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Collateral damage: the impact on outcomes from cancer surgery of the COVID-19 pandemic

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PII: S0923-7534(20)39825-2

DOI: <https://doi.org/10.1016/j.annonc.2020.05.009>

Reference: ANNONC 191

To appear in: *Annals of Oncology*

Received Date: 6 May 2020

Revised Date: 7 May 2020

Accepted Date: 10 May 2020

Please cite this article as: Sud A, Jones M, Broggio J, Loveday C, Torr B, Garrett A, Nicol DL, Jhanji S, Boyce SA, Gronthoud F, Ward P, Handy JM, Yousaf N, Larkin J, Suh YE, Scott S, Pharoah PDP, Swanton C, Abbosh C, Williams M, Lyratzopoulos G, Houlston R, Turnbull C, Collateral damage: the impact on outcomes from cancer surgery of the COVID-19 pandemic, *Annals of Oncology* (2020), doi: <https://doi.org/10.1016/j.annonc.2020.05.009>.

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1 **Collateral damage: the impact on outcomes from cancer surgery of the**
2 **COVID-19 pandemic**

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38

39

40 **ABSTRACT**

41

42 **Background:** Cancer diagnostics and surgery have been disrupted by the response of
43 healthcare services to the COVID-19 pandemic. Progression of cancers during delay will
44 impact on patient long-term survival.

45 **Methods:** We generated per-day hazard ratios of cancer progression from observational
46 studies and applied these to age-specific, stage-specific cancer survival for England 2013-
47 2017. We modelled per-patient delay of three months and six months and periods of
48 disruption of one year and two years. Using healthcare resource costing, we contextualise
49 attributable lives saved and life-years gained from cancer surgery to equivalent volumes of
50 COVID-19 hospitalisations.

51 **Findings:** Per year, 94,912 resections for major cancers result in 80,406 long-term survivors
52 and 1,717,051 life years gained. Per-patient delay of three/six months would cause
53 attributable death of 4,755/10,760 of these individuals with loss of 92,214/208,275 life-
54 years. For cancer surgery, average life-years gained (LYGs) per patient are 18.1 under
55 standard conditions and 17.1/15.9 with a delay of three/six months (an average loss of
56 0.97/2.19 LYG per patient). Taking into account units of healthcare resource (HCRU), surgery
57 results on average per patient in 2.25 resource-adjusted life-years gained (RALYGs) under
58 standard conditions and 2.12/1.97 RALYGs following delay of three/six months. For 94,912
59 hospital COVID-19 admissions, there are 482,022 LYGs requiring of 1,052,949 HCRUs.
60 Hospitalisation of community-acquired COVID-19 patients yields on average per patient 5.08
61 LYG and 0.46 RALYGs.

62 **Interpretation:** Modest delays in surgery for cancer incur significant impact on survival.
63 Delay of three/six months in surgery for incident cancers would mitigate 19%/43% of life-
64 years gained by hospitalisation of an equivalent volume of admissions for community-
65 acquired COVID-19. This rises to 26%/59% when considering resource-adjusted life-years
66 gained. To avoid a downstream public health crisis of avoidable cancer deaths, cancer
67 diagnostic and surgical pathways must be maintained at normal throughput, with rapid
68 attention to any backlog already accrued.

69

70 **KEY WORDS**71 **Oncology, Survival, Delay, COVID-19, Diagnostics**

72 **INTRODUCTION**

73 Following the first case reports in Hubei province, China in late 2019, a pandemic of COVID-
74 19 coronavirus was declared by the World Health Organisation in March 2020. Whilst
75 COVID-19 causes minimal or mild illness in most, a small but appreciable proportion of
76 individuals require oxygen therapy and often admission to an Intensive Care Unit (ICU). The
77 ensuing unprecedented pressure on hospital wards and ICUs has necessitated rapid
78 redeployment of staff and capacity towards the management of COVID-19 cases with
79 deprioritisation of non-emergency clinical services, including diagnostics and elective
80 specialist surgery. Concurrently, lockdown of the population has impacted dramatically on
81 presentation and referral of symptomatic patients from primary into secondary care[1].

82

83 For patients with cancer, delay of surgery has the real potential to increase the likelihood of
84 metastatic disease, with some patients' tumours progressing from being curable (with near
85 normal life expectancy) to non-curable (with limited life expectancy)[2]. The situation has
86 been further exacerbated by recent safety concerns regarding aerosol generation from
87 endoscopy, cystoscopy and surgery[3, 4].

88

89 Current projections indicate that COVID-19-related disruption may well last for 18 months
90 or more, until there is either long term effective containment in the population or large-
91 scale vaccination. To inform healthcare prioritisation and resource allocation, we have
92 examined the impact on cancer outcomes of different periods of delay of cancer surgery
93 with disruption extending over variable time periods, comparing resource-weighted
94 outcomes to hospital management of COVID-19 patients.

95

96 METHODS

97 Data sources

98 Number and age-specific five-year net survival of cancer patients that had potentially
99 curative surgical resections for non-haematological malignancies between 2013 and 2017
100 were obtained from Public Health England National Cancer Registration Service (NCRAS)[5].
101 As well as cancer stage at diagnosis for each cancer type, breast tumour receptor data
102 allowed subtyping of these cancers as ER+ HER2-, HER+ (any), ER- HER2-, and other.
103 Estimates for nosocomial infection rates, median duration of hospital stay for each cancer
104 type, staffing of theatres, ICU and surgical wards were based on information from three
105 large UK surgical oncology centres. Patterns of administration of adjuvant systemic anti-
106 cancer therapy (SACT) were based on oncologist-reviewed standard practice guidance[6].
107 ICU COVID-19 mortality, distribution by age, and duration of stay and proportion referred
108 into ICU were obtained from ICNARC and data from hospitalised UK cases[7, 8]. Due to lack
109 of UK data, data from Wuhan was used as the basis for the age distribution of community
110 infection, age-specific likelihoods of admission from community to hospital, and mortality
111 rates for non-ICU COVID-19 patients [9, 10] (Supplementary Table 1).

112

113 Analysis

114 Impact of COVID-associated delay on cancer outcomes

115 We used published data from studies examining the impact on overall survival from delay in
116 cancer surgery to estimate per day hazard ratios (HRs) associated with delay for different
117 cancers (the “Fatality HR”) [11-21]. We had sufficient data to generate Fatality HRs for three
118 tumour types and assigned these to other tumours, based on comparability of 5-year
119 survival as low (>90%) moderate (50-90%) or high (<50%) progressiveness tumours[5].
120 Because we were unable to identify any suitable observational data for tumours of high
121 progressiveness (e.g. oesophageal, gastric), we applied the Fatality HR from tumours of
122 moderate progressiveness; this is likely to be a conservative assumption (Supplementary
123 Table 2).

124 By accounting for COVID-related post-surgical mortality and changes in SACT, we adjusted
125 five-year net survival figures for each cancer for surgical patients under **standard** care to
126 estimate **current** five-year net survival. To model outcomes of surgery **post-delay**, we apply
127 to standard five-year net survival, the Fatality HR relating to the specified number of days of

128 delay, again including COVID-related post-surgical mortality. Based on estimates from a UK
129 surgical oncology centre, supported by the literature, we applied a current per day rate of
130 nosocomial infection of 5%. Assuming improvement in cold protocols, we modelled
131 reduction in this rate over time. We estimated COVID-associated surgical mortality based on
132 per day rate of nosocomial infection, operation-specific duration of post-surgical admission,
133 and age-specific mortality from infection. We estimated COVID-19 associated mortality for
134 SACT administration, based on per day rate of nosocomial infection, the frequency of SACT
135 scheduling, increased risk associated with immunosuppression, and age-specific mortality
136 from infection. We assumed, where standard-of-care, that SACT offers a uniform survival
137 benefit (5% in Stage 1, 7.5% in Stage 2 and 10% in Stage 3) and administration would only
138 continue where this benefit exceeds COVID-related mortality.
139 We used mean life-expectancies per 10-year age-group to calculate life years gained,
140 averaged per patient. We examined reduction in overall survival and life years gained (LYG),
141 comparing surgery under standard care, current conditions and post-delay, by cancer type
142 and by age and stage. Using 2013-2017 surgical workload data, we calculated across all
143 adult cancers examined, the total number of deaths and life years lost attributable to delay.
144 To address possible scenarios, we considered per-patient delay of up to six-months, and 1-
145 and 2-year periods of disruption.

146

147 **COVID-19 outcome**

148 To compare life years associated with timely cancer surgery with that afforded by
149 hospitalisation of COVID-19 patients, we modelled a volume of community-ascertained
150 COVID-19 infection resulting in an equivalent volume of hospital admissions to cancer
151 surgeries (**Supplementary Table 1**).

152

153 **Resource**

154 We analysed healthcare resource units (HCRU) focused specifically on frontline medical and
155 nursing staff, where one HCRU is one 12-hour shift of direct nursing or medical care. We up-
156 weighted for shifts from healthcare workers of high-salary (senior doctors) and/or of current
157 scarcity (anaesthetists, ICU nurses). We calculated HCRUs per patient using estimated
158 staffing ratios for theatres, ICU and ward care and operation-specific data for theatre hours,
159 ICU stay and ward days from oncology centres.

160 Details of assumptions and parameter estimates are detailed in **Table 1** and **Supplementary**
161 **Table 1**. Analyses were performed using STATA (version 15) and transcribed to Excel, to
162 provide a full visibility of parametrisation, model outputs, and opportunity for the reader to
163 customise parameters (**Supplementary Materials**).

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166 RESULTS

167 Impact of surgical delay on survival for different cancers

168 The greatest rates of deaths arise following even modest delays to surgery in aggressive
169 cancers, with over 30% reduction in survival at six months and over 17% reduction in
170 survival at three months for patients with stage 2 or 3 cancers of the bladder, lung,
171 oesophagus, ovary, liver, pancreas and stomach (**Table 2, Supplementary Table 3,**
172 **Supplementary Materials**). Accounting for nosocomial COVID-19 infection, for cancers with
173 a relatively good overall prognosis, delay of surgery by three months had a minimal impact
174 on survival: <1% for all Stage 1 ER+ and HER2+ breast cancers, for example. In older patients
175 (>70 years), for early stage colorectal, kidney and ER+ breast cancers, the current impact on
176 survival of COVID-related mortality exceeded the impact of three or even six months delay
177 (**Table 2, Supplementary Table 3**).

178

179 For a high proportion of solid cancers, survival at five years is generally considered to be
180 equivalent to cure. Predicated on this assertion, we considered life-years gained adjusting
181 for resource (resource adjusted life years (RALYGs)). Perhaps unsurprisingly, most benefit is
182 afforded in younger age groups for operations that are shorter with no associated ICU
183 requirement. For example, trans-urethral resection of stage 1 bladder cancers affords on
184 average 23.4 RALYG per patient age 30-39, whereas cystectomy for stage 2 bladder cancer is
185 only associated with 1.2 RALYGs in that age group (**Supplementary Table 4**). In the context
186 of prioritisation, avoidance of a six-month delay restitutes on average 4.1 RALYGs in the
187 former group, compared to 0.7 in the latter (**Table 3, Supplementary Table 5**). Wide local
188 excision for breast cancer has low resource requirement and therefore confers substantial
189 RALYGs, even in good prognosis subtypes.

190

191 Impact of surgical delay on cancer survival combined across cancer types

192 Each year, 94,912 surgical resections for common invasive adult cancer types are performed
193 in England, with 80,406 of those patients surviving their cancer at five years. A surgical delay
194 of three months across all incident solid tumours over one year would incur 4,755 excess
195 deaths, escalating to 10,760 excess deaths for a six-month delay. This includes at six
196 months, attributable deaths of 2,980 for colorectal cancer 1,439 for lung cancer and 804 for
197 breast cancer (**Figure 1**).

198

199 For a high proportion of solid cancers, five-year survival is generally considered to be
200 equivalent to cure. Predicated on this assertion, across all cancers a delay of three months
201 in treatment would lead to a reduction of 92,214 life-years and for six months' reduction of
202 208,275 life years (**Table 3**). Prior to the COVID-19 crisis, each year cancer surgery was
203 directly responsible for 1,717,051 LYGs. This represents on average 18.1 LYG per patient,
204 which markedly reduces to 17.1 with three months' delay and to 15.9 with six months'
205 delay. Cancer surgery per year requires 764,765 units of healthcare resource. Assuming this
206 to be unchanged by delay, this affords on average 2.25 RALYG per patient under standard
207 conditions, reducing to 2.12 with three months' delay and 1.97 with six months of delay, an
208 average loss of 0.12 and 0.27 RALYGs, respectively, per patient.

209

210 **Resource comparison for outcomes afforded by cancer surgery and COVID-19** 211 **management**

212 For contextualisation, we compare the impact of cancer surgery delay to hospital care for
213 patients with community-acquired COVID-19 infection. COVID-19 ICU admission for those
214 aged 40-49 yielded on average 27.5 LYG and 0.8 RALYG. Those aged >80 years admitted to
215 ICU benefit by on average 2.1 LYG and 0.06 RALYG. For non-ICU admission, average benefit
216 is 9.3 LYG and 1.5 RALYG for those aged 40-49 and 1.4 LYG and 0.2 RALYG for those aged
217 >80 years (**Supplementary Materials**). These estimates are inherently conservative as they
218 do not take into account the impact on life expectancy of the excess comorbidities
219 associated with many hospitalised COVID-19 cases.

220

221 COVID-19 community-acquired infection of 683,083 individuals would result in 94,912
222 hospital admissions (*i.e.* the equivalent number to number of annual admissions for cancer
223 surgery). For these 94,912 admissions, 16,135 will require ICU (critical cases) and 78,777 will
224 not require ICU (severe cases). 1,052,949 units of healthcare resource are required in total
225 and there are 15,587 deaths, 25,752 attributable lives saved, and 482,022 attributable LYGs
226 (8,241 deaths/7,894 attributable lives saved/223,227 LYGs for ICU admissions, 7,346/
227 17,858/ 258,795 for non-ICU). This represents on average 5.08 LYG and 0.46 RALYG per
228 hospitalised COVID-19 patient.

229

230 It is therefore noteworthy, that a delay of surgery by six months results in 208,275 lost life-
231 years for an annual quota of surgical patients: this equates to 43% of the total 482,022 life-
232 years gained from hospitalisation of an equivalent number of community-acquired COVID-
233 19 cases. This rises to 59% when adjusted for differences in resource (RALYGs).

234

235 **Sensitivity Analysis**

236 The outcomes from the model were mostly sensitive to changes in the Fatality HR for the
237 per-day delay: varying this by $\pm 8\%$ (1SD) caused the average LYG with a six-month delay to
238 range from 15.7-16.1, and attributable LY lost by 2.00-2.39. Sensitivity analysis for other
239 parameters is shown in **Supplementary Table 2**.

240

241

242 DISCUSSION

243 We provide estimates derived from reported surgical outcomes to quantify the impact on
244 survival of delay of cancer treatment, within the parameters of the assumptions of the
245 model.

246

247 Implications for healthcare planning

248 For aggressive cancers, our analysis demonstrates that even short delays (three months)
249 have a significant impact on patient survival. However, even for cancers of comparatively
250 favourable prognosis, a delay of six months will result in significant summed attributable
251 deaths as many of these cancers are common. Delay will also result in tumours being more
252 advanced, meaning not only is survival poorer, but that the upstaged cancers will be more
253 costly to treat both in terms of surgery and/or chemotherapy. Furthermore, resource
254 requirements (for example, ICU stay) are dramatically higher for the many who will
255 inevitably present as emergencies such as with obstruction, perforation or acute bleeding of
256 the gastrointestinal tract[22].

257

258 Critical to mitigating cancer deaths is recognition that delay or bottleneck may arise at any
259 point in the linear patient journey from (i) self-presentation of the symptomatic patient to
260 primary care, (ii) primary care review and referral into secondary care (iii) diagnostic
261 investigation, and (iv) surgery (or radiotherapy) with curative intent. Alongside any 'bulge' in
262 accumulated cases will be the normal stream of incident cancer presentations. In the face of
263 prolonged stress, it will be challenging to provide extra capacity to address these bulges
264 alongside standard demands. In the short term, to avoid knock-on delays, immediate
265 diversion of supra-normal resource volumes are required to process the backlog of cases
266 that will have accrued in the initial months of the pandemic, in which referrals,
267 investigations, and surgeries have been reduced by up to 80%[1]. In the medium-long term
268 (over the next 3-24 months), avoidance of delay to cancer surgery should be of the highest
269 priority: urgent attention is required to ensure sufficient resourcing for standard capacity of
270 all pathway elements in primary care, cancer diagnostic, and surgical.

271

272 Delay in cancer surgery will have a highly deleterious health and economic impact. For the
273 most part, the surgery will still be required (and may be more complex and costly) but

274 results in rapid diminution resultant life-years gained and resource-adjusted life-years.
275 Comparing equivalent-sized hospital populations adjusted for resource, the health impact of
276 delaying cancer surgery for six months will approximate 60% of health gains of
277 hospitalizations for community acquired COVID-19 infection. We need to consider
278 resourcing in the likely event of sizeable requirement for COVID-19 management for a
279 sustained period of time, potentially up to two years. Although large facilities may be
280 built/repurposed for COVID-19 management, these facilities are competing for the same
281 fixed pool of healthcare workers that provide care for treating non-COVID-19 disease.

282

283 Currently, where the rate of nosocomial infection is high, for older groups in particular,
284 surgery and/or SACT may in the short-term offer more risk than benefit (see Supplementary
285 Materials). Active focus is required to establish 'cold' sections of the healthcare system,
286 with rigorous protocols for staff screening and shielding protocols. This will serve to
287 minimise nosocomial acquisition and mortality from COVID-19, to protect staff, and also to
288 provide reassurance to the public regarding uptake of diagnostics and surgery for cancer.

289

290 Urgent review by professional bodies is required regarding best protection of their staffing
291 groups, and guidance on surgical and diagnostic practice commensurate with the true
292 risks[3].

293

294 **Implications for prioritisation amongst cancer patients**

295 Given an accrued backlog of cases and ongoing tight competition for resources, decisions
296 regarding surgical prioritisation may be required for a number of years, with capacity
297 varying geographically and temporally. Recognising its limitations regarding assumptions
298 and parameters, we propose a model that provides a rational approach by which to
299 evaluate across patients of different ages, tumour types, and stages, the benefit and
300 resource implications of their cancer surgery. We highlight in our model those age-stage
301 groups for which COVID-related mortality currently exceeds survival benefit for surgery
302 and/or SACT. Whilst these and other groups for whom benefit is marginal will be the most
303 rationale to delay, they will nevertheless require monitoring and surgery downstream.
304 Longitudinal planning, monitoring of progression, dynamic re-prioritisation, and capacity-
305 planning will inevitably be highly challenging.

306

307

308 Broader and International relevance

309 While we have used data for England, cancer survival is broadly similar across most
310 economically developed countries, so the impact of delay per tumour is broadly applicable
311 across Europe. However, variation in incidence of cancer, life expectancy and population
312 age structure mean that predictions regarding total case numbers and life-years gained and
313 lost are more difficult to extrapolate, even when scaling for relative size of reference
314 population.

315 Whilst customised for surgical delay due to the COVID-19 pandemic, this model could
316 readily be adapted to quantify the impact of surgical delay due to other causes.

317

318 Limitations

319 As with any model-based analysis, our predictions are predicated on the validity of
320 assumptions and estimates used for parameterisation. While we have made use of
321 observational data, our approach simplifies the complexity of cancer progression and is
322 solely survival-focused. For healthcare planning, a more elaborate model capturing stage-
323 shifting may offer additional utility. We base our analysis on survival data from 2013-17; for
324 some tumour types, standard-of-care and survival has evolved since this time. Our
325 modelling of the benefit of SACT is simplistic as the scheduling, benefits and
326 immunosuppressive consequences vary by chemotherapy regimen. Whilst we have included
327 in our model the impact withholding of SACT if nosocomial infection risk is high, we have
328 not modelled additional reduction in survival from delays in administration of adjuvant
329 therapy. Mortality from nosocomial COVID-19 infection during surgical admission or
330 attendance for chemotherapy is based on a uniform per-day risk of infection: these may
331 vary between institutions. While our resourcing analysis deliberately focuses on the
332 requirement for the direct medical and nursing staff who most limit healthcare provision,
333 we acknowledge it does not capture other 'costs' incurred in hospital care, primary care,
334 and social care.

335 Our model of COVID-19 admissions is limited by availability of detailed individual-level UK
336 data, in particular for non-CCU hospital admissions; this model is also conservative in regard
337 of disregarding impact of co-morbidities on life expectancy.

338

339 Further research

340 Within our current approach, we only estimate the effects of a specified period of per-
341 patient delay. Contemporaneous data for NHS activity offers the prospect of developing
342 dynamic models to predict the impact of (i) differential prioritisation of patient groups, (ii)
343 different patterns of re-presentation of 'accumulated' cases alongside incident cases, and
344 (iii) varying release of bottlenecks in primary care, diagnostics, and surgery. Evaluation is
345 also important for the alternative management approaches being adopted, such as
346 radiotherapy with curative intent where surgery is gold-standard or *a priori* hormonal
347 treatment for prostate and ER-positive breast cancers. For any strategies involving
348 deliberate delay to surgery, models for re-staging and dynamic re-prioritisation are
349 essential. We have focused on the impact to surgery with curative intent; analyses are also
350 required to quantify the impact on mortality of changes to life-extending chemo- and radio-
351 therapy for patients with Stage 4 disease.

352

353 CONCLUSION

354

355 Compared to COVID-19 management, cancer surgery is highly impactful in regard to life-
356 years gained per resource expended. Delay in diagnosis and surgery cause exponential
357 burden of attributable mortality. The COVID-19 pandemic has placed unprecedented strain
358 on health care provision. It is highly plausible that surges of population infection, lock-
359 downs, resource competition, bottlenecks, and back-logs could recur over the next two
360 years. Supra-normal capacity is required to manage backlogs of accumulated cancer cases
361 alongside ongoing incident cases. To avoid a deferred public health crisis of unnecessary
362 cancer deaths, urgent ringfencing of substantial resources is required.

363

364

365 LEGENDS FOR FIGURES

366

367 **Figure 1:** Impact from 6-months delay lasting one year for all solid cancers analysed and six
368 common cancer types in England expressed in **a:** Attributable deaths **b:** Life years Lost

369

370 Author contributions

371 C.T., M.E.J., A.S. and R.S.H. designed the model. M.E.J. provided cancer progression models.
372 J.B. generated and quality-assured the NCRAS datasets applied to the model. M.E.J., J.B.
373 C.T., R.S.H., A.S., C.A., G.L., M.W., and P.D.P.P provided epidemiological expertise in
374 parameterisation of the model. F.G provided microbiology expertise in estimation of
375 nosocomial infection rates. S.A.B, S.J., D.L.N, P.W., J.L., J.M.H, N.Y. and Y-E.S provided details
376 of clinical pathways and estimates of clinical resourcing. B.T., A.G. and C.L. quality assured
377 and user-tested the model. B.T. and C.L. assembled figures for presentation. C.T drafted the
378 manuscript, with substantial contribution from A.S., R.S.H., M.E.J., G.L., M.W. and C.S.. All
379 authors contributed to the final manuscript.

380

381 Acknowledgments

382 This work uses data that has been provided by patients and collected by the NHS as part of
383 their care and support. The data are collated, maintained and quality assured by the
384 National Cancer Registration and Analysis Service, which is part of Public Health England
385 (PHE).

386

387 Funding Statement

388 C.T., R.S.H and M.E.J are supported by The Institute of Cancer Research. M.E.J. additionally
389 received funding from Breast Cancer Now. B.T and A.G. are supported by Cancer Research
390 UK (C61296/A27223). C.L. is supported by and C.T. additionally receives funding from The
391 Movember Foundation. R.S.H. is supported by Cancer Research UK (C1298/A8362) and
392 Bobby Moore Fund for Cancer Research UK). A.S. is in receipt of an Academic Clinical
393 Lectureship from National Institute for Health Research (NIHR) and Biomedical Research
394 Centre (BRC) post-doctoral support. This is a summary of independent research supported
395 by the NIHR BRC at the Royal Marsden NHS Foundation Trust and Institute of Cancer
396 Research. The views expressed are those of the authors and not necessarily those of the

397 NHS, NIHR or the Department of Health. G.L. is supported by a Cancer Research UK
398 Advanced Clinician Scientist Fellowship Award (C18081/A18180) and is Associate Director of
399 the multi-institutional CanTest Collaborative funded by Cancer Research UK
400 (C8640/A23385).

401

402 **Disclosure**

403 The authors have no relevant disclosures to declare.

404

405 **Highlights**

- 406 • Lockdown and re-deployment due to the COVID-19 pandemic is causing significant
407 disruption to cancer diagnosis and management.
- 408 • 3-month delay to surgery across all Stage 1-3 cancers is estimated to cause >4,700
409 attributable deaths per year in England.
- 410 • The impact on life years lost of 3-6 month to surgery for Stage 1-3 disease varies
411 widely between tumour types.
- 412 • Strategic prioritisation of patients for diagnostics and surgery has potential to
413 mitigate deaths attributable to delays.
- 414 • The resource-adjusted benefit in avoiding delay in cancer management compares
415 favourably to admission for COVID-19 infection.

416

417

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COMPONENT OF MODEL	ELEMENTS	DATA SOURCE	COMMENT	Reference/specific values	
Life years lost due to delay in surgery	Proportion of patients surviving after surgery	5 year survival rates for cancer surgery in England	Age, site, and stage-specific 5-year cancer survival in individuals in whom major resection was performed	PHE NCRAS[4]	
	Decrease in survival due to delay in treatment	Observational studies of increased death rate due to delay in treatment	Hazard ratio for increase in death rate for each day delay in treatment based on estimates from literature, applied to standard survival rates. Applied to tumours depending on tumour aggressiveness	Cancer progressiveness based on 5y survival: Low: >90%, Moderate: 50-90% High: <50% Per day Hazard ratio for fatality [10-20]: Low: 0.0030, Mod: 0.0056 High: 0.0056	
	COVID-related post-surgical mortality. SACT-related mortality	Nosocomial infection rate	Nosocomial infection rate	Based on literature, estimate from clinical site data	5 % per day[29]
		Mortality from COVID-infection	Mortality from COVID-infection	Age-specific data from international series	0-39 y 0.2% 30-39 y 0.2% 40-49 y 0.4% 50-59 y 1.3% 60-69 y 3.6% 70-79 y 8.0% 80+ y 14.8%
		Survival benefit from SACT	Survival benefit from SACT	Expert clinical interpretation of literature	Stage 1: 5% Stage 2: 7.5% Stage 3: 10% [30]
		Increase in COVID-related mortality due to SACT	Increase in COVID-related mortality due to SACT	Based on UK and international literature	2-fold [7, 8]
	Life-expectancy after survival	General population mean life-expectancies per 10 year age-band	Expected remaining life years in treated group based on proportion who survive after treatment (with and without delay)	ONS Life Tables[31]	
Healthcare resourcing	Duration of operation, ICU and inpatient ward stay Staffing ratios in theatre, wards, ICU	Data from UK surgical oncology centres	Calculated as Healthcare Resource Unit (HCRUs) of direct clinical care. 1 HCRU= one 12 hour medical/nursing shift		

Table 1: Summary of sources for parameters estimates for cancer surgical model (see Supplementary Table 1 for full description)

	Stage	30-39 y	40-49 y	50-59 y	60-69 y	70-79 y	80+ y
Bladder	1	15.8%	15.8%*	26.3%	18.4%	21.9%	23.8%
	2	36.0%	35.9%	32.7%	31.9%	29.0%	28.6%
	3	35.9%	35.8%*	34.8%	34.1%	32.4%	29.3%
Breast (ER+, HER2-)	1	1.5%	0.6%	-0.3%	-1.5%	-3.2%	-3.1%
	2	5.9%	2.8%	2.4%	0.7%	-1.3%	-5.6%
	3	13.4%	8.2%	9.2%	9.2%	9.1%	2.5%
Breast (ER-, HER2-)	1	6.2%	4.3%	5.4%	2.3%	0.5%	4.1%
	2	13%	12.2%	11.3%	10.0%	12.7%	14.0%
	3	18.2%	19.8%	19.4%	18.5%	18.2%	16.0%
Breast (HER2+)	1	0.4%	0.9%	1.0%	0.5%	-1.7%	3.5%
	2	4.2%	3.1%	3.4%	3.0%	3.3%	6.5%
	3	11.3%	7.0%	9.6%	8.8%	13.9%	15.0%
Colon and rectosigmoid junction	1	2.1%	4.9%	4.5%	3.0%	-1.5%	-2.8%
	2	16.7%	15.9%	14.0%	14.7%	15.0%	4.8%
	3	29.9%	29.1%	29.2%	28.5%	30.2%	28.8%
Kidney	1	2.1%	2.6%	6.0%	5.1%	0.5%	-2.5%
	2	13.2%	17.0%	11.5%	16.1%	13.8%	26.4%
	3	19.8%	23.5%	25.7%	24.9%	23.5%	22.2%
Larynx	1	11.5%	16.3%	19.0%	16.9%	11.2%	20.1%
	2	29.5%	29.5%*	20.5%	31.7%	32.3%	32.5%
	3	33.9%	33.8%*	35.4%	34.2%	32.8%	20.7%
Lung (non-small cell)	1	5.4%	14.3%	25.4%	27.5%	29.6%	24.0%
	2	31.6%	34.2%	34.8%	34.5%	32.3%	29.6%
	3	35.7%	35.7%	34.1%	29.6%	27.9%	19.6%
Melanoma of skin	1	1.1%	2.5%	0.4%	1.2%	0.2%	2.8%
	2	19.9%	22.5%	24%	28.2%	27.1%	34.4%
	3	29.0%	30.8%	31.4%	33.5%	31.4%	31.5%
Oesophagus	1	31.6%	31.5%	29.8%	29.4%	24.7%	29.9%
	2	35.9%	35.8%*	35.4%	34.3%	32.2%	28.3%
	3	35.8%	34.2%	30.4%	31.9%	27.0%	25.3%
Ovary	1	4.6%	7.1%	10.8%	10.4%	11.3%	-1.1%
	2	16.9%	26.2%	28.9%	29.6%	31.9%	35.3%
	3	31.5%	35.9%	33.8%	31.5%	28.6%	21.0%
Pancreas	1	1.0%*	9.6%*	12.7%	15.4%	20.2%*	28.1%
	2	23.8%	35.9%*	27%	23.6%	21.4%	25.9%
	3	24.8%	24.7%*	32.3%	33.2%*	31.4%*	24.1%
Prostate	1	1.4%*	1.4%	-0.3%	-0.7%	1.6%	15.4%
	2	0.0%*	-0.1%	-0.3%	-0.7%	-1.5%	16.9%
	3	0.0%*	-0.1%	-0.3%	-0.7%	-1.5%	17.8%
Stomach	1	12.2%	18.6%*	29.3%	21.4%	11.1%	-6.5%
	2	35.0%	27.9%*	35.2%	34.4%	32.2%	18.0%
	3	35.0%	32.3%	33.2%	32.3%	28.9%	26.8%
Uterus	1	3.3%	5.6%	6.1%	9.5%	12.6%	6.0%
	2	13.2%	18.4%	18.9%	26.5%	32.6%	33.0%
	3	10.2%	31.1%	33.4%	35.8%	33.1%	33.6%

Table 2: Reduction in five-year net survival as a consequence of six-month delay to surgery for 13 cancer types, by tumour stage and age of diagnosis.

Reduction in survival above the median is represented in red, at the median in yellow and below the median in green. Survival analysis is based on per-day hazard ratios for disease fatality. * indicates strata estimates of lower confidence whereby crude rather than net survival estimates were applied.

	Stage	30-39	40-49	50-59	60-69	70-79	80+
Bladder	1	4.1*	3.3*	4.1	2.0	1.5	0.8
	2	0.7*	0.6	0.4	0.3	0.1	0.1
	3	0.7*	0.6*	0.4	0.3	0.2	0.1
Breast (ER+, HER2-)	1	0.3	0.1	0.0	-0.1	-0.2	-0.1
	2	1.2	0.5	0.3	0.1	-0.1	-0.2
	3	2.8	1.4	1.2	0.8	0.5	0.1
Breast (ER-, HER2-)	1	1.3	0.7	0.7	0.2	0.0	0.1
	2	2.7	2.0	1.4	0.9	0.7	0.4
	3	3.8*	3.3	2.4	1.6	1.0	0.5*
Breast (HER2+)	1	0.1	0.2	0.1	0.0	-0.1	0.1
	2	0.9	0.5	0.4	0.3	0.2	0.2
	3	2.4	1.2	1.2	0.8	0.8	0.4
Colon and rectosigmoid junction	1	0.1	0.1	0.1	0.0	0.0	0.0
	2	0.6	0.4	0.3	0.2	0.1	0.0
	3	1.0	0.8	0.6	0.4	0.3	0.1
Kidney	1	0.1	0.1	0.2	0.1	0.0	0.0
	2	0.5*	0.5	0.2	0.2	0.1	0.1
	3	0.7*	0.7	0.6	0.4	0.2	0.1
Larynx	1	0.4*	0.4	0.4	0.2	0.1	0.1
	2	0.9*	0.7*	0.4*	0.4	0.3	0.1*
	3	1.0*	0.8*	0.6	0.4	0.3	0.1*
Lung (non-small cell)	1	0.2	0.3	0.5	0.3	0.2	0.1
	2	0.9*	0.8	0.6	0.4	0.2	0.1
	3	1.1*	0.8	0.6	0.4	0.2	0.1
Melanoma of skin	1	0.4	0.7	0.1	0.2	0.0	0.1
	2	2.1	1.9	1.5	1.2	0.7	0.5
	3	3.0	2.6	2.0	1.5	0.9	0.4
Oesophagus	1	0.6*	0.4	0.3	0.2	0.1	0.1*
	2	0.6*	0.5*	0.4	0.3	0.1	0.1*
	3	0.6*	0.5	0.3	0.2	0.1	0.1*
Ovary	1	0.5	0.6	0.7	0.5	0.3	0.0
	2	1.8*	2.2	1.8	1.3	0.9	0.5
	3	0.8	0.8	0.5	0.4	0.2	0.1
Pancreas	1	0.0*	0.1*	0.1*	0.1	0.1*	0.1*
	2	0.4*	0.5*	0.3	0.2	0.1	0.1*
	3	0.4*	0.4*	0.4*	0.3*	0.1*	0.1*
Prostate	1	0.0*	0.0	0.0	0.0	0.0	0.1
	2	0.0*	0.0	0.0	0.0	0.0	0.1*
	3	0.0*	0.0	0.0	0.0	0.0	0.1*
Stomach	1	0.3*	0.3*	0.4	0.2	0.1	0.0
	2	0.7*	0.4*	0.4	0.3	0.2	0.0
	3	0.7*	0.5	0.4	0.3	0.1	0.1
Uterus	1	0.3	0.4	0.3	0.4	0.3	0.1
	2	1.1*	1.3	1.0	1.0	0.7	0.4
	3	0.9*	2.2	1.8	1.3	0.8	0.4

Table 3: Estimated average life years gained per unit of healthcare resource for cancer surgery for 13 cancer types, by tumour stage and age of diagnosis comparing current surgery to surgery after six months delay based on 5-year net survival.

* indicates strata estimates of lower confidence whereby crude rather than net survival estimates were applied. Values for LYG per HCRU above the median are represented in blue, at the median in white and below the median in red.

CANCER SURGERY					
Reference time period (months)		12		24	
Per patient delay (months)		3	6	3	6
Per day rate of nosocomial infection (current)		5%			
STANDARD CONDITIONS	Major resections for cancer-	94,912		189,823	
	HCRUs-total	764,765		1,529,529	
	LY gained-total	1,717,051		3,434,102	
	Lives saved-total	80,406		160,812	
	LY gained from cancer	18.1			
	LY gained from cancer	2.2			
IMPACT of DELAY	Deaths attributable to delay-total	4,755	10,760	9,511	21,521
	LY lost attributable to delay-total	92,214	208,275	184,428	416,549
	LY gained from cancer treatment post-delay- average per patient	17.1	15.9	17.1	15.9
	LY lost attributable to delay-average per patient	0.97	2.19	0.97	2.19
	LY gained per HCRU from cancer treatment post-delay-average per patient	2.12	1.97	2.12	1.97
	LY lost per HCRU attributable to delay-average per patient	0.12	0.27	0.12	0.27
HOSPITALISATION OF COMMUNITY-ACQUIRED COVID INFECTION					
Reference time period (months)		12		24	
Community infections		683,083		1,366,167	
Hospital Admissions	Total admissions	94,912		189,823	
	ICU admissions	16,135		32,270	
	non-ICU admissions	78,777		157,553	
Health care resource units (HCRUs)	Total	1,052,949		2,105,899	
	ICU	556,657		1,113,313	
	non-ICU	496,293		992,586	
Deaths	Total	15,587		31,173	
	ICU	8,241		16,481	
	non-ICU	7,346		14,692	
Total lives saved -attributable to hospital admission	All	25,752		51,504	
	ICU	7,894		15,789	
	non-ICU	17,858		35,715	
Total LY gained -attributable to hospital admission	All	482,022		964,044	
	ICU	223,227		446,454	
	non-ICU	258,795		517,591	
LY gained -average per patient	All	5.08			
	ICU	13.83			
	non-ICU	3.29			
LY gained per HCRU -average per patient	All	0.46			
	ICU	0.40			
	non-ICU	0.52			
Comparison	LY lost through <u>delay</u> in cancer treatment as a proportion of LY gaineds from hospitalisation from COVID-19	19%	43%	19%	43%
	RALY lost through <u>delay</u> in cancer treatment as a proportion of RALY gaineds from hospitalisation from COVID-19	26%	59%	26%	59%

Table 4: Summary outcomes from delays in cancer surgery, with comparison to an equivalent number of admissions for community-acquired COVID-19 infection. Only major resections for common adult cancers included. Reference population: England. LY: life years. RALY: resource adjusted life years. HCRU: healthcare resource units

