



Article

Theatres without borders: a systematic review of the use of intraoperative telemedicine in low- and middle-income countries (LMICs)

Subbiah Ponniah, Hariharan, Shah, Viraj, Arjomandi Rad, Arian, Vardanyan, Robert, Miller, George and Malawana, Johann

Available at <http://clock.uclan.ac.uk/39449/>

Subbiah Ponniah, Hariharan, Shah, Viraj, Arjomandi Rad, Arian, Vardanyan, Robert, Miller, George and Malawana, Johann (2021) Theatres without borders: a systematic review of the use of intraoperative telemedicine in low- and middle-income countries (LMICs). BMJ Innovations . ISSN 2055-642X

It is advisable to refer to the publisher's version if you intend to cite from the work.

<http://dx.doi.org/10.1136/bmjinnov-2021-000837>

For more information about UCLan's research in this area go to <http://www.uclan.ac.uk/researchgroups/> and search for <name of research Group>.

For information about Research generally at UCLan please go to <http://www.uclan.ac.uk/research/>

All outputs in CLoK are protected by Intellectual Property Rights law, including Copyright law. Copyright, IPR and Moral Rights for the works on this site are retained by the individual authors and/or other copyright owners. Terms and conditions for use of this material are defined in the [policies](#) page.

1 **Theatres without Borders: A Systematic Review of the Use of Intra-Operative**
2 **Telemedicine in Low- and Middle-Income Countries (LMICs)**

3 **(Running Head: Telesurgery in LMICs)**

4

5 **AUTHORS:**

6 Hariharan Subbiah Ponniah^{1*}; Viraj Shah^{1*}; Arian Arjomandi Rad^{1,2}; Robert Vardanyan^{1,2};
7 George Miller^{2,3}; Johann Malawana^{2,3}.

8 **INSTITUTION:**

- 9 1. Department of Medicine, Faculty of Medicine, Imperial College London,
10 London, United Kingdom.
- 11 2. The Healthcare Leadership Academy, London, United Kingdom.
- 12 3. University of Central Lancashire Medical School, Preston, United Kingdom.

13 ***authors contributed equally**

14 **Corresponding author:** Arian Arjomandi Rad, Imperial College London, Department of
15 Medicine, Faculty of Medicine, South Kensington Campus, Sir Alexander Fleming Building,
16 London, United Kingdom. Email: arian.arjomandi-rad16@imperial.ac.uk

17

18 **Word count: 3840**

19 **Number of Figures: 1**

20 **Number of Tables: 1**

21 **Conflict of interest: none**

22 **Funding: none**

23 **Data availability: data collection form and search results are available on enquiry to the**
24 **corresponding author (A.AR)**

25

26 **Abstract**

27 Objective: This systematic review aims to provide a summary of the use of real time
28 telementoring, tele-surgical consultation and telesurgery in surgical procedures in patients in
29 LMICs.

30 Design: A systematic review was conducted in accordance with the Preferred Reporting Items
31 for Systematic Reviews and Meta-Analyses (PRISMA) statement and the Cochrane
32 Collaboration published guidelines.

33 Data sources: EMBASE, MEDLINE, Cochrane, PubMed and Google Scholar were searched
34 for original articles and case reports that discussed telementoring, telesurgery or tele-surgical
35 consultation in countries defined as low or middle income (as per the World Banks's 2021-
36 2022 classifications) from inception to August 2021

37 Eligibility criteria for selecting studies: All original articles and case reports were included if
38 they reported the use of telemedicine, telesurgery or tele-surgical consultation in procedures
39 conducted on patients in LMICs.

40 Results: There were 12 studies which discussed the use of telementoring in 55 patients in
41 LMICs and included a variety of surgical specialities. There was 1 study that discussed in use
42 of telesurgical consultation in 15 patients in LMICs and 1 study that discussed the use of
43 telesurgery in 1 patient.

44 Conclusion: The presence of intraoperative telemedicine in LMICs represents a principal move
45 towards improving access to specialist surgical care for patients in resource-poor settings. Not
46 only do several studies demonstrate that it facilitates training and educational opportunities,
47 but it remains a relatively frugal and efficient method of doing so, through empowering local
48 surgeons in LMICs towards offering optimal care whilst remaining in their respective
49 communities.

50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74

Key points

- The development of global telecommunications, digital health technologies, and intraoperative navigation, guidance, and streaming have exponentially increased the accessibility to telesurgery and wider telemedicine in LMICs.
- Intraoperative telemedicine promises to improve access to specialist surgical care for patients in resource-poor settings through intraoperative guidance and telesurgical consultations.
- Intraoperative telemedicine and telementoring can alleviate the surgical brain-drain of many LMIC's through cost-effective and efficient training and educational opportunities.
- The fields in which this technology has been applied are general surgery, plastic surgery, urology, otolaryngology, and neurosurgery.
- A lack of an organised, unified system in providing telementoring, telesurgery, and telesurgical consultations to LMICs still exists and, therefore, many hurdles remain in its uptake, provision, and development in LMICs.

75

76 **Introduction**

77 It is well-documented that there is a growing disparity^{1,2} in the quality of healthcare delivered
78 around the world, particularly evident in Low- and Middle-Income Countries (LMICs) in the
79 field of surgery. Concomitantly, the lack of both infrastructure and local training opportunities
80 in these settings has led to many competent healthcare professionals leaving their countries in
81 search of specialist training and professional development opportunities³⁻⁵. This underpins the
82 “brain drain” phenomenon seen commonly in LMICs, a process that is often exacerbated by
83 the lack of rigorous domestic training structures^{1,6}. With increasing rates of morbidity, there is
84 an ever-increasing demand for specialist surgeons globally and, as a result, for surgical training
85 posts especially in LMICs⁷. A flourishing global telecommunications industry has led to an
86 increase in the ease of exchange of information, especially medical information, culminating
87 in the emergence of telemedicine - the use of technology to deliver care⁸. This growing sector
88 has already commenced its role in bridging the gap in the delivery of care between LMICs and
89 High-Income Countries (HICs)^{9,10}.

90

91 Telemedicine has been applied to various aspects of surgical care¹¹, but telemedicine during
92 surgical procedures can be broadly categorised as telesurgery, telementoring and tele-surgical
93 consultation^{12,13}. Telementoring can be defined as the use of telecommunication to guide and
94 assist the operating surgeon remotely during a procedure – ranging from basic audio commands
95 to the use of annotation on screen to guide the surgeon^{13,14}. Tele-surgical consultation is similar
96 to telementoring except the difference is both surgeons are experienced and use
97 telecommunication platforms to work through a complicated case¹⁵. Telesurgery can be defined
98 as the use of telecommunication in conjunction with a surgical robot to remotely operate on a
99 patient^{13,14}.

100

101 Although studies in the past have investigated the prevalence and implementation of the
102 various modes of intraoperative telemedicine or the use of a particular division of
103 intraoperative telemedicine in a particular surgical specialty¹⁶⁻¹⁹, there are no reviews that have
104 examined the use of intraoperative telemedicine in LMICs, especially the implementation of it
105 in intra-operative care. This systematic review aims to provide a summary of the use of real
106 time telementoring, tele-surgical consultation and telesurgery in surgical procedures in patients
107 in LMICs.

108

109 **Methods**

110 **Literature Search Strategy**

111 A systematic review was conducted in accordance with the Preferred Reporting Items for
112 Systematic Reviews and Meta-Analyses (PRISMA) statement and the Cochrane Collaboration
113 published guidelines. EMBASE, MEDLINE, Cochrane, PubMed and Google Scholar were
114 searched for original articles and case reports that discussed telementoring, telesurgery or tele-
115 surgical consultation in countries defined as low or middle income (as per the World Bank's
116 2021-2022 classifications)²⁰ from inception to August 2021. A priori protocol was devised for
117 the following study, available upon request. The search terms used included "Telementoring",
118 "Telesurgery", "Tele-surgical consultation", "Low Income" and "Middle Income" - the entire
119 search criteria, which was used across all databases, is attached in appendix 1. Further articles
120 were identified through a manual search of the references lists of articles found through the
121 original search and use of the 'related articles' function on MEDLINE. The only limits used
122 were the mentioned time frame and English language.

123

124 **Study inclusion and exclusion criteria**

125 All original articles and case reports were included if they reported the use of telemedicine,
126 telesurgery or tele-surgical consultation in procedures conducted on patients in LMICs. Studies
127 were excluded from the review if: 1) inconsistencies in the data impeded extraction of data, 2)
128 the study was performed in an animal model, 3) there was no mention of any surgical
129 procedures performed on patients and 4) the surgeries performed were in countries deemed to
130 be high in income. Reviews, editorials, abstracts from meetings and preclinical studies were
131 excluded. By following the aforementioned criteria, two reviewers (H.SP. and V.S.)
132 independently selected articles for further assessment following title and abstract review. A
133 third independent reviewer (A.AR.) resolved any disagreements between the two reviewers.
134 Potentially eligible studies were then retrieved for full text assessment. The software used for
135 the here described process was Covidence (Melbourne, Australia).

136

137 **Data extraction and critical appraisal of evidence**

138 All full texts of retrieved articles were read and reviewed by two authors (H.SP. and V.S.) and
139 a unanimous decision was made regarding inclusion or exclusion of studies. When there was
140 disagreement, the final decision was made by a third reviewer (A.AR.) Using a pre-established
141 protocol, the following data was extracted: first author, study design, type of surgical specialty
142 and the surgical procedure(s) discussed, population number, type of intraoperative
143 telemedicine used, method in which the type of intraoperative telemedicine was implemented,
144 and the qualitative and quantitative main outcomes. A data extraction sheet for this review was
145 developed and pilot-tested using 3 randomly selected included studies and subsequently was
146 refined accordingly. Data extraction was performed by 2 review authors (H.SP. and V.S.) who
147 carried out the process in duplicate on two separate extraction sheets. Correctness of the
148 tabulated data was validated by a third author (A.A.R) who evaluated both extraction sheets
149 and assessed full texts where incongruences existed.

150 Due to the high heterogeneity of the studies quality scoring through the use of the available
151 assessment tools was decided not to be carried out by the research group.

152

153 **Results**

154 **Study selection**

155 The literature search identified 1574 articles, of which 991 were screened following
156 deduplication and 143 were full-text reviewed and assessed in accordance with the inclusion
157 and exclusion criteria. Following critical appraisal, a total of 12 studies²¹⁻³² were included in
158 this review, featuring 71 patients. Figure 1 illustrates the entire study selection process. A
159 summary of the studies collected and their respective designs, type of intraoperative
160 telemedicine used and its implementation as well as the main reported outcomes are found in
161 *Table 1*.

162

163 **Telementoring**

164 There were 12 studies which discussed the use of telementoring in 55 patients in LMICs and
165 included a variety of surgical specialities^{21-27,29-32}.

166

167 **Telesurgical consultation**

168 There was 1 study that discussed the use of telesurgical consultation in 15 patients in LMICs²⁸.

169

170 **Telesurgery**

171 There was 1 study that discussed the use of telesurgery in 1 patient in LMICs²⁶.

172

173

174

175 **Discussion**

176 This systematic review is the first of its nature to provide a summary of the intraoperative uses
177 of telemedicine within surgery in LMICs. The results are indicative of the successes of specific
178 modes of telemedical approaches in such landscapes, most prominently telementoring^{21–27,29–}
179 ³², these examples represent both recent and limited phenomena. Care must be given in
180 recognising disparities in the standard of surgical care in even highly-specialist settings across
181 LMICs^{33,34}, with some of the most recent literature describing only novel approaches.

182

183 There is evident value to the continued use of intraoperative telemedicine as a novel approach
184 in providing specialist surgical care in resource-limited settings in LMICs; this can be further
185 stratified into positive outcomes in terms of viability^{30,35} and cost³⁶. Whilst there has been cited
186 successful adoption of such approaches in LMICs since 2000^{24,37}, more contemporary
187 technological advancements including the use of wearable technology^{27,29} and augmented
188 reality³⁰ may further encourage the growth and uptake of intraoperative telemedicine in years
189 to follow as well as drive further improvements to overcome current technological
190 shortcomings. All procedures undertaken within the 12 papers included in this review were
191 performed to successful completion via intraoperative telemedicine suggesting the need for
192 further investment in supporting the refinement and development of such technologies
193 accordingly. This will allow for greater mainstream adoption of telementoring and telesurgery
194 within LMIC settings in conjunction with ameliorating the cost-effectiveness of required
195 technologies.

196

197 **Surgical education versus urgent care provision**

198 This review raises questions pertaining to whether the primary objectives of intraoperative
199 telemedicine in LMICs should pivot towards bridging gaps in the lack of patient accessibility

200 to specialist surgical opinion and care in remote regions, or rather, be used primarily as
201 economical instruments of training and surgical education. Whilst the operative procedures
202 described in the 12 articles in this review all assumed a middle line between the provision of
203 specialist care and provision of training/mentoring, this line was nuanced in particular cases –
204 notably the description of reconstructive techniques in the McCullough et al. study (2018) and
205 a phacoemulsification surgery in the Geary et al. study (2019)^{31,32}. In the latter example, the
206 designated telementor would preoperatively review the case information prior to determining
207 cases suitable for telementored guidance. Subsequently, the delivery of the telementoring
208 sessions followed a structured approach through the establishment of learning objectives. This
209 stood out in marked contrast to the case report by Pradeep et al. (2006)²⁷ describing a patient
210 with debilitating hyperparathyroidism due to a persistent parathyroid tumour that had failed to
211 be removed previously. It was noted in this report that the patient’s condition was such that
212 travel to a specialist centre would have been unfeasible, thus making an urgent telementoring
213 approach particularly relevant to deliver satisfactory care. The difference in these highlighted
214 approaches suggests the multifaceted applications of intraoperative telemedicine to delivering
215 surgery in LMICs – this provides weight to its use in both elective surgeries (where a greater
216 focus may be placed on training) and in delivering emergency care in urgent situations (where
217 training, albeit provided, is less prioritised). It also highlights the impact of pre-operative co-
218 ordination to maximise the effectiveness of intraoperative telemedicine for training purposes,
219 as evidenced by the results of the post-CPD-session questionnaire in the Geary et al. study
220 (2019) where 100% of surgeons agreed or strongly agreed that this approach increased their
221 confidence and surgical skill³².

222

223 **Applicability to specific subspecialties and procedures**

224 In addition, this review highlights the applicability of intraoperative telemedicine across a
225 diverse and wide-ranging domain of surgical subspecialties comprising 5 of the list of 10
226 recognised surgical specialties as defined by the Royal College of Surgeons of England
227 including general surgery, plastic surgery, urology, otolaryngology, neurosurgery³⁸ as well as
228 ophthalmology. Hence, there is opportunity to trial the use of intraoperative telemedicine for
229 complex cases within subspecialties not covered by this list. Earlier applications of
230 intraoperative telemedicine in surgery in LMICs were centred around laparoscopic and
231 endoscopic procedures, utilising a telementored approach^{21,22}. The basis of this surrounded the
232 fact that cameras are incorporated natively into these procedures such that the surgical field of
233 view is identical for both the operating surgeon and the remote surgical ‘mentor’³¹. The
234 introduction of teleproctering via the use of wearable technology including Google Glass
235 (Google Inc., Mountain View, California)³⁹ has led to the potential for implementing
236 intraoperative telemedicine in surgeries traditionally classed as ‘open surgeries’, seen most
237 prominently in the McCullough et al. study (2018)³¹. This study exemplified its use for
238 supporting local surgeons in Mozambique with reconstructive procedures comprising regional
239 flaps, z-plasties and skin grafts for the care of patients with burn contractures³¹. Again, this is
240 suggestive of the fact that the delivery of intraoperative telemedicine in LMICs is continually
241 evolving parallel to the evolution of technology. As the incidence of non-communicable
242 diseases grows at disproportionate rate in LMICs as a direct consequence of the
243 epidemiological transition and growing industrialisation^{40,41}, the incidence of unmet need
244 including that of cardiovascular disease⁴² and road traffic injuries⁴³ in LMICs is also
245 increasing; with the latter accounting for 90% of the global burden of such injuries despite a
246 significantly lower prevalence of predisposing risk factors within these settings⁴⁴. Therefore, it
247 is not only essential for global efforts to focus on improving access to specialist cardiothoracic
248 and trauma care in the long-term but also necessary to provide innovative solutions to the

249 ongoing lack of trained surgical personnel in the short-term. This is an avenue where viable
250 implementation of intraoperative telemedicine could play a specialised role in improving
251 access^{33,45}.

252

253 **Heterogeneous platforms of intraoperative telemedicine in LMICs**

254 The heterogeneity in the examples of intraoperative telemedicine in LMICs, that met the
255 inclusion criteria for this review, made it difficult to ascertain the extent of the role played by
256 the specific method of intraoperative telemedicine employed on the overall outcomes for each
257 included study. Of the 12 studies included in this review: 7 were aggregated together as
258 adopting a standard “camera & live video-streaming” technique, a further 2 adopted similar
259 approaches but allowed for additional telerobotic control of the camera to optimise angles and
260 viewpoints by the ‘surgical mentor’^{25,26}, 2 used ‘wearable technology + live video-streaming’
261 techniques^{29,31} with both of these studies consistently deploying Google Glass (Google Inc.,
262 Mountain View, California)³⁹ to do so and a further singular study used the Proximie
263 augmented reality platform^{30,46}. In addition to the aforementioned potential of integrating
264 wearable technology into open surgery, wearable technology allows for greater practical
265 functionality of intraoperative telemedicine systems. Google Glass can be operated verbally,
266 allowing an operating surgeon the ability to use both hands unencumbered whilst ensuring a
267 sterile operating environment is maintained³¹. The use of telerobotic control in enhancing the
268 efficiency of intraoperative telepresence systems in LMICs has also been made apparent via
269 the Netto et al. (2003) study²⁶. In this report, the remote surgeon was able to control the imaging
270 presented via control of a robot attached to a laparoscope, achieved through the manipulation
271 of controllers embedded into the remote computer (AESOP300, ComputerMotion Inc.,
272 California)⁴⁷. The success of robotic control may provide tangible benefits such as maximising
273 efficiency by reducing operating times, which may off-set some of the time delays posed by

274 intraoperative telepresence including poor connection and lag^{48,49}. Although coalescing
275 platforms such as Proximie into intraoperative telemedicine brings forwards the innate set of
276 advantages of augmented reality, its most relevant applications might lie in the versatility of
277 such platforms such that they are cross-compatible with a range of devices. This enables a more
278 realistic introduction of intraoperative telemedicine in LMICs as the technology can be utilised
279 more accessibly through portable tablets. Platforms such as these provide more optimal
280 methods of delivering information to the operating surgeon, through the sharing of gestures to
281 guide the surgeon on practical techniques relevant to the procedure at hand.³⁰ Nevertheless, all
282 12 studies included in the review describe telepresence that allows simultaneous audio and
283 visual communication between the operating and remote surgeons and it is this feature that is
284 most central to the success of intraoperative telemedicine.

285

286 **Future directions**

287 The majority of examples of intraoperative telemedicine described in this review are trials.
288 Although the concept of telemedicine, specifically telementoring, is not entirely novel, its use
289 intraoperatively in LMICs remains one that requires significant further analysis from a public
290 health perspective⁴⁸. There is wide variability in the proposed costs associated with different
291 methods of intraoperative telepresence. Although the Geary et al. study (2019) suggests that
292 there is a \$8,000 to \$20,000 USD fee for the audiovisual technology required using a
293 ‘streaming’ approach³², alternative technologies including wearables have drastically different
294 price points. Google Glass is estimated to cost \$999 USD⁵⁰ and, at time of the review, is only
295 available to specific partners (only 2 out of 32 of which serve geographical regions that
296 comprise LMICs)⁵¹. Whilst alternative wearables are available⁵², these have not been trialled
297 as robustly in intraoperative clinical settings in LMICs. Literature relating to the cost-
298 effectiveness of using either robotic arms or augmented reality in surgery is also notably sparse.

299 Conversely, it must be stated that the most significant costs associated with using intraoperative
300 telemedicine in LMICs are fixed, only excluding the costs of subscriptions to video streaming
301 software³². Hence, there is sufficient rationale for conducting a large-scale costs analysis of the
302 use of different forms of intraoperative telemedicine in LMICs – this should soundly evaluate
303 the one-off fixed fees associated with their use against alternative options such as a physical
304 presence of experienced overseas surgeons acting as regular visitors. Only 3 of the 12 papers
305 included in this review^{23,28,32} provided satisfactory information relating to the costs associated
306 with technology employed, with only the Davis et al. (2016) study providing a sufficiently in-
307 depth total cost analysis.

308

309 Another avenue for incorporating intraoperative telemedicine might be through its application
310 in providing continuous professional development (CPD). 5 of the 12 papers that met the
311 inclusion criteria for the review^{22,26,29,31,32} described telementoring opportunities that spanned
312 multiple sessions. This was most exemplified in the Forgione et al. Study (2015) where, upon
313 completion of a 4-week telementored fellowship between teams in Italy and Russia, the
314 operating surgeon gained proficiency to operate whilst being telementored and further went on
315 to undertake 25 colorectal procedures without any remote supervision, despite no initial
316 experience with the procedure. Transparently, there are clear grounds to expand the use of
317 intraoperative telemedicine in LMICs as a more efficient model for supplementary continuous
318 training and one that allows surgeons to be trained from their respective geographical regions
319 without travelling. Over a longer time period, this would negate the effects of the “brain drain”⁵
320 that encourages talented surgeons from LMICs to travel overseas to receive more specialist
321 training and subsequently remain there permanently. This can additionally be further expanded
322 to wider aspects of surgical and, potentially, anatomical education, including improving access

323 to undergraduate medical teaching in resource-poor settings, although the efficacy of this
324 remains to be studied.

325

326 **Weaknesses of telesurgery**

327 This review has recognised that there are many integral limitations of intraoperative
328 telemedicine that exist across the papers selected. Quality control remains an important issue,
329 in part due to the diversity in the availability of methods of delivering it. The consistency of
330 operations is heavily skewed by the limitations of particular hardware and software used. As
331 all the papers describe elements of streaming, the technological faults of cameras, computers
332 and/or portable devices and software that provide both streaming and receipt of audiovisual
333 signals can heavily hinder the efficacy of any one particular procedure. As there is no single or
334 widely-accepted system optimised to the delivery of care in this way, the utility of
335 intraoperative telemedicine in LMICs is unpredictable. This is reinforced by the fact that the
336 use of existing infrastructure in LMICs would be preferred, and technology available in greater
337 abundance in LMICs may not necessarily match that described in this review's highly-
338 specialised settings in terms of factors spanning speed, reliability and display quality ⁵³.
339 Financial barriers such as this one still make the use of intraoperative telemedicine in LMICs,
340 even telementoring, a complex one. Although a relatively frugal innovation if robust systems
341 comprising high-quality computing, recording and streaming equipment are available, it is
342 impossible to use a "one-size-fits-all" policy when exploring its applicability to LMICs as a
343 whole and it is likely heavily dependent on the specific region in question. This is particularly
344 poignant due to the fact it is the least-resourced settings that could benefit the most from such
345 an innovation.

346

347 Access to reliable local wireless networks was seen as fundamental to ensure a sufficient
348 quality of transmission of audiovisual signal²⁹ and the overwhelming majority of issues across
349 this review that arose with intraoperative telemedicine were rooted in shortcomings in this area.
350 Although in many cases including the Nadjafi-Semnani et al. paper (2008) study²¹, sufficient
351 image quality and connection stability was maintained, there are many cited examples of where
352 this has not held true. The Rosser et al. study (1999)²⁴ notably describes the fact that
353 disconnection was experienced in 4 of the 5 included patients due to a combination of electrical
354 issues. Furthermore, time delays represent an area of challenge for intraoperative telemedicine
355 in all scenarios, including LMICs. Time delays are more pronounced where there is further
356 distance between the remote and operating teams²⁵ and although no paper included in this
357 review established this as a cause of significant detriment, it is worth exploring as an area of
358 study to further improve the efficiency of intraoperative telemedicine. On a similar nature,
359 although time difference between the remote and operating teams was not cited as a major
360 inconvenience in any of the papers included in this review, it is a point for further consideration
361 in aspiration of increasing intraoperative telemedicine's role in non-elective surgeries.

362

363 Finally, ethico-legal considerations including the protection of patient privacy and anonymity
364 must be further evaluated prior to the expansion of intraoperative telemedicine in LMICs; a
365 potential avenue for how this may be achieved is through the use of private communication
366 networks as outlined in the Forgione et al. study (2015)²² but this warrants further investigation.

367

368 **Limitations of review**

369 This systematic review is also subject to some inherent limitations. Primarily, due to the nature
370 of the studies included in the review, many were unable to adopt a methodology consisting of
371 blinding and, although this was unavoidable in most cases, it still represents a source of

372 significant cognitive bias. This review was additionally limited by the low sample sizes of all
373 studies included within it, with all studies having <16 patients and thus exhibiting bias through
374 statistical skew.

375

376 The majority of studies that met the inclusion criteria for this review were single-arm
377 interventional studies that are known to contain bias and are sources of error. The incorporation
378 of randomised controlled trials into this review may have improved its validity, but this was
379 restricted by the availability of data.

380

381 Another source of bias linked to reviews of this nature is publication bias, referring to the
382 common phenomenon seen that published academic literature is far more likely to report
383 statistically significant findings in comparison to insignificant findings⁵⁴. Thus, this review is
384 prone to publication bias which is made more significant by the inclusion of case reports. As a
385 result of the consequences of this bias in conjunction with the low samples described in this
386 review, meta-analysis has not been conducted.

387

388 This review contains literature published over a 22-year time period between 1999 and 2019
389 inclusive. As a result, there has been significant technological advancements since the
390 publication dates of earlier studies included in this review and, where this is applicable, these
391 studies' conclusions were recognised in the context of the time of their publication. Where
392 conclusions had been outdated by novel published literature, this was understood and these
393 conclusions were not used to guide the scope of this review. In addition, many of the included
394 studies suffer from a lack of longitudinal aspect to them to allow for follow-up of either patient
395 outcomes post-operatively or the retention of surgical skills by the operating surgeon. This
396 renders it difficult to examine the long-term benefits of intraoperative telemedical approaches

397 in LMICs. Hence, there is adequate grounding for the planning of additional prospective
398 randomised studies to measure both these characteristics and observe the impact of this
399 innovation in clinical practice.

400

401 **Conclusion**

402 The presence of intraoperative telemedicine in LMICs represents a principal move towards
403 improving access to specialist surgical care for patients in resource-poor settings. Not only do
404 several studies demonstrate that it facilitates training and educational opportunities, but it
405 remains a relatively frugal and efficient method of doing so, through empowering local
406 surgeons in LMICs towards offering optimal care whilst remaining in their respective
407 communities. The presence of tele-surgery continues to be negligible in LMICs due to
408 limitations including the inaccessibility of technology, lack of infrastructure or funding
409 difficulties. However, whilst the implementation of telesurgery has been scarce, many studies
410 have demonstrated that the use of other forms of telemedicine within surgery are gaining
411 significant momentum; these comprise telementoring featuring wearable technology,
412 augmented reality or audio-visual streaming alongside either unidirectional or bidirectional
413 communication. The advent of COVID-19 has certainly streamlined the implementation of
414 intraoperative telemedicine in HICs⁵⁵, which provides an opportunity to learn more about how
415 best it can be suited to improving care in LMICs. This is complemented by the 17 Sustainable
416 Development Goals (SDGs) as set out by the United Nations to be achieved by 2030, which
417 include provision of reliable and sustainable energy and the fostering of innovation⁵⁶. Although
418 current use is confined to limited settings, it is possible that the trajectory of applications of
419 intraoperative telemedicine will follow that of concurrent technological development in
420 LMICs. Nevertheless, prospective randomized studies will be needed to assess the “real-world”
421 impact of this technology.

422 **Contribution statement**

423 Concept and design, data interpretation, drafting article, approval of article: HSP, VS, AAR,

424 RV, GM, JM. Data collection, drafting article: HSP, VS, AAR, RV. Supervision, Critical

425 revision: AAR, RV, GM, JM

Table 1: Studies included discussing the use of intraoperative telemedicine in LMICs.

Study	Year	Study Design	Country	Type of Surgery/Surgical Specialty	Population Number †	Type(s) of intraoperative telemedicine discussed	Method of intraoperative telemedicine implementation	Main reported outcomes
Geary et al.	2019	Prospective study	USA* and Peru	Ophthalmology - Phacoemulsification	12	<ul style="list-style-type: none"> • Telementoring 	<ul style="list-style-type: none"> • Cases were sent to mentor surgeon by field surgeon and were screened based on whether procedure was compatible for remote guidance and then a pre-operative discussion took place to structure the teaching and learning objectives for that session. • Live phacoemulsification was streamed over internet using audio-visual equipment, accompanied with Zoom, a video conferencing software, which enabled the mentor Surgeon to be in constant touch with the operating surgeon. • A survey distributed following the mentorship to assess its acceptability as well as a self-assessment of their development in their surgical skills. 	<ul style="list-style-type: none"> • Latency recorded during surgery was well within margin of acceptability and video quality was clear enough for mentoring surgeon to observe the anatomy and manipulation of instruments. • 7 Surgeons over 4 sessions performed 12 phacoemulsification surgeries. 11 of the 12 patients achieved the best visual acuity postoperatively. • 4 Surgeons completed the post mentorship survey and 100% agreed or strongly agreed that learning objectives had been met and the teaching had enhanced their confidence and skills in the procedure.

McCullough et al.	2018	Prospective study	USA* and Mozambique	Plastics-Reconstructive Surgery	12	<ul style="list-style-type: none"> ● Telementoring 	<ul style="list-style-type: none"> ● Cases were sent to mentor surgeon by field surgeon and were screened based on operational difficulty and educational value to surgeon, including novel techniques for common presentations seen and dealt by the field surgeon. ● Google Glass with the ability to stream in real time was used to facilitate a reconstructive surgeon in USA to guide the surgeon in Mozambique over a period of 6 months. 	<ul style="list-style-type: none"> ● 12 Surgical Procedures were remotely guided by the mentor surgeon. There were no patient complications. ● Both mentor and field surgeon reported some disturbances in video, mainly image distortion and over-light exposure, alongside latency in streaming and connection disruption.
Greenfield et al.	2018	Case Report	Lebanon* and Palestine	Plastics-Reconstructive Surgery	1	<ul style="list-style-type: none"> ● Telementoring 	<ul style="list-style-type: none"> ● Operating surgeon in Gaza was guided through a complex hand reconstruction of an 18-year-old male patient by the mentor surgeon in Lebanon. ● Camera rig was set up over the operating field and using Proximie, an Augmented Reality software, the mentor surgeon was able to highlight structures on the virtual surgical field. 	<ul style="list-style-type: none"> ● The hand and its range of movements were assessed over video and then reconstruction was performed, resulting in increase in range of movements in finger abduction and extension post-operatively.

Davis et al.	2016	Prospective study	USA* and Vietnam	Neurosurgery - Neuroendoscopy	15	<ul style="list-style-type: none"> ● Telementoring 	<ul style="list-style-type: none"> ● An iPad-based tool known as VIPAR (Virtual interactive presence and augmented reality) allowed provision of long distance, virtual assistance to local operating surgeon. ● Local and International trials conducted initially during presence of visiting team, had any immediate assistance required. 	<ul style="list-style-type: none"> ● 15 neuroendoscopic procedures were performed in the local country under the guidance of mentor surgeons following the visit, with no significant complications.
--------------	------	-------------------	------------------	-------------------------------	----	-------------------------------------------------------------------	----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

Datta et al.	2015	Prospective study	USA*, Paraguay, and Brazil	General - Inguinal Hernia Repair	8	<ul style="list-style-type: none"> ● Telementoring 	<ul style="list-style-type: none"> ● Local surgeons in Brazil and Paraguay were taught the Lichtenstein inguinal hernia repair by a visiting international expert using a standard protocol. ● Successive procedures operated by the local surgeon were streamed in real time using Google Glass and enabled guidance by mentor surgeon in USA. 	<ul style="list-style-type: none"> ● 8 sequential training operations were conducted, 4 each in Brazil and Paraguay. ● Live streaming of the procedures was successful, and surgeons were able to demonstrate proficiency in the procedure at the completion of the final case, as judged by the respective Operative Performance Rating Scale.
--------------	------	-------------------	----------------------------	----------------------------------	---	-------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

Forgione et al.	2015	Prospective study	Italy* and Russia	General - laparoscopic colorectal resections	2	<ul style="list-style-type: none"> ● Telementoring 	<ul style="list-style-type: none"> ● Following a lab based intensive training program, including a 4-week intensive mini-fellowship, a surgeon previously with no experience in laparoscopic surgery was remotely guided by the mentor surgeon, using a highly integrated operation room and a regular secure network. 	<ul style="list-style-type: none"> ● Following training, 2 laparoscopic telementored colectomies were performed uneventfully and both patients discharged home in a stable condition. ● Local surgeon was then able to perform on 25 more patients using this newly acquired technique, without remote guidance.
Tamariz et al.	2009	Prospective study	USA*, Russia, and Romania	ENT - Thyroidectomies and parathyroidectomies	15	<ul style="list-style-type: none"> ● Tele-surgical consultation 	<ul style="list-style-type: none"> ● Multimedia indexation of a surgical procedure at various steps and stages were performed, following which a remote consultant surgeon was contacted during the procedure, with access to the steps that had been indexed thus far ● Consultants had control of remote camera to tilt and zoom to obtain their optimum view of the surgical field and identify anatomical structures. 	<ul style="list-style-type: none"> ● In 15 thyroidectomies and parathyroidectomies, teleconsultation was used to identify 22 recurrent laryngeal nerves (RLN). On average, consultants spent 6 minutes to review an average of 35 minutes of surgical records to identify the RLN.

Nadjafi-Semnani et al.	2008	Academic report	Iran	Urology - laparoscopic trigonoplasty	1	<ul style="list-style-type: none"> ● Telementoring 	<ul style="list-style-type: none"> ● 2 multimedia workstations connected with each other via the university's Local Area Network (LAN). This enabled communication between the operating surgeon and the mentor surgeon, accompanied by an audience who were able to ask questions as well. 	<ul style="list-style-type: none"> ● Procedure successfully completed. Streamed quality was of high quality and mentor surgeon was able to identify anatomical structures clearly.
Pradeep et al.	2006	Case Report	India	Parathyroid tumour removal	1	<ul style="list-style-type: none"> ● Telementoring 	<ul style="list-style-type: none"> ● 2 Centres 2500km apart were connected through a dedicated very small aperture terminal (VSAT) link and bi-directional audio-video connection for a patient who needed removal of the parathyroid tumour. 	<ul style="list-style-type: none"> ● Despite 2 previous unsuccessful attempts, when the operating surgeon was guided by an expert surgeon, the parathyroid tumour was successfully removed.

Netto et al.	2003	Prospective study	USA* and Brazil	Urology - laparoscopic bilateral varicocelectomy Percutaneous nephrolithotomy	2	<ul style="list-style-type: none"> • Telementoring • Telesurgery 	<ul style="list-style-type: none"> • A laparoscope was fitted to a surgical robot, AESOP (Automated Endoscopic System for Optimal Positioning), operated remotely by the mentor surgeon during the laparoscopic bilateral varicocelectomy • Surgeon was able to control remotely a PAKY (Percutaneous Access to the Kidney) robot to place a percutaneous needle into the renal collecting system 	<ul style="list-style-type: none"> • Audio and Video communication between the two sites deemed excellent. • Both procedures completed without any significant complications, and both were asymptomatic at the 3-month follow up.
--------------	------	-------------------	-----------------	----------------------------------------------------------------------------------	---	------------------------------------------------------------------------------------------	---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

Bauer et al.	2000	Prospective study	USA* and Thailand	Urology-Laparoscopic nephrectomy	1	<ul style="list-style-type: none"> ● Telementoring 	<ul style="list-style-type: none"> ● Connections between 2 countries established using ISDN lines, facilitating bi-directional audio and video. ● Analogue telephone line was used to enable AESOP (Automated Endoscopic System for Optimal Positioning) enabling the manipulation of the camera from a remote location. ● Second analogue POTS line enabled control of electrocautery 	<ul style="list-style-type: none"> ● Laparoscopic nephrectomy performed, first recorded time of control of electrocautery remotely over a very long distance
--------------	------	-------------------	-------------------	----------------------------------	---	-------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------

Rosser et al.	1999	Prospective study and discussion of a case	USA* and Ecuador	General - Laparoscopic cholecystectomy	1	<ul style="list-style-type: none"> ● Telementoring 	<ul style="list-style-type: none"> ● A mobile operating room was connected to a small hospital in a remote region of Ecuador via a low-bandwidth telephone line. Output of the laparoscope was then streamed to the mentor surgeon via this connection. 	<ul style="list-style-type: none"> ● Image quality of the procedure high enough to determine key anatomical structures to guide the operating surgeon through key stages of the procedure. ● Patient operated on successfully and discharged next day with no significant complications.
---------------	------	--------------------------------------------	------------------	----------------------------------------	---	-------------------------------------------------------------------	------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

Asterisk (*) denotes the country in which the remote surgeon was based if more than one country was involved in the study.

† Population number included those only in LMICs.

References

1. Meara JG, Leather AJM, Hagander L, Alkire BC, Alonso N, Ameh EA, et al. Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *The Lancet*. 2015 Aug;386(9993).
2. Ruger JP, Kim H-J. Global health inequalities: an international comparison. *Journal of Epidemiology & Community Health*. 2006 Nov 1;60(11).
3. Lantz A, Holmer H, Finlayson SRG, Ricketts TC, Watters DA, Gruen RL, et al. Measuring the migration of surgical specialists. *Surgery*. 2020 Sep;168(3).
4. Gajewski J, Wallace M, Pittalis C, Mwapasa G, Borgstein E, Bijlmakers L, et al. Why Do They Leave? Challenges to Retention of Surgical Clinical Officers in District Hospitals in Malawi. *International Journal of Health Policy and Management*. 2020 Aug 5;
5. Hagander LE, Hughes CD, Nash K, Ganjawalla K, Linden A, Martins Y, et al. Surgeon Migration Between Developing Countries and the United States: Train, Retain, and Gain from Brain Drain. *World Journal of Surgery*. 2013 Jan 4;37(1).
6. Saluja S, Rudolfson N, Massenburg BB, Meara JG, Shrime MG. The impact of physician migration on mortality in low and middle-income countries: an economic modelling study. *BMJ Global Health* [Internet]. 2020 Jan 1 [cited 2021 Aug 20];5(1):e001535. Available from: <https://gh.bmj.com/content/5/1/e001535>
7. Gosselin RA, Gyamfi Y-A, Contini S. Challenges of Meeting Surgical Needs in the Developing World. *World Journal of Surgery* 2010 35:2 [Internet]. 2010 Nov 23 [cited 2021 Aug 20];35(2):258–61. Available from: <https://link.springer.com/article/10.1007/s00268-010-0863-z>
8. Telemedicine I of M (US) C on ECA of, Field MJ. Evolution and Current Applications of Telemedicine. 1996 [cited 2021 Aug 20]; Available from: <https://www.ncbi.nlm.nih.gov/books/NBK45445/>
9. Hoffer-Hawlik MA, Moran AE, Burka D, Kaur P, Cai J, Frieden TR, et al. Leveraging Telemedicine for Chronic Disease Management in Low- and Middle-Income Countries During Covid-19. *Global Heart* [Internet]. 2020 [cited 2021 Aug 20];15(1):63. Available from: </pmc/articles/PMC7500231/>

10. Sayani S, Muzammil M, Saleh K, Muqet A, Zaidi F, Shaikh T. Addressing cost and time barriers in chronic disease management through telemedicine: an exploratory research in select low- and middle-income countries: <https://doi.org/10.1177/2040622319891587> [Internet]. 2019 Dec 4 [cited 2021 Aug 20];10. Available from: <https://journals.sagepub.com/doi/10.1177/2040622319891587>
11. Asiri A, AlBishi S, AlMadani W, ElMetwally A, Househ M. The Use of Telemedicine in Surgical Care: a Systematic Review. *Acta informatica medica : AIM : journal of the Society for Medical Informatics of Bosnia & Herzegovina : casopis Drustva za medicinsku informatiku BiH* [Internet]. 2018 Oct;26(3):201–6. Available from: <https://pubmed.ncbi.nlm.nih.gov/30515013>
12. Cheriff AD, Schulam PG, Docimo SG, Moore RG, Kavoussi LR. Telesurgical consultation. *Journal of Urology* [Internet]. 1996;156(4):1391–3. Available from: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-0029845916&doi=10.1016%2fS0022-5347%2801%2965596-4&partnerID=40&md5=574300b76e06c2fb8ee964b9953f5f22>
13. Raison N, Khan MS, Challacombe B. Telemedicine in Surgery: What are the Opportunities and Hurdles to Realising the Potential? *Current Urology Reports* [Internet]. 2015;16(7):43. Available from: <https://doi.org/10.1007/s11934-015-0522-x>
14. (SAGES) S of AGES. Guidelines for the surgical practice of telemedicine. *Surgical Endoscopy* [Internet]. 2000;14(10):975. Available from: <https://doi.org/10.1007/s004640000290>
15. Huang EY, Knight S, Guetter CR, Davis CH, Moller M, Slama E, et al. Telemedicine and telementoring in the surgical specialties: A narrative review. *The American Journal of Surgery* [Internet]. 2019;218(4):760–6. Available from: <https://www.sciencedirect.com/science/article/pii/S0002961019301291>
16. El-Sabawi B, Magee 3rd W. The evolution of surgical telementoring: current applications and future directions. *Annals of translational medicine* [Internet]. 2016 Oct;4(20):391. Available from: <https://pubmed.ncbi.nlm.nih.gov/27867943>
17. Valente DS, Silveira Eifler L, Carvalho LA, Filho GAP, Ribeiro VW, Padoin AV. Telemedicine and Plastic Surgery: A Pilot Study. *Pu LLQ*, editor. *Plastic Surgery International* [Internet]. 2015;2015:187505. Available from: <https://doi.org/10.1155/2015/187505>
18. Mendez I, Hill R, Clarke D, Kolyvas G, Walling S. Robotic Long-distance Telementoring in Neurosurgery. *Neurosurgery* [Internet]. 2005 Mar 1;56(3):434–40. Available from: <https://doi.org/10.1227/01.NEU.0000153928.51881.27>
19. Eadie LH, Seifalian AM, Davidson BR. Telemedicine in surgery. *British Journal of Surgery* [Internet]. 2003 Jun 1;90(6):647–58. Available from: <https://doi.org/10.1002/bjs.4168>

20. World Bank Country and Lending Groups – World Bank Data Help Desk [Internet]. [cited 2021 Aug 20]. Available from: <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>
21. Nadjafi-Semnani M., Simforoosh N., Nahid Ghanbarzadeh N., Miri MR. Real-time point-to-point wireless intranet connection: first implication for surgical demonstration and telementoring in urologic laparoscopic surgery in Khorasan. *Urology Journal*. 2008;5(2):74–8.
22. A F, V K, SY G, E K, R P. Safe introduction of laparoscopic colorectal surgery even in remote areas of the world: the value of a comprehensive telementoring training program. *Journal of laparoendoscopic & advanced surgical techniques Part A* [Internet]. 2015 [cited 2021 Aug 20];25(1):37–42. Available from: <https://pubmed.ncbi.nlm.nih.gov/25469662/>
23. Davis MC, Can DD, Pindrik J, Rocque BG, Johnston JM. Virtual Interactive Presence in Global Surgical Education: International Collaboration Through Augmented Reality. *World Neurosurgery*. 2016 Feb 1;86:103–11.
24. Rosser JC, Bell RL, Harnett B, Rodas E, Murayama M, Merrell R. Use of mobile low-bandwidth telemedical techniques for extreme telemedicine applications. *Journal of the American College of Surgeons*. 1999 Oct 1;189(4):397–404.
25. Bauer JJ, Lee BR, Bishoff JT, Janetschek G, Bunyaratavej P, Kamolpronwijit W, et al. International Surgical Telementoring Using a Robotic Arm: Our Experience. <https://home.liebertpub.com/tmj> [Internet]. 2004 Jul 9 [cited 2021 Aug 20];6(1):25–31. Available from: <https://www.liebertpub.com/doi/abs/10.1089/107830200311824>
26. Jr. NRN, Mitre AI, Lima SVC, Fugita OE, Lima ML, Stoianovici D, et al. Telementoring Between Brazil and the United States: Initial Experience. <https://home.liebertpub.com/end> [Internet]. 2004 Jul 6 [cited 2021 Aug 20];17(4):217–20. Available from: <https://www.liebertpub.com/doi/abs/10.1089/089277903765444339>
27. PV P, SK M, S V, CG N, K R, R B. Telementoring in endocrine surgery: preliminary Indian experience. *Telemedicine journal and e-health : the official journal of the American Telemedicine Association* [Internet]. 2006 Feb [cited 2021 Aug 20];12(1):73–7. Available from: <https://pubmed.ncbi.nlm.nih.gov/16478416/>
28. Tamariz F, Merrell R, Popescu I, Onisor D, Flerov Y, Boanca C, et al. Design and Implementation of a Web-Based System for Intraoperative Consultation. *World Journal of Surgery* 2008 33:3 [Internet]. 2009 Jan 3 [cited 2021 Aug 20];33(3):448–54. Available from: <https://link.springer.com/article/10.1007/s00268-008-9858-4>

29. Datta N, Macqueen IT, Schroeder AD, Wilson JJ, Espinoza JC, Wagner JP, et al. Wearable Technology for Global Surgical Teleproctoring. *Journal of Surgical Education*. 2015 Nov 1;72(6):1290–5.
30. Greenfield MJ, Luck J, Billingsley ML, Heyes R, Smith OJ, Mosahebi A, et al. Demonstration of the effectiveness of augmented reality telesurgery in complex hand reconstruction in Gaza. *Plastic and Reconstructive Surgery - Global Open* [Internet]. 2018 [cited 2021 Aug 20];6(3). Available from: https://journals.lww.com/prsgo/Fulltext/2018/03000/Demonstration_of_the_Effectiveness_of_Augmented.26.aspx
31. McCullough MC, Kulber L, Sammons P, Santos P, Kulber DA. Google glass for remote surgical tele-proctoring in low- And middle-income countries: A feasibility study from Mozambique. *Plastic and Reconstructive Surgery - Global Open* [Internet]. 2018 [cited 2021 Aug 20];6(12). Available from: https://journals.lww.com/prsgo/Fulltext/2018/12000/Google_Glass_for_Remote_Surgical_Tele_proctoring.20.aspx
32. Geary A, Benavent S, Cruz EAD la, Wayman L. Distance Surgical Mentorship for Ophthalmologists in Northern Peru. *MedEdPublish* [Internet]. 2019 Mar 11 [cited 2021 Aug 20];8(1). Available from: <https://doi.org/10.15694/mep.2019.000045.1>
33. Ologunde R, Maruthappu M, Shanmugarajah K, Shalhoub J. Surgical care in low and middle-income countries: Burden and barriers. *International Journal of Surgery*. 2014 Aug 1;12(8):858–63.
34. Friedrich MJ. Worldwide Disparities in Surgical Care. *JAMA* [Internet]. 2015 Jun 16 [cited 2021 Aug 20];313(23):2311–2311. Available from: <https://jamanetwork.com/journals/jama/fullarticle/2320327>
35. Ngwa W, Olver I, Schmeler KM. The Use of Health-Related Technology to Reduce the Gap Between Developed and Undeveloped Regions Around the Globe. https://doi.org/10.1200/EDBK_288613. 2020 Mar 31;(40):227–36.
36. Challacombe B, Wheatstone S. Telementoring and Telerobotics in Urological Surgery. *Current Urology Reports* 2010 11:1 [Internet]. 2010 Jan 5 [cited 2021 Aug 20];11(1):22–8. Available from: <https://link.springer.com/article/10.1007/s11934-009-0086-8>
37. Shimizu S, Nakashima N, Okamura K, Han H-S, Tanaka M. Telesurgery System with Original-Quality Moving Images over High-Speed Internet: Expansion Within the Asia-Pacific Region. <https://home.liebertpub.com/lap> [Internet]. 2007 Oct 2 [cited 2021 Aug 20];17(5):673–8. Available from: <https://www.liebertpub.com/doi/abs/10.1089/lap.2007.0017>
38. Surgical Specialties — Royal College of Surgeons [Internet]. [cited 2021 Aug 20]. Available from: <https://www.rcseng.ac.uk/careers-in-surgery/trainees/foundation-and-core-trainees/copy-of-surgical-specialties/>

39. Glass – Glass [Internet]. [cited 2021 Aug 20]. Available from: <https://www.google.com/glass/start/>
40. Ebrahim S, Pearce N, Smeeth L, Casas JP, Jaffar S, Piot P. Tackling Non-Communicable Diseases In Low- and Middle-Income Countries: Is the Evidence from High-Income Countries All We Need? PLOS Medicine [Internet]. 2013 Jan [cited 2021 Aug 20];10(1):e1001377. Available from: <https://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1001377>
41. Bawah A, Houle B, Alam N, Razzaque A, Streatfield PK, Debpuur C, et al. The Evolving Demographic and Health Transition in Four Low- and Middle-Income Countries: Evidence from Four Sites in the INDEPTH Network of Longitudinal Health and Demographic Surveillance Systems. PLOS ONE [Internet]. 2016 Jun 1 [cited 2021 Aug 20];11(6):e0157281. Available from: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0157281>
42. Mendoza W, Miranda JJ. Global shifts in cardiovascular disease, the epidemiologic transition and other contributing factors: Towards a new practice of Global Health Cardiology. Cardiology clinics [Internet]. 2017 Feb 1 [cited 2021 Aug 20];35(1):1. Available from: </pmc/articles/PMC5134924/>
43. Staton C, Vissoci J, Gong E, Toomey N, Wafula R, Abdelgadir J, et al. Road Traffic Injury Prevention Initiatives: A Systematic Review and Metasummary of Effectiveness in Low and Middle Income Countries. PLOS ONE [Internet]. 2016 Jan 6 [cited 2021 Aug 20];11(1):e0144971. Available from: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0144971>
44. Tackling the global burden of road traffic injuries - Institute of Global Health Innovation [Internet]. [cited 2021 Aug 20]. Available from: <https://blogs.imperial.ac.uk/ighi/2020/08/03/tackling-the-global-burden-of-road-traffic-injuries/>
45. Vervoort D, Swain JBD, Pezzella AT, Kpodonu J. Cardiac Surgery in Low- and Middle-Income Countries: A State-of-the-Art Review. The Annals of Thoracic Surgery. 2021 Apr 1;111(4):1394–400.
46. PROXIMIE. Home - Proximie - Saving lives by sharing the world's best clinical practice [Internet]. [cited 2021 Aug 20]. Available from: https://proximie.com/?gclid=Cj0KCQjwP2IBhDkARIsAGVo0D3ru4_KwAI1Geca7fYTMeIozU8cRjJpk0BdT3oYruBlxLs16GbLmXEaAgsyEALw_wcB#
47. Sackier JM, Wang Y. Robotically assisted laparoscopic surgery. Surgical Endoscopy 1994 8:1 [Internet]. 1994 Jan [cited 2021 Aug 20];8(1):63–6. Available from: <https://link.springer.com/article/10.1007/BF02909496>

48. El-Sabawi B, Magee W, III. The evolution of surgical telementoring: current applications and future directions. *Annals of Translational Medicine* [Internet]. 2016 Oct 1 [cited 2021 Aug 20];4(20). Available from: [/pmc/articles/PMC5107399/](#)
49. Amato M, Eissa A, Puliatti S, Secchi C, Ferraguti F, Minelli M, et al. Feasibility of a telementoring approach as a practical training for transurethral enucleation of the benign prostatic hyperplasia using bipolar energy: a pilot study. *World Journal of Urology* 2021 [Internet]. 2021 Feb 4 [cited 2021 Aug 20];1–7. Available from: <https://link.springer.com/article/10.1007/s00345-021-03594-9>
50. Google Glass Enterprise Edition 2 announced for \$999 [Internet]. [cited 2021 Aug 20]. Available from: <https://www.cnbc.com/2019/05/20/google-glass-enterprise-edition-2-announced-price.html>
51. Providers – Glass [Internet]. [cited 2021 Aug 20]. Available from: <https://www.google.com/glass/providers/>
52. McKnight RR, Pean CA, Buck JS, Hwang JS, Hsu JR, Pierrie SN. Virtual Reality and Augmented Reality—Translating Surgical Training into Surgical Technique. *Current Reviews in Musculoskeletal Medicine* [Internet]. 2020 Dec 1 [cited 2021 Aug 20];13(6):663. Available from: [/pmc/articles/PMC7661680/](#)
53. Madder R. Robot surgery could be the future of remote health care | Fortune. *Fortune* [Internet]. 2020 Feb 11 [cited 2021 Aug 20]; Available from: <https://fortune.com/2020/02/11/tele-robotics-surgery-5g-health/>
54. Song F, Hooper L, Loke YK. Publication bias: what is it? How do we measure it? How do we avoid it? *Open Access Journal of Clinical Trials* [Internet]. 2013 Jul 4 [cited 2021 Aug 20];5(1):71–81. Available from: <https://www.dovepress.com/publication-bias-what-is-it-how-do-we-measure-it-how-do-we-avoid-it-peer-reviewed-fulltext-article-OAJCT>
55. Zemmar A, Lozano AM, Nelson BJ. The rise of robots in surgical environments during COVID-19. *Nature Machine Intelligence* 2020 2:10 [Internet]. 2020 Oct 13 [cited 2021 Aug 20];2(10):566–72. Available from: <https://www.nature.com/articles/s42256-020-00238-2>
56. S M, D P, N S. Sustainable Development Goals (SDGs), and their implementation: A national global framework for health, development and equity needs a systems approach at every level. *British medical bulletin* [Internet]. 2017 Dec 1 [cited 2021 Aug 20];124(1):81–90. Available from: <https://pubmed.ncbi.nlm.nih.gov/29069332/>

Figure legends:

Figure 1: PRISMA Flow chart

Figure 1



