0.99 x + 6.49$
Lot 2: S5VC13B14	$y = 0.98 x + 6.76$
Lot 3: S4VC13A21	$y = 1.01 x + 5.68$

3.6.2 Summary of system accuracy analysis applying performance criteria defined by ISO 15197:2013

3.6.2.1 Summary of combined system accuracy

<i>n</i> = 200	Combined system accuracy	Criteria of ISO 15197:2013 met?
Lot 1: S5VC13B07	196 / 200 (98.0%)	YES
Lot 2: S5VC13B14	191 / 200 (95.5%)	YES
Lot 3: S4VC13A21	194 / 200 (97.0%)	YES

3.6.2.2 Summary of Consensus Error Grid analysis

	n	Percentage of results within zones A and B
Lot 1: S5VC13B07	200	100%
Lot 2: S5VC13B14	200	100%
Lot 3: S4VC13A21	200	100%

- See appendix

3.7 System accuracy analysis versus Cobas c111

- See appendix

4 Summary and Conclusions

- Accuracy evaluation following EN ISO 15197:2003 was performed for GlucoCheck Excellent with three different lots of test strips. In addition data were analyzed applying performance criteria defined by ISO 15197:2013.
- Comparison method: YSI 2300 STAT PLUS

Accuracy evaluation following EN ISO 15197:2003

- Minimum acceptable accuracy according to EN ISO 15197:2003:
 - ≥ 95% of the individual results shall fall within ± 15 mg/dl of the comparison measurement at glucose concentrations < 75 mg/dl and within $\pm 20\%$ at glucose concentrations ≥ 75 mg/dl.
- In the current evaluation
 - 99.0% of results with GlucoCheck Excellent Lot 1
 - 98.5% of results with GlucoCheck Excellent Lot 2
 - 99.0% of results with GlucoCheck Excellent Lot 3
 fell within the limits for system accuracy defined by EN ISO 15197:2003, thus fulfilling the standard's system accuracy criteria with each test strip lot.

Accuracy evaluation applying performance criteria defined by ISO 15197:2013

- Minimum acceptable accuracy according to ISO 15197:2013:
 - a) $\geq 95\%$ of the individual results shall fall within ± 15 mg/dl of the comparison measurement at glucose concentrations < 100 mg/dl and within $\pm 15\%$ at glucose concentrations ≥ 100 mg/dl.
 - b) $\geq 99\%$ of individual glucose results shall fall within zones A and B of the Consensus Error Grid.
- In the current evaluation
 - 98.0% of results with GlucoCheck Excellent Lot 1
 - 95.5% of results with GlucoCheck Excellent Lot 2
 - 97.0% of results with GlucoCheck Excellent Lot 3
 fell within the limits for system accuracy defined by ISO 15197:2013.
- In the current evaluation, 100% of results fell within zones A and B of the Consensus Error Grid for all systems.
- When applying the performance criteria defined by ISO 15197:2013 to the dataset obtained in this study, the criteria are fulfilled by the GlucoCheck Excellent system.

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Appendix