The diagnostic test accuracy of telemedicine for detection of surgical site infection: a systematic review and meta-analysis

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Abstract

Introduction

The Sars-CoV-2 pandemic catalysed integration of telemedicine worldwide. This systematic review assesses it's accuracy for diagnosis of Surgical Site Infection (SSI).

Methods

Databases were searched for telemedicine and wound infection studies. All types of studies were included, only paired designs were taken to meta-analysis. QUADAS-2 assessed methodological quality.

Results

1400 titles and abstracts were screened, 61 full text reports were assessed for eligibility and 17 studies were included in meta-analysis, mean age was 47.1±13.3 years. Summary sensitivity and specificity was 87.8% (95% CI, 68.4-96.1) and 96.8% (95% CI 93.5-98.4) respectively. The overall SSI rate was 5.6%. Photograph methods had lower sensitivity and specificity at 63.9% (95% CI 30.4-87.8) and 92.6% (95% CI, 89.9-94.5).

Conclusion

Telemedicine is highly specific for SSI diagnosis is highly specific, giving rise to great potential for utilisation excluding SSI. Further work is needed to investigate feasibility telemedicine in the elderly population group.

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Background

Surgical site infections (SSI) complicate up to 40% of surgical procedures depending on operative type and procedure[1]. By definition, an SSI occurs within 30 days of surgery (or within 90 days if an implant is left in place)[2]. Given the current health landscape, the mean postoperative inpatient stay is four days, therefore the majority of SSI become apparent after discharge[3 4]. Early recognition of SSI is essential to minimise associated morbidity and mortality, and patients frequently seek care from primary or community care providers, who may not be familiar with managing surgical complications. Strategies are required to enable secondary care providers to conduct robust surveillance and follow up of surgical wounds[5 6].

Telemedicine is an innovative solution for monitoring patients and their wounds postoperatively. Remote consultations ameliorate the need to leave home and associated carer requirement, reduce travel times and costs, and reduce waiting room times and risk of nosocomial infection[7–9]. Patients frequently find the experience reassuring and many would prefer future consultations by this method[10–12]. A reduction in patient travel seems to have wider implications still; a recent review concluded that the use of telemedicine consistently reduces carbon footprint compared with face-to-face reviews, even when factoring the impact of equipment and resource use[13]. With national targets such as net zero emissions by 2045, implementation of remote measures may become a mainstay of practice in years to come[14]. The SARS-CoV-2 pandemic catalysed integration of digital health models worldwide and telemedicine was applied at the forefront of many patient facing services. Surgical follow-up has followed with rapid adoption of remote post-operative follow-up, but cautious examination is warranted before being welcomed as standard practice[15]. Telephone consultations, whilst providing invaluable information at a fraction of clinic resource use, do not provide direct visualisation of a patient's post-operative wound. However, even with the addition of a visual aspect in photo- or video-based approaches, there are barriers to this service. For example, erythema, a hallmark characteristic of accepted SSI definitions, has poor levels of interobserver agreement on photograph assessment[16–18]. Before telemedicine can be unanimously recognised as established practice substantial evidence of diagnostic accuracy is required.

The aim of this study was to (1) establish the overall accuracy of telemedicine for diagnosis of SSI; (2) identify factors associated with heterogeneity of findings between studies; and (3) assess the effect of individual telemedicine methods and impact of varying reference standards on diagnostic accuracy.

Methods

This study was conducted in accordance with the Cochrane handbook for systematic reviews of diagnostic test accuracy, and has been reported in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-DTA) statement, a copy of which is attached to this article as an Appendix (Appendix 1)[19–21]. The protocol for this review was prospectively registered with PROSPERO (ID CRD42021290610) and has been submitted for peer reviewed publication, with a pre-print available online[22].

Search strategy and selection criteria

Studies meeting the following criteria were considered for inclusion:

i. Participants: All post-operative patients over 18, of any operation type. No restrictions were placed on the study setting or length of follow-up.
ii. Index tests: Telemedicine by any method (telephone, photograph or questionnaire), including the use of questionnaires as these can be delivered remotely.

iii. Reference Standards: Face to face review, as per the United States (US) Centres for Disease Control and Prevention (CDC) criteria for SSI is deemed the gold standard, but no restrictions were placed if other methods were use. This was to ensure all available evidence would be synthesised.

iv. Target condition: SSI as defined by the CDC criteria; infection within 30 days of surgery or within 90 days if an implant is left in place[23].

v. Study design: Abstracts, reviews and conference proceeding were excluded. All other research designs were included in the systematic review, but only comparative, paired methodologies were taken forward to meta-analysis as all patients would experience index tests and reference standards.

Studies were excluded if they did not meet the inclusion criteria or were not presented in English (for lack of resources to translate other languages). The following databases were searched from inception to January 2022: Medline, Embase, CENTRAL and CINAHL. A combination of synonyms related to the keywords; “telemedicine” AND “surgical wound infection” formulated the terms used. The strategy used for Medline, Embase and CINAHL can be found in appendix 2.

The search strategy was developed with and conducted by an information specialist who uploaded results onto the Rayyan, a bespoke tool for conducting systematic reviews[24]. These were deduplicated before screening of titles and abstracts by two independent reviewers against the inclusion criteria. Relevant manuscripts were retrieved for full text review, and assessed for eligibility by two independent reviewers. Reference lists of these articles were searched manually for any additional studies not identified in preliminary search. Any disagreement at each stage was resolved by a third reviewer for consensus.

There were no limitations placed on study design for qualitative synthesis to comprehensively synthesise the literature. Reports with paired designs were taken forward for quantitative analysis to enable random-effects bivariate meta-analysis, and summary receiver operator characteristic (SROC) curves to be plotted.

Data extraction

A bespoke data spreadsheet (Microsoft Excel Version 16.59) was designed and utilised for data extraction by two independent authors. Data on study and diagnostic characteristics (author, year, country, study design, sample size, gender, age, telemedicine method, reference standard, type of surgery, follow-up schedule) among potential confounding factors (diabetes, BMI, and smoking status) were collected in addition to SSI rates, sensitivity, and specificity of diagnosis.

Surgical site infections were defined as per CDC criteria[2]. Only superficial SSI were included due to inherent barriers of diagnosing deep SSI remotely. No restrictions were placed on classification of telemedicine, reference standard type, or other characteristics.

Assessment of methodological quality

Risk of bias and the applicability of studies were assessed again by two independent reviewers with the QUADAS-2 tool[25]. Agreement of 80% across all categories on two included studies was considered sufficient before further assessment of remaining studies, as recommended by the Cochrane handbook for systematic reviews of diagnostic test accuracy[20]. Risk of bias and applicability scores were taken into consideration for subgroup meta-analysis, ascertaining a strength of recommendation from data retrieved.

Statistical analysis

Continuous descriptive characteristics were expressed as weighted mean averages with standard error. A bivariate model for meta-analysis was used to produce summary measures of sensitivity and specificity with confidence regions. All studies with paired designs had pooled forest plots and summary receiver operator characteristic curves synthesised in the initial exploratory analysis. Analysis was conducted with MetaDTA and plots constructed with Review Manager 5.4[26 27]. Additional sources of heterogeneity were investigated through covariates (study country, type of surgery, telemedicine method, reference standard used).

For cases of multi-threshold test positivity, the cut-off achieving the maximum possible sensitivity – specificity trade off were taken forward. Indeterminate index test results were classified as ‘no SSI’ as this more closely reflects what would happen in practice. Tests were grouped as a unified ‘telemedicine’ and through the sub-groups; ‘photograph,’ ‘telephone,’ and ‘questionnaire.’ No studies reported video-based methods.

Subgroup analysis

All studies which compared photograph to face to face review will be referred to as photograph based telemedicine methods. Photograph-based methods utilise visual input whereas questionnaire and telephone do not incorporate trained physicians viewing a patient’s wound. As such, pre-specified analysis is conducted for studies including these methods for their sensitivity and specificity. Further analyses are performed as per the reference standard used and whether a pre-specified threshold was stated.

Results

Study selection

The study selection process flow diagram is shown in figure 1. A total of 1400 records were screened after 488 duplicates removed. After title and abstract screening, 61 full text reports were assessed for eligibility. The final review included 19 studies, and 17 had paired designs taken into a meta-analysis[16 28-45]. 11,437 observations were made in 19,090 patients as ten studies only included telemedicine investigation in a subset of patients[28-32 35 36 38 40 42].Three

reports were unable to be retrieved. For each, contact was attempted through the publishing journal and first author on two separate occasions, after which studies were excluded from review.

Characteristics of included studies

Studies were conducted in nine countries across five continents globally. Five were in low or lower-middle income economies, as per the World Bank classification[28 29 32 37 38]. The remaining reports were from high income economies. Weighted mean age of participants across the included reports was 47.1 ±13.3 years. Female patients made up 57.4% participants. Pooled SSI rate was 5.6% (95% CI, 5.49-5.74). Individual study characteristics can be found in table 1.

Methodological quality of included studies

A summary of QUADAS-2 assessments is presented in figure 2. Risk of bias was present in all studies, and two studies were scored as high risk of bias in all domains[32 40]. This was largely owing to inconsecutive sampling, clarity over interpretation of index tests without knowledge of the reference standard (and vice versa), the interval time between interpretation of index test and reference standard, and only subgroups of patients being included in study analysis. Nine reports had high applicability concerns, principally from the index test, patients or reference standard differing from the review question[32-34 36 38 39 42 44]. Risk proportions are displayed in figure 3.

Synthesis of results

Individual study estimates of test accuracy are presented in figure 4 as a coupled forest plot of sensitivity and specificity. Index tests were categorised into photograph, telephone and questionnaire based methods, with five[16 31 33-35], nine[28 29 32 37-41 43] and three studies[30 36 42] available for each respectively. 15 manuscripts[16 28-31 34-43] utilised a CDC based reference standard, with the remaining two[32 33] having empirical or site-specific protocol for these. Two studies[32 33] conducted follow up within 14 days, and a further four studies[34 36 40 42] were unclear as to the timeframe for reference standard review. There were no studies available that compared multiple index tests or reference standards.

The mean sensitivity of all telemedical methods for SSI diagnosis is 87.9% (95% CI, 68.4-96.1) and mean specificity is 96.8% (95% CI, 93.5-98.4). Mean values broken down by index test is shown in table 2. Youden's index is acceptable at 0.847. Random effects SROC curve for all methods of telemedicine in diagnosis of SSI shows a symmetric design approaching the top left corner and is plotted in figure 5. Heterogeneity seen in the 95% prediction region is explored further in subgroup analysis. Overall diagnostic odds ratio indicates high effectiveness for SSI diagnosis at 217.6 (95% CI, 47.0-1006.8).

Subgroup analysis

Five studies utilised photograph based telemedicine[16 31 33-35]. A total of 1638 observations were available in 2287 patients, again due to subsets being included in diagnostic test accuracy analysis. The weighted average age was 46.8 ± 11.7 years and 35.8% of patients were female. All studies were conducted in high income countries (HIC). SSI rate across the available studies was 3.72% (95% CI, 3.16-4.29). The mean sensitivity for photograph based methods is 63.9% (95% CI, 30.4-87.8) and mean specificity 92.6% (95% CI, 89.9-94.5). The random effects SROC curve for photograph based methods shows a symmetric distribution and is displayed in figure 6. Overall diagnostic odds ratio indicates good test effectiveness at 22.0 (95% CI, 4.7-102.5). Heterogeneity is largely reduced, although the region of confidence is conversely enlarged.

Comparative index test SROC curve analysis reveals three distinct distributions of symmetric plots with telephone methods showing superior test accuracy, approaching the upper left corner (Appendix 3). CDC criteria were used as the reference standard in all but two studies[32 33]. Analysis of tests standardised by CDC reference standard marginally increases overall sensitivity to 90.3% (95% CI, 0.695-0.974) but has no significant impact on specificity (96.8%, 95% CI, 0.932-0.985). SROC curve for telemedicine using CDC criteria reflects this marginal increase in sensitivity but 95% prediction region is also increased in size (Appendix 4). Summary test accuracy by CDC reference standard are represented in Appendix 5. All methods of telemedical follow-up are informative with diagnostic odds ratios >10.

Discussion

Study selection

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Conclusion

The evidence suggests that using telemedicine to diagnose SSI is highly specific and as such could be utilised as an effective screening tool in patients post discharge. Implementation of this method has great potential in the reduction of resource use, associated healthcare cost, and patient and clinician time expenditure. It has widespread applications spanning geographical and socioeconomic barriers and would improve the carbon footprint of health services globally. However, the average age of participants in all studies is relatively young and as such may under-represent the surgical population. Widespread adoption of telemedicine without strategies to improve inclusion may therefore disproportionately discriminate against the elderly or infirm. Included studies were also at risk of bias which may impact upon the validity of results. Further work is required to maximise engagement with telemedicine in digitally naïve or incapable populations, and to determine the specific utility of telemedicine within clinical practice in order to maximise its benefits.

Declarations

Competing Interests

The authors declare no competing financial interests, but the following competing non-financial interests; authors JT, GS and IC were co-authors on one study included in the meta-analysis[16].

Data Availability

The source data, and results of analysis, can be released upon reasonable request to the corresponding author.

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Tables

Table 1: Individual study characteristics. SD: Standard Deviation. BMI: Body mass index.

Author	*Year*	*Country*	*Mean Age (+/-SD)*	*Total events*	*Total Patients*	*Female Gender (%)*	*Telemedicine method*	*Reference standard*	*Type of surgery*	*Diabetes (%)*	*Smoking (%)*
Abu-sheasha	2020	Egypt	-	309	351	-	Telephone	CDC	Multispecialty	-	-
Aiken	2013	Kenya	30.0 (9.0)	89	1172	1060	Telephone	CDC	Multispecialty	-	-
Bluebelle	2019	UK	53.2 (17.5)	208	732	428	Questionnaire	CDC	Multispecialty	60 (7.7)	350 (45.1)
Bruce	2021	UK	44.1 (14.1)	1036	1550	302	Photograph	CDC	Trauma	63 (8.1)	218 (28.6)
Cherian	2020	Rwanda	26.5	219	596	456	Telephone	Empirical	O&G	-	-
Gunter	2018	USA	63.0	40	40	10	Photograph	Site protocol	Vascular	-	-
Halwani	2016	USA	28.5 (6.8)	177	193	193	Telephone	CDC	O&G	-	-
Hedrick	2015	USA	59.5 (6.7)	171	171	89	Photograph	CDC	General	21 (12.3)	28 (16.4)
McLean	2021	UK	44.3 (17.3)	335	489	266	Photograph	CDC	General	23 (4.7)	-
Mitchell	1999	Australia	63.3	649	1360	636	Questionnaire	CDC	Multispecialty	-	-
Mousa	2019	USA	64.0 (7.2)	30	30	14	Photograph		Vascular	12 (40.0)	15 (50.0)
Nguhuni	2017	Tanzania	26.3 (6.5)	484	324	324	Telephone	CDC	Obstetrics	-	-
Pathak	2015	India	-	156			Telephone	CDC	-	-	-
Pham	2016	USA	54.1(19.0)	2853	2853	1844	Telephone	CDC	Multispecialty	367 (12.9)	359 (12.6)
Reilly	2005	UK	67.0 (10.4)	105	422	201	Telephone	CDC	Orthopaedics	-	-
Richter	2017	Israel	50.5 (17.7)	263	266	125	Telephone	CDC	General	-	-
Sands	1996	USA	42.0	1799	5572	3343	Questionnaire	CDC	Multispecialty	-	-
Taylor	2003	UK	-	2665	-		Telephone	CDC	General	-	-
Totty	2018	UK	61.1	56	37	14	Photograph	ASEPSIS/CDC	Vascular	10 (27.0)	28 (75.7)

Table 2: Summary test accuracy of surgical site infection diagnosis by index test method. SSI: surgical site infection. CI: confidence interval

Index Test	Reference Standard	Number of Studies (Participants)	Number with SSI (%)	Summary sensitivity % (95% CI)	Summary Specificity % (95% CI)	Diagnostic Odds Ratio (95% CI)
All	All	17 (11437)	642 (5.6)	87.9 (68.4-96.1)	96.8 (93.5-98.4)	217.6 (47.0-1006.8)
Photograph	All	5 (1638)	61 (3.7)	63.9 (30.4-87.8)	92.6 (89.9-94.5)	22.0 (4.7-102.5)
Telephone	All	9 (7143)	360 (5.0)	97.0 (70.8-99.8)	97.7 (92.0-99.4)	1351.5 (73.1-24994.7)
Questionnaire	CDC	3 (2656)	221 (8.3)	69.8 (32.6-91.7)	97.6 (88.7-99.5)	93.8 (6.4-1366.8)

Figures

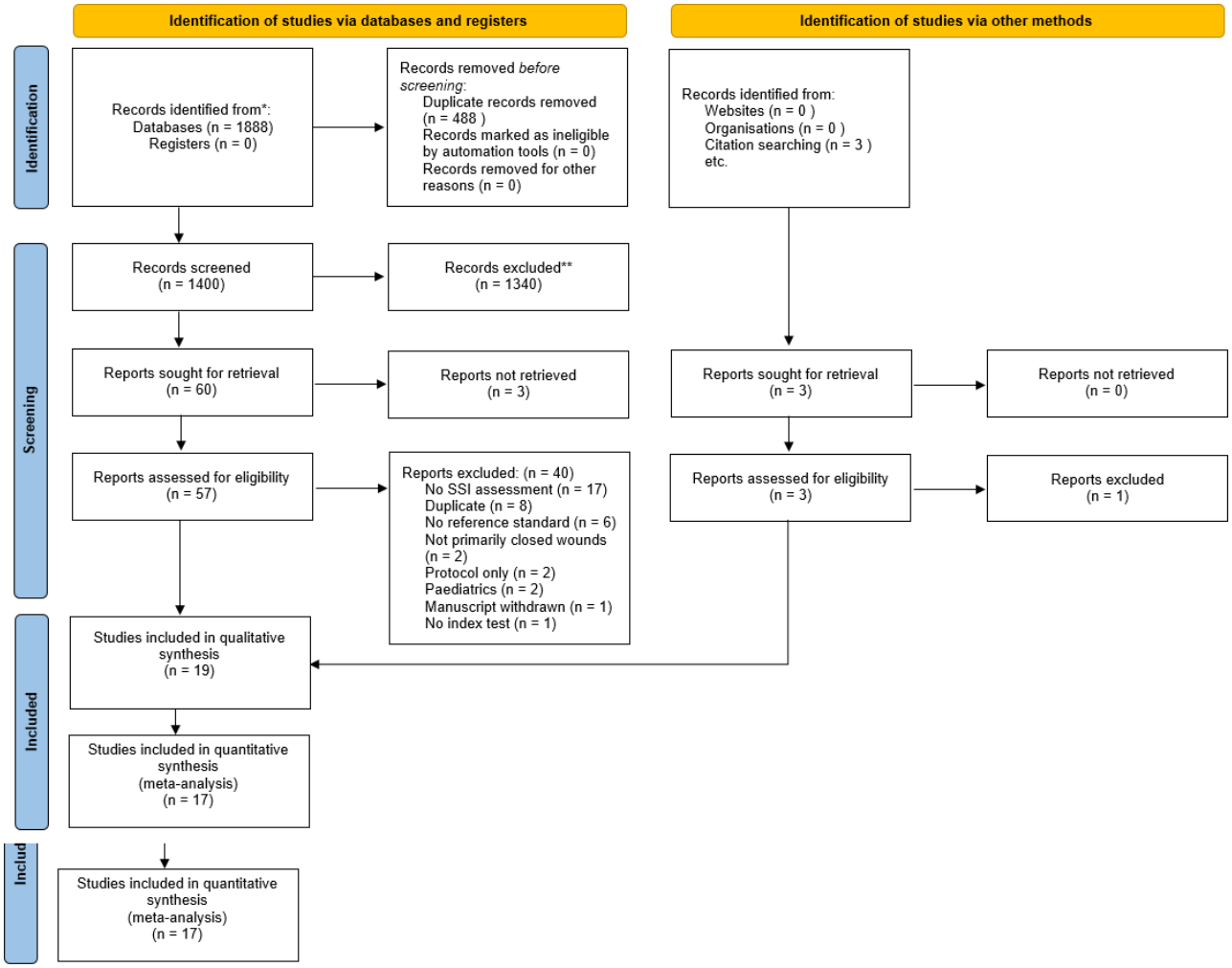

Figure 1

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources

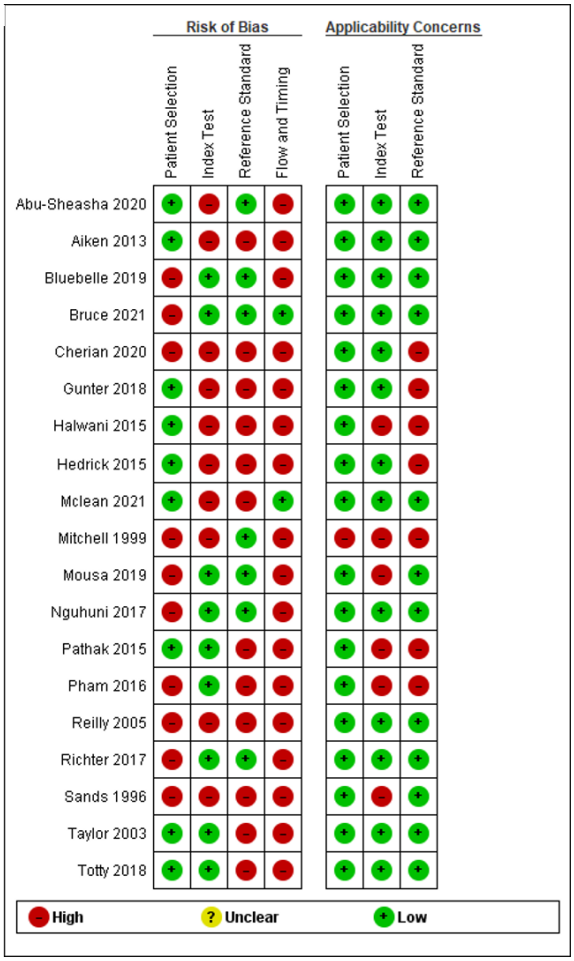

Figure 2

Risk of bias and applicability concerns summary: review authors' judgements about each domain for each study

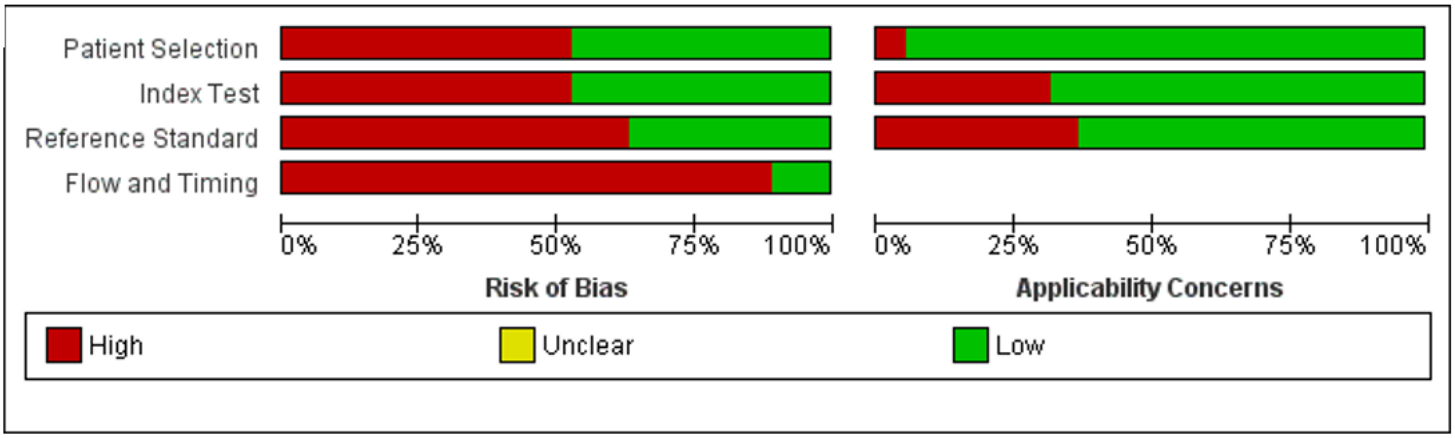

Figure 3

Risk of bias and applicability concerns graph: review authors' judgements about each domain presented as percentages across included studies

Study	TP	FP	FN	TN	Total SSI	Index Test	Total Particpants	Sensitivity (95% CI)	Specificity (95% CI)
Abu-Sheasha 2020	34	1	0	274	34.0	Telephone	308.0	1.00 [0.90, 1.00]	1.00 [0.98, 1.00]
Aiken 2013	16	0	7	66	23.0	Telephone	5572.0	0.70 [0.47, 0.87]	1.00 [0.95, 1.00]
Bluebelle 2019	25	19	7	157	32.0	Questionnaire	536.0	0.78 [0.60, 0.91]	0.89 [0.84, 0.93]
Bruce 2021	9	93	31	903	40.0	Photograph	1550.0	0.23 [0.11, 0.38]	0.91 [0.89, 0.92]
Cherian 2020	9	17	15	178	24.0	Telephone	219.0	0.38 [0.19, 0.59]	0.91 [0.86, 0.95]
Gunter 2018	7	0	1	32	8.0	Photograph	40.0	0.88 [0.47, 1.00]	1.00 [0.89, 1.00]
Hedrick 2015	3	17	1	150	4.0	Photograph	171.0	0.75 [0.19, 0.99]	0.90 [0.84, 0.94]
Mclean 2021	4	21	3	307	7.0	Photograph	489.0	0.57 [0.18, 0.90]	0.94 [0.90, 0.96]
Mitchell 1999	74	2	8	565	82.0	Questionnaire	456.0	0.90 [0.82, 0.96]	1.00 [0.99, 1.00]
Nguhuni 2017	18	0	7	459	25.0	Telephone	324.0	0.72 [0.51, 0.88]	1.00 [0.99, 1.00]
Pathak 2015	24	10	0	122	24.0	Telephone	422.0	1.00 [0.86, 1.00]	0.92 [0.87, 0.96]
Pham 2016	67	55	0	2731	67.0	Telephone	309.0	1.00 [0.95, 1.00]	0.98 [0.97, 0.99]
Reilly 2005	10	22	1	72	11.0	Telephone	266.0	0.91 [0.59, 1.00]	0.77 [0.67, 0.85]
Richter 2017	8	25	4	226	12.0	Telephone	1360.0	0.67 [0.35, 0.90]	0.90 [0.86, 0.93]
Sands 1996	30	53	77	1639	107.0	Questionnaire	732.0	0.28 [0.20, 0.38]	0.97 [0.96, 0.98]
Taylor 2003	140	57	0	2468	140.0	Telephone	1172.0	1.00 [0.97, 1.00]	0.98 [0.97, 0.98]
Totty 2018	2	4	0	50	2.0	Photograph	37.0	1.00 [0.16, 1.00]	0.93 [0.82, 0.98]

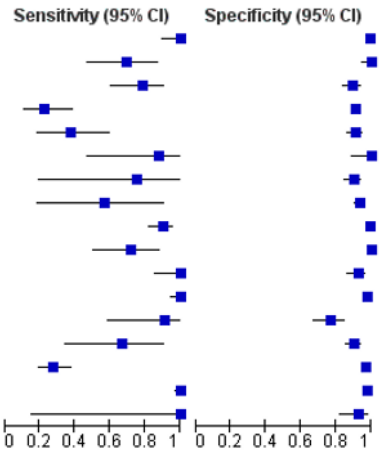

Figure 4

Coupled forest plot presenting sensitivity and specificity of SSI diagnosis by telemedical methods

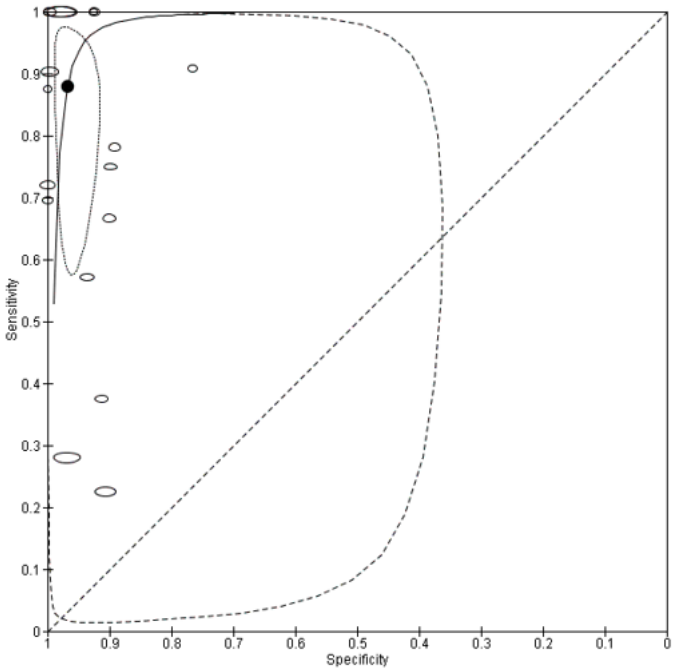

Figure 5

Random effects bivariate summary receiver operator characteristic curve of telemedicine for the diagnosis of surgical site infection. Summary curve and point estimates display high levels of accuracy.

Elliptical data points represent the weighted sensitivity-specificity trade-off for each study. The summary point is expressed on the summary curve with dotted line 95% confidence region and dashed line 95% prediction region.

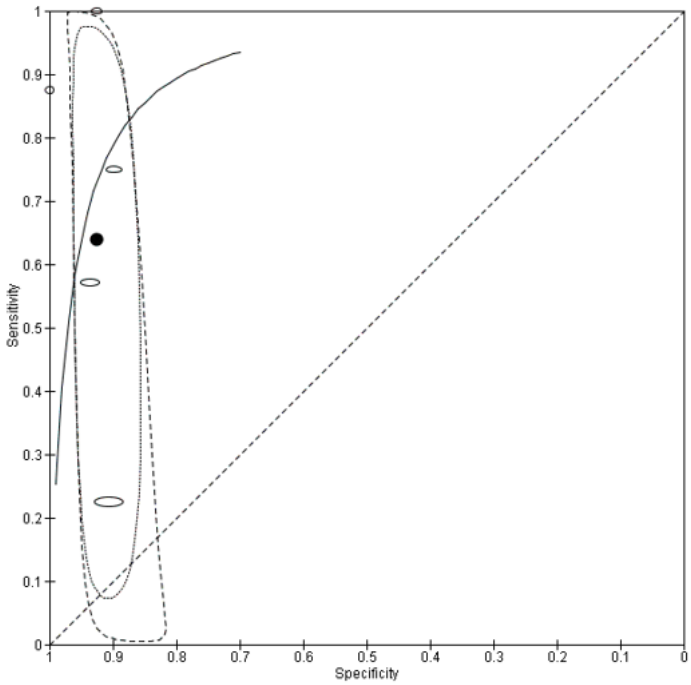

Figure 6

Random effects bivariate summary receiver operator characteristic curve for photograph based recognition of surgical site infection.

Elliptical data points represent the weighted sensitivity-specificity trade-off for each study. The summary point is expressed on the summary curve with dotted line 95% confidence region and dashed line 95% prediction region.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix1PRISMADTAChecklist.doc
- Appendix2Searchstrategy.docx
- Appendix3ComparativeindextestSROCanalysis.docx
- Appendix4CDCSROC.docx
- Appendix5SummarytestaccuracyCDCreferencestandard.docx