JWC International Consensus Document

Remote digital surgical wound monitoring and surveillance using smartphones

ISWCAP
INTERNATIONAL SURGICAL WOUND COMPLICATIONS ADVISORY PANEL

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Foreword

Melissa Rochon, Chair

The use of patient smartphones for remote monitoring and surveillance of surgical wounds presents an exciting opportunity to bridge the gap between national surveillance standards for surgical infections and their practical application in care delivery. Patient-reported outcomes, including digital images, could drive efficiency in surveillance, improve patient care directly and help identify trends in complication rates and outbreaks.[1] This would take a proactive approach to monitoring, rather than a quasi-retrospective 30-day follow up, and it could incorporate additional information such as pain scores to help provide responsive patient care.[2–4]

Digital post-operative wound monitoring using patient smartphones is in the early stages of implementation.[5] However, a combination of high-quality evidence,[6] real-world data implementation[4,7] and ongoing studies,[8,9] suggests numerous benefits, including earlier detection of surgical site infections, reduced morbidity, fewer healthcare visits and high patient satisfaction. There is also emerging evidence for the sustainability of this approach.[10,11]

Routine use of remote monitoring needs to be acceptable and accessible to patients, with consideration of their needs and preferences. This will involve a focus on improving access to healthcare and two-way communication with care professionals.[12] Successful uptake will also require healthcare workers to adopt new ways of working,[4] which could be assisted with workforce solutions and artificial intelligence.[13]

Consensus panel

Introduction

This international consensus document presents evidence-based best-practice recommendations for remote monitoring of surgical wounds.

The document's recommendations have been developed from the outcomes of an expert panel meeting held in London on 3 May 2024. The in-depth discussion and resulting document aimed to:

- Identify key issues surrounding remote monitoring of surgical wounds
- Review the evidence supporting these key issues
- Make best-practice recommendations based upon this evidence
- Identify gaps in the evidence as areas for future research.

To ensure that these objectives were met, the document was reviewed and approved by the author panel, as well as a panel of expert peer reviewers and representatives from the sponsors. Where possible, the consensus recommendations are evidenced with citations to published literature. Expert-opinion and advice proposed by the panel, for which there is not strong supporting evidence but applied research and clinical judgement, is presented as a 'consensus statement'.

The consensus document is aimed at a multidisciplinary readership, including physicians, nurses and allied health professionals, whether or not they specialise in surveillance or infection prevention and control, or if they work in acute-, primary- or home-care settings. Its recommendations should apply to all surgical disciplines. Its scope is global, including both high-income and low-to-middle-income health systems, as well as those serving marginalised populations.

Monitoring for surgical wound complications

Surgical wound complications

The normal healing trajectory of a post-operative wound can be disrupted by surgical wound complications (SWCs).[2] The two most common SWCs are surgical site infection (SSI) and surgical wound dehiscence (SWD):

- The US Centers for Disease Control and Prevention (CDC) define an SSI as an infection that occurs near or at a surgical site after the surgical procedure.[6] This window is either 30 or 90 days, depending on the type of procedure and whether an implant was inserted.[6]
- SWD is the separation of the margins of a closed surgical incision. Separation may occur at single or multiple regions, or involve the full length of the incision. SWD involves the skin, with or without exposure or protrusion of underlying tissue, organs or implants. SWD is not necessarily related to pathogenic activity, and it may or may not display clinical signs and symptoms of infection.[14] It can be caused by mechanical stress, such as coughing, suture disruption or poor healing capacity due to comorbidities.[14–16]

SSIs can have many negative impacts on patients, from pain, anxiety and delayed wound healing to increased emergency department attendance, hospital readmissions and additional surgical procedures, with potential financial losses and increased post-operative mortality.[17] SSIs can also negatively impact mental health and quality of life,[18] as well as risk progression to secondary complications, such as sepsis.[19]

SWCs, including SSI and SWD, are a substantial global concern affecting millions of patients each year. Of the 310 million people undergoing major surgeries each year,[20] around 15% will develop an SWC, and 5–15% will be readmitted to hospital in 30 days,[20] while 2.5% will develop an SSI (and this may be a significant underestimate).[21] The incidence may be higher for specific diagnoses, such as head and neck cancers.[22] SSIs are the leading type of healthcare-associated infection (HAI) in low- and middle-income countries, impacting up to a third of patients undergoing surgery. The global pooled incidence of SSIs was reported at 2.5%.[21] While the incidence is lower in high-income countries, SSIs still rank as the second most common HAI, after pneumonia, in both Europe and the US.[23] In the US, the estimated cost attributable to SSIs ranges from $3.5 to $10 billion USD annually,[24] while in Europe, this figure may be as high as $21 billion USD per year (inflated to 2023 costs).[25] At an organisational level, institutions performing 10 000 surgical procedures annually may experience 300–400 surgical infections, resulting in 3300–4400 excess bed-days or approximately £2.09–£2.79 million GBP a year (inflated to 2023 costs) ($2.66–$3.54 million USD).[26] In low-resource settings where patients face catastrophic expenditure from their index operation, the cost of complications and additional healthcare resource can mean financial hardship and collapse of families and communities.

SSIs also contribute to the spread of antibiotic-resistant bacteria, making SSI prevention a global priority to preserve antibiotic efficacy for future generations.[23]

Consensus statement: This international consensus document predominantly focuses on detection of SSI, in line with most national and international surveillance programmes, but remains relevant for all SWCs.

Surgical wound monitoring

Traditionally, SSI prevention and detection have focussed on primary admission within the hospital. However, most surgical patients are discharged home or to another facility with a wound that is still healing, and, depending on the specialism, the majority of SSIs present after the patient leaves hospital.[27] This proportion is likely to increase and become more problematic because of shorter hospital stays,[28] driven by a growing focus on safe early discharge initiatives, such as Enhanced Recovery After Surgery (ERAS) and day-case surgery.[29,30] In-hospital SSI cannot be used as a valid surrogate for 30-day SSI detection and should not be used in research or surveillance studies.[31] Therefore, greater emphasis should be placed on monitoring surgical wounds after discharge.

The risk presented by SSIs necessitates post-operative monitoring of all surgical patients. Surgical wound monitoring aims to capture information needed to either reassure the patient and the provider that the incision is healing along a healthy trajectory or to allow timely detection for specific signs and symptoms of an SSI.[2,32] To guide the most appropriate treatment option, SSIs can be categorised as a superficial incisional, deep incisional or organ/space SSI, based on the depth and type of tissue, organ or implant involved (*Box 1*).[33] Early detection of an SSI allows treatment to be initiated as soon as possible. It should be noted that a positive result from a wound culture swab is not always required to diagnose SSI.[33]

Consensus statement: Post-operative monitoring should be an option for all surgical patients and provided to all patients at high risk of an SSI.

Pre-discharge monitoring

Surgical patients should undergo a wound assessment prior to leaving the hospital (or day surgery unit, if practical). This provides a baseline for post-discharge monitoring and is the gold standard in all healthcare systems.[34] Before discharge,

patients should be assessed for factors that could indicate a need for more-frequent post-discharge monitoring. These factors could include:

- Older age
- Poor blood supply
- Excessive movement or pressure on the wound site
- Evidence of incisional disruption at the time of discharge
- Underlying health conditions, such as diabetes or immune disorders
- Higher infection risk due to contaminated wound class, colonisation by resistant bacteria or pre-existing infection
- Lifestyle factors, such as obesity, malnutrition, smoking, substance abuse or improper wound care (for example, poor hygiene or non-compliance with dressing advice).[35]

Where possible, at least one photograph of the surgical wound should be taken as part of the pre-discharge assessment, whether the patient is being treated as an inpatient or in theatre as a day patient.[36] A photograph of a surgical wound can help identify characteristics that may place the patient at higher risk of developing an SSI, such as suture visibility, apposition of the wound edges, gaps in the wound or tethering of the skin edges.[37] A wound photograph taken at discharge (or in theatres in day cases, if practical) is a valuable component of post-operative monitoring, providing a baseline to compare with any images taken after discharge. It can also help with medical auditing from regulatory agencies.[38] Pre-discharge photographs should be shared with the patient to help them identify adverse changes in their post-discharge wound healing.[39]

Box 1. Definition and classification of surgical site infection (SSI)[33]

Superficial incisional SSIs
- Occurs within 30 days after the procedure
- Involves only the skin or subcutaneous tissue of the incision
- Includes at least one of the following:
  - Purulent drainage from the superficial incision
  - Microbes from an aseptically obtained specimen from the superficial incision
  - At least one symptom of infection (pain or tenderness, localised swelling, erythema, warmth) and the incision is deliberately opened by the surgeon, unless the culture is negative
  - Diagnosis of superficial incisional SSI by a physician or physician designee

Deep incisional SSIs
- Occurs within 30 or 90 days (if implant present) after surgery
- Involves deep soft tissue (e.g., fascia or muscle)
- Includes at least one of the following:
  - Purulent drainage from the deep incision
  - Spontaneous dehiscence or deliberate opening by the surgeon when the patient has fever (>38 °C) or localised pain or tenderness, unless the culture is negative
  - An abscess or evidence of infection in the deep tissue upon direct examination, during reoperation, or by histopathologic or radiologic examination

Organ/space SSI
- Occurs within 30 or 90 days (if implant present) after surgery
- Involves any part of the body deeper than fascia or muscle manipulated during the surgery
- Includes at least one of the following:
  - Purulent drainage from a drain placed into the organ/space
  - Microbes identified from an aseptically obtained fluid or tissue in the organ/space culture or nonculture-based microbiologic testing method performed for clinical diagnosis
  - An abscess or evidence of infection involving the organ/space detected on direct examination or by histopathologic or radiologic examination
  - AND meets at least one criterion for a specific organ/space infection site (e.g., mediastinitis, osteomyelitis, etc)

Adapted from US Centers for Disease Control prevention guidelines, which provide complete definitions[32]

Remote surgical wound monitoring

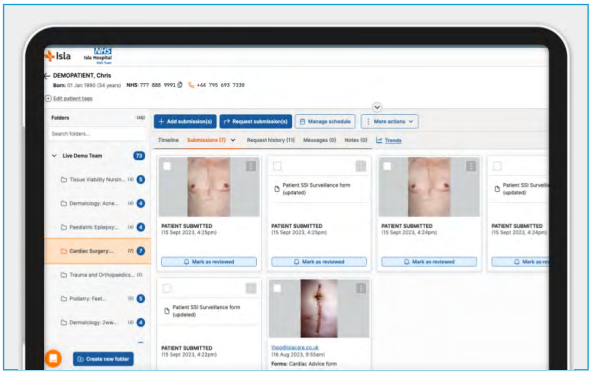
Post-discharge surgical wound monitoring has benefited from advances in telemedicine, meaning any technology that allows real-time remote interactions between healthcare providers and patients. Telemedicine has long included remote verbal consultations and follow up using traditional landline and mobile telephones, as well as text-based patient–provider communication, such as email, mobile text messages and instant messaging apps. Compared with in-person clinic visits, remote communication has advantages in time, cost and convenience for patients and professionals alike. For example, a review found that the use of mobile technology in wound care resulted in reduced transportation costs compared with clinic visits.[40] A GlobalSurg Collaborative international cohort study, covering all specialisms and income settings, found that telephone-based surgical wound monitoring was feasible for post-discharge assessment; it was also well liked by patients, with 99% reporting an improved patient experience overall in comparison to routine clinical care.[41] However, a systematic review of 'unstructured methods of SSI detection' found fewer SSIs were detected in patients followed up by telephone than in those attending in-person-follow up, suggesting a risk of underreporting.[41]

Consensus statement: As a means of communication, telemedicine is more efficient than postal letters and typically better liked by patients.

The more recent proliferation of camera-equipped smartphones, tablets and videocall software (such as Facetime, Skype, Zoom and Microsoft Teams) has given telemedicine an additional visual component. This allows the appearance of a post-operative incision to be communicated to the provider as a video or image, so the provider can visually compare the wound at different stages and observe for signs of healing or complications (*Figure 1*). Smartphones and tablets allow patients not only to upload images and transmit video but also to complete questionnaires and communicate with providers via an installed application or web browser (that does not require download or installation) (*Figure 2*). Such communication can also facilitate live video assessments with a clinical assessor, emulating a face-to-face clinical contact.

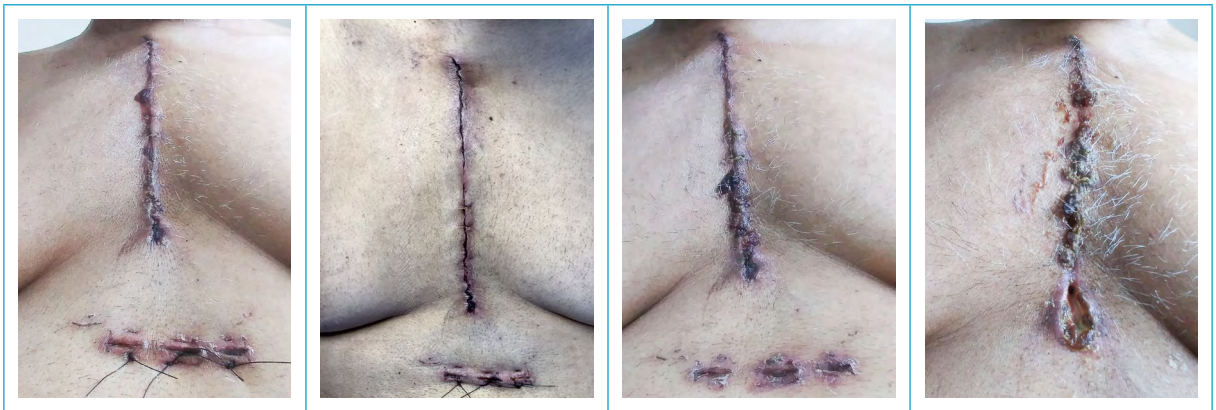
Consensus statement: Any system of post-operative incision monitoring that uses one or more smartphone features, such as photography, videocalls or dedicated monitoring apps (installed or browser-based), can be described as remote digital surgical wound monitoring (RDSWM).

Figure 2. Example of web application for surgical wound monitoring (clinician view)



Courtesy of Isla Health (https://isla.health/)

Figure 1. Wound images taken by a patient for remote digital surgical wound monitoring



Baseline | Day 7 | Day 12 | Day 19

Courtesy of Guy's and St Thomas' NHS Foundation Trust

Accompanying form results containing information on wound healing not shown

RDSWM should allow for more rapid and accurate diagnosis of SWCs, facilitate their earlier treatment and decrease the frequency of emergency care, thereby ultimately reducing the severity of SWCs and the related cost of care.[42,43] A scoping review found that RDSWM using images, questionnaires and integrated data evaluation improved detection of SSIs, resulting in lower costs and increased patient satisfaction across multiple surgical disciplines and countries (although largely in the US).[44]

All studies in a systematic review of RDSWM, covering all specialisms and largely high-income settings, reported success in monitoring post-operative recovery or identifying potential complications, without reductions in quality of life or patient-reported outcomes.[5] A majority of studies found that RDSWM could minimise use of outpatient and community services.[5] Most patients viewed RDSWM interventions positively in terms of improved care quality and patient experience, through community support and empowerment for self- care.[5]

An evidence appraisal by Health Technology Wales found that most patients perceived RDSWM to be valuable for self-care, especially in seeing their healing progress, which encouraged them to continue with their wound healing at home. Improvements in understanding of their care also helped patients to make better decisions, resulting in improved outcomes. Patients found digital tools mostly easy to use, helpful and engaging. Other benefits included having questions answered, receiving training and support, communicating with healthcare professionals and storing information in one place. Being able to perform actions from home had benefits for patient wellbeing, including less travel time, better sleep and other daily functions, and improved relationships with friends, family and health professionals.[45]

Telemedicine in general and RDSWM in particular reduce patients' need to travel to clinic. This is not only convenient for the patient in terms of time and money saved, it also reduces their travel time and resulting greenhouse gas emissions.[46–50] The carbon emissions of RDSWM range from 5 kg to 2615 kg CO2e, which, if not carbon neutral, has significant carbon savings over in-person monitoring.[4,51]

Consensus statement: Although not carbon neutral, RDSWM has the potential to reduce carbon emissions and facilitate sustainability.

Patient-reported outcome measures

RDSWM apps can present the user with a self-reporting checklist of signs and symptoms of SWCs (*Box 2*). A structured patient-reported outcome measures (PROMs) tool for abdominal surgery, the Bluebelle Wound Healing Questionnaire, is available and undergoing validation. These PROMs can provide an efficient way to collect important monitoring information from the patient or carer. The checklist should include the traditional signs of inflammation (pain, heat, swelling and redness), as well as need for analgesia, beyond the expected inflammatory response 2–3 days after surgery.[2] It is also important to monitor wound exudate for increases in quantity or changes in quality from serous to sanguineous or purulent, as well as signs of a seroma, haematoma or abscess.[2] The skin should also be monitored for any changes in texture or tightness, as well as crepitus, defined as a crackling sound or feeling with palpation of the peri-incision tissue and indicative of gas in the soft tissue.[2] It is also important to check for sternum clicking in cardiothoracic patients.

Consensus statement: Signs and symptoms may vary between patients of different skin tones and in different cultures and contexts, which should be considered by the clinical teams

PROMs are valuable for clinical decision making. For example, RDSWM self-reporting checklists may collect data on the post-operative use of antibiotics after discharge. A UK single-centre study examined one quarter of patient-reported antibiotic use for their cardiac surgical wound and found an approximate positive confirmatory proportion of 91% and negative confirmatory proportion of 97%.[7] A Brazilian prospective observational cohort study found that adherence to prophylactic antibiotics after post-operative discharge was as low as 1.7% (n=7/527), as well as that poor adherence to the prophylaxis protocol was linked to greater risk of SSIs and

Box 2. Self-reporting checklist for remote surgical wound monitoring[2]

Surgical incision
- Separation (coming apart) of the incision edges*
- Unpleasant odour
- Increased amount of fluid
- Pinkish or watery straw-coloured fluid
- Thick and white, yellow, green or brown fluid
- Bleeding

Skin around the incision
- Discolouration or redness
- Unusual warmth
- Tenderness or pain
- Swelling
- Tightness
- Unusual texture
- Cracking sound or feeling when touched

Whole body
- Fever and/or chills
- Lack of energy (malaise)
- Confusion or disorientation
- Increased heart rate
- Increased respiratory rate
- Increased blood glucose levels (for people with diabetes)

Medical care
- Antibiotics
- Tissue swab
- Pain medications
- Any other new medical care

*Separation indicates surgical wound dehiscence, while all others are potential signs or symptoms of surgical site infection

subsequent complications.[52] A US retrospective study of pharmacy data from patients' electronic medical records (EMRs) found that an antibiotic prescription within 30 days of a surgical procedure was a valuable predictive indicator of SSI.[53]

Similar to other forms of PROMs for wounds, there may be a risk that, in some cases, RDSWM may disproportionately capture follow-up data for patients who are worried, whether or not they are well or unwell, compared with patients who are not worried and may be unwell.[54]

Consensus statement: RDSWM should include a self-reporting checklist as well as wound images to detect changes that may not be visible in photographs.

Timing

RDSWM varies in the timing and frequency of requests for images and other wound information, with no absolute timeframe established in the literature. This timing and frequency can be dependent on patient risk factors. For example, dressings could be left in place for around 7 days post-operatively to promote undisturbed healing.[55] While surveillance data is captured at 30 days,[51] the key benefit of RDSWM is its prospective regular review of wounds up until 30 days, or longer if required. Weekly requests for images and information about the wound are standard, with published approaches to RDSWM requesting data on post-operative days 9 and 14,[56]; days 14–30,[44] or days 1, 11 and 30.[57]

Consensus statement: Post-operative patients should be actively followed up for 30 days post-procedure at regular intervals, ideally on a weekly basis. Follow-up routines should be pragmatic, balancing the advantages of more frequent and regular data capture with the risks of increased patient burden, potential contamination and disturbed wound healing from earlier dressing removal. Self-reporting at any interval should also be permitted (i.e. patient self-directed assessment). In addition to scheduled requests, patients should also be able to initiate follow up. Responses to the patient submissions should be timely, in order for the patient to benefit from two-way communication and access to healthcare professionals. Follow up should be more frequent if indicated by patient risk factors or the surgical procedure. For example, 48-hour follow up is recommended for patients who demonstrate impaired healing at the time of discharge. The process and timing of RDSWM should be established and communicated to the patient as part of a post-discharge care plan. It should be clear when patients will be expected to engage in RDSWM activities.

Accuracy, sensitivity and specificity

Research on RDSWM has often focused on diagnostic accuracy, sensitivity and specificity, as these are essential for safe and successful use of telemedicine services and systems.

A UK randomised control trial (RCT) comparing RDSWM with routine care after abdominal surgery found no significant differences in SSI incidence or time to diagnosis, but did find that the RDSWM group had higher odds of diagnosis within 7 days, as well as reduced community care attendance and significantly better experience in accessing care.[6] A study of surgical diagnoses based on variables (e.g., medical history or radiograph) received from another clinician via a telemedicine app found that these matched diagnoses from in-person surgical assessment in 84% of cases.[58]

A UK mixed-methods study of RDSWM using images reported a 90% specificity in detecting SSIs after vascular surgery.[59]

A US web-based simulation survey compared RDSWM with and without images. The addition of images improved diagnosis by surgeons (n=83), increasing accuracy from 67% to 76%, specificity from 77% to 92% and sensitivity from 55% to 65%, although this was not statistically significant. Meanwhile, overtreatment recommendations decreased from 48% to 16%.[60]

A study of inter-rater agreement found similarly high specificity and sensitivity for providers using smartphone images for RDSWM and those conducting in-person visual assessment after vascular surgery.[61] Another study of RDSWM with images found that inter-rater reliability among the 131 participants was significantly increased from 67.6% to 76.2% (P=0.001; 95% CI 1.8–2.2) after training based on the World Union of Wound Healing Societies (WUWHS) definition.[62]

A systematic review, covering all income settings, found that all forms of telemedical surgical wound monitoring (including telephone calls, questionnaires and photography) had an overall mean diagnostic sensitivity of 88% and specificity of 97%, which were not significantly affected by geographic location or socioeconomic status.[63] However, the same systematic review found a lower sensitivity and specificity for RDSWM with images alone compared with telephone calls.[63] Many of the included studies were of low or very low quality, making synthesis difficult. A high-quality assessment in low-to-middle-income countries with a representative cut-off score of ≥4 displayed a sensitivity of 0.701 (0.610-0.792) and a specificity of 0.911 (0.878-0.943).[64]

A UK pilot study compared diagnosis of deep SSI (based on CDC definitions) after lower-limb fracture surgery based on either digital images taken by providers or an in-person assessment.[65] Photographic assessment alone resulted in overestimation of deep SSI rates, and the authors concluded that images are useful for screening but should not be used alone for surgical wound monitoring.[65]

Using PROMs alongside wound images has important advantages for balancing sensitivity and specificity.[6,63] Validated PROMs tools, such as the Bluebelle Wound Healing Questionnaire,[66] could be adapted to proactive monitoring rather than retrospective diagnosis at 30 days.

Consensus statement: To improve diagnostic accuracy, RDSWM with images could be supported by telephone conversations, at-home visits and validated PROMs.

Challenges of remote surgical wound monitoring

Two-way and in-person communication

Online communication via forms and messaging has notable limitations compared with two-way communication, which may increase a patient's engagement and perceived value of an intervention.[12,54] However, two-way communication in RDSWM can increase the burden on clinicians and create the risk of scope creep to encompass concerns unrelated to the wound.[12]

With an in-person visit, providers have the expertise to palpate for warmth, textural changes and skin tightness, all of which may indicate underlying inflammation or infection. Likewise, the provider may be able to more accurately visually examine a wound when seeing the patient in person rather than seeing an image, which may be necessary to detect more subtle visual signs of SSI, such as erythema. Erythema detection is a limitation of image-based RDSWM, although asking patients to take another image with different lighting may also help to detect erythema. Most research on technological erythema detection refers to early detection of pressure injuries and involves equipment unavailable in the home setting, such as colorimeters[67] and subepidermal moisture monitors.[68]

RDSWM interventions should be conceptualised as screening tools to allow proactive identification of patients with evidence of SSI, as well as facilitate diagnosis through triage to the appropriate location for assessment (whether community or urgent care services).

Consensus statement: The two-way communication provided by interpersonal follow-up contacts creates an opportunity to answer patients' questions, reassure them if their wound is healing well and offer expert advice if there are issues. RDSWM should have clear referral pathways for in-person review, if required. It should be clear which providers will be responsible for any additional follow up, including two-way telemedicine contacts and healthcare visits

Equity and access

The uptake of telemedicine has traditionally been limited by inequalities in access to the necessary digital devices and the skills to use them. Older age, lower socioeconomic status, belonging to an ethnic minority and living in rural or coastal areas are all linked to reduced access to and proficiency with digital technologies.[70–72] This may not exclude people from telehealth entirely but may limit what modalities they can use. This is poorly studied in the literature, and while there is limited evidence to support a substantial impact on equity and access in practice, this remains a significant concern.[5] For example, a 2024 US study found that patients who were older than 75 years, ethnically non-White, without private insurance or more socially deprived were more likely to only have access to a telephone for audio-only telemedicine but not a smartphone for audio-visual telemedicine.[73] Likewise, a 2023 systematic review covering all income settings found that older vascular patients were more likely to be under-reported by or even excluded from using RDSWM.[63]

Consensus statement: Providers should assess all patients' access to and proficiency with the devices necessary for RDSWM and involve them in telehealth at the appropriate level.

Not everyone can or will use a smartphone. Not everyone who has a smartphone has the technical competence to use it for data collection.[74] A 2021 UK RCT of RDSWM not only had to exclude 11.4% (n=82) of potential participants because they lacked a smartphone, it also found that 32.3% of actual participants did not use the smartphone app provided.[6]

Consensus statement: To ensure inclusive and equitable access to post-operative monitoring and care, patients who are unable or unwilling to use RDSWM should be provided with alternative follow-up methods, such as scheduled in-person visits, phone consultations or postal surveys, depending on the patient's preferences and availability of resources. Where available, hospitals should also register for programmes that help to provide patients with smartphones. Patients with limited vision or dexterity may find a tablet easier to use than a smartphone for accessing app- and browser-based RDSWM tools.

However, inequalities in smartphone access and proficiency are a declining concern in the 2020s. Around 1617.5 million smartphones were sold in 2021, and around 75% of the global population were using smartphone by 2022.[75,76] With the proliferation of smartphones all over the world, most of the global population is now digitally connected or close to a digital connection, with a feasibility and validation study finding a 90% contact rate even in the most austere and rural hospitals.[64] Smartphones have been adopted across practically all demographic groups, including by age, ethnicity and socioeconomic status, and thus they are more likely to bridge than deepen gaps in access to follow-up care in underserved communities.[42] For example, remote reporting may be particularly useful in areas where patients may have to travel long distances to see a healthcare provider. Recent UK studies have reported that patients were able to successfully use an RDSWM tool on their smartphones without needing to

download and install an app, demonstrating a patient response rate of over 85%.[7,9]

Consensus statement: RDSWM should be designed to be accessible, acceptable and usable for patients of all ages, ethnicities, skin tones and socioeconomic groups. Equally, it should not be assumed that patients cannot or will not participate based on these characteristics, and patients should have equal opportunities for involvement.

In settings where patients may not be able to carry out RDSWM themselves, RDSWM can be facilitated by carers or community health workers (CHWs). A study in rural Haiti looked at the feasibility of CHWs following surgical patients after discharge home. The CHWs used smartphones to take images of incisions at 117 30-day follow-up visits. Surgeons and CHWs agreed on the diagnosis of SSI in 84.8% (n=28/33) of photographs taken. The authors concluded that the CHW-led RDSWM programme needed further validation before use.[77] A study of image-based telemedicine after caesarean section in Rwanda found that patient trust in the CHWs who were taking the images was essential to acceptance and success of the programme.[78]

Adherence

Effective RDSWM requires patients to adhere to relevant instructions regarding when and how to use their smartphone for monitoring tasks. However, adherence cannot be guaranteed.

In a UK cohort study evaluating the feasibility, acceptability and usability of RDSWM with images, only 58% of participants took one or more images (n=52/89), while 88% of these successfully transmitted the images (n=46/52). Failure to take or transmit an image was attributed to health issues, lack of time or poor engagement in the study, rather than technical, competency or practical issues. Of the 102 images received, 85% were of sufficient quality to remotely assess for SSI. Despite the limitations, the authors concluded that this RDSWM method was suitable for use in clinical care and research.[79]

In a Canadian study of an RDSWM app with images for patients after caesarean section, only 45% of participants submitted images (n=47/105), leading to the detection of one SSI. Patients with a diabetes diagnosis or Asian ethnicity were less likely to submit images.[70]

A UK single-centre cardiac study had an overall response rate to RDSWM of 86.6%, which was lower in patients who were female, from areas of higher deprivation or lived closer to a hospital.[7] Similarly, a UK study involving over 5800 women after caesarean section using patient smartphones reported a response rate of 84%.[80] Women from Black and mixed ethnicity and lower socioeconomic status were less likely to engage.[80]

A systematic review and clinical innovation network analysis in mostly high-income settings found usage of RDSWM among those able to participate was consistently high (typically over 90%).[5] However, per-protocol adherence to the recommended RDSWM regimen was lower and more variable than participation.[5] Nonetheless, two assessed studies noted that target adherence was substantially higher for RDSWM compared with existing types of non-digital monitoring.[5] Of the few studies that assessed adherence by patient groups, none reported significantly worse adherence associated with older age, sex or education level, although one study found differential adherence by ethnic group.[5]

Adherence can be improved with regular reminders from providers or their representatives.[6,12]

Surveillance data

Surgical wound surveillance

Information collected through surgical wound monitoring of an individual patient may be entered into an institution's database for a broader programme of surveillance.

Consensus statement: Although sometimes used interchangeably with monitoring, surveillance refers to data collection at the level of an institution, medical system or community (rather than the level of the individual patient).

Surveillance data can be managed, analysed and interpreted to provide hospitals with information to identify wider processes and track trends in disease outbreaks and treatment performance.[81] As part of a broad prevention strategy, surgical wound surveillance can help to reduce SSI risk by 35%.[82] Effective surveillance methods for surgical patients should help achieve a global decrease in the incidence of SWCs.[2] The CDC lists the following active, patient-based, prospective methods to collect surveillance data:

- Reviewing patient medical records (in hospital or clinic)
  - Admission, readmission or emergency records
  - Laboratory, imaging or other diagnostic test reports
  - Clinician notes
  - Diagnostic codes to prompt further review
- Visiting patients before discharge and talking with primary care staff
- Surveying surgeons by mail or telephone
- Surveying patients post-discharge by mail or telephone.[69]

Consensus statement: Patients should be informed of how their data may be used to assist in institutional surgical wound surveillance.

Surveillance programmes

Participation in mandatory or voluntary national or international surveillance programmes offers centres a comprehensive and representative overview of SSI rates. By participating, hospitals contribute to a larger dataset that allows for better monitoring and evaluation of SSI trends. A UK in-depth exploration study identified several drivers for surveillance,[28] while other publications have established factors that prevent institutions from performing adequate surveillance programmes (*Box 3*).[83–85]

Consensus statement: Surveillance programmes can help to reduce SSIs, but implementing them can be resource-intensive.

An International Surgical Wound Complications Advisory Panel (ISWCAP) survey found that less than 10% of respondents had active surveillance programmes for SSI.[86] In England, most hospitals do not participate in the national surveillance scheme, and, of those that do, less than half undertake post-discharge surveillance.[32] As with surgical wound monitoring, surveillance must also emphasise follow-up after discharge. The proportion of post-discharge SWCs is set to increase as hospital stays shorten. Indeed, reductions in inpatient SSI rates may be due to the shift in community presentation.[23]

Once the patient leaves the hospital, surveillance is variable across specialities, with some teams relying on face-to-face clinic follow ups or home visits, and others only engaging at 30 days post-discharge via postal or telephone questionnaires, or not at all. Indeed, reductions in hospital rates may be due to the shifting burden of SSIs to the community setting.[23] As a result, surgeons may be unaware of the true measure of their outcomes, because most of the costs and care falls to the community,[56,87] and approximately 25% of patients with post-operative complications do not present to the operating institution.[88] Thus, post-discharge surveillance presents an important opportunity to improve patient care, safety and outcomes.[4,89]

Consensus statement: National and international post-operative surveillance protocols could be updated to require regular wound images and wound-healing information that are collected proactively, to improve patient care directly, as well as to inform performance measures. This data should be reported separately to 30-day retrospective PROMs. This kind of initiative would enable efficient, low-cost research designs, such as trials within registries.

Box 3. Drivers and inhibitors of surveillance

Drivers of surveillance[28]

- Provision of additional resources
- Enhanced use of digital tools (such as remote surgical wound monitoring)
- Embedding surveillance within everyday clinical practices
- Establishing advocates or champions
- Mandatory surveillance systems
- Strengthening links between surveillance efforts and better patient outcomes
- Emphasising post-discharge monitoring
- Data integration with primary care

Inhibitors of surveillance[83–85]

- Inadequate data collection infrastructure
- Lack of staffing for a labour-intensive process
- Costs incurred in collecting and analysing data
- Inconsistency in definitions and criteria of surgical site infection
- Lack of engagement from surgeons and administrators
- Pressure to appear to have good outcomes

Patient and provider education

A successful monitoring and surveillance programme will require education for both patients and providers.

Patient education

Before discharge, surgical patients and their carers should be educated with appropriate individualised discharge instructions on how to care for and monitor their surgical incisions.[2] This information should cover the following:

- How to care for their incision at home, including advice on showering and how to remove, cleanse and replace their dressing (if applicable),[55] as well as how to optimise the cosmetic outcome of the incision
- What normal healing looks like, including how the wound's appearance and healing trajectory may be affected by medications or comorbidities, such as diabetes
- How to recognise observable signs and symptoms of SWC, as well as who to contact if an abnormality is observed. If the patient or carer is being asked to send in photos, information provided should include examples of incisions of the relevant type of surgery, so that they can see what is expected content of the photo, as well as information on who will be reviewing their submissions and when a response can be expected.

Consensus statement: It should be made clear to patients that most wounds heal well, but that it is important to provide monitoring and surveillance information, including images, even if the wound is healing as expected, rather than only if there is a concern.

There is mixed evidence on the quality of existing educational materials. A study examining patient awareness, knowledge and perceptions about the risks and consequences of SSIs revealed that 16% could not recall discussing SSI risk and prevention with a healthcare worker, and only 60% could remember receiving any written material during their hospitalisation.[90] A study using the Patient Education Materials Assessment Tool found that available patient education materials for SSIs performed poorly and concluded that more research was needed to develop effective patient education materials.[91] However, several more recent studies have found that patient education programmes could significantly reduce the incidence of SSIs in all surgical specialties and throughout the world, including in low- and middle-income countries.[92–95] A study comparing discharge instructions for self-monitoring surgical incisions found that patients given text, pictures and a mirror, compared with a text-only group, showed better day-7 comprehension of instructions and ability to inspect for SSIs.[96]

Patient recall and understanding of discharge instructions can be verified with the teach-back method, an evidence-based technique in which the patient is asked to repeat the given instructions in their own words, thus giving the provider an opportunity to correct misunderstandings.[97–99] To ensure that education has been successful, patient understanding and recall should be reviewed with pre-discharge questions, such as those suggested by the International Surgical Wound Complications Advisory Panel (IWSCAP) (*Box 4*).[3]

Consensus statement: To suit patients' diverse educational needs, patient education materials for RDSWM should ideally comprise a combination of text, images and videos, and they should be communicated in both print and digital media formats. These published patient education materials should be supported by opportunities for verbal two-way interpersonal communication with a provider; include consideration of accessibility options; and be translated into the patient's primary language where necessary.

Provider education

Providers working with surgical patients need to be instructed on how to recognise SWCs and deliver patient education on doing so, as well as how and where to refer patients who report a suspected SWC. A systematic review found that knowledge regarding identification and prevention of SSIs among healthcare providers was poor, although attitudes toward their role in prevention were positive.[100] Thus, providers responsible for reviewing photographs and other data submitted by patients through RDSWM need to be specifically trained in diagnosis, including visual identification of SSIs and other SWCs.

A pre-test/post-test study investigated the inter-rater reliability among healthcare and wound care professionals using the WUWHS definition and classification for SWD. Only 33% of the participants knew the WUWHS definition. After video training

Box 4. Questions to ask patients prior to discharge[3]

- Do you understand how to look after your own wound at home?
- Do you have support from carer/family members?
- Have you been given all the information you need about your wound?
- Have you been informed about the signs and symptoms of your wound not healing and what to look out for?
- Do you know when/how to contact your healthcare professional if you have concerns?
- Have you been given guidelines on your activity level?
- Have you been informed about nutrition and lifestyle factors in regards to your wound healing?

on identifying SWD on digital images, post-test inter-rater reliability increased significantly from 67.6% to 76.2%.[62]

A multicentre study evaluated the implementation, fidelity and sustainability of Photo at Discharge (PaD), a nurse-led discharge strategy for improved wound care information for both patients and healthcare providers. Implementation of the IT component of PaD took an average of 16 months, while 474 nursing staff and 9007 patients received PaD training, with a 1-month compliance of 96%. The authors concluded that implementing PaD requires collaboration and a change in both behaviour and service to be effective.[101]

Photography technique

Providers often need to take photographs of wounds under their care to track progress or deterioration.[38] Providers can optimise the quality of the images they take by learning relevant photography techniques (*Box 5*).[102–106] Digital cameras may have features to can help optimise the quality and comparability of wound images by (1) indicating when the distance to the wound is optimal and (2) providing ghost images that allow the clinician to take all the photographs with the same orientation.

Image-based RDSWM requires the patient or their carer to photograph the wound after discharge. Before discharge, patients and caregivers should be instructed on the following:

- Why wound images are important
- Who will be responsible for taking the photographs
- When the images should be taken (on what days and when in the dressing changing process)[55]
- How to take good-quality images
- How images should be shared with the provider
- Who will be monitoring the images.

Consensus statement: Dressings should never be removed solely to take a photo unless instructed to do so by a healthcare professional.

Patients and carers should be given simple, plain-language instructions for photographing wounds (*Box 6*).[105] The patient or carer should demonstrate their understanding by taking a photo with the device that will be used at home. Educating patients and caregiver before discharge on how to take images and send them to the provider is helpful in facilitating patient engagement and adherence, as well as obtaining quality information.[36,38,104,105] A guideline-development study involved a literature review to identify key components of photography relevant to taking wound images, development of instructions for patients on how to take photographs, and pre-testing of the methods with 16 patients.[79] The study was influenced by guidelines on wound photography from the Institute of Medical Illustrators.[107] Guidelines may cover how to approach photographing wounds in areas considered particularly sensitive and private, such as the groin or buttocks.

Consensus statement: Image-based wound monitoring is only effective if the images are of sufficient quality to be useful for assessment. If an image is poorly lit or out of focus, it will not accurately show the appearance of the wound. Ideally, photographs should be taken at a similar angle and distance and in similar light conditions to enable accurate comparison of the same wound taken at different timepoints. Therefore, wound care providers, patients and carers alike should be instructed on the necessary photography skills. Likewise, any care providers involved in wound care need to be proficient in photographing a wound using facility-compliant technology and in uploading an image to the patient's clinical record. Before discharge, patients and carers expected to perform RDSWM should receive thorough instruction on photography, with a return demonstration of their ability to capture a usable image with their smartphone camera.

Box 5. How to photograph wounds, for providers[102–104]

- Ideally use ambient (natural) light or artificial light with the same temperature to natural light (5000–6500 K)
- Close curtains or shades so that only fluorescent light exists in the room; this also minimises glare
- Position the patient so the incision can be easily visualised
- Adjust the lighting for equal illumination to eliminate shadows
- Use blue or green towels around the incision to eliminate busy backgrounds and other features that may identify the patient, as well as to absorb light and prevent reflecting light waves that may wash out the skin colour
- Position the camera so it is not facing a light source
- Do not use flash
- Place a disposable ruler at the edges of the incision to assess size
- Provide information on location of the wound (e.g., write it on the disposable ruler or use a digital avatar)
- Hold the camera at a 90-degree angle to the incision to avoid distortion of the shape and size
- Centre the incision in the view box so that the entire length of the incision is visible

Box 6. How to photograph wounds, for patients[105]

- Keep the background free of clutter
- Take the photo from close enough that the wound fills most of the picture
- Take the photo from far enough away that the entire wound is shown
- Take the photo from directly above the wound, rather than at an angle
- Make sure the wound is well lit and not in shadow
- Make sure the picture is not blurred by tapping the screen to focus on the wound and holding the phone or camera still while taking the picture

Implementation

Any telemedical monitoring and surveillance programme, including RDSWM, must be implemented in a way that meets the needs and expectations of both patients and providers. This should involve a structured implementation framework, with broad stakeholder engagement and protections for patient consent and privacy.

Implementation framework

The World Health Organization (WHO) provides a common framework outlining expectations for monitoring and evaluation that are applicable across different income settings and healthcare contexts.[25] The WHO framework makes it possible to comprehensively assess digital health interventions across several key domains (*Box 7*).[25] New technology should be inclusive, usable and acceptable in a way that meets the following WHO readiness criteria:[25]

- Functional, with sufficient connectivity via Wi-Fi or mobile data
- Accessible to all users
- Usable and supportive of adherence (the technology consistently being used as intended)
- Accepted by key stakeholders.

The Mobile Health Evidence Reporting and Assessment Checklist can be used to ensure that these key aspects are reported appropriately in studies.[108]

Programme design can take inspiration from a nuanced understanding of published qualitative studies,[108] although these are limited in number and generally focus on the US context.[54,110–112] Programme design also needs to consider the local patient population and organisational context, as interventions that are effective in some contexts may not be effective elsewhere.[113] Although there is little specific guidance on implementing RDSWM,[114] principles can be adapted from evidence-based guidelines on implementation of research. For example, the WHO has shown the advantages of an active implementation strategy.[114] While a passive strategy is limited to the provision of print and digital education materials, an active strategy should be multifaceted, employing a variety of effective active and passive implementation techniques (*Box 8*).[114,115] Implementation strategies may also be policy-based, including recommendations to government and other stakeholders before implementing the recommendations, adapting the guideline to local settings and developing financial incentives to increase adherence.[114] A secure, patient-centred RDSWM programme should have solutions to certain key questions (*Box 9*).

Consensus statement: The strategy for surgical wound care requires a plan that includes wound monitoring to promote self-management, improve patient/provider communication and inform treatment, if required.

Stakeholder engagement

Successful and sustainable implementation of a new post-discharge monitoring and surveillance programme requires engagement with all relevant stakeholders to ensure their acceptance of the process, as well as their engagement and contribution:

- Buy-in from clinical staff is essential for successful integration of new interventions into routine care that might be considered a disruption to established standard processes.[86] Surgeons may need to help overcome known issues regarding reliable interpretation of image-based RDSWM data.[120]

Box 7. Assessment domains for digital health interventions[25]

Technological readiness
Technological readiness refers to an intervention's functionality (whether it can fulfil the intended purpose) and feasibility (whether it is deliverable in the context). In the context of post-operative wound monitoring, this may include whether there are errors in the online platform or if there are issues with internet connectivity in the patient's home that could prevent participation.

Usability
Usability is the quality of the interaction between the user and the technology, in terms of the adherence, acceptance and accessibility among patients or staff. In the context of post-operative wound monitoring, this may include the overall proportion of patients using the intervention, those satisfied with the intervention as part of their post-operative care or if particular subpopulations of patients report barriers to participation.

Healthcare impact
Healthcare impact refers to both the clinical efficacy (how the technology influenced clinical outcomes) and process improvement (how the technology improves service delivery, in terms of the cost, efficacy, quality or utilisation of healthcare). In the context of post-operative wound monitoring, this may include the time-to-diagnosis of SSI, the overall SSI rate, or attendance at community or urgent hospital care.

Box 8. Active implementation techniques[114]

- Audit of user adherence
- User feedback
- Educational outreach, through a variety of mediums
- Reminders, through a variety of mediums to increase adherence
- Follow-up and personal interaction with the implementers
- Involvement of opinion leaders

Box 9. Questions for planning remote surgical wound monitoring

- How is a patient's risk for surgical site infection assessed?
- What criteria determines the optimum frequency and duration of follow-up for each patient?
- Who is responsible for receiving, reviewing and responding to data?
- What is the protocol for patient follow-up?
- How is patient confidentiality protected, particularly in handling sensitive images?
- What processes ensure that patients who are not able or do not wish to use telemedicine receive comparable levels of care?
- How is reimbursement handled to maintain system sustainability, and who is responsible for this?
- How can monitoring be implemented within the routine care pathway without overloading staff resources?

- The involvement of IT colleagues is essential to build and maintain the necessary technological infrastructure for RDSWM and ensure that data is integrated into the clinical workflow and EMR.[93]
- Support from medical governance and the wider hospital system is key, as institutions may need to be encouraged to recognise SSI as an issue that warrants monitoring and surveillance to reduce the incidence, as well as see that the potential benefits and cost savings of earlier detection and treatment outweigh the implementation costs.[42]
- Involvement of administrative and support staff may be needed to resolve any issues with third-party reimbursement, as well as assure appropriate licensure of providers practicing across state or national borders.[42,116,117]
- Engagement with patients can determine their level of enthusiasm, access to equipment and technical proficiency. This is key to advocating for the content of patient education at an appropriate level for all patients. Patients tend to embrace the use of RDSWM and the opportunity to participate in their own care. However, a literature review of patient perspectives of mobile health interventions found that patients are unlikely to be involved in the development of tools for patient-generated health data.[79,118–120]

Consensus statement: It is essential that surveillance and monitoring include feedback to key stakeholders, including staff in theatres, wards and intensive-care, high-dependency, maternity-assessment and recovery units, as well as surgical, infection-prevention, microbiology and procurement teams.

The importance of stakeholder engagement and agreement was underlined in the development of an RDSWM programme in the Philippines, where institutional limitations stalled the integration of the software into the local healthcare providers' practice, emphasising the importance of collaboration between IT teams and surgeons.[93]

Consensus statement: Institutions may be reluctant to report SSI incidence if it potentially affects their reimbursement, and surgeons may be hesitant to send their patients to wound clinics for fear that it may affect their reputation. Data must be handled in a non-punitive manner, while maintaining the focus on improved patient care and decreased incidence of SSI.

Patient consent and privacy protection

When using telemedicine for wound monitoring and surveillance, it is essential to obtain patients' consent and protect their personal information. Confidentiality safeguards are essential for securing a patient's privacy and dignity. All monitoring and surveillance systems must comply with the laws and regulations for data management and have an audit trail based on local policies and specific to the country in which they are being used.

Consensus statement: Although consent requirements can vary from country to country and facility to facility, any RDSWM system should have consent, information-governance and safeguarding protocols in place. These protocols should address issues such as how images are transferred to the patient's EMR, encrypting processes to prevent data breaches and compliance with privacy regulations – or, more simply stated, who is viewing the images and where are they being viewed. Patients should be informed of who will have access to their images and under what conditions, ensuring alignment with diverse patient preferences and ethical standards.

Patient-captured wound images and the accompanying information are legal documents that form part of a patient's record, and their use requires secure transmission and storage to protect patient confidentiality and privacy.[121] However, a scoping review of the literature provided little guidance on legal and ethical issues regarding patient and physician responsibilities, as well as how records, images and

Box 10. Caldicott principles for using and storing patient information[122]

- Justify the purpose(s) for using confidential information
- Use confidential information only when necessary
- Use the minimum necessary confidential information
- Access to confidential information should be on a strict need-to-know basis
- Everyone with access to confidential information should be aware of their responsibilities
- Comply with the law
- The duty to share information for individual care is as important as the duty to protect patient confidentiality
- Inform patients and services users about how their confidential information is used and what choice they have; there should be no surprises

information are stored, transferred and managed. This was found to be especially true with unsolicited images.[121]

Consensus statement: To comply with privacy standards, the consent process for taking, using and sharing wound images must specify how these images may be used, whether for clinical care, education, research, artificial intelligence (AI) development or publication purposes. The intended use(s) should be clearly stated on the consent form and verbally explained to the patient so they fully understand.

The Caldicott principles, first introduced in the UK in 1997, provide guidelines for using and storing patient information. The eight principles apply to all data collected for health and social services where patients and providers can be identified and are expected to remain confidential (*Box 10*).[122]

Consensus statement: Consent processes for RDSWM must also consider cultural and religious beliefs and sensitivities that may affect a patient's comfort with having photographs taken and shared.

Technical considerations

Advantages and limitations of smartphone cameras

The use of mobile phone cameras for post-operative site monitoring presents both significant advantages and notable technical challenges, particularly in accurately capturing and assessing skin tone changes. Modern smartphones are equipped with advanced colour processing capabilities, including high dynamic range (HDR) technology that captures multiple exposure levels simultaneously and wide colour gamut support for detailed colour reproduction.[123] These features, combined with sophisticated white balance algorithms, enable phones to adjust for various lighting conditions. The high-resolution sensors, typically 12MP or greater, can capture fine details of surgical sites, while macro capabilities and multiple lens systems provide flexibility in imaging approach.[123] Most phones also offer built-in light-emitting diode (LED) flash and auto-focus systems, making it easier for patients to capture clear and well-lit images.[124]

However, several technical limitations must be considered when implementing mobile phone-based monitoring systems. Colour accuracy remains a significant challenge, as phone cameras can struggle with consistent colour reproduction under varying light conditions. Auto white balance features, while helpful in general photography, may incorrectly adjust skin tones, potentially masking important clinical changes. The variation in screen display quality between devices can affect how healthcare providers view and interpret these images, and different phone models may process colours differently, leading to inconsistency in documentation. Lighting presents another substantial challenge, as indoor lighting can create colour casts that affect skin tone appearance, while shadows can mask subtle changes. Flash photography, while sometimes necessary, may wash out important details or create a glare that compromises image quality.[125,126]

Technical variables such as image compression, varying camera sensor quality between phone models, and auto-enhancement features can all impact the accuracy of wound assessment. To address these challenges, healthcare providers should implement standardised imaging protocols that specify consistent distance, lighting, and angle requirements. The use of colour reference cards in photos can help calibrate colour accuracy, and establishing minimum camera requirements for participating patients can ensure adequate image quality.[127,128] Comprehensive training programmes should educate patients on proper lighting techniques and optimal camera settings, supported by clear examples distinguishing good from poor quality images.[129,130]

Quality control measures are essential for successful implementation. These should include automated image quality checks and clear protocols for rejecting inadequate images. Healthcare providers might also consider recommending standardised lighting accessories to improve consistency. The effectiveness of mobile phone-based monitoring ultimately depends on these technical factors being properly addressed in the implementation protocol, while maintaining a balance between technical requirements and patient usability. Understanding and accounting for these limitations is crucial when developing monitoring programmes, ensuring that adequate support systems are in place to overcome technical challenges while maintaining clinical efficacy.[131,132]

Skin tone

The accurate photography and assessment of surgical sites presents distinct challenges across the spectrum of skin tones, with both translucent and dark skin presenting unique technical considerations (*Figure 3*).[133] While mobile phone cameras have historically been optimised for lighter skin tones, this creates different challenges at both ends of the spectrum. In translucent skin, the visibility of underlying blood vessels and tissues can create complex imaging scenarios, where cameras may struggle to accurately capture subtle changes in both surface and subsurface features. The semi-transparent nature of translucent skin can lead to overexposure issues, particularly when trying to capture both surface detail and deeper tissue changes simultaneously.[134] For darker skin tones, higher melanin density can interfere with the visibility of certain clinical signs, making accurate depiction challenging.[125,135]

Mobile phone cameras face contrasting challenges when dealing with translucent versus darker skin tones. With translucent skin, the challenge lies in preventing overexposure while maintaining the ability to detect subtle variations in both surface inflammation and underlying tissue changes. The auto-exposure systems may struggle to balance the visibility of surface features with the subtle colouration of deeper tissues.[127,128] Conversely, with darker skin tones, cameras often struggle with dynamic range and detail preservation in shadows, potentially missing important clinical indicators. The auto-exposure systems can result in underexposure of darker skin or fail to capture subtle colour variations that might indicate early complications.[136,137]

Environmental lighting affects these skin types differently. In translucent skin, harsh lighting can create excessive glare and wash out important details, while too little light might fail to illuminate underlying tissue changes. Indoor lighting with yellow or fluorescent casts can distort the natural coloration of translucent skin, making it difficult to distinguish between normal variation and potential concerns.[138] For darker skin tones, these same lighting conditions can mask subtle colour changes, making it particularly challenging to discern early signs of complications.[139] Natural lighting, while generally

Figure 3. Incision images following Caesarian section in patients of different skin tones

Courtesy of Guy's and St Thomas' NHS Foundation Trust

preferred, presents different challenges for each skin type – potentially creating too much contrast in translucent skin while potentially underexposing darker skin tones.[139]

To address these varied challenges, healthcare providers need to implement protocols that account for the full spectrum of skin tones. This should include specific guidance for photographing translucent skin (such as avoiding direct light that might create glare or wash out underlying features) as well as darker skin tones (ensuring adequate lighting without losing detail).[134] Colour calibration cards should include references across the full spectrum of skin tones, and healthcare providers should receive training in interpreting wound characteristics across all skin types, recognising that clinical signs may present differently in translucent skin (where underlying changes might be more visible) compared to darker skin tones.[125,135] Accurate depiction of skin tones in medical photography is crucial for proper diagnosis and treatment, especially for patients with darker skin tones where higher melanin density can interfere with the visibility of certain clinical signs.[127,128]

From a development perspective, imaging solutions need to be validated across the complete spectrum of skin tones, with specific attention to the unique challenges presented by both translucent and darker skin.[136,137] This includes ensuring algorithms can properly process the complex light interactions in translucent skin while maintaining sufficient sensitivity to detect subtle changes in darker skin tones.[140,141] The effectiveness of these technological solutions requires ongoing evaluation across all skin types to ensure consistent clinical efficacy.[142]

There are tools for objective measurement of a patient's skin tone. The Ho and Robinson colour bar tool can be used to capture and record a baseline assessment.[143] Other tools such as the Monk Skin Tone Scale have been developed for digital use.[144] A survey of skin tone assessment in prospective research advised taking into account external factors that affect skin tone, such as artificial tanners, makeup, tattoos, pigmentary disorders (e.g., vitiligo or melasma) and medical conditions (e.g., anaemia and jaundice).[104] This assessment should also consider perfusion-related changes in the skin, such as flushing and blanching.[104] Photographs used for skin tone assessment should ideally be taken in natural ambient light or under artificial light with the same temperature to natural light (5000–6500 K).[104]

Artificial intelligence in surgical wound monitoring and surveillance

Image-based RDSWM can automatically collect patient-generated data, such as PROMs and wound images. This data is ideal for use as a large training database for the machine learning required to develop artificial intelligence (AI) models. AI is a general term to describe the use of computers to model intelligent behaviour with minimal human intervention.[145] With current computational power, AI models can evaluate complex data in real time,[146] and there is increasing evidence that AI models can meet or even exceed clinician diagnostic capabilities.[147] The healthcare sector is making increasing use of predictive AI models to increase the speed and accuracy of diagnostic processes and thus improve patient care.[146] These AI models could be incorporated into clinical pathways for assessment, surveillance and care of surgical wounds.[148]

Numerous studies have demonstrated the feasibility of AI models to determine risk factors for SSIs using data from retrospective patient chart reviews.[149–154] However, research on the application of AI to monitor surgical wounds and detect SWCs remains at an early stage.[155]

A scoping review found scarce research on image-based AI models for SSI detection, reporting that most current post-surgical surveillance depends on follow-up visits, which may not be timely nor frequent enough, or on patient self-assessment, which may not be reliable.[156] Examples of AI models for RDSWM using images include Deepwound, which helps stratify surgical wounds according to their risk of SSI to help identify incisional concerns.[157–159] An image-based AI model designed to detect SSIs after hip replacement surgery was reported to reduce both monitoring time and volume of clinical records that needed to be reviewed.[160] An AI model for detecting SSI, based on natural language processing (NLP) of oral, typed and hand-written communication and three markers for infection (positive cultures, prescription of clindamycin and use of 'infection' in the text), was validated in four hospitals in Madrid, Spain.[160] Using NLP in conjunction with structured EMR data has been reported to improve the performance of AI models for detecting SSIs.[161]

A US proof-of-concept study showed that AI models for early detection of SSIs could be trained on thermal images as well as normal colour photography.[162] A Canadian systematic review and meta-analysis of AI models to detect SSI found that more were used for prediction rather than for detection of SSI.[163] There was also a lack of reporting risk of bias in the studies reviewed. Models that used both structured data and textual data performed better than those using structured data only and concluded that adding free text as a data source for the model could improve SSI detection and prediction.[163] The need for outside validation of any AI models was reinforced in most of the literature reviewed.

A study of AI usage in European studies concluded that complex data regulations, lack of human resources, limited skills and problems with data governance were obstacles to routine data linkage for public health surveillance and research.[164]

Consensus statement: AI presents major opportunities to provide real-time clinical recommendations on a large scale, without significantly burdening healthcare staff. The overall effectiveness of AI-enhanced surgical wound surveillance will depend on the accuracy of the model and how it is used within the care pathway.

Emerging diagnostic technologies for wound assessment by clinicians

In some clinical settings, clinicians can use emerging imaging diagnostic technologies to assess wounds at the time of discharge. While evidence on the prognostic significance is still to be definitively established, this may help determine wound status and identify potential risk.

- Near-infrared spectroscopy (NIRS) uses a hand-held device to emit near-infrared light (650–1100 nm) and measure the absorption of the light by haemoglobin in the microvascular network, thus providing immediate point-of-care visualisation of tissue oxygenation.[165] The results can provide information on potential hypoperfusion of tissue around the incision that may predict impaired wound healing and/or increased risk of SWC and thus the need for earlier and more frequent post-operative monitoring.[166,167] One caution needed for the use of NIRS is that results can be altered in dark skin tones due to the relatively high amount of melanin in the skin.[168] NIRS imaging provides valuable information for wound assessment at discharge as well as during subsequent follow-up visits. The data captured creates a sequential visual report of tissue healing, documenting the normalisation of oxy- and deoxyhaemoglobin levels in the wound and periwound tissues, and the improved overall tissue oxygen saturation with healing progression. Additionally, any hyperperfusion captured by the NIRS images at the surgical site can indicate an inflammatory state, alerting the clinician to potential infection. Finally, a recent update to the processing algorithm has vastly improved NIRS diagnostics in darker skin tones.
- Fluorescence imaging is a non-invasive point-of-care modality that uses violet light to detect bacterial loads greater than 10^4 CFU/g of tissue, termed the chronic inhibitory bacterial load (CIBL). Bacteria at this level can be detrimental to wound healing without causing the clinical signs and symptoms of infection that may be missing, especially in immunocompromised patients.[169] Identification of bacteria in the incision prior to discharge can help drive decisions on dressings, need for oral antibiotics and frequency of post-operative monitoring.
- Thermal imaging assesses the skin's temperature profile, which can help detect SSI through well-documented thermographic changes that occur early in the course of an infection. Mobile thermal imaging devices provide a relatively inexpensive and portable technology that can be used in outpatient and home-care settings.[162] Furthermore, thermal imaging may better generalise to different skin colours than conventional photography.[156]

Conclusion

SSI is a widespread and impactful post-operative complication that requires careful monitoring before and after discharge. RDSWM that incorporates images and self-reporting checklists is a valuable tool for post-discharge incision monitoring. It allows wound healing progress to be tracked, communicated and assessed, enabling timely diagnosis and appropriate intervention. This technology is developing through ongoing research into its accuracy, sensitivity and specificity, as well as an emerging consensus on the timing of the monitoring process. However, RDSWM programmes must ensure equitable access to all patients, encourage lasting adherence and allow for interpersonal contact with clinical experts.

RDSWM presents opportunities to gather data, both for conventional surveillance purposes and for training AI models, which have the potential to enhance SSI monitoring and diagnosis. Smartphone cameras allow almost anyone to take and share high-quality digital images, but there are still technical challenges, such as adjusting for variation in skin tone and colour, that must be overcome for optimal image quality. Therefore, both providers and patients should receive appropriate training, not only on SWC assessment, but also on photographic technique.

Post-operative monitoring and surveillance programmes should be implemented in a structured, evidence-based manner, with active stakeholder engagement and adequate protections for patients' consent and privacy. The recommendations in this international consensus document are intended to help guide institutional providers and clinical teams in implementing an RDSWM programme in accordance with local requirements. These recommendations are general, global and multidisciplinary in scope, but they are based on evidence drawn from specific disciplines and localities, and they should be appropriately adapted to particular local contexts.

More large-scale, multicentre clinical trials and real-world data are needed to establish the efficacy, safety and best practice for post-surgical wound monitoring and surveillance. However, an effective remote monitoring and surveillance programme for surgical wounds making use of smartphones should reduce the incidence of SWCs and improve patient care.

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