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REVIEW ARTICLE

Blood glucose monitoring in critically ill adult patients: type of sample and method of analysis. Systematic review and meta-analysis

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KEYWORDS
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Point-of-care testing;
Data accuracy;
Predictive value of tests

Abstract
Introduction: The clinical guideline for the management of sepsis, recommends using arterial blood samples for glycaemic control. A multicentre study in 86 Spanish intensive care units (ICU) revealed that 85.4% of ICUs used capillary puncture.
Objective: To analyse the reliability of glycaemia by comparing different blood samples (arterial, venous, capillary) and instruments (glucometers, gasometers, central laboratory). Secondarily, to estimate the effect of confounding variables and the performance of measuring instruments as determined by different quality standards.
Methodology: Systematic review and meta-analysis with search in PubMed, CINAHL and Embase databases in September-2021 and September-2022, with no time or language limits. Grey literature sources: DART-Europe, OpenGrey and Google Scholar. Results summarised by qualitative (description of results, study characteristics) and quantitative (meta-analysis to assess standardised mean difference) synthesis. Methodological quality of articles assessed with Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2). Protocol: https://osf.io/ DOI 10.17605/OSF.IO/T8KYP.

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Results: A total of 32 articles and 5451 patients were included. No discrepancies were obtained between arterial glucometer vs laboratory samples [bias (95%CI): 0.01 (−0.12 to 0.14) mg/dL]. In contrast, arterial samples with a gasometer did significantly overestimate [bias (95%CI): 0.12 (0.01 to 0.24) mg/dL]. The same trend is seen in capillaries with a glucometer, although not significantly [bias (95%CI): 0.07 (-−0.02 to 0.15) mg/dL]. There is discrepancy between studies on the effect of haematocrit and acid-base balance. The greatest consensus is on the poor agreement of glucometer with capillary vs laboratory samples in the presence of shock and vasopressor support, renal failure or during vitamin C treatment.
Conclusions: The evidence to date recommends the use of arterial blood with a blood glucose meter for better reliability of glycaemic analysis and less effect of possible confounding variables, frequently present in the critically ill adult patient.

PALABRAS CLAVE
Unidades de cuidados intensivos;
Enfermedad crítica;
Adulto;
Control de la glucemia;
Pruebas en el punto de atención;
Exactitud de los datos;
Valor pronóstico de las pruebas

Monitorización de la glucemia en el paciente crítico adulto: tipo de muestra y método de análisis. Revisión sistemática y metanálisis

Resumen
Introducción: La guía clínica para el manejo de la sepsis, recomienda usar muestras de sangre arterial para el control glucémico. Un estudio multicéntrico en 86 unidades de cuidados intensivos (UCI) españolas reveló que el 85,4% de las UCI utilizaban punción capilar.
Objetivo: Analizar la fiabilidad de la glucemia comparando diferentes muestras sanguíneas (arterial, venosa, capilar) e instrumentos (glucómetros, gasómetros, laboratorio central). Secundariamente, estimar el efecto de variables confusoras y el rendimiento de los instrumentos de medición determinados por las diferentes normas de calidad.
Metodología: Revisión sistemática y metanálisis con búsqueda en bases de datos PubMed, CINAHL y Embase en septiembre-2021 y septiembre-2022, sin límites temporales ni idiomáticos. Fuentes de literatura gris: DART-Europe, OpenGrey y Google Académico. Resultados resumidos mediante síntesis cualitativa (descripción de resultados, características de los estudios) y cuantitativa (metanálisis para evaluar la diferencia de medias estandarizadas). Calidad metodológica de artículos evaluada con Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2). Protocolo: https://osf.io/ DOI 10.17605/OSF.IO/T8KYP.
Resultados: Se incluyeron un total de 32 artículos y 5451 pacientes. No se obtuvieron discrepancias entre muestras arteriales con glucómetro vs laboratorio [sesgo (IC95%):0,01 (−0,12 a 0,14) mg/dL]. En cambio, arteriales con gasómetro sí sobrestimaron de forma significativa [sesgo (IC95%):0,12 (0,01 a 0,24) mg/dL]. La misma tendencia presentan capilares con glucómetro, aunque no de forma significativa [sesgo (IC95%):0,07 (−0,02 a 0,15) mg/dL]. Hay discrepancia entre los estudios sobre el efecto del hematocrito y el equilibrio ácido-base. El mayor consenso se da en la poca concordancia del glucómetro con muestras capilares vs laboratorio en presencia de shock y soporte vasopresor, situación de fallo renal o durante el tratamiento con vitamina C.
Conclusiones: La evidencia hasta el momento recomienda el uso de sangre arterial con gasómetro para una mejor fiabilidad del análisis glucémico y menor efecto de posibles variables confusoras, frecuentemente presentes en el enfermo crítico adulto.

Introduction

According to the clinical guide for the management of sepsis, *Surviving Sepsis Campaign*,[1] intravenous insulin should be administered when glycaemia values are >180 mg/dL, keeping it within a range from 140 to 180 mg/dL (strong recommendation). Although the latest edition of the clinical guide for sepsis treatment[1] does not offer recommendations about how to monitor glycaemia, the 2016 guide[2] states that it should be measured every 1−2 hrs. until glycaemia levels and insulin infusion rates stabilize. It is recommended that arterial blood samples should be used to monitor glycaemia instead of capillary blood (weak recommendation, evidence

of low quality) due to a possible lack of precision, especially in the ranges of hypoglycaemia and hyperglycaemia and in patients in shock with vasopressor treatment.[2]

Bedside glucometers should only be used when the patient has no catheters to obtain samples of venous or arterial blood, when the only alternative is therefore capillary puncture.[3] The latest generation of glucometers are more promising in terms of reliability, although special care has to be taken when certain factors may make them less accurate, such as haematocrit, partial oxygen pressure and vasoactive drugs.[4,5]

The most recent systematic review found in the literature,[6] from 2013, concluded that the most reliable method for analysis of glycaemia uses arterial blood with a gas analyser, followed by arterial blood with a glucometer. Nevertheless, within the hypoglycaemia range (< 81 mg/dL), the incidence of error in devices using arterial samples was greater than it was in normal ranges of glycaemia (odds ratio of gas analyser vs. glucometer error: 1.86 vs. 2.33).

Within the context of the MOviPre multicentre national study to analyse early mobilisation in Spanish intensive care units (ICU), and given that hyperglycaemia is a risk factor for muscular weakness, the collaborating researchers were asked about the type of blood sample and analyser they used for the analysis of glycaemia.[7] 85.4% of the ICU used capillary puncture to analyse glycaemia, and 94.4% used glucometers. Of the glucometers used, only 36.2% were AccuChek®. This glucometer is able to reduce the deviation generated by haematocrit when measuring glycaemia, and only one ICU (1.2%) used Stata-Strip®, a latest generation glucometer. These results were ratified by García del Moral-Martín et al.[8] in Andalusia, in a broad homogeneous sample, as representative at the level of an autonomous community. Nevertheless, although the evidence about how glycaemia monitoring should take place was published more than five years ago, it has yet to be applied in practice.

Given that the latest guide[1] on sepsis management does not examine how to monitor glycaemia and recommends broadening research to control it more safely, we consider it to be timely to undertake a review that is able to offer new evidence about glucose monitoring in critical adult patients. We will analyse the reliability of this control, comparing different blood samples and instruments, and secondarily estimate the effect of the confusion variables and the performance of measuring instruments as determined by different quality standards.

The question for this review was drawn up using the acronym PICOS (patient/population, intervention, comparison, outcome-results, study type), where each item corresponds to: (P) critical adults patients treated in an ICU, and who may correspond to different types: medical, surgical, polyvalent, cardiological or neurological, as well as emergency department critical units; (I) studies that evaluate the precision of glycaemia analysis by glucometers or gas analysers; (C) with or without comparison with glycaemia values analysed in a central laboratory; (O) the magnitude of the difference in comparison with glycaemia measurements in different samples, according to the instruments and analytical methods used (the main result) and the performance of glucometers and/or gas analysers according to the different quality criteria or interchangeability (secondary result), and analysis of the influence of possible confusion variables on the inaccuracy of the measurement (secondary result), and (S) observational, experimental and quasi-experimental studies.

The research question was: what type of blood (arterial, venous, capillary) and analytical instrument (glucometer, gas analyser) should I use to measure glycaemia at the bedside of a critical adult patient?

Methodology

A systematic review and meta-analysis according to Joanna Briggs Institute (JBI) methodology for reviews of exactitude of diagnostic tests, and reported according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[9,10] The study protocol has been published in OSF (https://osf.io/ DOI 10.17605/OSF.IO/T8KYP).

Inclusion criteria

To respond to the research question a bibliographical search was undertaken in any published language and without exclusion due to publication date. The following inclusion criteria were applied: (1) study type: randomized and non-randomized clinical trials, before and after studies, observational, prospective and retrospective studies, cases-control and cross-sectional studies, as well as qualitative studies; (2) studies whose abstract reports comparisons that were implemented using different analytical instruments (intraclass correlation coefficient, Bland and Altman); (3) studies in which critical adults patients participated; (4) studies which analysed the precision of glycaemia analysis using bedside instruments (point of care [POC]) using glucometers or gas analysers, and which express their results according to the concordance between glycaemia values measured by the different instruments and samples (arterial, venous or capillary).

Studies which evaluated glycaemia using laboratory-manipulated human blood samples were excluded, as were those which analysed continuous interstitial glucose monitors. Studies undertaken in major burns units, congress summaries, books and editorials were all excluded, following the recommendations for a systematic review.

Sources of information and the search strategy

In September 2021 we carried out a preliminary search to locate systemic reviews that had been published or were underway, as well as to identify potentially relevant papers and identify terms and descriptors that would be relevant for the definitive search. The databases consulted were PROSPERO (https://www.crd.york.ac.uk/prospero/), Cochrane Database of Systematic Reviews (Wiley, 1995-), PubMed (1945-), Embase (Elsevier, 1947-), JBI EBP Database (Ovid) and ClinicalTrials.gov.

The definitive bibliographical search to identify potentially relevant documents was carried out in September 2021 and updated in September 2022. It included the databases PubMed (1946-), Embase (Elsevier, 1947-) and CINAHL (EBSCO, 1937-).

The search strategies were prepared by an experienced librarian (CCA) and revised by another information specialist (JMM) prior to their execution using the *Peer Review of Electronic Search Strategies*[11] checklist. The search strategy for each database is described in the supplementary material (Appendix A Table S1). The search was designed with the aid of the following tools: Yale MeSH Analyzer,[12] PubReMiner[13] and Polyglot Search Translator.[14]

The search in electronic databases was supplemented by a search in DART-Europe for access to theses, OpenGrey and Google Académico, and experts were contacted too. A supplementary search was also undertaken in the references lists of the studies selected for inclusion in this review, to identify additional relevant studies. A systematic search of citations was then carried out, compiling all of the studies that cited the selected papers for inclusion by using CitationChaser (https://estech.shinyapps.io/citationchaser/).[15]

The authors of key papers and summaries were also contacted to request more information about their studies.

The final results of the search were exported to Zotero and duplicates were eliminated.

The selection process

Prior to selecting studies we carried out a pilot test with 15 papers in each one of both screening process phases, considering a coincidence in more than 75% as the consensus criterion; both reviewers obtained an agreement of 96%. All of the references were independently screened using their titles and abstracts according to the inclusion criteria described above. After the selection of titles and abstracts the complete texts of the remaining papers were recovered. The complete texts were then reviewed independently according to the inclusion criteria. Discrepancies were resolved by agreement. The resulting references were then loaded in the Rayyan programme (https://www.rayyan.ai/).[16]

Data extraction

A standard formulation was used that had initially been piloted in 5 of the included studies. The reviewers extracted data from the selected studies: the first author, year and country of publication, methodology, number of patients, number of paired samples, sample type used, instruments used, the analytical method used by the instruments, results in terms or reliability, confusion variables analysed, analysis based on quality criteria and the authors' conclusions.

Critical evaluation of the studies

The methodological quality of the selected papers was independently evaluated by 2 reviewers using the *Quality Assessment of Diagnostic Accuracy Studies-2* (QUADAS-2) tool.[17] The reviewers then went on to agree a shared result, resolving any discrepancies by consensus.

Data analysis

The results were summarised by qualitative and quantitative synthesis. In the qualitative synthesis a table was prepared containing the description of the results and the characteristics of the studies. A meta-analysis was performed in the quantitative synthesis to evaluate the magnitude of the difference in the results. All of the meta-analytical methods used in this study are based on the guide by Harrer et al.[18]

Version 4.0.3 of R software was used for all of the analyses and graphs. All of the studies with sufficient data to calculate the difference of standardized averages were included in the meta-analyses. Averages were calculated based on the median and range in the studies that did not present their results in this form.[19] When standard deviations were not available they were calculated using the *P* value, the tabulated t value, the difference between averages and the standard error.[20]

Results

1,196 abstracts from the database search were analysed, of which the complete text was evaluated in 130 cases. 30 of these papers plus 2 others located in a secondary review of a citation search were included. The selection process was recorded in sufficient detail to complete a PRISMA flow diagram (Fig. 1) and a list of excluded studies with the reasons for exclusion.

Of the 32 studies included, 26 are prospective observational studies, 5 are retrospective and one consists of cases and controls. 10 studies compare different instruments, 2 compare different samples and 20 studies compare different samples and instruments. A total number of 5.451 patients were analysed in all 32 studies (Table 1).

A very heterogeneous set of glucometers were analysed in this review, and different methods of analysis were used (Appendix A Supplementary Material Table S2).

Reliability of capillary determinations by glucometer

19 studies used capillary samples measured by a glucometer compared with central laboratory values or a POC blood gas analyser. Of the 17 studies that compared glycaemia measured using a glucometer with a laboratory measurement, 11 authors[21–31] contraindicate their use and 2 authors[32,33] do not recommend them if patients are receiving intravenous treatment with catecholamine. Only 3 studies[34–36] consider that the differences found between both types of measurement should not restrict the use of glucometers when monitoring glycaemia, as do both studies[37,38] that compared capillary samples measured with a glucometer vs. a POC blood gas analyser. Cordero Saucedo et al.[39] consider that more studies are required to evaluate efficacy: their results are not conclusive. Rodríguez-Delgado et al.[40] compared capillary, arterial and venous samples using the same glucometer, and they advise against using capillary samples, especially when patients are receiving a perfusion of vasoactive drugs.

In the meta-analysis of the 17 studies (21 comparisons) that analysed capillary samples using a glucometer vs. lab-

Tabla 1 Características y resultados de los estudios incluidos en la revisión sistemática (n = 32)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Ray et al.[41]/2001/Canadá	Observacional prospectivo	10 pacientes	105	OneTouch®	NP	Cobas®	Arterial	BA: sesgo (límites de acuerdo 95%): −0,72 (−41,4 a 39,6) mg/dL CCI: 0,86	La medición de glucosa POC puede ser una alternativa precisa a la medición en plasma en adultos críticos
Cordero Saucedo et al.[39]/2005/México	ND	25 pacientes	489	1) Ascensia Elite™, 2) Precision QID®, 3) SureStep™ Plus	NP	Vitros®250	Capilar y venosa (glucómetros), venosa (laboratorio)	BA: sesgo (límites de acuerdo 95%): 1 a) Laboratorio vs. Ascensia Elite™ capilar: −5,47 (−54,7 a 43,82) mg/dL 1 b) Laboratorio vs. Ascensia Elite™ venosa: −5,87 (−54,1 a 42,4) mg/dL 2 a) Laboratorio vs. Precision QID® capilar: −9,46 (−57,7 a 38,7) mg/dL 2 b) Laboratorio vs. Precision QID® venosa: −12,04 (−57,2 a 33,1) mg/dL 3 a) Laboratorio vs. SureStep™ capilar: −9,40 (−48,0 a 29,2) mg/dL 3 b) Laboratorio vs. SureStep™ venosa: −10,43 (−50,89 a 30,0) mg/dL	Los 3 glucómetros fueron muy similares, aunque el que presentó mejores límites de concordancia fue el sistema SureStep™ Plus
Finkielman et al.[51]/2005/EE. UU.	Observacional retrospectivo	197 pacientes	816	SureStep® Flexx	NP	Glucose Analyzer 2 o Hitachi 747-200 Analizer o Modular P800	Arterial/venoso o venoso y capilar (ND)	BA: sesgo (límites de acuerdo 95%): 7,9 (−27,2 a 43,1) mg/dL Con glucemias > 400 mg/dL: 7,6 (−26,6 a 41,8) Con glucemias 50-400 mg/dL: 9 (−29,2 a 47,3)	El glucómetro a pie de cama proporciona una estimación razonable de la glucemia, pero es poco fiable con respecto a la glucemia plasmática

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Kulkarni et al.[37]/ 2005/ Australia	Observacional prospectivo	54 pacientes	493	Accu-Chek® Advantage	ABL 700	NP	Capilar y arterial	BA: sesgo (límites de acuerdo 95%): arterial vs. capilar: 2,15 (−2,5 a 29,8) mg/dL	Existe concordancia estadística entre la sangre capilar y la glucemia en gases arteriales
Soussi Tanani et al.[31]/2006/ Marruecos	Observacional prospectivo	198 pacientes	245	Accu-Chek® Active	NP	CX7 Delta	Capilar (glucómetro), venosa (laboratorio)	BA: sesgo (límites de acuerdo 95%): 7,2 (−43,24 a 59,45) mg/dL Con glucemias < 99 mg/dL: −4,14 mg (−33,48 a 25,2) Con glucemias 99-198 mg/dL: 3,24 (−23,94 a 30,6) mg/dL Con glucemias > 198 mg/dL: 28,8 (−48,6 a 106,2) mg/dL	La fiabilidad de la glucemia capilar no fue satisfactoria, con poca precisión y alto porcentaje de discrepancia. La glucemia capilar debe interpretarse con mucha precaución en UCI
Arias-Rivera et al.[22]/2007/España	Observacional prospectivo	70 pacientes	630 muestras (210 capilares, 350 arteriales y 70 plasmáticas)	MediSense® Optium	NP	SYNCHRON CX3 Delta	Capilar y arterial (glucómetro), arterial (gasómetro), arterial (laboratorio central)	BA: sesgo (límites de acuerdo 95%): Capilar glucómetro vs. laboratorio: 11 (−22 a 44) mg/dL Arterial glucómetro vs. laboratorio: 2 (−27 a 31) mg/dL Arterial (jeringa gases) glucómetro vs. laboratorio: 5 (−24 a 34) mg/dL	La determinación de la glucemia a pie de cama en los enfermos críticos es más fiable cuando se mide en muestras de sangre arterial que en sangre capilar

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Critchell et al.[28]/2007/EE. UU.	Observacional prospectivo	80 pacientes	277	Accu-Chek® Inform	NP	Coulter LX-20	Capilar y venosa	BA: sesgo (límites de acuerdo 95%): Capilar vs. laboratorio: 8,6 (−28,6 a 45,8) mg/dL	La glucemia capilar no ha cumplido los requisitos reglamentarios de precisión y, por lo tanto, esta técnica de medición y/o el glucómetro deben utilizarse con gran precaución en pacientes con protocolos glucémicos estrictos; pueden dar lugar a episodios de hipoglucemia no detectada
Karon et al.[35]/2007/EE. UU.	ND	20 pacientes	96	Accu-Chek® Inform	NP	Double P	Arteriales, capilares y venosas (glucómetro) Arteriales o venosas (laboratorio)	BA: sesgo (RIC): Capilar vs. laboratorio (arterial o venoso): 2 (−27 a 29) mg/dL Con glucemias < 160 mg/dL: −3 (−7 a 3) mg/dL Con glucemias ≥ 160 mg/dL: 10 (1 a 16) mg/dL Arterial glucómetro vs. laboratorio (arterial o venoso): 15 (−3 a 33) mg/dL Con glucemias < 160 mg/dL: 10 (7 a 13) mg/dL Con glucemias ≥ 160 mg/dL: 18 (13 a 26) mg/dL Venoso glucómetro vs. laboratorio (arterial o venoso): 15 (−28 a 58) mg/dL Con glucemias < 160 mg/dL: 9 (−1 a 12) mg/dL Con glucemias ≥ 160 mg/dL: 26 (15 a 41) mg/dL CCI: sangre capilar-glucómetro vs. laboratorio: 0,94 Glucosa venosa-glucómetro vs. laboratorio: 0,92 Glucosa arterial-glucómetro vs. laboratorio: 0,94	No se han encontrado diferencias entre la medida capilar y el laboratorio, por lo que el glucómetro con muestra capilar es apropiado para medir glucemias. Las glucemias arterial y venosa medidas con el glucómetro fueron significativamente superiores a la del laboratorio central. Las diferencias entre los niveles de glucosa en sangre total arterial y venosa y en plasma de laboratorio aumentaron en función de la concentración de glucosa

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Lacara et al.[21]/2007/EE. UU.	Comparación de métodos	49 pacientes	49 (42 arteriales y 7 venosas)	SureStep® Pro	NP	Model RxL	Capilar, arterial/venosa (glucómetro), arterial/venosa (laboratorio)	BA: sesgo (límites de acuerdo 95%): 1) Arterial/venoso laboratorio vs. capilar glucómetro: 2,1 (−22,5 a 26,7) mg/dL 2) Arterial/venoso laboratorio vs. arterial/venoso glucómetro: 0,6 (−20,6 a 21,8) mg/dL 3) Arterial laboratorio vs. capilar glucómetro: 1 (−19,6 a 21,6) mg/dL 4) Arterial laboratorio vs. arterial glucómetro: −0,1 (−21,6 a 22,6) mg/dL	Los hallazgos validaron la práctica en UCI de obtener sangre para pruebas con glucómetro a partir de catéteres arteriales o venosos en lugar de una fuente de punción digital. El sesgo y la precisión del análisis de glucosa capilar fue ligeramente más alto que el sesgo y precisión de muestras arteriales o venosas, pero las diferencias no fueron estadísticamente significativas
Desachy et al.[27]/2008/ Francia	Prospectivo	85 pacientes	273	Accu-Chek®	NP	Dimension Vista®	Capilar y sangre total venosa o arterial (glucómetro), sangre total venosa o arterial (laboratorio)	BA: sesgo (límites de acuerdo 95%): Capilar vs. laboratorio: 1,5 (−55,3 a 58,3) mg/dL Sangre total glucómetro vs. laboratorio: 1,4 (−39,5 a 2,4) mg/dL	Las mediciones a pie de cama en sangre total deberían preferirse a las pruebas de sangre capilar. Los resultados deben interpretarse con cuidado
Hoedemaekers et al.[45]/2008/ Países Bajos	Observacional prospectivo	32 pacientes	32	NP	RAPIDLab®	Aeroset® (Abbott)	Arterial	BA: sesgo (IC95%): −2,7 (−22,34 a 16,94) mg/dL	ND
		85 pacientes	197	Accu-Chek®	RAPIDLab®	NP	Arterial	BA: sesgo (IC95%): −1,8 (−22,66 a 16,94) mg/dL	

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
		53 pacientes	82	1) Accu-Chek® 2) Precision® 3) HemCue®	RAPIDLab®	NP	Arterial	BA: sesgo (IC95%): 1) −1,8 (−32,43 a 28,83) mg/dL 2) 1,8 (−25,22 a 27,02) mg/dL 3) −2,7 (−22,34 a 16,94) mg/dL	
Vlasselaers et al.[44]/2008/Bélgica	Observacional prospectivo	37 pacientes	452	1) Accu-Chek® Inform 2) HemoCue® Glucose 201	ABL 700	NP	Arterial	BA: sesgo (límites de acuerdo 95%): 1) ABL 700 vs. Accu-Chek®: −6,3 (−26,5 a 14,0) mg/dL 2) ABL 700 vs. HemoCue®: −10,9 (−29,5 a 7,6) mg/dL	Ninguno de los glucómetros mostró una completa fiabilidad clínica. Accu-Chek® parece un dispositivo más preciso, pero es imprevisible en cuanto a la dirección del error de medición. HemoCue® es algo menos preciso, pero el error de medición es más persistente, en particular sobreestimando la glucemia real
Cook et al.[24]/2009/EE. UU.	Comparación de método	67 pacientes	ND	SureStep® Flexx	NP	Olympus AU640	Capilar y venosa (glucómetro), venosa (laboratorio)	BA: sesgo (límites de acuerdo 95%): Capilar glucómetro vs. laboratorio: 9,54 (−12,5 a 31,5) mg/dL Venosa glucómetro vs. laboratorio: 9,51 (−10,3 a 26,5) mg/dL Capilar glucómetro vs. venosa glucómetro: 0,03 (−24 a 24,1) mg/dL	La magnitud de las diferencias entre POC y laboratorio es tal que el uso de un dispositivo POC en situaciones en las que es necesario conocer valores de glucosa precisos puede conducir a decisiones terapéuticas erróneas

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Meynaar et al.[42]/2009/Países Bajos	Observacional prospectivo	32 pacientes	239	AccuChek®	NP	Abbott Architect CI 8200	Arterial	239 pares: CCI (IC95%): 0,934 (0,915-0,948) BA sesgo (IC95%): 11 (9-13) mg/dL, p < 0,001 32 pacientes: CCI (IC95%): 0,939 (0,880-0,970) BA sesgo (IC95%): 13 (9-16) mg/dL, p < 0,001	La medición de glucosa mediante AccuChek® da valores similares a los de suero con sangre total
Pulzi et al.[29]/2009/Brasil	Observacional transversal	40 pacientes	40	FreeStyle® Optium	NP	Olympus Au640e	Capilar y arterial (glucómetro), arterial y venosa (laboratorio)	BA: sesgo (límites de acuerdo 95%): Capilar glucómetro vs. arterial laboratorio: −9,87 (−72,12 a 52,37) mg/dL Arterial glucómetro vs. arterial laboratorio: −6,75 (−44,13 a 30,63) mg/dL Venoso laboratorio vs. arterial laboratorio: −4,20 (−59,81 a 51,41) mg/dL	Los glucómetros sobreestiman la glucosa en sangre, pudiendo exponer a los pacientes a eventos hipoglucémicos más frecuentes. La determinación arterial con glucómetro es el más representativo y debería adoptarse como alternativa al laboratorio central
Shearer et al.[25]/2009/EE. UU.	Comparación de métodos	62 pacientes	ND	SureStep® Flexx	NP	Olympus AU 604	Capilar y venosa (glucómetro), venoso (laboratorio)	BA: sesgo (límites de acuerdo 95%): Venoso glucómetro vs. laboratorio: 7,0 (−21,1 a 35,0) mg/dL Capilar glucómetro vs. laboratorio: 8,7 (−18,7 a 36,1) mg/dL Capilar glucómetro vs. venosa glucómetro: 1,7 (−31 a 34,5) mg/dL	La magnitud de las diferencias halladas entre el POC y el laboratorio pone en duda la práctica generalizada de utilizar las pruebas de glucosa POC en la gestión de la glucosa. No se hallaron diferencias entre las muestras capilares y las venosas con los POC

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Fekih et al.[33]/2010/Túnez	Prospectivo comparativo no aleatorizado	43 pacientes (Grupo 1: 23; Grupo 2: 20)	ND	Accu-Chek®	NP	Dade-Behring Multichannel Analyzer	Capilar (glucómetro), venosa (laboratorio)	BA: sesgo (límites de acuerdo 95%): Grupo 1 (pacientes estables): 0,9 (−74,34 a 72,54) mg/dL Grupo 2 (pacientes con catecolaminas): 5,22 (−90,9 a 101,34) mg/dL	ND
Juneja et al.[46]/2011/India	Prospectivo, casos y controles	200 pacientes: 100 casos con soporte vasopresor y 100 controles sin apoyo vasopresor	200	OneTouch® Ultra	NP	NP	Capilar y arterial	BA casos: sesgo (límites de acuerdo 95%): 7,28 (−49,1 a 63,7) mg/dL BA controles: sesgo (límites de acuerdo 95%): −0,43 (−26,1 a 25,2) mg/dL	La monitorización de la glucemia capilar solo es fiable en un grupo de pacientes de UCI. Se debe tener precaución en pacientes con shock, donde es preferible la sangre arterial para la monitorización de la glucosa
Stadlbauer et al.[47]/2011/Austria	Observacional prospectivo	17 pacientes	74	NP	1) Cobas B®221 2) ABL800 Flex 3) GEM® Premier™	Modular	Arterial	BA[a]: sesgo (límites de acuerdo 95%): 1) 8,36 (−5,35 a 22,08) mg/dL 2) 7,57 (−1,85 a 16,99) mg/dL 3) 4,56 (−7,91 a 17,03) mg/dL	La correlación entre los 3 diferentes gasómetros POC y el laboratorio central fue buena
Castaño López et al.[50]/2012/España	Observacional prospectivo	89 pacientes	89	StatStrip®	NP	Cobas®6000	Sangre total (no especifican si arterial o venosa)	CCI (IC95%): 0,99 (0,98-0,99) BA: sesgo (±1,96 DE): 5,9 (−15,7 a 27,5) mg/dL	El glucómetro evaluado presenta buena precisión al compararlo con el laboratorio
DuBose et al.[26]/2012/EE. UU.	Observacional retrospectivo	1.215 pacientes	1.935	Accu-Chek® Advantage	NP	LX20	Capilar (glucómetro), arterial o venosa (laboratorio)	BA: sesgo (límites de acuerdo 95%): 12,4 (−22,4 a 47,2) mg/dL Con shock: 13,4 (−27,1 a 53,9) mg/dL No shock: 12,6 (−20,6 a 45,8) mg/dL	La correlación entre valores de glucosa capilar y de laboratorio en estados de shock y sin shock es baja

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Lonjaret et al.[30]/2012/Francia	Observacional	75 pacientes	302	CONTOUR® TS	NP	Olympus AU 2007	Arterial y capilar (glucómetro), arterial (laboratorio)	CCI (IC95%) laboratorio vs. glucómetro capilar: 0,91 (0,89 a 0,93) CCI (IC95%) laboratorio vs. glucómetro arterial: 0,92 (0,90 a 0,93)	Las POC en pacientes críticos mediante un glucómetro no son precisas. La precisión parece ser ligeramente mejor en las muestras de sangre arterial que en las capilares
Watkinson et al.[43]/2012/RU	Observacional prospectivo	206 pacientes	ND	1) Precision PCx® 2) HemoCue® 201 DM	Radiometer 700	1) Siemens ADVIA®2400 2) YSI 2300 STAT plus™	Arterial	BA: sesgo (límites de acuerdo 95%): 1) YSI 2300 STAT plus glucosa sangre total vs. glucosa en plasma: 14,4 (−1,8 a 30,6) mg/dL 2) Precision PCx vs. Siemens ADVIA: 0,0 (−25,2 a 25,2) mg/dL 3) HemoCue 201 DM vs. Siemens ADVIA: 0,0 (−21,6 a 19,8) mg/dL 4) Radiometer 700 vs. Siemens ADVIA: −3,6 (−16,2 a 10,8) mg/dL	Los medidores de glucosa en el punto de atención estiman de forma fiable la glucosa en pacientes críticos
Garingarao et al.[32]/2014/ Filipinas	Observacional transversal	180 pacientes (89 normotensos y 91 hipotensos)	186 (92 en normotensos y 94 en hipotensos)	Accu-Chek® Active	NP	I-Lab 300 Plus	Capilar (glucómetro), venosa (laboratorio)	BA: sesgo (límites de acuerdo 95%): Normotenso: −12,4 (−86,0 a 61,2) mg/dL Hipotensos: −34,9 (−207,1 a 137,4) mg/dL	En pacientes críticos e hipotensos con apoyo vasopresor, los valores del medidor de glucosa POC tenían menor precisión que en los pacientes normotensos

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Pereira et al.[23]/2015/EE. UU.	Prospectivo transversal	145 pacientes	145	1) Precision PCx® 2) Accu-Chek Advantage II®	NP	Vitros®	Arterial (Precision® PCx), arterial, capilar y venosa (Accu-Chek® Advantage II), arterial (laboratorio)	BA: sesgo (límites de acuerdo 95%): 1) Arterial laboratorio vs. arterial Precision: 18,6 (−12,4 a 49,5) mg/dL 2 a) Arterial laboratorio vs. arterial Accu-Chek®: 10,7 (−21,3 a 42,7) mg/dL 2 b) Arterial laboratorio vs. capilar Accu-Chek®: 10 (−31,8 a 51,8) mg/dL 2 c) Arterial laboratorio vs. venosa Accu-Chek®: 15,1 (−51,7 a 81,9) mg/dL	No se debe realizar un control glucémico con muestras de catéteres venosos centrales por su alta variabilidad. La fiabilidad de estos glucómetros es insuficiente en condiciones críticas. Las muestras arteriales parecen ser lo suficientemente precisas para ser utilizadas con glucómetros similares
Allardet Servent et al.[48]/2017/ Francia	Observacional prospectivo	51 pacientes	306	NP	Siemens RAPIDPoint® 500	AU 5800	Arterial	BA: sesgo (± 1,96 DE): −10,7 (−30 a 8,6) mg/dL	El gasómetro es una alternativa fiable. Aunque los valores de glucosa fueron bastante cercanos en promedio, observaron discrepancias clínicamente relevantes en el rango de hipoglucemia
Prakash et al.[49]/2018/EE. UU.	Observacional retrospectivo	1.765 pacientes	9.192	NP	ABL800 Flex	Roche	Arterial o venosa	BA: sesgo (límites de acuerdo 95%): 1,8 (−12,8 a 16,61) mg/dL CCI (IC95%): 0,98 (0,980 a 0,982)	Existe concordancia de moderada a sustancial entre laboratorio central y gasómetro. Sin embargo, los 2 métodos pueden utilizarse indistintamente. Para la práctica clínica es importante utilizar el mismo método de prueba

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Pilackas et al.[34]/2020/EE. UU.	Prospectivo de cohorte	46 pacientes	85	Precision Xceed Pro®	NP	ND	Capilar (glucómetro), venosa (laboratorio)	BA: sesgo (límites de acuerdo 95%): 5,23 (−32,2 a 42,7) mg/dL	Existe una pequeña diferencia media entre las mediciones. La prueba de glucosa capilar POC en pacientes críticos similares es probablemente segura y efectiva
Deng et al.[38]/2021/China	Observacional prospectivo	73 pacientes	ND	CONTOUR® TS	GEM® Premier™ 3000	NP	Capilar (glucómetro), arterial (gasómetro)	BA: sesgo (IC95%): 14,58 (−13,86 a 43,02) mg/dL	Se obtuvieron diferencias estadísticamente significativas pero aceptables en el entorno clínico
He et al.[52]/2021/China	Observacional retrospectivo, serie de casos	82 pacientes	ND	Medisafe®	NP	Beckman Coulter AU5800	ND	BA: sesgo (límites de acuerdo 95%): −43,83 (−177,97 a 90,32) mg/dL	Las imprecisiones de las lecturas de glucosa en el punto de atención no representan un riesgo clínico significativo. Los valores fueron significativamente más bajos con el glucómetro

Tabla 1 (*continuación*)

Autor/año/país	Diseño del estudio	Tamaño muestral	Datos emparejados	Glucómetros POC	Gasómetros POC	Laboratorio central	Muestra utilizada	Resultados	Conclusiones
Howell et al.[36]/2021/EE. UU.	Observacional retrospectivo, serie de casos (cohorte)	14 pacientes	46	Accu-Chek® Inform II	NP	Cobas® c702	Capilar (glucómetro), venosa (laboratorio)	BA: sesgo (IC95%): 0,33 (−57,7 a 58,1) mg/dL	Muchos pacientes con sepsis y terapia de vitamina C intravenosa pueden ser controlados con la monitorización de glucosa POC utilizando el Accu-Chek® Inform II POC BGM sin un impacto clínico significativo
Rodríguez-Delgado et al.[40]/2022/ España	Observacional transversal	54 pacientes	297	FreeStyle® Optium Neo	NP	NP	Capilar, venosa y arterial	BA: sesgo (±2 DE): Arterial vs. capilar: 5,01 (±41,32) mg/dL Arterial vs. venosa: −11,80 (±61,13) mg/dL Venosa vs. capilar: 16,81 (±71,26) mg/dL	La concordancia de las muestras arteriales, capilares y venosas son bajas con glucómetro. El control de la glucemia con glucómetros, en pacientes críticos, deben utilizar muestras arteriales y en caso de hipoglucemia deben comprobarse con un analizador de gases

BA: Bland y Altman; CCI: coeficiente de correlación intraclase; DE: desviación estándar; IC95%: intervalo de confianza del 95%; ND: no describe; NP: no precisa; POC: point of care; RIC: rango intercuartílico; UCI: Unidad de Cuidado Intensivos.

[a] Datos proporcionados por la autora.

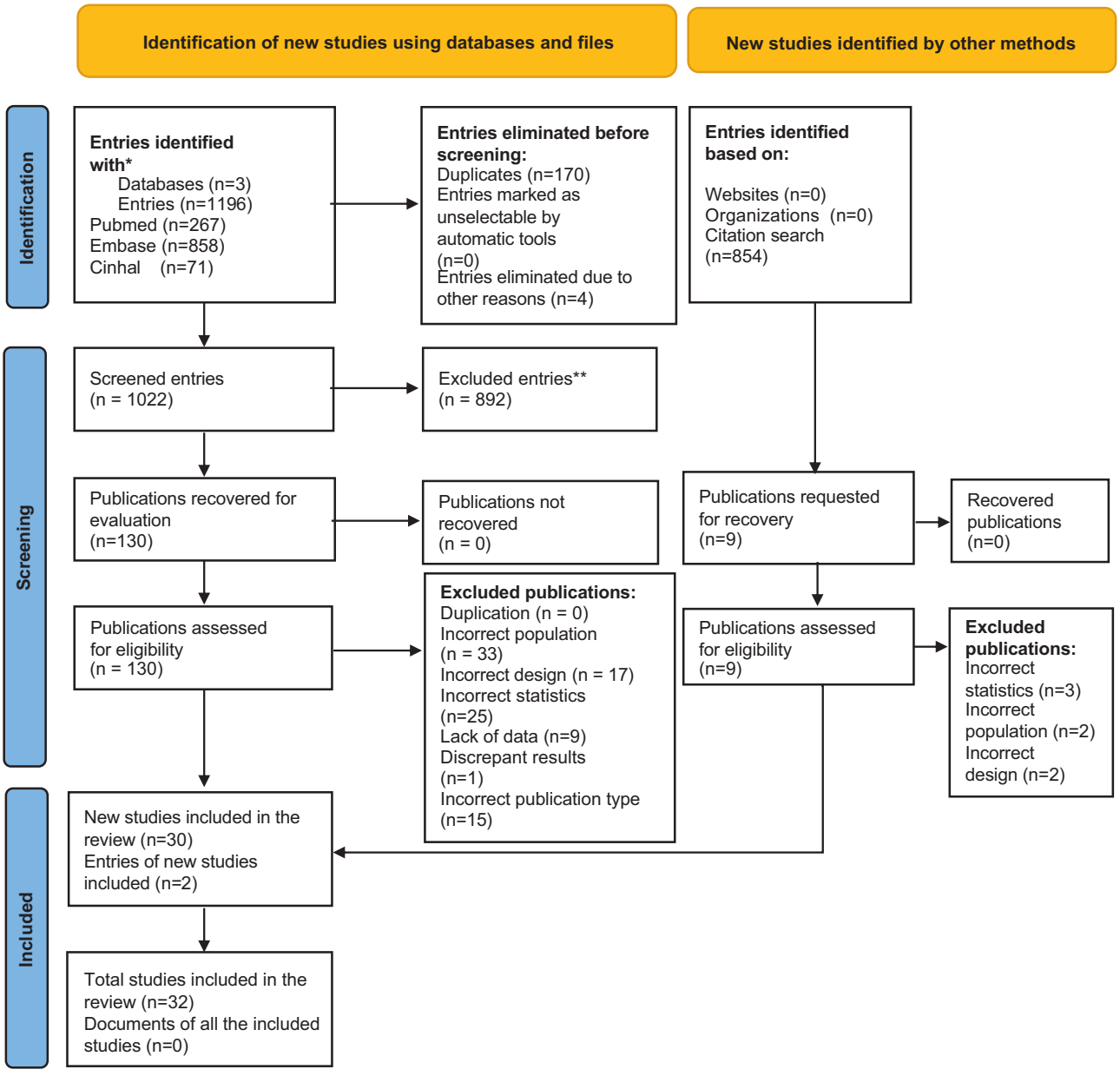


Figure 1 PRISMA 2020 flow diagram.

oratory technique, 4 comparisons in 3 studies[22,26,39] found that glucometer readings were significant over-estimates, while 2 comparisons[30,32] found they were significant under-estimates. Globally the determinations measured using a glucometer were found to be over-estimates, although the differences in the measurements (95% CI) are not significant (0.07 [−0.02 to 0.15] mg/dL) (Fig. 2a).

Reliability of arterial determinations by glucometer and POC blood gas analyser

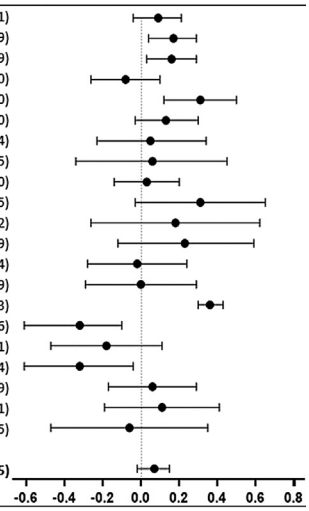
11 authors analysed arterial samples, 9 comparing glucometer determinations with laboratory values[21–23,29,30,35,41–43] and 2 comparing a glucometer with a POC blood gas analyser.[44,45] OF the 9 studies that compared glycaemia determinations by a glucometer and a laboratory, 7 recommend using them[21–23,29,41–43] and 2[30,35] consider that there is no good concordance between glucometer and laboratory, advising against their use, as did both studies that compared a glucometer with a POC blood gas analyser.[44,45] Both of the studies[40,46] which compared samples from different sources using the same glucometer are in favour of using one with arterial samples.

Significant differences were observed in the meta-analysis of 3 of the 8 studies (9 comparisons) which evaluated the differences between glycaemia measured using a glucometer vs. a central laboratory: Karon et al.[35] found that the glucometer over-estimated glycaemia, while Lonjaret et al.[30] and Meynaar et al.[42] found that it under-estimated it. However, the overall difference in the average

A

Study (year)	POC glucometer Mean	DE	n	Central laboratory Mean	DE	n	Weight (%)	Standardised mean difference (IC 95%)
Cordero Saucedo (2005) [1]	157.0	59.0	489	152	54	489	6.5	0.09 (-0.04: 0.21)
Cordero Saucedo (2005) [2]	161.0	55.0	489	152	54	489	6.5	0.17 (0.04:0.29)
Cordero Saucedo (2005) [3]	161.0	58.0	489	152	54	489	6.5	0.16 (0.03:0.29)
Soussi Tanani (2006)	149.5	82.9	245	156.7	99.1	245	5.7	-0.08 (-0.26: 0.10)
Arias-Rivera (2007)	149.0	38.0	210	138	33	210	5.5	0.31 (0.12: 0.50)
Critchell (2007)	129.0	45.0	277	123	44	277	5.9	0.13 (-0.03: 0.30)
Karon (2007)	151.0	40.0	96	149	35	96	4.1	0.05 (-0.23: 0.34)
Lacara (2007)*	137.1	37.8	49	135	37.1	49	2.9	0.06 (-0.34: 0.45)
Desachy (2008)	156	65	273	154	71	273	5.8	0.03 (-0.14: 0.20)
Cook (2009)	123.9	30.4	67	114.4	30.1	67	3.5	0.31 (-0.03: 0.65)
Pulzi (2009)	150.7	55.8	40	140.8	51.9	40	2.5	0.18 (-0.26: 0.62)
Shearer (2009)	127.4	35.1	62	118.7	38.7	62	3.3	0.23 (-0.12: 0.59)
Fekih (2010) [4]*	194.6	87	112	196.4	89.9	112	4.4	-0.02 (-0.28: 0.24)
Fekih (2010) [5]*	203.8	87.2	92	203.6	89.2	92	4.1	0.00 (-0.29: 0.29)
DuBose (2012)	126.4	36.3	1935	113.6	34	1935	7.2	0.36 (0.30: 0.43)
Lonjaret (2012)	126	52	302	143	54	302	5.9	-0.32 (-0.61: -0.16)
Garingarao (2014) [6]*	151.6	64	92	164	72.6	92	4.1	-0.18 (-0.47: 0.11)
Garingarao (2014) [7]*	172.6	81.8	94	207.5	128.1	94	4.1	-0.32 (-0.61: -0.04)
Pereira (2015)	151	74	145	146	91	145	4.9	0.06 (-0.17: 0.29)
Pilackas (2020)*	137.6	49.2	85	132.37	45.4	85	3.9	0.11 (-0.19: 0.41)
Howell (2021)*	149.6	43.4	46	152.4	44	46	2.8	-0.06 (-0.47:0.35)
Total (IC 95%)			**5689**			**5689**	**100%**	**0.07 (-0.02: 0.15)**

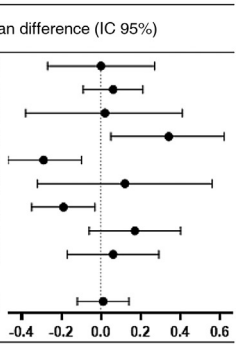
Heterogeneity: $Tau^2 = 0.026$: $Chi^2 = 109.75$: gl = 20 (p< 0.001): $I^2 = 82\%$



B

Study (year)	POC glucometer Mean	DE	n	Central laboratory Mean	DE	n	Weight (%)	Standardised mean difference (IC 95%)
Ray (2001)	185.6	55.9	105	185.56	57.65	105	10.4	0.00 (-0.27: 0.27)
Arias-Rivera (2007)	140.0	34.0	350	138	33	350	14.9	0.06 (-0.09: 0.21)
Lacara (2007)*	135.6	34.3	49	135	37.1	49	7.0	0.02 (-0.38:0.41)
Karon (2008)	161.0	36.0	96	149	35	96	9.9	0.34 (0.05: 0.62)
Meynaar (2009)	126.0	37.0	239	137	39	239	13.7	-0.29 (-0.47: -0.11)
Pulzi (2009)	147.5	56.1	40	140.8	51.9	40	6.1	0.12 (-0.32: 0.56)
Lonjaret (2012)	133.0	50.0	302	143	54	302	14.4	-0.19 (-0.35: -0.03)
Pereira (2015) [8]	160.0	71	145	146	91	145	11.8	0.17 (-0.06: 0.40)
Pereira (2015) [9]	151.0	69	145	146	91	145	11.8	0.06 (-0.17: 0.29)
Total (IC 95%)			**1471**			**1471**	**100%**	**0.01 (-0.12: 0.14)**

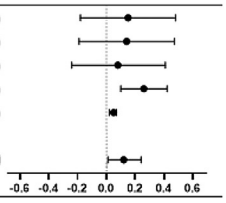
Heterogeneity: $Tau^2 = 0.025$: $Chi^2 = 23.70$: gl = 8 (p< 0.001): $I^2 = 66\%$



C

Study (year)	POC blood gas Mean	DE	n	Central laboratory Mean	DE	n	Weight (%)	Standardised mean difference (IC 95%)
Stadbahuer (2011) [10]**	151.2	56.5	72	142.8	53.3	72	9.7	0.15 (-0.18: 0.48)
Stadbahuer (2011) [11]**	150.4	53.0	72	142.8	53.3	72	9.7	0.14 (-0.19: 0.47)
Stadbahuer (2011) [12]**	147.4	54.7	72	142.8	53.3	72	9.7	0.08 (-0.24;0.41)
Allardet-Servent (2017)	135.4	41.5	306	124.8	41.0	306	24.7	0.26 (0.10: 0.42)
Prakash (2018)	141.4	40.7	9192	139.6	38.7	9192	46.2	0.05 (0.02: 0.07)
Total (IC 95%)			**9714**			**9714**	**100%**	**0,12 (0,01; 0,24)**

Heterogeneity: $Tau^2 = 0.00$: $Chi^2 = 7.20$: gl = 4 (p=0.125): $I^2 = 47.1\%$



D

Study (year)	POC glucometer Mean	DE	n	Central laboratory Mean	DE	n	Weight (%)	Standardised mean difference (IC 95%)
Cordero Saucedo (2005) [1]	158.0	58.0	489	152	54	489	26.7	0.11 (-0.02: 0.23)
Cordero Saucedo (2005) [2]	164.0	54.0	489	152	54	489	26.6	0.22 (0.10: 0.35)
Cordero Saucedo (2005) [3]	162.0	60.0	489	152	54	489	26.6	0.18 (0.05:0.30)
Karon (2008)	162.0	53.0	96	149	35	96	5.2	0.29 (0.00: 0.57)
Shearer (2009)	125.7	37.5	62	118.7	38.7	62	3.4	0.18 (-0.17: 0.54)
Cook (2009)	123.9	31.4	67	114.4	30.1	67	3.6	0.31 (-0.03: 0.65)
Pereira (2015)	162.0	90.0	145	146	91	145	7.9	0.18 (-0.05: 0.41)
Total (IC 95%)			**1837**			**1837**	**100%**	**0.18 (0.12; 0.25)**

Heterogeneity: $Tau^2 = 0.00$: $Chi^2 = 2.83$: gl = 6 (p=0.830): $I^2 = 0\%$

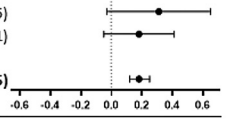


Figure 2 Meta-analysis. (2a) Meta-analysis of capillary samples with a POC glucometer vs. central laboratory. (2b) Meta-analysis of arterial samples with a POC glucometer vs. central laboratory. (2c) Meta-analysis of arterial samples with a POC blood gas analyser vs. central laboratory. (2d) Meta-analysis of venous samples with a POC glucometer vs. central laboratory.
95% CI: 95% confidence interval; df: degrees of freedom; [1]: Ascensia Elite™; [2]: Precision Q.I.D®; [3]: SureStep™ Plus; [4]: stable patients; [5]: patients with catecholamine; [6]: normotensive patients; [7]: hypotensive patients; [8]: Precision PCX®; [9]: Accu-check Advantage II®; [10]: Cobas B 221; [11]: ABL800 Flex; [12]: GEM Premier; *: estimated data; **: data supplied by the author.

(95% CI) is very small and it is not significant (0.01 [−0.12 to 0.14] mg/dL) (Fig. 2b).

The 4 studies[43,47–49] which compare glycaemia measured with POC blood gas analysers and in a laboratory consider blood gas analyser measurements to be reliable. In the meta-analysis (Fig. 2c) the blood gas analyser can be seen to always over-estimate, and the differences between the determination measured using a POC blood gas analyser and in a laboratory are significant in 2 comparisons.[48,49] The overall determination of the difference in the averages (95% CI) is also significant (0.12 [0.01 to 0.24] mg/dL).

The reliability of determinations in venous blood using a glucometer

The 5 studies found which compare venous glycaemia measured with a glucometer and in a laboratory[23–25,35,39] advise against using a glucometer. The meta-analysis of these 5 studies (7 comparisons) showed that the overall value shows a significant over-estimation in the difference between the averages (95% CI) of measurements using the glucometer vs. the laboratory (0.18 [0.12 to 0.25] mg/dL) (Fig. 2c).

Reliability of determinations in samples without a specified origin

Some authors analysed the reliability of glycaemia measurements without specifying the origin of the sample. Castaño López et al.[50] and Lacara et al.[21] recommend using a glucometer if the blood sample is arterial or venous, and they advise against this in the case of capillary samples. Finkielman et al. and He et al.[51,52] consider that glucometer measurements are not very reliable.

Analysis of the factors which influence the imprecision of glucose measurements by POC devices

Of the 32 papers included in this review, 15 (46.87%) analyse the influence of specific variables on the lack of precision of POC devices in comparison with laboratory measurements. The influence of a total of 18 variables was analysed, as these may explain the lack of agreement between measurements made using different devices (Table 2).

Haematocrit

The 4 studies[21,23,40,42] which analyse the influence of haematocrit on the lack of precision of POC devices were found to reach different conclusions. Two authors[40,42] find that haematocrit does not systematically influence the precision of a POC device, while the other 2[21,23] conclude that it does affect precision. Pereira et al.[23] consider that this imprecision increases when capillary blood samples are used in glucometers which base their analysis on pyrroloquinoline quinone glucose dehydrogenase (GDH-PQQ). Lacara et al.[21] observe that when haematocrit levels are below normal ranges, a glucometer with arterial samples tends to over-estimate glucose levels.

Haemoglobin

Only one study[22] analysed haemoglobin as a factor which may influence the discrepancy between glycaemia measured in different devices. This study finds that POC measurements of glycaemia in arterial blood are less precise due to the concentration of haemoglobin in a patient; when haemoglobin levels >12 mg/dL, the POC device tends to under-estimate glycaemia, while when haemoglobin levels are <10 mg/dL it overestimates glycaemia.

Acid-base balance: concentration of hydrogen ions and partial pressure of carbon dioxide

Three studies analyse the influence of the acid-base balance on the lack of agreement between glycaemia levels measured using different methods. They do so based on the concentration of hydrogen ions (pH)[23,40] and partial pressure levels of carbon dioxide (pCO_2).[21]

The results were found to be discrepant. While Rodríguez-Delgado et al.[40] determine that acid-base balance disorders do not influence the concordance of arterial and capillary blood glycaemia values in critical patients, Pereira et al.[23] determine that glycaemia values are over-estimated when the pH is low, and that this error increases with increasingly low levels of pH values.

Lacara et al.[21] conclude that pCO_2 should be considered a factor that influences imprecision, although they do not specify how.

Haemodynamic status

Nine papers analyse the influence of haemodynamic status on the lack of conformity in the results obtained by instruments and samples using different parameters: lactic acid and the SOFA score,[40] state of shock,[26,32,33,46] arterial hypotension,[51] average arterial pressure[21,27] and arterial hypertension.[22]

In general, 6 of these studies find that haemodynamic status influences the lack of precision of a POC device, 3 find that it under-estimates glycaemia[32,40,46] and 3 others find that it leads to over-estimation.[26,27,33] Three of these studies[21,22,51] found that haemodynamic status does not affect the concordance between POC values and those detected in a laboratory.

Rodríguez-Delgado et al.[40] observe that in patients with hyperlactacidaemia (>2 mmol/L), delay in capillary filling (>2 s) and in a situation of haemodynamic failure (SOFA > 4), the concordance between capillary and arterial glycaemia levels is affected. They found that capillary blood samples lead to under-estimation of glycaemia in comparison with levels determined in arterial blood, and that on the contrary, venous samples lead to over-estimation. The only possible explanation is contamination of the sample, so that they advise against using this type of blood sample for this purpose.

On the other hand, 4 of the studies evaluate shock as a confusion variable for lack of POC device precision, although here too a disparity in the results was observed. 2 of these studies[26,33] found systematic over-estimation of glycaemia in the POC device in patients who were in shock, as opposed to

Table 2 Influence of confusion variables on the differences in glycaemia values between methods and/or samples.

Study	Confusion variable	Results	Conclusions
Finkielman et al.[51], 2005, U.S.A.	Hypotension (ABP < 60 mmHg): Glucometer (SND) and laboratory (SND)	BA: deviation (95% limits of agreement): No hypotension: deviation 8 (−27.2–43.7) mg/dL Hypotension: deviation 8.9 (−19.8–37.6) mg/dL	The presence of hypotension does not seem to affect the difference between the glucometer and laboratory values.
	Vasopressors: Glucometer (SND) and laboratory (SND)	BA: deviation (95% limits of agreement): No vasopressors: 7.8 (−31.2–46.7) mg/dL Vasopressors: 9 (−12.2–30.2) mg/dL	The presence of vasopressors does not seem to affect the difference between the glucometer and laboratory values. No repercussion.
Kulkarni et al.[37], 2005, Australia	Systemic hypoperfusion (SBP < 90 mmHg or need for NAD or adrenalin): POC gas analyser-arterial blood and glucometer-capillary blood	BA: deviation (95% limits of agreement): Systemic hypoperfusion: 4 (−36.8–28.4) mg/dL	In patients with systemic hypoperfusion, hypoglycaemia may go undetected if both techniques are used indistinctly. Precaution is advisable when they are used interchangeably.
Arias-Rivera et al.[22], 2007, Spain	Haemoglobin: Glucometer-arterial blood and laboratory-arterial blood	BA: deviation (95% limits of agreement): < 10 g/dL: 8 (−9 to 26) mg/dL; > 12 g/dL: −13 (−50 to 24) mg/dL	Measurements made using capillary blood may be less precise depending on the concentration of haemoglobin. Over-estimation exists with levels of < 10 mg/dL, and under-estimation if the level is > 12 mg/dL
	HT: Glucometer-arterial blood and laboratory-arterial blood	BA: deviation (95% limits of agreement): HT: 0.4 (−27 to 27) mg/dL No HT: 4 (−25 to 34) mg/dL	HT does not influence the difference in values between methods when arterial blood is used, although a greater difference is observed than is found in normotensive patients.
	IV insulin therapy: Glucometer-arterial blood and laboratory-arterial blood	BA: deviation (95% limits of agreement): IV insulin: 5 (−23 to 33) mg/dL	Measurement error may increase in patients who are receiving insulin perfusion. The POC device may over-estimate in comparison with glycaemia values obtained in the laboratory.
	DM: Glucometer-arterial blood and laboratory-arterial blood	BA: deviation (95% limits of agreement): DM: 5 (−27 to 37) mg/dL No DM: 1 (−26 to 29) mg/dL	Measurement error and dispersion may increase in patients with previous diabetes in comparison with those who do not have diabetes, with a tendency towards over-estimation.
	Disease at admission: Glucometer-arterial blood and laboratory-arterial blood	BA: deviation (95% limits of agreement): Medical: 2 (−27 to 31) mg/dL Surgical: 1 (−27 to 29) mg/dL Multiple trauma: 7 (−17 to 31) mg/dL	Measurement error and dispersion may increase in patients with multiple trauma in comparison with those admitted due to medical disease or surgery. The POC over-estimated glycaemia in comparison with the laboratory.
Critchell et al.[28], 2007, U.S.A.	Vasopressors: Glucometer-capillary blood and laboratory-venous blood	RA: OR (95% confidence interval): OR: 2.81 (1.5−5.4)	The use of vasopressor agents is associated with a higher risk of discordant results, over-estimating glucose values in comparison with the laboratory.

Table 2 (*Continued*)

Study	Confusion variable	Results	Conclusions
	Oedema in an upper limb (0: no; 1: slight; 2: moderate; 3: severe): Glucometer-capillary blood and laboratory-venous blood	RA: OR (95% confidence interval): OR oedema grade 2—3: 2.1 (1.05—4.19)	Moderate or severe oedema in an upper limb is associated with an increase in the probability of discordant glycaemia results between the laboratory and glucometer.
Lacara et al.[21], 2007, U.S.A.	Haematocrit: Glucometer-arterial blood/capillary blood and laboratory-arterial/venous blood	RA (*P*): Capillary puncture in all patients, *P* = .10 POC arterial or central venous catheter in all patients, *P* = .04 POC capillary puncture in patients with an arterial catheter, *P* = .24 POC arterial catheter in all patients with arterial catheter, *P* = .02	When haematocrit levels are below normal ranges and a glucometer and arterial blood are used to measure glycaemia then glucose levels tend to be over-estimated in comparison with laboratory readings. In individual situations with abnormal levels of haematocrit the exactitude of the POC readings should be verified by comparing them with those of a laboratory using samples obtained at the same time.
	pCO_2 levels: Glucometer-arterial/capillary blood and laboratory-arterial/venous blood	RA (*P*): Capillary puncture in all patients, *P* = .09 POC arterial or central venous catheter in all patients, *P* = .004 POC capillary puncture in patients with an arterial catheter, *P* = .04 POC arterial catheter in all patients with arterial catheter, *P* = .002	pCO_2 levels influence the difference in glycaemia values between methods and samples.
	ABP: Glucometer-arterial/capillary blood and laboratory-arterial/venous blood	RA (*P*): Capillary puncture in all patients, *P* = .43 POC arterial or central venous catheter in all patients, *P* = .77 POC capillary puncture patients with arterial catheter, *P* = .40 POC arterial catheter all patients with arterial catheter, *P* = .55	ABP values do not influence the difference between methods and samples
Desachy et al.[27], 2008, France	ABP < 70 mmHg and need for NAD or adrenalin: Glucometer-capillary blood and laboratory (SND)	RA: OR (95% confidence interval), *P*: OR 0.96 per 1 mmHg (0.93—0.99 per 1 mmHg), *P* = .007	ABP is associated with values that conflict between the difference in values between POC-capillary blood and laboratory values, over-estimating the values of the latter.

Table 2 (*Continued*)

Study	Confusion variable	Results	Conclusions
	Perfusion index (low: < 0.3; acceptable: 0.3–1; optimum: > 1) Glucometer-capillary blood and laboratory (SND)	RA: OR (95% confidence interval), *P*: OR 1 unit point, 0.80 (0.65 to 0.99), *P* = .04	Low perfusion index values reflect peripheral hypoperfusion and are associated with a higher risk of erroneous capillary blood glycaemia values, so that in these cases capillary tests may not be justified.
	Generalized mottling (subjective cutaneous acrocyanosis and vasoconstriction on finger) Glucometer-capillary blood and laboratory (SND)	RA: OR (95% confidence interval), *P*: OR 3.58 (1.09–11.84), *P* = .04	The presence of generalized mottling is associated with a higher number of values in conflict between the difference in POC capillary blood values and those of the laboratory, over-estimating the values of the latter.
Meynaar et al.[42], 2009, The Netherlands	Haematocrit: Glucometer (corrected haematocrit 1.086 mg/dL)-arterial blood, and laboratory-arterial blood	BA: deviation (VC [%]): Haematocrit 15 %–19 %: 9 mg/dL (VC 6%) Haematocrit 20 %–24 %: −2 mg/dL (VC 2%) Haematocrit 25 %–29 %: −3 mg/dL (VC − 2%) Haematocrit 30 %–34 %: 3 mg/dL (VC 1%) Haematocrit 35 %–39 %: −2 mg/dL (VC − 2%) Haematocrit 39 %–44 %: 2 mg/dL (VC 1%) Haematocrit 45 %–49 %: 30 mg/dL (VC 25%)	The precision of AccuChek® is independent of haematocrit. Haematocrit does not systematically influence the corrected AccuChek® result in the range from 0.20 to 0.45. There were insufficient data outside this range.
Fekih et al.[33], 2010, Tunisia	Shock (SBP ≤ 90 mm Hg) and vasopressor therapy: Glucometer-capillary blood and laboratory-venous blood	BA: deviation (95% limits of agreement): No shock or catecholamine: 0.9 (−74.34–72.54) mg/dL Shock and catecholamine: 5.22 (−90.9–101.34) mg/dL	Measuring glycaemia using capillary puncture does not accurately reflect the level of glucose in serum in critical patients who receive catecholamine infusions, over-estimating in comparison with laboratory findings.
Juneja et al.[46], 2011, India	Shock and vasopressors (≥ 0.1 μg/kg/min. NAD to maintain ABP > 70 mmHg): Glucometer Arterial and capillary samples	BA: deviation (95% limits of agreement): Shock: 7.28 mg/dL (−49.1–63.7) mg/dL No shock: −0.43 (−26.1–25.2) mg/dL	Monitoring glycaemia using capillary blood is only reliable in a group of ICU patients. Precaution is required in patients in shock and receiving vasoactive drugs, and arterial blood is preferable. Capillary samples under-estimate arterial glucose values.

Table 2 (*Continued*)

Study	Confusion variable	Results	Conclusions
DuBose et al.[26], 2012 , U.S.A.	Shock (SBP ≤ 90 mmHg or ABP < 70 mHg): Glucometer-capillary blood and laboratory-arterial/venous blood (SND) Agreement defined as a difference in glucose values between instruments < 15%	BA: deviation (limits of agreement): All samples: 12.4 (−22.4–47.2) mg/dL Shock: 13.4 (−27.1–53.9) mg/dL No shock: 12.6 (−20.6–45.8) mg/dL Degree of agreement according to glycaemia level and situation of shock: General population: total agreement 59.9% (hypoglycaemia 34.0%; normoglycaemia 62.9%; hyperglycaemia 68.4%) Shock: total agreement 62.9% (hypoglycaemia 41.5%; normoglycaemia 69.1%; hyperglycaemia 56.8%) No shock: total agreement 59.2% (hypoglycaemia 30.3%; normoglycaemia 61.4%; hyperglycaemia: 78.5%)	There is poor correlation between the capillary blood glucose values and those of the laboratory in states of shock and without shock following injury. In ranges close to or below hypoglycaemia thresholds traditional laboratory measurements should be used to confirm the values registered using capillary sampling methodology before starting treatment. With capillary blood glycaemia levels are over-estimated in comparison with those determined in a laboratory.
Garingarao et al.[32], 2014, Philippines	Shock (ABP < 70 mmHg or the need for vasopressor support): Glucometer-capillary blood and laboratory-venous blood (SND)	BA: deviation (95% limits of agreement): Normotension: −12.4 (−86.0–61.2) mg/dL Hypotension: −34.9 (−207.1–137.4) mg/dL	Glucose measurements using the POC device and capillary blood in critical but normotensive patients offer an acceptable level of precision (at least with the measurement technology used) on condition that no known confusion factors are present and standardized sample-taking techniques are followed.
Pereira et al.[23], 2015, U.S.A.	Haematocrit: Glucometer 1 (GDH-NAD)-arterial blood Glucometer 2 (GDH-PQQ)-arterial/capillary/venous blood Laboratory-arterial blood	BA: deviation (95% limits of agreement), *P*: Glucometer 1-arterial blood: −0.89 (−1.38 to −0.40) mg/dL, *P* < .001 Glucometer 2-arterial blood: −0.74 (−1.29 to −0.19) mg/dL, *P* = .009 Glucometer 2-capillary blood: −1.04 (−1.75 to −0.32) mg/dL, *P* = .005	Haematocrit level influence the lack of precision in glycaemia values using the POC device, over-estimating the glucose values found in a laboratory.
	pH: Glucometer 1-arterial blood Glucometer 2-arterial/capillary/venous blood Laboratory-arterial blood	BA: deviation (95% limits of agreement), p: Glucometer 2-venous: −77,4 (−135,7 a −19,1) mg/dL, p = 0,010 Glucometer 2-arterial: −34,8 (−62,8 a −6,7) mg/dL, p = 0,009	The error with the Accu-Chek® Advantage II glucometer (GDH-PQQ) increases at lower pH levels. Capillary glycaemia is an over-estimation compared to laboratory values.

Table 2 (*Continued*)

Study	Confusion variable	Results	Conclusions
	Vasopressors: Glucometer 1 (GDH-NAD)-arterial blood Glucometer 2 (GDH-PQQ)-arterial/capillary/venous blood Laboratory-arterial blood	BA: deviation (95% limits of agreement), *P*: Glucometer 2-capillary blood: −25.8 (−40.1 to −11.5) mg/dL, *P* = .001 As well as being associated with the average deviation, increasing glycaemia levels are also associated with broader limits of concordance, which implies that precision declines during hyperglycaemia.	The error which arises when using the Accu-Chek® Advantage II POC device (GDH-PQQ) and capillary blood increases when noradrenalin is used. Capillary blood glycaemia under-estimates laboratory glycaemia findings.
He et al.[52], 2021, China	Ascorbic acid Glucometer-capillary blood and laboratory (SND)	BA: deviation (95% limits of agreement): Ascorbic acid therapy: −43.83 (−177.97 to 90.32) mg/dL Compliance according to the dose of vitamin C administered (%): Low dose 38.30% High dose 34.29% Precision according to the presence of kidney failure (%): No deterioration 45.24% Kidney failure: 37.50% RRT 22.22% Increased renal clearance 20%	High doses of vitamin C in IV infusion may interfere with measurements of the POC device in comparison with the laboratory, under-estimating glycaemia values. The patients who receive high doses of vitamin C should adjust glucometer results using those of the laboratory. Moreover, kidney function may represent another important factor in reducing the precision of POC devices.
Howell et al.[36], 2021, U.S.A.	Ascorbic acid Glucometer-capillary blood and laboratory-venous blood	BA: deviation (95% limits of agreement): Ascorbic acid therapy: 0.33 (−57.7–58.1) mg/dL Compliance with ISO criteria according to kidney function: No KF 82.4% KF 45.55% RRT 83.3%	Treatment with vitamin C increases the disagreement between POC device measurements and those of a laboratory. Our study shows that kidney function affects the risk of imprecision in a POC device, over-estimating in comparison with the values found in a laboratory.
Rodríguez-Delgado et al.[40], 2022, Spain	Haematocrit: Glucometer Arterial, capillary and venous blood samples	Disagreement-survival analysis (*P*): Haematocrit levels ($\leq$ 25% or > 25%): Log Rank test, *P* = .1	Haematocrit levels do not influence the concordance of arterial, capillary and central venous blood glycaemia determined by a POC device (GDH-NAD).

Table 2 (*Continued*)

Study	Confusion variable	Results	Conclusions
	pH: Glucometer Arterial, capillary and venous blood samples	Disagreement-survival analysis (*P*): pH (< 7.35; 7.35−7.45; > 7.45): Log Rank test, *P* = .7	Acid-base balance disorders do no influence the concordance of arterial, capillary and central venous blood glycaemia.
	Lactate: Glucometer Arterial, capillary and venous blood samples	Disagreement-survival analysis (*P*): Level of lactic acid in serum ($\leq$ 2 or > 2 mmol/L): Log Rank test, *P* = .002	Using capillary blood samples leads to under-estimation of glycaemia in patients with lactic acidosis, while the use of venous blood samples leads to over-estimation due to sample contamination.
	Haemodynamic failure: Glucometer Arterial, capillary and venous blood samples	Disagreement-survival analysis (*P*): Haemodynamic failure (SOFA score $\geq$ 4): Log Rank test, *P* = .02 Subpopulation without haemodynamic failure (SOFA score < 4): the degree of concordance improves in all of the patients. The cut-off values for 10% disagreement is an absolute difference of 16 mg/dL	Venous blood samples lead to over-estimation of glycaemia (due to contamination of the sample), while it is under-estimated in capillary blood samples.
	Vasopressors: Glucometer Arterial, capillary and venous blood samples	Disagreement-survival analysis (*P*): Treatment with noradrenalin (capillary and arterial). Analysis of atypical values (difference > 40 mg/dL): supportive treatment with noradrenalin was significantly greater (0.27 μg/kg/min. dose as opposed to 0.69 μg / kg / min., *P* = .003) for atypical values.	Capillary blood samples lead to under-estimation of glycaemia in patients receiving vasoactive drugs (noradrenalin at a dose of 0.1 μg/kg/min.).
	Capillary filling: Glucometer Arterial, capillary and venous samples	Disagreement-survival analysis (*P*): Reduced capillary filling (> 2 s): Log Rank test (arterial and capillary blood), *P* < .001)	Reduced capillary filling affects arterial and capillary concordance in glucometry determinations, under-estimating values when capillary blood is used.
	IV insulin: Glucometer Arterial, capillary and venous blood samples	Disagreement-survival analysis (*P*): IV insulin therapy: Log Rank test (capillary and arterial), *P* = .03	Capillary blood samples lead to under-estimation of glycaemia in patients receiving IN insulin therapy.

ABP: Average blood pressure; BA: Bland and Altman; DM: Diabetes mellitus; GDH-NAD: Glucose dehydrogenase with nicotinamide-adenine-nucleotide; GDH-PQQ: Glucose-dehydrogenase-pyrrolquinoline quinone; HT: Hypertension; ICU: Intensive Care Unit; IV: Intravenous; KF: Kidney failure; NAD: Noradrenalin; OR: Odds ratio; POC: Point of care; RA: Regression analysis; RRT: Renal replacement therapy; SBP: Systolic blood pressure; SND: Sample not described; VC: Variation coefficient.

normotensive patients. DuBose et al.[26] also found that this difference in glycaemia values between methods increases within the range of hypoglycaemia. The studies by Juneja et al.[46] and Garingarao et al.[32] find that shock influences the lack of precision of POC devices, with a clear tendency to over-estimate capillary glycaemia. They therefore advise against using them in haemodynamically unstable patients, and they recommend using arterial blood samples for glucose monitoring. Nevertheless, Finkielman et al.[51] conclude that hypotension in a critical patient does not seem to affect the difference in glucose values measured by different devices.

With respect to the possible role of average arterial pressure as a confusion factor, Lacara et al.[21] found no relationship between it and differences in glycaemia depending on the test method used, while Desachy et al.[27] associated it with a higher number of conflicting values, observing systematic over-estimation of capillary blood glycaemia with a POC device.

For patients with arterial hypertension, the research undertaken by Arias-Rivera et al.[22] concludes that it does not affect the precision of a measuring device when arterial blood samples are used.

Perfusion

Four studies analyse perfusion as a confusion variable for the precision of POC devices, and the majority conclude that it may be considered to be a factor that influences the precision of these devices.

Critchell et al.[28] state that oedema in the fingers in grade II-III affects the precision of a glucometer when it is used for capillary blood samples, with a tendency to over-estimate. On the contrary, Desachy et al.[27] evaluate the state of perfusion by using the perfusion index and the presence of cutaneous vascular alterations (generalized mottling), observing that low perfusion index values and the existence of generalized mottling as an indicator of peripheral hypoperfusion are associated with a higher risk of erroneous values in capillary blood glycaemia, which may be over- or under-estimated. Rodríguez-Delgado et al.[40] find that reduced capillary filling may affect the concordance between arterial and capillary samples determined by glucometry, although they do not specify how it is affected.

The results obtained by Kulkarni et al.[37] are not able to prove that there is an association between a lack of precision when using capillary samples with a glucometer and systemic hypoperfusion.

Vasopressor therapy

Six studies analyse the influence of vasopressor drugs on the precision of POC devices in critical patients. Five of these studies[23,28,33,40,46] show that there is a higher risk of discordant results when glycaemia in capillary blood from critical patients with vasopressor support is measured. It was found to be systematically under-estimated, especially with noradrenalin doses higher than 0.1 μg/kg/min.

On the contrary, Finkielman et al.[51] did not find that vasopressor drugs affect glucose determinations measured using a glucometer based on the glucose-oxidase analytical technique, although their study does not specify the type of sample they used.

Other pharmacological therapies: intravenous insulin and vitamin C

Four studies analyse the influence of drug therapy on discordancy in glucose values.

The studies by Arias-Rivera et al.[22] and Rodríguez-Delgado et al.[40] agree that intravenous insulin therapy should be considered a factor that causes imprecision in the determination of glycaemia measured by glucometry, although they disagree about its mode of action: while the first believe that the said values are over-estimated, the latter believe that they are under-estimated.

Two other studies[36,52] analyse the influence of treatment with ascorbic acid as a confusion factor in septic patients, and they agree that this therapy increases the risk of POC device imprecision. While Howell et al.[36] observe a tendency to over-estimate, He et al.[52] determine that this therapy leads to under-estimation in capillary samples, especially in patients with deterioration of kidney function, a need for renal replacement therapy or altered renal clearance.

A history of diabetes mellitus and reasons for admission to intensive care

Only one study was found which analyses the influence of previous metabolic alterations and the type of disease which leads to admission to an ICU. Arias-Rivera et al.[22] find that patients with diabetes mellitus are at higher risk of lack of precision in glycaemia determination using arterial blood samples and a POC device, while traumatology is associated with greater discordancy than surgery or medical disease.

Analytical performance of POC devices based on interchangeability criteria

Of the 32 papers selected in the review, 17 (53.12%) analyse the performance of a POC device (glucometer/blood gas analyser) using different interchangeability criteria (Appendix A Supplementary Material. Table S3).

The majority of the studies carried out[24,27–30,32,36,42–46,50,52] consider that monitoring glycaemia in critical patients is less precise in terms of concordance than the benchmark method (laboratory analysis). This is chiefly because it is determined using capillary samples, in the presence of shock and vasopressor support, when there is kidney failure or during treatment with vitamin C.

Only 2 authors[38,50] conclude that using a glucometer is exact and reliable in terms of quality and device performance when measuring glucose in intensive care settings, above all when arterial samples are used.

On the contrary, 5 studies[38,43,45,48,49] favour determining glycaemia in an ICU using a POC blood gas analyser, which they find has a good level of compliance with interchangeability criteria in comparison with the benchmark method (laboratory analysis). No study considers POC blood gas analysers to be a low precision device.

Methodological quality of the included studies

The majority of the studies are of acceptable quality in spite of their observational design, with a low probability of deviation and low risk in the applicability of their findings. The highest risk of distortion was found in patient selection, where 53% of the studies have an uncertain or high risk (Appendix A Supplementary Material Table S4 and figure* S1).

Discussion

After this systematic review of 32 papers, we consider determinations using arterial blood samples and POC glucometers to be reliable for bedside glycaemia monitoring of critical adult patients, although this reliability depends on many factors which in turn could be partially overcome by using latest generation instruments. The determinations made using POC blood gas analysers are also reliable, and their precision is unaffected by confusion factors.

The studies analysed in this review compare the levels of glycaemia measured using arterial blood samples with laboratory determinations. They show a deviation that varies from −0.1 to 18.6 mg/dL when measured using a glucometer and from −3.6 to 10.7 mg/dL when measured with a POC blood gas analyser. These deviations are less than those reported by Inoue et al.[6] (from −10 to 23 mg/dL with a glucometer and from −2.7 to 25.2 when a POC blood gas analyser was used). Arterial blood samples are the ones that offer the best concordance in the meta-analysis, and they are recommended by Finfer et al.[3]

Nevertheless, if no arterial catheter is in place, the recommendation is to extract samples using a venous catheter.[3] The meta-analysis of this review shows that the differences in the resulting values in comparison with laboratory determinations are significantly higher, and all of the authors in this review[23–25,35,39] advise against using these.

The majority of the studies located analyse glucose measured using capillary blood samples in a glucometer and compared to determination in a laboratory. These studies found deviations from −9.87 to 12,4 mg/dL, and this deviation increases (−34.9–13.4 mg/dL) in unstable patients or those receiving catecholamine. These data are similar to those reported in the review by Inoue et al.,[6] with deviations from −16 to 9.9 mg/dL and an increase in inaccuracy in patients treated with vasopressors. On the other hand, as well as finding that glycaemia measured using glucometers is over-estimated, we also found that this deviation increases in the case of higher levels of glycaemia.[31,35] The consensus recommendations published by Finfer et al.[3] consider that capillary blood samples from ICU patients, and particularly those who are haemodynamically unstable or receiving catecholamine, may lead to major errors in comparison with the benchmark method. Although capillary samples are the most accessible and the least invasive, there is no doubt that they are the least advisable form of sample when monitoring glycaemia in critical patients. Capillary samples would only be recommendable for use in stable patients without an arterial catheter who do not require strict control of glycaemia. Therefore, and as these recommendations state,[3] intermittent glycaemia monitoring in a critical and haemodynamically unstable patient should use a POC blood gas analyser instead of a glucometer, as the former comply more closely with the criteria governing the precision and quality of these devices.

Glucose values determined using a POC blood gas analyser differ from 0.5% to 8%[43,48,49] in comparison with the benchmark method. This method has a lower percentage of variability (2%)[43] and an average difference in glycaemia values of −10.7 mg/dL.[48] This appears to be an acceptable deviation in critical patients, and it would be unlikely to lead to a clinically relevant therapeutic error. On the contrary, the habitual practice of using a glucometer should be ruled out, as the performance of these devices is affected by numerous variables. Their lack of exactitude increases under conditions of clinical instability or the need for vasopressor support,[29,32,46] kidney failure,[36,52] hypoglycaemia,[42,44,50] the administration of high doses of ascorbic acid,[52] higher scores on severity scales and mortality predictors in critical patients,[45] as well as when they are used with capillary blood samples.[24,28,30]

Although the influence of many variables on the difference in values between POC devices and the benchmark method has been studied, no study has analysed the impact of the deviation caused by the sum of all of the confusion variables on lack of device precision and the resulting clinical risk and morbimortality.

This review has certain limitations. Firstly, the instruments used and the analytical methods are highly heterogeneous, and this hinders comparison of the studies. All of the selected studies are observational and some of them are retrospective, so that the conclusions should be accepted with precaution. No studies report on how the different instruments behave when patients have hypoglycaemia, so that we do not know how reliable they are in these critical situations; we have only found studies that modified the sample in the laboratory, so that they were not included in the review. Some authors do not specify the origin of the blood sample used, so that we cannot compare the studies in question with others to evaluate the reliability of the instruments used.

It should be underlined that the majority of the studies which find that glucometers perform sufficiently well were based on the most permissive international norms governing precision and interchangeability, all of which were designed for non-critical patients. Furthermore, different standards were used to evaluate the instruments, so that this may have distorted the results. Lastly, no single criterion has been agreed to delimit the amount of deviation that is acceptable for an instrument to be considered reliable; each author uses their own criterion, so that we are unable to specify which instruments are reliable, only that some are more reliable than others as they show less deviation.

Conclusions

In spite of the heterogeneity of the instruments and samples used in the studies that were analysed, we consider that glycaemia monitoring in critical patients who are haemodynamically unstable and require intensive monitoring of glycaemia should be undertaken using arterial blood samples and POC blood gas analysers, as this is more reliable

and is not affected by the variability of different confusion factors. Determining glycaemia in capillary blood using glucometry may be suitable in stable patients or when close monitoring of glycaemia is not required.

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Conflict of interests

The authors have no conflict of interests to declare.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.enfi.2023.02.003.

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