

1 **New WHO recommendations on intraoperative and postoperative measures for** 2 **surgical site infection prevention: an evidence-based global perspective**

3 This is the second in a Series of two papers about surgical site infections.

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47 **1 Table and 1 Figure**

48 **Table 1:** Summary of the WHO recommendations for intraoperative and postoperative measures to
49 prevent SSIs*

50 **Figure 1:** Patient receiving oxygen in the immediate postoperative period. Courtesy of Shutterstock.

51 **ABSTRACT**

52 Surgical site infections (SSIs) are the most common health-care-associated infections in developing
53 countries, but they also represent a substantial epidemiological burden in high-income countries.
54 The prevention of these infections is complex and requires the integration of a range of preventive
55 measures before, during, and after surgery. No international guidelines are available and
56 inconsistencies in the interpretation of evidence and recommendations in national guidelines have
57 been identified. Considering the prevention of SSIs as a priority for patient safety, WHO has
58 developed evidence-based and expert consensus-based recommendations on the basis of an
59 extensive list of preventive measures. We present in this Review 16 recommendations specific to the
60 intraoperative and postoperative periods. The WHO recommendations were developed with a global
61 perspective and they take into account the balance between benefits and harms, the evidence
62 quality level, cost and resource use implications, and patient values and preferences.

63

64 **INTRODUCTION**

65 Surgical site infections (SSIs) are largely preventable, but they represent a considerable burden for
66 health-care systems, particularly in low-income and middle-income countries. For these reasons, and
67 the fact that no general set of international recommendations exists, WHO prioritised the
68 development of evidence-based global guidelines for the prevention of SSIs. A panel of international
69 experts developed recommendations on the basis of predetermined research questions and the
70 results of related systematic literature reviews. The description of the intended audience for these
71 recommendations, the methods used, and the first group of recommendations regarding
72 preoperative preventive measures are provided in paper 1 of this Series,¹ which should be read in
73 conjunction with this Review. We present here the recommendations (table) to be applied in the
74 intraoperative and postoperative periods. Important topics such as asepsis in the operating room
75 and sterilisation are not mentioned because they were not the object of formal recommendations,

76 but they are included and extensively reviewed in the WHO guidelines, as cornerstones of SSI
77 prevention.

78

79 **RECOMMENDATION 1: PERIOPERATIVE OXYGENATION**

80 The panel recommends that adult patients undergoing general anaesthesia with endotracheal
81 intubation for surgical procedures should receive an 80% fraction of inspired oxygen (FiO₂)
82 intraoperatively and, if feasible, in the immediate postoperative period for 2–6 h, to reduce the risk
83 of SSI (strong recommendation, moderate quality of evidence).

84 Adequate surgical site tissue oxygenation is thought to have a role in preventing SSIs. A high partial
85 pressure of oxygen in the blood achieved through the administration of high-concentration oxygen
86 (hyperoxia, defined as oxygen at 80% FiO₂) provides more adequate oxygenation at the surgical
87 incision—particularly at infected tissue,⁴ which has a lower oxygen tension than non-infected
88 tissue⁵—and might enhance oxidative killing by neutrophils.⁶ We did a systematic review to assess
89 the effect of high FiO₂ (80%) compared with standard FiO₂ (30–35%) for the prevention of SSI.
90 We identified 15 randomised controlled trials (RCTs)^{7–21} comparing the perioperative administration
91 of 80% FiO₂ with 30–35% FiO₂ in adults. We did a meta-analysis that included studies in which
92 patients underwent general anaesthesia with endo tracheal intubation and mechanical ventilation.^{7–}
93 ¹⁷ Ventilation control (and therefore the actual administration of FiO₂) with a facemask or nasal
94 cannulae in neuraxial anaesthesia was considered to be a different intervention from mechanical
95 ventilation. Furthermore, a meta-regression analysis showed that the type of anaesthesia
96 independently modified the effect of hyperoxygenation. The 11 RCTs included in the meta-analysis
97 showed that increased perioperative FiO₂ is beneficial in reducing SSI compared with standard
98 perioperative FiO₂ (odds ratio [OR] 0.72; 95% CI 0.55–0.94). The quality of the evidence was rated as
99 moderate.

100 On the basis of this evidence, patients undergoing general anaesthesia with endotracheal intubation
101 for surgical procedures should receive 80% FiO₂ intraoperatively and, if feasible, for 2–6 h in the

102 immediate postoperative period. The expert panel noted that the benefits of this intervention can
103 be observed only when implemented by both intubation during the operation, and using a high-flux
104 mask in the immediate postoperative period (figure). The benefits are also maximised when
105 normothermia and normovolaemia are maintained. In low-resource settings in which medical
106 oxygen is scarce and its increased use could place a burden on available resources, this
107 recommendation might not be considered as a priority by policymakers.

108

109 **RECOMMENDATION 2: MAINTAINING NORMAL BODY TEMPERATURE (NORMOTHERMIA)**

110 The panel suggests the use of warming devices in the operating room and during the surgical
111 procedure for patient body warming with the purpose of reducing SSI (conditional recommendation,
112 moderate quality of evidence).

113 Hypothermia is defined as a core temperature less than 36°C. It commonly occurs during and after
114 surgical procedures lasting more than 2 h because of impairment of thermoregulation by anaesthesia,
115 combined with exposure to a cold environment (the operating room).^{22,23} Unintended hypothermia is
116 considered to be an adverse event of general and regional anaesthesia and might be associated with
117 increased cardiac complications, blood loss due to impaired coagulation, impaired wound healing,
118 decreased drug metabolism, decreased immune function, and an increased risk of SSI.^{22,24–27} We did a
119 systematic review to assess the effectiveness of perioperative body warming on the prevention of
120 SSIs.

121 We found two RCTs^{28,29} comparing the effect of preoperative and intraoperative body warming on SSIs
122 in adults with no body warming. Meta-analysis showed that body warming was significantly associated
123 with a reduced risk of SSIs (OR 0.33; 95% CI 0.17–0.62); the quality of the evidence was rated as
124 moderate. However, in developing countries, the equipment and maintenance costs of electrical
125 body-warming equipment represent a substantial financial burden, and availability and procurement
126 are additional issues. Blankets can be considered as a low-cost, effective option in low-resource
127 settings.

128

129 **RECOMMENDATION 3: USE OF INTENSIVE PROTOCOLS FOR PERIOPERATIVE BLOOD GLUCOSE**
130 **CONTROL**

131 The panel suggests the use of protocols for intensive perioperative blood glucose control for both
132 diabetic and non-diabetic adults undergoing surgical procedures, to reduce the risk of SSI (conditional
133 recommendation, low quality of evidence).

134 A rise in blood glucose concentration is commonly observed in the operative and postoperative
135 periods because of a surgical stress response, resulting in increased secretion of catabolic hormones
136 (eg, catecholamines or cortisol), inhibition of insulin secretion, and insulin resistance.³⁰ Observational
137 studies have shown that hyperglycaemia is associated with an increased risk of SSIs in both diabetic
138 and non-diabetic patients.^{31–33} Although the importance of perioperative blood glucose control is
139 agreed upon, there is controversy regarding the best treatment options, the optimal target
140 concentration of blood glucose, and the optimal timing of glucose control. The concern is due to the
141 risk of developing hypoglycaemia, which is also associated with increased morbidity and mortality.^{34–}

142 ³⁷ We did a systematic review to investigate whether the use of intensive protocols for perioperative
143 blood glucose control is more effective in reducing the risk of SSI in both diabetic and non-diabetic
144 patients than conventional protocols with less stringent target blood glucose concentrations.

145 We identified 15 RCTs^{38–52} in adults. Overall, an intensive protocol with strict blood glucose target
146 concentrations was associated with significantly decreased SSI incidence compared with a
147 conventional protocol (OR 0.43; 95% CI 0.29–0.64). Because of the heterogeneity of the timing of
148 application of the protocols (intraoperative vs intraoperative-and-postoperative vs postoperative),
149 study population (patients with diabetes vs patients without diabetes vs mixed population), and the
150 upper limit of the target concentration of blood glucose (≤ 110 mg/dL [6.1 mmol/L] vs 110–150 mg/dL
151 [6.1–8.3 mmol/L]), we decided to do separate meta-analyses for each of these comparisons. No
152 significant difference in the effect on SSI reduction was observed between studies of patients with
153 and without diabetes in meta-regression analyses ($p=0.590$). There was some evidence that the SSI

154 reduction effect was smaller in studies that used intensive blood glucose control intraoperatively only
155 (OR 0.88; 0.45–1.74) compared with studies that used intensive blood glucose controls
156 postoperatively or both intra operatively and postoperatively (OR 0.37; 0.25–0.55; $p=0.049$ for
157 difference between these ORs).

158 No significant difference was observed ($p=0.328$) between studies that used low upper limit target
159 blood glucose concentrations (≤ 110 mg/dL; 6.1 mmol/L), versus studies with high upper limit
160 concentrations (110–150 mg/dL; 6.1–8.3 mmol/L). The overall quality of the evidence was rated as
161 low. Further analysis of adverse events showed no difference between the use of an intensive protocol
162 and a conventional protocol in the risk of death (OR 0.74; 95% CI 0.45–1.23; $p=0.2$) or stroke (OR 1.37;
163 0.26–7.20; $p=0.7$). However, there was an overall increased risk of hypoglycaemia (OR 5.55; 2.58–
164 11.96). Meta-regression analyses showed no difference in the risk of hypoglycaemia between studies
165 that used low or high upper limit target blood glucose concentrations ($p=0.413$).

166 In conclusion, using a protocol with strict blood glucose target concentrations is associated with a
167 substantial benefit for the reduction of SSI prevalence, but neither the optimal blood glucose target
168 concentration nor the perioperative timing of glucose control could be defined. However, it should be
169 noted that hypoglycaemia is a possible serious side-effect associated with these intensive protocols
170 and close reliable monitoring of blood glucose concentrations is crucial for this intervention.

171

172 **RECOMMENDATION 4: MAINTENANCE OF ADEQUATE CIRCULATING VOLUME CONTROL**
173 **(NORMOVOLAEMIA)**

174 The panel suggests the use of goal-directed fluid therapy (GDFT) intraoperatively to reduce the risk of
175 SSI (conditional recommendation, low quality of evidence).

176 Adequate intravascular volume is an essential component of tissue perfusion and an important aspect
177 of tissue oxygenation.⁵³ In unbalanced fluid states—ie, hypovolaemia and hypervolaemia—tissue
178 oxygenation is compromised and might increase the risk of SSI.⁵⁴ The optimal type of fluid (colloid or
179 crystalloid) or strategy of fluid management (goal-directed, liberal, or restrictive) remain controversial

180 topics, partly because of the absence of a universal definition of normovolaemia or a standardised
181 method for its assessment. We did a systematic review to assess whether specific fluid management
182 strategies for the maintenance of normovolaemia are more effective in reducing the risk of SSI than
183 standard fluid regimens administered during surgery.

184 We identified 24 RCTs⁵⁵⁻⁷⁸ comparing specific strategies of fluid management with standard
185 management. Because of substantial heterogeneity in the type of specific fluid management strategy
186 used, separate meta-analyses were done for GDFT or restrictive fluid regimens versus standard
187 regimens in the preoperative, intraoperative, and postoperative periods. GDFT refers to a
188 haemodynamic treatment based on the titration of fluid and inotropic drugs according to cardiac
189 output or similar parameters. Restrictive fluid management refers to the administration of a regimen
190 with a reduced volume of fluids in the bolus or over time, compared with local standard fluid
191 maintenance. A meta-analysis of 14 RCTs⁵⁵⁻⁶⁸ showed that intraoperative GDFT was significantly
192 associated with lower incidence of SSIs than standard intraoperative fluid management (OR 0.56; 95%
193 CI 0.35-0.88). Meta-analysis of five RCTs⁶⁹⁻⁷³ showed that restrictive intraoperative fluid management
194 did not significantly affect SSI incidence compared with standard intraoperative management (OR
195 0.73; 0.41-1.28). Meta-analysis of two RCTs^{76,77} showed that postoperative GDFT was associated
196 with a decreased risk of SSI compared with standard postoperative management (OR 0.24; 0.11-0.52).
197 One RCT⁷⁴ showed that preoperative GDFT did not significantly affect SSI incidence compared with
198 standard preoperative management (OR 0.47; 0.13-1.72).

199 Considering the evidence (rated as low quality), the panel suggested the use of GDFT intraoperatively
200 to prevent SSI. Its postoperative use might also be beneficial to reduce SSI. However, restrictive fluid
201 management and preoperative GDFT were not associated with the reduction of SSI compared with
202 standard fluid management.

203

204 **RECOMMENDATION 5 AND 6: DRAPS AND GOWNS**

205 The panel suggests that either sterile disposable non-woven or sterile reusable woven drapes and
206 surgical gowns be used during surgical operations for the purpose of preventing SSI (conditional
207 recommendation, moderate to very low quality of evidence); and suggests that plastic adhesive incise
208 drapes with or without antimicrobial properties should not be used (conditional recommendation,
209 low to very low quality of evidence).

210 Drapes and gowns are available for single-use or multiple-use, with varying compositions. Adhesive
211 plastic incise drapes are used on a patient's skin after surgical site preparation, with or without
212 antimicrobial impregnation, and the surgeon performs the incision of the drape and the skin
213 simultaneously. In available guidelines, there are conflicting recommendations on the use of plastic
214 adhesive drapes, mainly discouraging their use.⁷⁹ There are no recommendations on the use of single-
215 use or reusable drapes and gowns for the purpose of SSI prevention. We did a systematic review to
216 investigate the use of sterile disposable or reusable drapes and surgical gowns, and separately the use
217 of plastic adhesive incise drapes, for the purpose of SSI prevention.

218 We identified 11 studies^{80–90} (four RCTs^{81,86,89,90}). Meta-analysis of five studies (one RCT,⁸¹ one quasi-
219 RCT,⁸² and three observational studies^{80,83,84}) comparing sterile disposable non-woven drapes and
220 gowns with sterile reusable woven drapes and gowns showed no difference in the SSI risk (RCTs,
221 moderate quality evidence: OR 0.85; 95% CI 0.66–1.09; observational studies, very low quality
222 evidence: OR 1.56; 0.89–2.72). Meta-analysis of four studies (one RCT,⁸⁶ one quasi-RCT,⁸⁵ and two
223 observational studies^{87,88}) comparing adhesive iodine-impregnated incise drapes with no drapes
224 showed no difference in the SSI risk (RCTs: OR 2.62; 0.68–10.04; observational studies: OR 0.49; 0.16–
225 1.49). Similarly, meta-analysis of two RCTs^{89,90} comparing non-impregnated adhesive incise drapes
226 to no drapes showed no difference in the SSI risk (OR 1.10; 0.68–1.78). The quality of the evidence
227 was rated low to very low.

228 Considering the evidence, including potential issues of availability and costs in low-resource settings
229 and the ecological effect, the expert panel suggested that either sterile disposable non-woven or

230 sterile reusable woven drapes and gowns can be used. However, adhesive incise drapes (with or
231 without antimicrobial properties) should not be used for the purpose of preventing SSI.

232

233 **RECOMMENDATION 7: WOUND-PROTECTOR DEVICES**

234 The panel suggests considering the use of wound-protector devices in clean-contaminated,
235 contaminated, and dirty abdominal surgical procedures for the purpose of reducing the rate of SSIs
236 (conditional recommendation, very low quality of evidence).

237 Wound-protector devices (or wound-edge protectors) are comprised of a non-adhesive plastic sheath
238 attached to a single or double rubber ring that firmly secures the sheath to the wound edges. They
239 facilitate the retraction of the incision during surgery and are aimed at reducing wound-edge
240 contamination to a minimum during abdominal surgical procedures. Notably, they have been on the
241 market despite scarce evidence supporting their usefulness. We did a systematic review to assess the
242 effectiveness of wound-protector devices for the reduction of SSI risk compared with conventional
243 wound protection in abdominal surgery.

244 We found 11 studies (ten RCTs,^{91–100} and one prospective controlled trial¹⁰¹) in adults. Meta-analysis
245 showed that the use of a wound-protector device (single-ring or double-ring) was associated with a
246 significantly lower risk of SSI than with conventional wound protection (OR 0.42; 95% CI 0.28–0.62).
247 Meta-regression analyses showed no evidence of a difference in the effect between single-ring and
248 double-ring wound-protector devices or between clean-contaminated, contaminated, or dirty surgery
249 and other surgery.

250 Considering the evidence (rated as very low quality), the panel suggests the use of wound-protector
251 devices in clean-contaminated, contaminated, and dirty abdominal surgical procedures for the
252 prevention of SSI. The panel highlighted that wound-protector device use should not always be
253 prioritised in low-resource settings over other interventions that prevent SSI, because of their scarce
254 availability and associated costs.

255

256 **RECOMMENDATION 8 AND 9: INCISIONAL WOUND IRRIGATION**

257 The panel suggests considering the use of irrigation of the incisional wound with an aqueous povidone-
258 iodine solution before closure for the purpose of preventing SSI, particularly in clean and clean-
259 contaminated wounds (conditional recommendation, low quality of evidence); but the panel suggests
260 that antibiotic incisional wound irrigation before closure should not be done (conditional
261 recommendation, low quality of evidence); insufficient evidence was available to recommend for or
262 against saline irrigation of incisional wounds before closure for the purpose of preventing SSIs.

263 Intraoperative wound irrigation refers to the flow of a solution across the surface of an open wound.
264 It is a widely practised procedure and considered to help prevent SSIs.^{102–104} Among other benefits,
265 wound irrigation is intended to physically remove cellular debris, surface bacteria, and body fluids, to
266 dilute possible contamination, and to function as a local antibacterial agent when an antiseptic or
267 antibiotic agent is used. Practices vary depending on the patient population, the surface of application,
268 and solutions used. We did a systematic review to investigate whether intraoperative wound irrigation
269 (with or without active agents or pressured application) affects the incidence of SSI. Studies
270 investigating the topical application of antibiotics or antiseptics (eg, powder, gels, sponges) were not
271 included. We also excluded studies in which surgical antibiotic prophylaxis was not administered
272 appropriately (ie, preoperatively and intravenous) or wound irrigation represented a therapeutic
273 intervention for a pre-existent infection rather than a prophylactic measure.

274 We identified 21 RCTs^{105–125} comparing wound irrigation with no wound irrigation in patients
275 undergoing various surgical procedures, and the results were substantially heterogeneous. The panel
276 decided to restrict the recommendation to incisional wound irrigation, because too little (and
277 heterogeneous) evidence was available to address other applications of irrigation—ie, intraperitoneal
278 or mediastinal irrigation.

279 Moderate to very low quality evidence from four studies using irrigation with a saline solution
280 administered with different methods provided conflicting results.^{110,113,115,117} Irrigation with saline
281 solution using pulse pressure or applied with force had a marked benefit in terms of SSI

282 reduction.^{110,115,117} A meta-analysis of seven RCTs^{105–108} showed a significant benefit of irrigation of the
283 incisional wound with aqueous povidone-iodine solutions in different concentrations compared with
284 irrigation with a saline solution (OR 0·31; 95% CI 0·13–0·73; p=0·007). Further stratification according
285 to the wound contamination class and povidone-iodine solution showed that the effect was
286 attributable to incisional wound irrigation in clean and clean-contaminated procedures with povidone-
287 iodine 10% and povidone-iodine 0·35%. A meta-analysis of five studies^{119–121,123,124} showed no
288 significant difference between antibiotic irrigation of the incisional wound and no irrigation or
289 irrigation with a saline solution (OR 1·16; 0·64–2·12; p=0·63).

290 The panel concluded that the evidence was insufficient to recommend for or against saline irrigation
291 of incisional wounds for the purpose of preventing SSIs. By contrast, incisional wound irrigation with
292 an aqueous povidone-iodine solution might have a benefit, particularly in clean and clean-
293 contaminated wounds. Finally, antibiotic incisional wound irrigation before closure should not be used
294 for the purpose of preventing SSI. The expert panel strongly emphasised that this practice is associated
295 with an unnecessary risk of antimicrobial resistance.

296 Allergic reactions and metabolic adverse events should be considered as potential harms of iodine
297 uptake. Although the panel recognises that saline and povidoneiodine solutions are readily available
298 in most settings, sterile products might be scarce in low-income and middle-income countries. In many
299 settings, the availability and costs of pulse-pressure devices represent a high financial burden,
300 including not only their purchase, but also waste disposal, procurement, energy, and machine
301 maintenance.

302

303 **RECOMMENDATION 10: PROPHYLACTIC NEGATIVE-PRESSURE WOUND THERAPY**

304 The panel suggests the use of prophylactic negative-pressure wound therapy (pNPWT) on primarily
305 closed surgical incisions in high-risk wounds, for the purpose of preventing SSI, while taking resources
306 into account (conditional recommendation, low quality of evidence).

307 pNPWT consists of a closed sealed system connected to a vacuum pump, which maintains negative
308 pressure on the wound surface. Although used for several other purposes since the late 1990s, it is
309 also applied on primarily closed surgical incisions to prevent SSIs. We did a systematic review to
310 establish whether the use of pNPWT is more effective in reducing the risk of SSIs than the use of
311 conventional wound dressings.

312 We identified 19 publications describing 20 studies (six RCTs^{126–130} and 14 observational studies^{131–144}).
313 Overall, meta-analyses of RCTs and observational studies showed that pNPWT has a significant benefit
314 in reducing the risk of SSI in patients with a primarily closed surgical incision compared with
315 conventional postoperative wound dressings (RCTs: OR 0.56; 95% CI 0.32–0.96; observational studies:
316 OR 0.30; 0.22–0.42). When stratified by type of surgery, this effect was observed in abdominal (nine
317 observational studies;^{132–136,140,141,143,144} OR 0.31; 0.19–0.49) and cardiac (two observational
318 studies;^{137,138} OR 0.29; 0.12–0.69) surgery, but it was not statistically significant in orthopaedic or
319 trauma surgery. Stratification by wound contamination class showed a significant benefit in reducing
320 SSI prevalence with the use of pNPWT in clean surgery (eight observational studies;<sup>131,135,137–
321 139,141,142,144</sup> OR 0.27; 95% CI 0.17–0.42) and in clean-contaminated surgery (eight observational
322 studies;^{132–134,136,140,141,143,144} OR 0.29; 0.17–0.50).

323 On the basis of the low-quality evidence available, the panel suggests the use of pNPWT on primarily
324 closed surgical incisions in high-risk conditions (eg, poor tissue perfusion due to surrounding soft tissue
325 or skin damage, decreased blood flow, bleeding or haematoma, dead space, or intraoperative
326 contamination) for the purpose of the prevention of SSIs, taking available resources into account. The
327 panel highlighted that the use of pNPWT might not be prioritised in low-resource settings compared
328 with other interventions to prevent SSI considering its poor availability and potential associated costs.

329

330 **RECOMMENDATION 11: ANTIMICROBIAL-COATED SUTURES**

331 The panel suggests the use of triclosan-coated sutures to reduce the risk of SSIs, independent of the
332 type of surgery (conditional recommendation, moderate quality of evidence).

333 Sutures with antimicrobial properties were developed with the aim to prevent microbial colonisation
334 of the suture material in operative incisions. Early studies showed a reduction of the number of
335 bacteria in vitro and wound infections in animals^{145–147} using triclosan-coated sutures and this effect
336 was subsequently confirmed in clinical studies. Several novel antimicrobial coatings are now available,
337 but still no clinical studies have been done that compare the efficacy with non-coated sutures.^{148,149}
338 We did a systematic review to assess whether the use of antimicrobial-coated sutures is more effective
339 in reducing the risk of SSIs than the use of non-coated sutures.
340 We found 18 studies (13 RCTs^{150–162} and five cohort studies^{163–167}). All studies investigated triclosan-
341 coated sutures and focused on adult patients, apart from one¹⁵² done in a paediatric population. The
342 overall meta-analysis showed that antimicrobial-coated sutures have a significant benefit in reducing
343 SSI incidence in patients undergoing surgical procedures compared with non-coated sutures (RCTs: OR
344 0.72; 95% CI 0.59–0.88; observational studies: OR 0.58; 0.40–0.83). When considering specific types
345 of sutures, only the meta-analyses of the studies comparing triclosan-coated polyglactin 910 suture
346 with polyglactin 910 suture featuring a braided suture construction showed that the use of
347 antimicrobial-coated sutures significantly reduces SSI prevalence compared with the non-coated
348 sutures (OR 0.62; 0.44–0.88 for RCTs; OR 0.58; 0.37–0.92 for observational studies). In meta-
349 regression analysis, we found no evidence that the effect of antimicrobial coating of sutures differed
350 between braided and monofilament sutures ($p=0.380$), or between clean ($p=0.690$), cardiac ($p=0.900$),
351 or abdominal ($p=0.832$) surgeries and other surgical procedures.
352 We highlighted that the quality of the evidence was moderate to low and that many studies had
353 several limitations, including industry sponsorship or conflicts of interest with a commercial entity. On
354 the basis of the evidence but also considering these limitations, the panel suggests the use of
355 antimicrobial-coated sutures for the purpose of reducing the risk of SSI. Because the effect appears to
356 be independent of the type of procedure or wound contamination classification, this recommendation
357 applies to any type of surgery. Availability and costs should be considered in low-income and middle-

358 income countries. Further studies are needed also on sutures coated with an alternative antimicrobial
359 agent to triclosan.

360

361 **RECOMMENDATION 12: LAMINAR AIRFLOW VENTILATION SYSTEMS IN THE CONTEXT OF**
362 **OPERATING ROOM VENTILATION**

363 The panel suggests that laminar airflow ventilation systems should not be used to reduce the risk of
364 SSIs for patients undergoing total arthroplasty surgery (conditional recommendation, low to very low
365 quality of evidence).

366 Conventional ventilation systems pass air with a mixed or turbulent flow into the operating room.
367 These systems aim to homogenise the fresh air, the air, and aerosols and particles within the room.
368 Laminar airflow systems pass the fresh air unidirectionally with a steady velocity and approximately
369 parallel streamlines to create a zone in which the air, aerosols, and particles within the room are driven
370 out. Systems with laminar airflow are frequently used in an environment where contamination with
371 particles is a serious adverse event—eg, orthopaedic implant surgery. However, laminar airflow
372 systems are complex and expensive and require careful maintenance. In many settings in low-income
373 countries, neither conventional nor laminar flow systems are affordable or maintained effectively on
374 a regular basis and often, natural ventilation is the only option.

375 We did a systematic review to assess whether a laminar airflow ventilation system is more effective
376 in reducing the risk of SSI than a conventional ventilation system. We also investigated whether fans
377 or cooling devices and natural ventilation are acceptable alternatives to conventional ventilation for
378 the prevention of SSI. We only identified one observational study¹⁶⁸ that compared natural ventilation
379 with conventional ventilation in the operating room. No difference was observed in the risk of SSI
380 following both total hip and knee arthroplasty. One systematic review¹⁶⁹ and eight observational
381 studies^{168,170–176} comparing laminar airflow with conventional ventilation were identified. Most studies
382 focused on total hip and knee arthroplasty and only a few single studies were available for other types
383 of surgery.^{170,171,173} Meta-analyses showed that laminar airflow ventilation has no benefit compared

384 with conventional ventilation in reducing the SSI incidence in total hip (OR 1.29; 95% CI 0.98–1.71) or
385 knee (OR 1.08; 0.77–1.52) arthroplasty. The quality of the evidence was rated as very low. Considering
386 these results and associated costs, the expert panel decided to suggest that laminar airflow ventilation
387 systems should not be used as a preventive measure to reduce the risk of SSI in patients undergoing
388 total arthroplasty surgery.

389

390 **RECOMMENDATION 13 AND 14: ANTIMICROBIAL PROPHYLAXIS IN THE PRESENCE OF A DRAIN AND**
391 **OPTIMAL TIMING FOR WOUND DRAIN REMOVAL**

392 The panel suggests not continuing perioperative antibiotic prophylaxis because of the presence of a
393 wound drain (conditional recommendation, low quality of evidence). They also suggest removing the
394 wound drain when clinically indicated, but they found no evidence to recommend an optimal time for
395 wound drain removal (conditional recommendation, very low quality of evidence).

396 Drainage tubes are widely used in surgery to remove any fluid or blood that collects in the wounds
397 and cavities created by the surgical procedure and thus might cause complications. However, drains
398 might adversely affect surgical outcomes—eg, affecting anastomotic healing by causing infection in
399 the anastomotic area and the abdominal wound. Many systematic reviews investigating the effect of
400 drains on the related infection risk compared with no wound drainage have been published with
401 conflicting results. The optimal time for drain removal after surgery might influence this risk, but it
402 remains unknown. Furthermore, in most cases, antibiotic prophylaxis is continued postoperatively
403 when a drain is used, but this practice is not evidence-based and raises serious concerns in terms of
404 contributing to the emergence of antimicrobial resistance. We did a systematic review to investigate
405 whether prolonged antibiotic prophylaxis in the presence of a wound drain is more effective in
406 reducing the risk of SSIs than standard perioperative prophylaxis alone. The review also assessed
407 whether the early removal of wound drains more effectively prevents SSIs than late removal.

408 Regarding the first question, seven RCTs^{177–183} were identified. The meta-analysis showed that
409 prolonged antibiotic prophylaxis in the presence of a wound drain has no benefit in reducing SSI

410 compared with perioperative prophylaxis alone (OR 0.79; 95% CI 0.53–1.20). We identified 11
411 RCTs^{184–194} comparing early with late removal of closed wound drains. However, there was
412 heterogeneity in the study definitions for early and late drain removal. For the purposes of the
413 analysis, early removal was considered to be from postoperative day 1 to day 5. Two main groups
414 were identified for defining late wound drain removal—ie, drain removal at postoperative day 6 or
415 later (three studies^{187,189,192}) and removal on the basis of drainage volume (six studies^{184–}
416 ^{187,188,190,191}). Studies not falling into these categories were excluded from the analysis. The meta-
417 analysis showed that early drain removal does not affect SSI incidence compared with late removal
418 (OR 0.86; 0.49–1.50).

419 On the basis of this low to very low quality evidence, the panel suggests that antibiotic prophylaxis
420 should not be continued in the presence of a wound drain for the purpose of preventing SSI. Given
421 the results and very low quality of the evidence about optimal timing for removal, wound drains
422 should be removed when clinically indicated.

423

424 **RECOMMENDATION 15: WOUNDS DRESSINGS**

425 The panel suggests not using any type of advanced dressing over a standard dressing on primarily
426 closed surgical wounds for the purpose of preventing SSIs (conditional recommendation, low quality
427 of evidence).

428 A wide variety of wound dressings are available. Advanced dressings are mainly hydrocolloid,
429 hydrogels, fibrous hydrocolloid, or polyurethane matrix hydrocolloid dressings and vapour-permeable
430 films. A Cochrane review¹⁹⁵ and its update¹⁹⁶ on the effect of dressings for the prevention of SSI found
431 no evidence to suggest that one dressing type was better than any other. We did a systematic review
432 to assess whether the use of advanced dressings is more effective in reducing the risk of SSIs than
433 standard wound dressings.

434 We identified ten RCTs^{197–206} in adult patients undergoing various types of surgical procedures. There
435 were variations in the definition of SSIs, the duration of postoperative follow-up, and in the type of

436 dressing (hydrocolloid, hydroactive and silver-impregnated, or polyhexamethalene biguanide-
437 impregnated dressings). Overall, the meta-analysis showed that advanced dressings do not
438 significantly reduce SSI occurrence compared with standard dressings (OR 0.80; 95% CI 0.52–1.23);
439 the quality of the evidence was rated as low. In specific meta-analyses, hydrocolloid, silver-
440 impregnated, and hydroactive dressings were non-effective in reducing the risk of SSI compared with
441 standard dressings. On the basis of the evidence, the panel recommended that advanced dressings
442 should not be used for the prevention of SSIs.

443

444 **RECOMMENDATION 16: POSTOPERATIVE SURGICAL ANTIBIOTIC PROPHYLAXIS PROLONGATION**

445 The panel recommends against the prolongation of surgical antibiotic prophylaxis (SAP)
446 administration after completion of the operation for the purpose of preventing SSIs (strong
447 recommendation, moderate quality of evidence).

448 The preventive effect of the routine use of SAP has long been recognised; however, the necessary
449 duration of SAP to achieve the desired effect has been a matter of debate. Most guidelines
450 recommend a maximum postoperative SAP duration of 24 h, but increasing evidence shows that using
451 only a single preoperative dose (and possible additional intraoperative doses according to the duration
452 of the operation) might be non-inferior. Despite this, surgeons still often routinely continue SAP up to
453 several days after surgery, which leads to serious concerns for the risk of antimicrobial resistance. We
454 did a systematic review to investigate whether prolonged SAP in the postoperative period is more
455 effective in reducing the risk of SSIs than perioperative prophylaxis (defined as a single dose before
456 incision and possible intraoperative additional dose[s] according to the duration of the operation).

457 We found 69 RCTs^{177–180,183,207–270} investigating the optimal duration of antibiotic prophylaxis in a
458 variety of surgical procedures. The overall meta-analysis, which pooled studies using any prolonged
459 SAP regimens, showed no benefit in terms of reducing the SSI incidence compared with a single dose
460 of antibiotic prophylaxis (OR 0.89; 95% CI 0.77–1.03). However, a meta-analysis of studies showed
461 that SAP continuation might be beneficial in reducing SSI compared with a single prophylactic dose in

462 cardiac (OR 0.43; 0.25–0.76)^{232,233} and orthognathic (OR 0.30; 0.10–0.88)^{242–244} surgery. Considering
463 the low quality of the evidence and the results of the overall meta-analysis (moderate quality), the
464 expert panel decided to strongly recommend against SAP prolongation, also because of the
465 widespread risk of antimicrobial resistance. Continuing antibiotic administration in cardiac and
466 orthognathic surgery has potential benefit, but further well designed RCTs on this topic are needed.

467

468 **CONCLUSION**

469 We discuss the evidence for a broad range of intraoperative and postoperative preventive measures
470 identified by an expert panel as potentially contributing to reducing the risk of SSI. For some of these,
471 the evidence shows no benefit and the panel advises against the adoption of these interventions,
472 particularly when considering resource implications or other consequences, such as antimicrobial
473 resistance. However, the panel identified a range of key measures for SSI prevention to be
474 implemented in the intraoperative and postoperative periods, together with other preoperative
475 measures discussed in paper 1 of this Series. Adoption of the recommendations should be facilitated
476 by sound implementation strategies and practical tools. Notably, careful assessment of feasibility and
477 cost implications in low-resource settings is needed.

478

479 **Contributors**

480 BA led the writing of and BZ, PB, NZK, SdJ, MA, DP, and JSS contributed to the manuscript. All
481 authors contributed to the development of the WHO Global Guidelines for the Prevention of Surgical
482 Site Infection. BZ, PB, NZK, SdJ, FdV, SMG, SG, EDW, XW, MAB, EPD, ME, PG, XG, JR, and JSS
483 contributed to the performance and interpretation of some systematic reviews and meta-analyses.

484

485 **Declaration of interests**

486 MA received grants and non-financial support from the Innovative Medicines Initiative Joint
487 Undertaking under the Combatting Bacterial Resistance in Europe (COMBACTE-Net) grant

488 agreement (no. 115523). These resources are composed of financial contributions from the
489 European Union's 7th Framework Programme (FP7/2007–2013) and the European Federation of
490 Pharmaceutical Industries and Associations companies' in-kind contribution during the study. MAB
491 has previously received a research grant from Johnson & Johnson, and also grants or honoraria for
492 delivering lectures on surgical site infection or serving on scientific advisory boards for
493 Abbott/Mylan, Acelity, Bard, Baxter, GlaxoSmithKline, Ipsen, and Johnson & Johnson. EPD received
494 honoraria from WHO during the study and previously received personal fees from Merck, Baxter,
495 Ortho-McNeil, Targanta, Schering-Plough, Astellas, Allergan, Care Fusion, Durata, Pfizer, Applied
496 Medical, Rib-X, Affinium, Tetrphase, Televancin, R-Pharm, Cubist, 3M, and Melinta, and grants
497 from Motif, and other from Microdermis. ME received personal fees from WHO during the study. XG
498 previously received personal fees from MSD, Pfizer, AstraZeneca, and Novartis. All other authors
499 declare no competing interests.

500

501 **Acknowledgments**

502 This article should be read in combination with the first paper in this Series on the new WHO
503 recommendations on preoperative measures to be implemented for the prevention of SSI. These
504 papers are an abbreviated version of the full WHO Global Guidelines for the Prevention of Surgical
505 Site Infection, which was published simultaneously on Nov 3, 2016. The development of the
506 guidelines was supervised by a WHO steering committee and we thank the following members:
507 Sergey Eremin, Edward Kelley, Walter Johnson, and Valeska Stempluk. We thank the following
508 experts who served on the Systematic Reviews Expert Group: Jasper Atema, Nizam Damani, Miranda
509 van Rijen, Jan Kluytmans, Sandra Pequeño, and Caroline Landelle. We are grateful to the following
510 experts who served as external peer reviewers of the draft guideline documents: Emmanuel Ameh,
511 Kamal Itani, Fernando Otaíza, Val Robertson, and Ilker Uçkay. We also thank Rosemary Sudan for
512 editing assistance, and Tomas Allen and Jose Luis Garnica Carreno who provided assistance for the
513 systematic review searches. Funding for the development of these guidelines was mainly provided

514 by WHO; the Swiss Government and OASIS Global (Cincinnati, OH, USA) also provided essential
515 financial support. The systematic reviews done by the external expert teams were done free of
516 charge as in-kind contributions by the following institutions: Amphia Hospital Breda (Breda,
517 Netherlands); Academic Medical Center Amsterdam (Amsterdam, Netherlands); University of Berlin
518 (Berlin, Germany); University of Cincinnati (Cincinnati, OH, USA); Hospital Universitari Parc Tauli,
519 Sabadell (Barcelona, Spain); Jinling Hospital and the Medical School of Nanjing University (Nanjing,
520 China).

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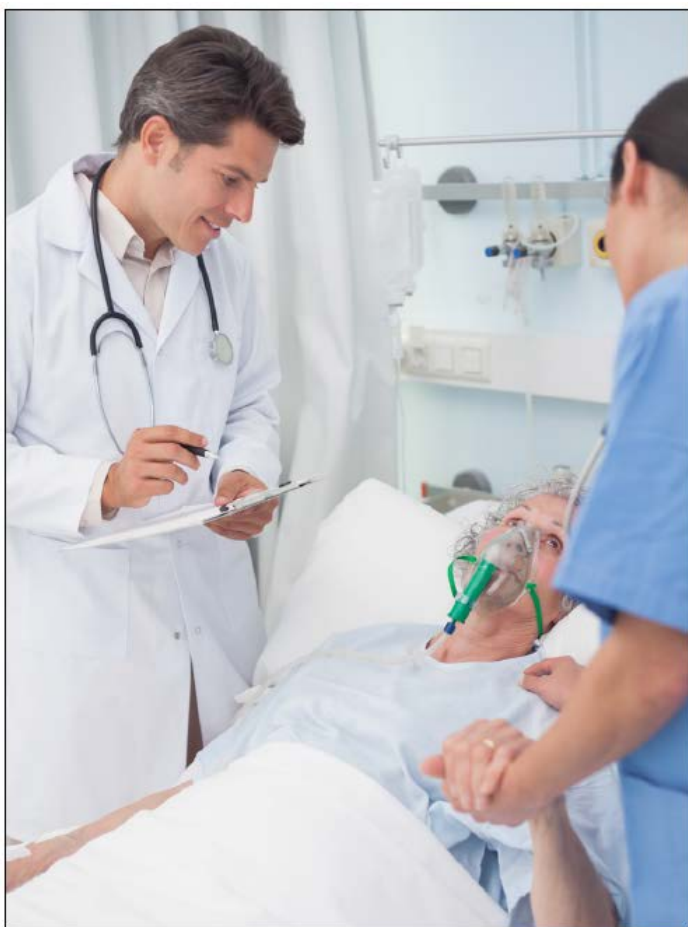
1235 **TABLE 1** Summary of the WHO recommendations for intraoperative and postoperative measures to prevent SSIs*

Key research question	Recommendations for prevention of SSIs	Strength of recommendation (quality of evidence retrieved†)	Notes for implementation in low-income and middle-income countries	
(1) Perioperative oxygenation	How safe and effective is the perioperative use of high fraction of inspired oxygen in reducing the risk of SSI?	Adult patients undergoing general anaesthesia with endotracheal intubation for surgical procedures should receive 80% fraction of inspired oxygen intraoperatively and, if feasible, in the immediate postoperative period for 2–6 h	Strong recommendation (moderate)	Oxygen availability is low; oxygen and high-flow masks are an additional cost for the health-care facility or patient
(2) Maintaining normal body temperature (normothermia)	In surgical patients, should systemic body warming vs no warming be used for the prevention of SSI?	Warming devices are suggested for use in the operating room and during the surgical procedure for patient body warming	Conditional recommendation (moderate)	Availability of warming devices is low, particularly in low-resource settings; they are an additional cost for the health-care facility and require maintenance; simple blankets might function as efficiently as electrical devices
(3) Use of protocols for intensive perioperative blood glucose control	Do protocols aiming to maintain optimal perioperative blood glucose concentrations reduce the risk of SSI; and what are the optimal perioperative glucose target concentrations in diabetic and non-diabetic patients?	Protocols are suggested to be used for intensive perioperative blood glucose control for both diabetic and non-diabetic adult patients undergoing surgical procedures	Conditional recommendation (low)	Monitoring blood glucose adequately and treating hypoglycaemic events might be hard as medical staff training is required; availability, purchase, and storage (refrigerator) of insulin might cause financial burden
(4) Maintenance of adequate circulating volume control (normovolaemia)	Does the use of specific fluid management strategies during surgery affect the incidence of SSI?	Goal-directed fluid therapy is suggested for use intraoperatively	Conditional recommendation (low)	Some types of intravenous fluids might not be available; expertise in anaesthesia and medical staff training are required for the management of goal-directed fluid therapy and are often unavailable
(5) Disposable non-woven vs reusable woven drapes and gowns	Is SSI incidence affected by the use of disposable non-woven drapes and gowns vs reusable, woven drapes and gowns?‡	Either sterile disposable non-woven or sterile reusable woven drapes and surgical gowns can be used during surgical operations	Conditional recommendation (moderate to very low)	Availability of disposable drapes and gowns may be low and costs might cause a high financial burden, whereas labour costs for reprocessing reusable items may be less of an issue; the ecological effect of the additional clinical waste generated by use of single-use drapes and gowns should also be considered
(6) Adhesive incise drapes	Does the use of disposable adhesive incise drapes reduce the risk of SSI?	Plastic adhesive incise drapes with or without antimicrobial properties should not be used	Conditional recommendation (low to very low)	This recommendation avoids inappropriate resource allocation, because plastic adhesive incise drapes (in particular with antimicrobial properties) usually have an increased cost and they are not readily available in low-income and middle-income countries
(7) Wound-protector devices	Does the use of wound-protector devices reduce the incidence of SSI in open abdominal surgery?	Consider the use of wound-protector devices in clean-contaminated, contaminated, and dirty abdominal surgical procedures	Conditional recommendation (very low)	Wound-protector device availability is low and it is an additional cost for the health-care facility or patients; staff training is required; conflicting results exist from cost-effectiveness studies
(8) Incisional wound irrigation§ with an aqueous povidone-iodine solution	Does intraoperative wound irrigation with an aqueous povidone-iodine solution reduce the risk of SSI?	Consider the use of irrigation of the incisional wound with an aqueous povidone-iodine solution before closure, particularly in clean and clean-contaminated wounds	Conditional recommendation (low)	Availability of sterile products might be low; pulse pressure devices are scarce and have high costs, including purchase, waste disposal, procurement, energy, and machine maintenance

	Key research question	Recommendations for prevention of SSIs	Strength of recommendation (quality of evidence retrieved†)	Notes for implementation in low-income and middle-income countries
(Continued from previous page)				
(9) Incisional wound irrigation with antibiotics	Does intraoperative wound irrigation with antibiotics reduce the risk of SSI?	Antibiotic incisional wound irrigation before closure should not be used	Conditional recommendation (low)	This recommendation leads to a cost reduction because of reduced antibiotic use; it also contributes to preventing antimicrobial resistance
(10) Prophylactic negative-pressure wound therapy	Does prophylactic negative-pressure wound therapy reduce the incidence of SSI compared with the use of conventional dressings?	Prophylactic negative-pressure wound therapy on primarily closed surgical incisions is suggested in high-risk wounds, while taking resources into account	Conditional recommendation (low)	Prophylactic negative-pressure wound therapy device availability is low and is an additional cost for the health-care facility or patients (also because it can prolong hospital stay); however, evidence of cost-effectiveness in gynaecological patients has been shown; could construct a non-portable, locally made device at low cost
(11) Antimicrobial-coated sutures	Are antimicrobial-coated sutures effective to prevent SSI; if yes, when should they be used?	Triclosan-coated sutures are suggested to be used in all types of surgery	Conditional recommendation (moderate)	Antimicrobial-coated suture availability is low and they are an additional cost for the health-care facility or patient
(12) Laminar airflow ventilation systems in the context of operating room ventilation	Is the use of laminar airflow in the operating room associated with the reduction of overall or deep SSI; does the use of fans or cooling devices increase incidence of SSI; is natural ventilation an acceptable alternative?¶	Laminar airflow ventilation systems should not be used for patients undergoing total arthroplasty surgery	Conditional recommendation (low to very low)	In particular for the construction of future health-care facilities, this recommendation will reduce costs
(13) Antimicrobial prophylaxis in the presence of a drain	In the presence of drains, does prolonged antibiotic prophylaxis prevent SSI?	Perioperative surgical antibiotic prophylaxis should not be continued because of the presence of a wound drain for the purpose of preventing SSI	Conditional recommendation (low)	This recommendation leads to a cost reduction because of reduced antibiotic use; it also contributes to preventing antimicrobial resistance
(14) Optimal timing for wound drain removal	When using drains, how long should they be kept in place to minimise SSI as a complication?	The wound drain should be removed when clinically indicated; no evidence was found to make a recommendation on the optimal exact timing	Conditional recommendation (very low)	This recommendation has the potential to reduce costs because of a shortened hospital stay as a result of early drain removal
(15) Wound dressings	In surgical patients, should advanced dressings vs standard sterile wound dressings be used for the prevention of SSI?	No type of advanced dressing should be used over a standard dressing on primarily closed surgical wounds	Conditional recommendation (low)	This recommendation avoids inappropriate resource allocation, because advanced dressings are expensive and poorly available in low-income and middle-income countries
(16) Surgical antibiotic prophylaxis prolongation	Does continued postoperative surgical antibiotic prophylaxis reduce the risk of SSI compared with preoperative and (if necessary) intraoperative prophylaxis only?	Surgical antibiotic prophylaxis administration should not be prolonged after completion of the operation	Strong recommendation (moderate)	This recommendation leads to a cost reduction because of reduced antibiotic use; it also contributes to preventing antimicrobial resistance
<p>SSI=surgical site infection. *WHO recommendations for preoperative measures are included in paper 1¹ of this surgical site infections Series, to be read in combination with this Review. †The Grading of Recommendations Assessment, Development, and Evaluation method²³ was used to assess the quality of the retrieved evidence. ‡We could not assess separately the use of sterile disposable non-woven vs sterile reusable woven drapes and sterile disposable non-woven vs sterile reusable woven gowns, because no specific evidence was retrieved. §We could not assess saline irrigation of incisional wounds before closure, because insufficient evidence was found. ¶We could not assess the use of fans or cooling devices vs conventional operating room ventilation, or whether natural ventilation an acceptable alternative to conventional ventilation, because insufficient evidence was retrieved.</p>				

1238 **FIGURE 1:**

1239 Patient receiving oxygen in the immediate postoperative period. Courtesy of Shutterstock.



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