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# Criteria for preclinical models of cholangiocarcinoma: scientific and medical relevance

Diego F Calvisi,<sup>1</sup> Luke Boulter,<sup>2</sup> Javier Vaquero,<sup>3,4</sup> Anna Saborowski,<sup>5</sup> Luca Fabris,<sup>6,7</sup> Pedro M Rodrigues,<sup>4,8,9</sup> Cédric Coulouarn,<sup>10</sup> Rui E Castro,<sup>11</sup> Oreste Segatto,<sup>12</sup> Chiara Raggi,<sup>13</sup> Luc JW van der Laan,<sup>14</sup> Guido Carpino,<sup>15</sup> Benjamin Goeppert,<sup>16</sup> Stephanie Roessler,<sup>17</sup> Timothy Kendall,<sup>18</sup> Matthias Evert,<sup>1</sup> Ester Gonzalez-Sanchez,<sup>3,4,19</sup> Juan W Valle,<sup>20,21</sup> Arndt Vogel,<sup>5</sup> John Bridgewater,<sup>22</sup> Mitesh J Borad,<sup>23</sup> Gregory J Gores,<sup>24</sup> Lewis R Roberts,<sup>24</sup> Jose J.G. Marin,<sup>4,25</sup> Jesper B Andersen,<sup>26</sup> Domenico Alvaro,<sup>27</sup> Alejandro Forner,<sup>4,28</sup> Jesus M Banales,<sup>4,8,9,29</sup> Vincenzo Cardinale,<sup>30</sup> Rocio IR Macias,<sup>4,25</sup> Silve Vicent,<sup>31,32,33</sup> Xin Chen,<sup>34</sup> Chiara Braconi,<sup>35</sup> Monique MA Verstegen,<sup>14</sup> Laura Fouassier<sup>36</sup>; CCA model consortium

<sup>1</sup> Institute of Pathology, University of Regensburg, Regensburg, Germany;

<sup>2</sup> MRC-Human Genetics Unit, Institute of Genetics and Molecular Medicine, University of Edinburgh, Edinburgh, UK;

<sup>3</sup> TGF- $\beta$  and Cancer Group, Oncobell Program, Bellvitge Biomedical Research Institute (IDIBELL), Barcelona, Spain;

<sup>4</sup> National Biomedical Research Institute on Liver and Gastrointestinal Diseases (CIBEREHD), Instituto de Salud Carlos III, Madrid, Spain;

<sup>5</sup> Department of Gastroenterology, Hepatology and Endocrinology, Hannover Medical School, Hannover, Germany;

<sup>6</sup> Department of Molecular Medicine, University of Padua School of Medicine, Padua, Italy;

<sup>7</sup> Digestive Disease Section, Yale University School of Medicine, New Haven, CT, USA;

<sup>8</sup> Department of Liver and Gastrointestinal Diseases, Biodonostia Health Research Institute - Donostia University Hospital, University of the Basque Country (UPV/EHU), San Sebastian, Spain;

<sup>9</sup> Ikerbasque, Basque Foundation for Science, Bilbao, Spain;

<sup>10</sup> Inserm, Univ Rennes 1, OSS (Oncogenesis Stress Signaling), UMR\_S 1242, Centre de Lutte contre le Cancer Eugène Marquis, F-35042, Rennes, France;

<sup>11</sup> Research Institute for Medicines (iMed.U LISBOA), Faculty of Pharmacy, Universidade de Lisboa, Lisbon, Portugal;

<sup>12</sup> Unit of Oncogenomics and Epigenetics, IRCCS Regina Elena National Cancer Institute, Rome, Italy;

<sup>13</sup> Department of Experimental and Clinical Medicine, University of Florence, Florence, Italy;

<sup>14</sup> Department of Surgery, Erasmus MC Transplantation Institute, University Medical Center Rotterdam, The Netherlands;

<sup>15</sup> Department of Movement, Human and Health Sciences, Division of Health Sciences, University of Rome "Foro Italico", Rome, Italy;

<sup>16</sup> Institute of Pathology and Neuropathology, Ludwigsburg, Germany;

<sup>17</sup> Institute of Pathology, Heidelberg, Germany;

<sup>18</sup> Centre for Inflammation Research, University of Edinburgh, Edinburgh, UK;

<sup>19</sup> Department of Physiological Sciences, Faculty of Medicine and Health Sciences, University of Barcelona, Spain

<sup>20</sup> Department of Medical Oncology, The Christie NHS Foundation Trust, Manchester, UK;

<sup>21</sup> Division of Cancer Sciences, University of Manchester, Manchester, UK;

<sup>22</sup> Department of Medical Oncology, UCL Cancer Institute, London, UK;

<sup>23</sup> Mayo Clinic Cancer Center, Mayo Clinic, Phoenix, AZ, USA;

<sup>24</sup> Division of Gastroenterology and Hepatology, Mayo Clinic College of Medicine and Science, Rochester, MN, USA;

48 <sup>25</sup> Experimental Hepatology and Drug Targeting (HEVEPHARM), IBSAL, University of Salamanca,  
49 Salamanca, Spain;  
50 <sup>26</sup> Biotech Research and Innovation Centre (BRIC), Department of Health and Medical Sciences,  
51 University of Copenhagen, Copenhagen, Denmark;  
52 <sup>27</sup> Department of Precision and Translational Medicine, Sapienza University of Rome, Rome, Italy;  
53 <sup>28</sup> Liver Unit, Barcelona Clinic Liver Cancer (BCLC) Group, Hospital Clinic Barcelona, IDIBAPS,  
54 University of Barcelona, Barcelona, Spain;  
55 <sup>29</sup> Department of Biochemistry and Genetics, School of Sciences, University of Navarra, Pamplona.  
56 <sup>30</sup> Department of Medico-Surgical Sciences and Biotechnologies, Sapienza University of Rome, Rome,  
57 Italy;  
58 <sup>31</sup> University of Navarra, Centre for Applied Medical Research, Program in Solid Tumours, Pamplona,  
59 Spain;  
60 <sup>32</sup> IdiSNA, Navarra Institute for Health Research, Pamplona, Spain;  
61 <sup>33</sup> Centro de Investigación Biomédica en Red de Cáncer (CIBERONC, Instituto de Salud Carlos III),  
62 Madrid, Spain;  
63 <sup>34</sup> Department of Bioengineering and Therapeutic Sciences and Liver Center, University of California,  
64 San Francisco, USA;  
65 <sup>35</sup> Institute of Cancer Sciences, University of Glasgow, Glasgow, UK;  
66 <sup>36</sup> Sorbonne Université, Inserm, Centre de Recherche Saint-Antoine (CRSA), Paris, France  
67

68 **Corresponding author**

69 Laura Fouassier, Ph.D.

70 Sorbonne Université, INSERM Centre de Recherche Saint-Antoine

71 27 rue Chaligny

72 75571 Paris cedex 12

73 France

74 E-mail: [mailto: laura.fouassier@inserm.fr](mailto:laura.fouassier@inserm.fr)

75 Phone: +33-698774001

76

77

78 **Abstract**

79 Cholangiocarcinoma (CCA) is a rare malignancy developing at any point along the biliary tree. CCA has  
80 a poor prognosis, its clinical management remains challenging, and effective treatments are lacking.  
81 Preclinical research, therefore, is of pivotal importance and necessary to acquire a deeper  
82 understanding of CCA and improve therapeutic outcomes. Preclinical research involves developing and  
83 managing complementary experimental models from *in vitro* assays using primary cells or cell lines  
84 cultured in 2D or 3D to *in vivo* models with engrafted material, chemically-induced CCA, or genetically-  
85 engineered models. All are valuable tools with well-defined advantages and limitations. The choice of  
86 preclinical model is guided by the question(s) to be addressed, and ideally, results should be  
87 recapitulated in independent approaches. Here, a task force of 45 experts in CCA molecular and cellular  
88 biology, clinicians, including pathologists, from 10 countries, provides recommendations on the minimal  
89 criteria for preclinical models to provide a uniform approach. These recommendations are based on two  
90 rounds of questionnaires completed by 37 (first round) and 45 (second round) experts to reach a  
91 consensus with 13 statements. An agreement was defined when at least 90% of the participants voting  
92 anonymously agreed with a statement. The ultimate goal is to transfer (basic) laboratory research to the  
93 clinics through increased disease understanding and develop clinical biomarkers and innovative  
94 therapies for patients with CCA.

95

96

97 During the last decade, we witnessed considerable advances in understanding the molecular  
98 pathogenesis of cholangiocarcinoma (CCA). However, early diagnosis and effective treatments for this  
99 aggressive cancer lag behind other fields. To accelerate the development of novel clinical strategies,  
100 preclinical models of CCA are essential <sup>1</sup>. Critical points to consider when using or developing these  
101 tools are the tumour anatomical origin (i.e., intrahepatic, perihilar, or distal CCA), the cell(s) of origin  
102 (e.g., preneoplastic lesions), and the histomorphological tumour features (e.g., large vs. small bile duct  
103 type) <sup>2</sup>.

104 Historically, 2D cell cultures have been widely used as *in vitro* model of CCA. In addition to  
105 experimentally-immortalized or primary cultures of normal cholangiocytes derived from normal bile  
106 ducts, over 50 CCA-derived cell lines have been established <sup>3</sup>. A limitation of these models is the lack  
107 of resemblance to the original tumours upon the continuous culturing, making it difficult to infer which  
108 therapeutics would have been efficient to treat the original neoplasm <sup>4</sup>. Moreover, 2D mono-cultures do  
109 not accurately mimic the characteristic features of biliary tumours, namely the three-dimensional  
110 architecture, cell-to-cell, and cell-to-matrix interactions, cellular heterogeneity, and the effect of the  
111 tumour microenvironment in cancer progression. To overcome these limitations, multicellular 3D  
112 models, such as spheroids and organoids, have been developed. Although they constitute valuable  
113 models to study CCA <sup>5</sup>, spheroids usually do not precisely recapitulate the native tissue architecture and  
114 function of the tissue of origin <sup>6</sup>. In contrast, organoids maintain a higher and more predictable physical  
115 order in the cellular self-assembly and display a marked interaction with the extracellular matrix, thereby  
116 retaining most of the histological and malignant characteristics of the original neoplasm <sup>6-9</sup>. In addition  
117 to cell culture-based models, different *in vivo* CCA models have been developed. CCA induction through  
118 administering hepatocarcinogens or liver fluke infestation has the advantage of mimicking cancer  
119 pathogenesis. However, animal studies are time-consuming, expensive, ethically challenging, and  
120 sometimes, hepatocellular carcinoma (HCC) rather than CCA preferentially develops. To give *in vivo*  
121 context to 2D cell lines, CCA cells have been used to generate subcutaneous or orthotopic xenografts  
122 in mice. However, these approaches remain limited by poor rates of tumor engraftment. Technological  
123 advancements have made it possible to grow liver organoids, i.e., 3D cultures of bipotent liver  
124 precursors, and therefore develop mouse models based on transplantation of genetically modified liver  
125 organoids that undergo *in vivo* oncogenic transformation along the cholangiocellular lineage <sup>10</sup>.

126 Alternatively, genetically-engineered mouse models (GEMMs) recapitulating the most frequent genetic  
127 alterations detected in CCA have been generated <sup>11</sup>.

128 International collaborations to study CCA, spearheaded by the European Network for the Study of  
129 Cholangiocarcinoma (ENS-CCA) and the European H2020 COST Action CA18122, have been crucial  
130 to fostering recent advances in this field. To improve the accuracy in obtaining and exchanging  
131 information among groups, it is now essential to establish consensus criteria regarding the minimal  
132 standardized characteristics required from preclinical CCA models or describing a new model. Here, we  
133 detail these criteria for the available and forthcoming *in vitro* and *in vivo* models and document the  
134 international, inter-disciplinary process used for their development.

135

## 136 **Methods**

### 137 ***Panel of experts***

138 A core group of 8 core group members, all active researchers with significant contributions to the CCA  
139 field, initiated and led a Delphi study to define recommendations on the minimal criteria for experimental  
140 CCA models to provide a uniform approach for future studies. Furthermore, core group members  
141 identified 27 additional experts to be invited to join the steering committee and to be actively involved in  
142 implementing the Delphi process. These core and steering team members filled the initial Delphi  
143 questionnaire and are listed authors, and they proposed 10 additional experts to fill the second and final  
144 questionnaire. These 10 experts, not actively involved in writing the recommendations but providing  
145 their precious input by filling the second questionnaire, are listed as one collaborative author; CCA Model  
146 consortium. Thus, the final panel consisted of 45 individual experts from 10 countries located in Europe,  
147 Asia, and USA. **Supplementary Table S1** summarizes the expert panel's names, institutes, and  
148 demographics.

### 149 ***Building consensus***

150 We used a modified Delphi method for two rounds of questionnaires. A statement consensus was  
151 reached when  $\geq 90\%$  agreement. Statements or questions that were agreed upon using this criterion in  
152 the first round were omitted in the second round.

### 153 ***Questionnaires***

154 The core team generated the questionnaires using an online Google Form (Alphabet Inc., CA) before  
155 sending them out to the experts. The first questionnaire consisted of 47 questions, divided over 4 parts:

156 Part 1. Defining minimal and advanced criteria for experimental models, Part 2. *In vivo* model for CCA,  
157 Part 3. *In vitro* models for CCA, and Part 4. Preclinical models for CCA. Based on questionnaire 1  
158 (Supplemental data 1), a second questionnaire was designed, including 13 statements, of which 12  
159 could be solely answered with 'yes' or 'no' (Table 1). All experts could comment on every question. Both  
160 questionnaires and summaries of the outcome are shared in Supplementary Data 1. Through the  
161 consensus of experts in the field, we propose overarching criteria to be used when establishing or using  
162 preclinical models of CCA and linking this to the clinic (Figure 1). From the second questionnaire, core  
163 recommendations were edited (new Box 1).

#### 164 **Clinical features to consider when using experimental models**

##### 165 ***Clinics***

166 Experimental models of CCA must reflect the natural history of the known subtypes of CCA, their  
167 molecular heterogeneity, and the impact of clinical or therapeutic interventions. In ICD11, published in  
168 2022, CCA is classified according to its origin as intrahepatic (iCCA) and extrahepatic (eCCA)  
169 (<https://icd.who.int>). iCCA arises from intrahepatic bile ducts, i.e., it grows in the liver. Consequently, it  
170 is more often surgically resectable than perihilar CCA (pCCA), the latter arising at the liver hilum where  
171 the likelihood of local vascular invasion is greater<sup>12</sup>. The impact of tumour biology on local invasion is  
172 poorly understood and requires further examination.

173 The biology of CCA subtypes also differs significantly. Approximately 50% of iCCAs have actionable  
174 molecular alterations, and targeted therapies against *FGFR2* fusions and *IDH1* mutation-driven cancers  
175 are already approved<sup>13-16</sup>. The reason why iCCAs are more molecularly heterogeneous than p/dCCAs  
176 is not fully understood and requires detailed examination. In addition, the influence of biology on the  
177 natural history of iCCA and its impact on surgical, local, and systemic treatment options necessitate  
178 further studies<sup>17</sup>. dCCA more closely resembles pCCA, but, again, the effect of both anatomy and  
179 biology on outcome has not been fully elucidated. However, many tools only seek to mimic iCCA, and  
180 there is a critical absence of pCCA and dCCA models.

181 A second essential requirement of an experimental model is to reflect the interventional outcome.  
182 Although chemotherapy remains the standard of care, the increasing use of targeted therapies requires  
183 a deeper examination of molecular mechanisms and critical mechanisms of resistance<sup>18-21</sup>. As such,  
184 any model must reflect molecular changes in the patient that can be measured to provide hypotheses

185 to overcome this commonly occurring resistance. Furthermore, such resistance mechanisms should be  
186 unraveled to develop and assess novel interventions to overcome resistance before clinical testing.

### 187 **Pathology**

188 Separate classifications (UICC, AJCC, WHO) exist for iCCA, pCCA, and dCCA. Macroscopic features  
189 divide iCCA into two subtypes: large duct and small duct<sup>22</sup>. Large duct iCCAs typically arise near large  
190 central ducts and grow along the ductal wall. Small duct iCCAs are usually peripheral mass-forming  
191 tumours in the hepatic parenchyma. Four patterns of growth are described for CCA: mass-forming,  
192 periductal infiltrating, intraductal, and mixed types<sup>23</sup>.

193 **Histopathology.** Small duct iCCAs are typically non-mucin-secreting adenocarcinomas with a ductular  
194 or tubular pattern. Large duct iCCAs are generally mucin-secreting tubular adenocarcinomas resembling  
195 perihilar and distal CCAs<sup>24</sup>. Most p/dCCAs are adenocarcinomas with pancreaticobiliary morphology,  
196 comprising glandular structures and/or small groups of cells within the desmoplastic stroma<sup>24</sup>.

197 **Immunohistochemistry.** No specific immunohistochemical pattern for CCA lesions exists. However,  
198 they typically show an upper gastrointestinal/pancreaticobiliary pattern of cytokeratin (CK) expression  
199 (CK7+, CK19+, CK20-negative) when they still exhibit some degree of differentiation. In addition, large  
200 duct iCCAs sometimes express intestinal markers (e.g., CK20 and CDX2)<sup>25</sup>. CCA is usually  
201 immunonegative for HepPar-1, arginase-1, and glypican-3, distinguishing it from HCC and combined  
202 HCC/CCA. Transcription factors marking cell-specific lineages such as TTF-1 (lung and thyroid  
203 cancers), PAX8 (renal, thyroid, ovarian, and endometrial cancers), and GATA-3 (breast and urothelial  
204 cancers) are not usually expressed in CCA.

205 **Biliary precursor lesions.** CCA could develop from precursor lesions. Most cases of large duct iCCA  
206 and p/dCCA presumably originate from biliary intraepithelial neoplasia<sup>26</sup>. Intraductal papillary neoplasm  
207 of the bile duct (IPNB) is an intraductal papillary proliferation that develops in intrahepatic (70%) or  
208 perihilar ducts (30%)<sup>27,28</sup>. Invasive malignancy is evident in > 50% of IPNBs at presentation.  
209 Furthermore, the mucinous cystic neoplasm is a cystic epithelial tumour occurring almost exclusively in  
210 females, associated with CCA in 5% of cases<sup>29,30</sup>.

### 211 **Molecular profiling**

212 Efforts to understand the heterogeneity of CCA have provided insights into the molecular pathogenesis  
213 and anatomical complexity of this disease<sup>13,31-38</sup>. The genetic landscapes fall midway in the mutational  
214 spectrum of cancers<sup>39</sup>, with shared genetic alterations between iCCA, pCCA, and dCCA<sup>36</sup>. Although



215 the gained comprehensive insight into the underlying pathobiological processes of resectable invasive  
216 tumours, the precise involvement of genetic and epigenetic mechanisms in the onset of CCA is still  
217 insufficient.

218 Integrated genomics approaches have been used to classify CCA patients based on prognosis <sup>40-43</sup>,  
219 emphasizing dysregulated oncogenic signalling pathways, including WNT-CTNNB1, MYC, PI3K-AKT-  
220 mTOR, ERBB, RAS-RAF-ERK, TNF, PLK1, TGF $\beta$ , NOTCH, IGFR1, VEGF, and the Hippo cascade.

221 This predominant molecular classification highlights distinct tumour phenotypes of either inflammatory  
222 or proliferative in nature <sup>41</sup>. Moreover, iCCA can be classified based on driver-gene mutations elucidating  
223 unique mutational signatures, structural variants, and epigenomic alterations <sup>35</sup>. Of note, specific  
224 oncogenic mechanisms in distinct patient subsets with potential unique drug responses like RNA  
225 synthesis inhibition in *IDH*-mutant, microtubule modulator in *KRAS*-mutant, topoisomerase inhibition in  
226 *TP53*-mutant, and mTOR inhibitors in wild-type tumours enriched in FGFR2 fusions <sup>13</sup>.

227 As the three anatomical CCA subtypes differ in their molecular alterations <sup>36</sup> and potentially in the cell-  
228 of-origin <sup>44-47</sup>, the CCA subtypes should be studied in separate experimental models <sup>2</sup>. However, the  
229 step-wise progression of human CCA and thus the accumulation of a wide variety of molecular  
230 alterations may not be reflected in the most rapid mouse models. Furthermore, the available  
231 experimental models represent specific subsets of patients with CCA, and it is essential to consider the  
232 molecular heterogeneity of patients with CCA when using these models. With this in mind, integrative  
233 transcriptomics may represent a relevant strategy to define the best-fit models as previously  
234 demonstrated for HCC <sup>48,49</sup>.

### 235 ***In vivo* CCA models**

#### 236 ***Engrafted models***

237 ***Xenograft.*** Xenografts consist of transplanting tissues or cells from a different species into an  
238 immunodeficient host <sup>50</sup>. Xenograft CCA models are generated by either implanting human neoplastic  
239 CCA cells subcutaneously into the flanks of immunodeficient or athymic mice (ectopic grafts) or directly  
240 in the liver (orthotopic grafts). These experimental animal models help evaluate the therapeutic efficacy  
241 and safety of novel candidate drugs or physical-based therapies for treating CCA *in vivo*. They are highly  
242 reproducible, cost-efficient, technically easy and feasible, with limited adverse effects related to the  
243 procedure, and they only require short periods for evaluation <sup>50-53</sup>. Furthermore, when engrafted  
244 subcutaneously, the generated tumours are easily accessible throughout the duration of the *in vivo*

245 model, which enables the real-time measurement of tumour volume growth with a caliper. Several  
246 studies have investigated the therapeutic efficacy and safety of different compounds <sup>54 55-58</sup>. Additionally,  
247 the role of various proteins <sup>59-64</sup> and miRNAs <sup>65-69</sup> were evaluated in ectopic xenograft models by  
248 implanting genetically-manipulated CCA cells. Nevertheless, ectopic xenografts also have intrinsic  
249 limitations. Xenografts usually reflect advanced tumour stages, growing rapidly, and making the study  
250 of early CCA challenging. At the same time, distinct CCA cell lines display different implantation rates,  
251 with some not generating tumours after injection. Furthermore, these tumours are implanted in a non-  
252 physiological site, seldom metastasize, and may lose the molecular heterogeneity characteristic of  
253 human CCA. Most importantly, they do not allow the study of the crosstalk between tumour cells, the  
254 multicellular microenvironment milieu, and the immune system <sup>50-53</sup>.

255 Using orthotopic xenograft models may overcome some of these limitations by developing tumours  
256 directly in the organs of origin. Orthotopic grafts are more likely to trigger tumour dissemination, with the  
257 development of distant metastases. Intrahepatic implantation of CCA cells can be achieved either by  
258 injecting cells directly into the liver parenchyma using ultrasound-guided injection <sup>70</sup> or through the portal  
259 or splenic vein <sup>50</sup>. Small fragments of CCA tumours previously generated in subcutaneous xenografts  
260 or cancer stem cell-derived spheroids can also be orthotopically implanted <sup>71,72</sup>. Although intrasplenic  
261 injection is technically easier than intraportal administration and carries fewer post-operative  
262 complications, the implantation of CCA cells by intrasplenic injection resulted in successful engraftment  
263 not only in the liver, but also in the spleen <sup>73</sup>. Of note, intrasplenic injection of EGI-1 CCA cells also  
264 induced the development of lung metastases <sup>74</sup>. Still, generating orthotopic models is more time-  
265 consuming, and some post-operative complications may arise. Furthermore, the tumour development,  
266 growth, and metastases assessment requires imaging techniques or is only determined at sacrifice <sup>50,53</sup>.  
267 In this sense, using luciferase-expressing CCA cells is an excellent choice to monitor tumour growth  
268 over time <sup>73</sup>. However, this tool might not be accessible to all.

269 Engrafting cells or tissues directly obtained from patients may result in the development of patient-  
270 derived xenografts (PDXs). Subcutaneous or orthotopic tumours usually maintain the original genetic  
271 and epigenetic features and surrounding stroma observed in the initial mass, thus constituting the ideal  
272 model to predict therapeutic responses and being excellent tools in personalized medicine. Indeed,  
273 several studies have already used PDXs to examine tumours harbouring specific mutational patterns  
274 and test the use of specific targeted therapies <sup>75-79</sup>. Nevertheless, the success of PDX engraftment is

275 relatively low, depending on the primary tumour itself and the experimental design for tumor engraftment.  
276 Thus, they constitute a time and resource-intensive model and may require several months for successful  
277 implantation <sup>50</sup>. Based on the available data and unanimous agreement, the expert panel strongly  
278 suggests that the type of CCA should be defined by a pathologist for PDX models, with the histology of  
279 the tumor shown in the publication (Box1).

280 ***Allograft (syngeneic)***. Syngeneic models have the advantage of implanting murine CCA cells into an  
281 immunocompetent host, displaying a fully-functional immune system. The first syngeneic model was  
282 developed when 2 rat CCA cell lines (BDEneu and BDEsp) were directly implanted in the biliary tract of  
283 Fisher 344 rats. While BDEsp engraftment induces the development of non-metastatic iCCA, BDEneu-  
284 derived tumours were more aggressive, with the rapid and consistent formation of CCA lesions and  
285 metastases <sup>80,81</sup>. This model was used to elucidate the mechanisms underlying tumour progression and  
286 evaluate the efficacy of novel drug candidates <sup>81-85</sup>. More recently, a novel syngeneic murine model was  
287 reported by engrafting the malignant mouse cell lines SB1-7, obtained from a bile-duct ligation and  
288 transposon-based CCA model into mice <sup>86,87</sup>. The obtained cell lines were successfully implanted,  
289 leading to CCA lesions resembling human CCAs <sup>87</sup>. In addition, foetal liver cells obtained from  
290 genetically-modified mouse embryos may also be implanted in the mouse liver, inducing CCA formation  
291 <sup>88</sup>. Furthermore, the cells mentioned above can be genetically manipulated before engraftment,  
292 revealing insights into the mechanisms governing cholangiocarcinogenesis and allowing the  
293 implantation of the cells in already established knockout mice strains, thus permitting the study of  
294 alterations in specific genes in the tumour stroma <sup>89</sup>. In this line, unpublished observations from the SB1  
295 orthotopic model indicate that extending 2 weeks the frequently used endpoint (4 weeks) allows the  
296 formation of extrahepatic metastases in the lung. Therefore, further characterization of this timeline in a  
297 genetically malleable immunocompetent host, coupled with the isolation of tumor cells from the original  
298 site of injection and the metastatic sites, could provide an excellent model to understand, and perhaps  
299 even prevent, a rather understudied process such as CCA metastatic spreading. Overall, these models  
300 may overcome xenograft limitations, such as the absence of the immune system, are ideal for studying  
301 tumour-stroma interactions, and are an excellent alternative to test immunotherapy-based strategies.  
302 Still, they require microsurgical procedures, increasing the probability of procedure-related  
303 complications.

304 **Chemically-induced models**

305 High levels of inflammation, fibroblast activation, and rich extracellular matrix deposition in the tumour  
306 typify CCA in patients <sup>90</sup>. In some cases, these tumours develop in the context of chronic diseases, and  
307 the cells associated with these pre-cancerous conditions contribute to cancer formation. Several  
308 chemical models that generate chronic and iterative injury, leading to tumour formation, have been  
309 developed to recapitulate this complex microenvironment in CCA.

310 Early work demonstrated that administering thiourea or thioacetamide (TAA) to rats triggers liver cancer  
311 formation over two years <sup>91</sup>. TAA is a potent hepatotoxin that induces hepatic fibrosis and cirrhosis in  
312 rodents owing to progressive damage of hepatocytes and biliary epithelium. TAA-induced biliary  
313 damage reproduces the typical dysplasia-carcinoma sequence, ultimately evolving to invasive iCCA <sup>92</sup>.  
314 Consequently, the use of TAA to induce tumour-initiating injury in rodents has become a cornerstone of  
315 CCA research. However, as detailed in this early work, CCA formation in TAA-treated rats is very  
316 variable, with only ~50% of animals developing frank carcinomas. Results are even more variable in  
317 wild-type mice. TAA is not mutagenic *per se*; instead, the initiation of chronic sclerosing inflammation  
318 and continuous regeneration drives the spontaneous accumulation of mutations in biliary cells, which  
319 then become cancerous, akin to what is observed in patients with chronic cholangiopathies. Therefore,  
320 combined with bile duct ligation (BDL), a classical model of obstructive cholestasis and subsequent bile  
321 duct proliferation, TAA accelerates the formation of biliary tumours <sup>93</sup>. Different from TAA, several  
322 mutagenic models have also been developed to induce CCA in rodents. For instance, diethylnitrosamine  
323 (DEN) and dimethylnitrosamine (DMN) generate DNA adducts in the liver and suffice for liver  
324 carcinogenesis <sup>94</sup>, and in combination with inflammatory injury (BDL or *O. viverrini* infection), drive CCA  
325 development in mice and hamsters <sup>95-97</sup>. Furan is a potent mutagen capable of initiating CCA in rats <sup>98</sup>.  
326 Long-term furan treatment is currently the only chemically-induced model of CCA with nearly 100% of  
327 tumour incidence, which results in multi-organ metastases and closely recapitulates the primary and  
328 secondary pathologies of human CCA. Available models are summarised in **Table 2** and **Figure 2**.

329 Although many rat and mouse models driven by chemical insults reflect both the pre-cancerous disease  
330 history and molecular and histopathological features of human CCA, their use is becoming less popular,  
331 primarily due to their long latency, cost, and variability (both in terms of tumour penetrance and high  
332 molecular heterogeneity). Recent work has focused on combining the disease-inducing aspects of these  
333 models, such as inflammation and fibrosis, with GEMMs, discussed in more detail in the following  
334 section. A critical point to consider is the control tissue that should be compared with malignant biliary

335 cells. Indeed, as the whole liver is inappropriate since hepatocytes are the prevalent cell population,  
336 isolated bile ducts should be considered the best control.

### 337 **Genetically Engineered Mouse Models (GEMMs)**

338 GEMMs are advanced animal models of human cancer (Table 3). They are rationally designed to mimic  
339 human CCA's genetic and epigenetic alterations, aberrant activation of signalling pathways, and the  
340 sequence of preneoplastic and early and late tumour stages, including metastasis. In addition, GEMMs  
341 can be coupled to *in vivo* transfection (HTVI and/or electroporation) or injection (adeno-associated-  
342 viruses, AAV) approaches to activate/express transgenes in adult hepatocytes to further expand the  
343 mouse model toolbox<sup>99</sup>.

344 General concerns precluding the use of GEMMs are their high cost, tumour latency, and embryonic Cre  
345 expression in non-inducible models that may compromise translation to human disease. However,  
346 adopting CRISPR/Cas9 strategies to generate new GEMM strains and the development of tamoxifen-  
347 inducible, organ-specific Cre-recombinase strains circumvented some of these limitations. A summary  
348 of selected GEMMs is provided herein.

349 Most CCA GEMMs incorporate common oncogenic alterations found in humans, including inactivation  
350 of tumour suppressor genes (*PTEN*, *SMAD4*, *P53*) or induction of oncogenes (*KRAS*, *IDH1/2*, *AKT1*,  
351 *NOTCH1*) to investigate the consequences of cell-autonomous effects on cholangiocarcinogenesis. In  
352 the first reported CCA GEMM, ablation of *Pten* and *Smad4* in fetal bipotential hepatic progenitors (liver  
353 progenitor cells, LPCs) was achieved during embryogenesis using an Albumin Cre (*Alb-Cre*) strain<sup>100</sup>.  
354 *Alb-Cre*; *Smad4*<sup>flox/flox</sup>; *Pten*<sup>flox/flox</sup> mice displayed the histopathological stages detected in human  
355 disease, from bile duct hyperplasia and dysplasia to carcinoma *in situ* and invasive CCA.

356 Another model closely recapitulating human cholangiocarcinogenesis consists of the concomitant *Trp53*  
357 abrogation and *KrasG12D* expression in the Alb-Cre mouse background<sup>101</sup>. This model features  
358 premalignant biliary lesions (intraductal papillary neoplasms and Von Meyenburg complexes), leading  
359 to invasive carcinoma and distal metastases. To directly probe the cell of origin in this model, *Kras*<sup>LSL-</sup>  
360 *G12D/+*; *Trp53*<sup>flox/flox</sup> mice were bred to the tamoxifen-inducible *Sox9-Cre*<sup>ERT2+</sup> strain (targeting  
361 cholangiocytes) or intravenously administered the AAV8 vector expressing Cre under the thyroxine-  
362 binding protein (targeting adult hepatocytes)<sup>102</sup>. *KrasG12D* activation and *Trp53* loss in adult  
363 hepatocytes required co-administration of DDC-diet to form tumours (iCCA and HCC with a similar  
364 incidence, in addition to combined HCC/CCA), highlighting the role of inflammation on liver cancer

365 formation. By contrast, activation of the transgenes in the adult ductal compartment in the *Sox9-Cre*<sup>ERT2+</sup>  
366 accelerated the development of hepatic tumours, mainly iCCA, from preneoplastic lesions (not found in  
367 AAV8-injected mice) without the need for inflammatory cues.

368 Targeting *Kras*<sup>G12D</sup> activation and *Pten* deletion triggered the fastest GEMM in Alb-Cre mice <sup>103</sup>. In  
369 *Kras*<sup>LSL-G12D/+</sup>; *Pten*<sup>flor/flor</sup>; Alb-Cre mice, early hyperplastic biliary foci were detected by 4 weeks of age,  
370 and mice died by 7 weeks. Tumours were multifocal, stroma-rich localized iCCA. Interestingly, mice with  
371 heterozygous *Pten* deletion and *Kras*<sup>G12D</sup> activation developed tumours after longer latency, showing  
372 hepatocyte and cholangiocyte differentiation features. By using Alb-Cre<sup>ERT2+</sup> or K19Cre<sup>ERT/+</sup> mouse  
373 strains to activate the oncogenic alterations in adult hepatocytes or cholangiocytes, respectively, the  
374 authors reported the development of HCC and HCC-precursor lesions, but not iCCA, in 8-week old Alb-  
375 Cre<sup>ERT2+</sup>; *Kras*<sup>LSL-G12D</sup>; *Pten*<sup>flor/flor</sup> mice, while tamoxifen injection on day 10 elicited iCCA. The formation  
376 of iCCA in Alb-Cre<sup>ERT2+</sup>; *Kras*<sup>LSL-G12D</sup>; *Pten*<sup>flor/flor</sup> mice might be because Alb-Cre is still active in biliary  
377 cells at 10 days of age and indicates that cholangiocytes are the cell of origin of CCA in these models,  
378 which was later independently confirmed using similar approaches <sup>104</sup>.

379 IDH1/2 oncogene modelling in mice was employed <sup>105,106</sup>. Breeding of *Idh2*<sup>LSL-R172K</sup> and *Kras*<sup>LSL-G12D</sup> mice  
380 in the *Alb-Cre* background yielded multifocal iCCA-like liver masses with invasive growth and metastatic  
381 capacity. Furthermore, adjacent to the tumours, oval cell expansion and biliary intra-epithelial neoplasia-  
382 like lesions, suggestive of preneoplastic stages, occurred. In more recent work, the same group  
383 generated *Idh1*<sup>LSLR132C</sup> mice that developed iCCA upon crossing with *Kras*<sup>LSL-G12D</sup> mice in the *Alb-Cre*  
384 background <sup>107</sup>. Another oncogene investigated in *Alb-Cre* mice was *Notch1*, via a mouse strain  
385 expressing the Notch 1 intracellular domain (NICD) from the *Rosa26* locus <sup>108</sup>. By 8 months post-birth,  
386 malignant foci were detected, leading to CCA formation in transplanted immunodeficient mice.

387 Two GEMMs highlighted the importance of a pro-inflammatory environment in cholangiocarcinogenesis.  
388 In the first model, severe liver damage by inflammatory cues originating from mitochondrial dysfunction  
389 characterized *Hspd1*<sup>flor/flor</sup> mice bred to the *Alb-Cre* strain <sup>109</sup>. Mice developed hepatocyte and  
390 cholangiocyte regenerative foci, the latter resembling human biliary intra-epithelial neoplasia. The  
391 lesions arose in the context of an injured microenvironment and not through cell-autonomous  
392 mechanisms, as most regenerative liver foci exhibited Hspd1 expression. In the second model,  
393 *Kras*<sup>G12D</sup> expression and deletion of both *Tgfr2* and *Cdh1* (E-cadherin) were achieved in adult CK19+  
394 biliary cells, leading to early-onset metastatic tumours in the extrahepatic and hilar bile duct <sup>110</sup>. Dying

395 cholangiocytes in response to E-cadherin ablation released IL-33 to foster a proliferative phenotype in  
396 biliary epithelial cells that contributed to neoplastic transformation. However, after 4 weeks of tamoxifen  
397 administration, mice succumbed to liver and/or respiratory failure. In these models, transplantation of liver  
398 tissues in immunodeficient mice <sup>109</sup> or derivation of tumour organoids from mice <sup>110</sup> allowed follow-up  
399 experiments otherwise limited by the mice's short life span.

400 Additional carcinogen-exposed GEMMs modeling the consequences of an inflammatory environment,  
401 a frequent risk factor in human CCA, have also been reported. However, both the low penetrance and  
402 the high latency jeopardized their use <sup>111,112</sup>. Nonetheless, co-exposure with carcinogens might be a  
403 strategy in GEMMs to accelerate cholangiocarcinogenesis by providing a pro-inflammatory and pro-  
404 fibrogenic environment recapitulating the human context <sup>113</sup>.

405 Orthotopic or subcutaneous allografts models of premalignant liver cells (LPCs or adult liver organoids)  
406 or GEMM-derived CCA cell lines provide an alternative experimental strategy to time-consuming  
407 GEMMs <sup>10,64,88,107</sup>. These cellular models are amenable to gene editing, and their orthotopic  
408 transplantation in syngeneic mice enables tumour growth in an immune-competent microenvironment.  
409 Additionally, the plasticity of LPCs and liver organoids to originate CCA- or HCC-like tumours, depending  
410 on the genetic context, is preserved.

411 GEMMs showed that LPCs, cholangiocytes (intra- and extrahepatic), and mature hepatocytes can be  
412 the cell of origin of CCA in mice <sup>47,114</sup>. However, the relevance of these findings for human CCA remains  
413 under evaluation. Indeed, various elements, including the targeted cell population (differentiated vs.  
414 stem cells; additional cell types only present in humans), the tissue location (intra- vs. -extrahepatic),  
415 the increased complexity of oncogenic alterations, the type, degree, and duration of the pro-oncogenic  
416 and pro-inflammatory stimuli, the liver status, etc., might ultimately affect CCA development.

417

418 For all preclinical *in vivo* models, based on statements on histological assessment and a unanimous  
419 agreement (Table 1 & Box 1), the expert panel strongly suggests that :

- 420 - The invasion of the basement membrane and tumorigenic capacity of isolated cells engrafted  
421 subcutaneously in immune-deficient mice are the most critical malignant features of CCA.
- 422 - Morphological examination by H&E and immunohistochemistry should be conducted to  
423 characterize an early-stage tumour in the preclinical CCA model.

- 424 - Immunohistochemistry of at least one biliary cytokeratin (CK7 or CK19) should always be  
425 performed to characterize a lesion as CCA in the absence of hepatobiliary primary lesions in a  
426 preclinical model.
- 427 - Three histopathological features of human CCA must be assessed in a preclinical model: (a.)  
428 intra-tumoral heterogeneity (high stroma, inflammatory response, epithelial phenotype), (b)  
429 pattern of growth (mass-forming, periductal infiltration, intraductal growth), and (c)  
430 immunopositivity for CK7 or CK19.
- 431 - The expert panel recommends classifying preclinical CCA models as intrahepatic, perihilar, and  
432 distal CCA, and suggests that focal desmoplastic stroma is a morphological feature required to  
433 classify a lesion as CCA in a preclinical model.
- 434 - A drug should be tested in more than one model.

435

436 Lastly, to adopt a shared tool for defining the CCA experimental models homogeneously, an  
437 “experimental model sheet” was generated based on an initial expert discussion done in a physical  
438 ad hoc meeting (Malta meeting 20189; WG1 meeting) (**Table 4**) to provide complete information on  
439 animal experimentations to the scientific community through publications.

440

#### 441 ***In vitro* CCA models**

##### 442 ***2D-culture with cell lines or primary cells***

443 The urgent need to understand the biological processes of CCA progression and drug resistance has  
444 led to the widespread use of *in vitro* models represented by human and animal primary cultures and  
445 established cell lines. In 1985, the first CCA cell line - HChol-Y1 - was established from a patient with  
446 iCCA and characterized <sup>115</sup>. Later, an assortment of CCA cell lines of intrahepatic and extrahepatic origin  
447 was generated from primary tumours, ascites, metastases, and patient-derived xenografts  
448 (**Supplementary Table 2**). Besides human CCA cells, several lines derived from mouse, rat, and  
449 hamster models have been described (**Supplementary Table 2**). As proper control cells, primary  
450 cultures of normal cholangiocytes should be used.

451 Molecular studies performed in human CCA tissues have uncovered recurring genomic alterations in  
452 specific genes such as mutations in *TP53*, *IDH1*, *KRAS*, and *SMAD4* genes, *FGFR2* receptor fusions,  
453 or *ERBB* family gene amplifications <sup>116</sup>, which, in part, qualify as targets for molecular approaches.



454 Although most described CCA cell lines have been studied in terms of phenotypic and functional  
455 characterization of some parameters, only recently, with the development of high-throughput  
456 sequencing techniques, three studies have used exome sequencing or RNA-seq analyses to perform  
457 deep molecular phenotyping of some of the most widely used CCA cell lines (**Supplementary Table 2**)  
458 <sup>117-119</sup>. This has allowed the selection of cell lines with specific genetic alterations representing valuable  
459 drug screening tools, particularly for targeted therapy.

460 Most cell lines were established before the release of the latest WHO guidelines <sup>120</sup>, and potential  
461 misclassification of the origin of some cell lines may impact the clinical translation of some molecular  
462 and functional studies. For instance, Mz-ChA-1 cells have been traditionally used as a CCA cell line  
463 <sup>121,122</sup>, but they are classified as a gallbladder carcinoma cell line. Thus, results extrapolated from this  
464 cell line should be considered for patients with this specific type of tumour.

465 In general, the well-established cell lines represent an easy model to explore mechanisms of  
466 tumorigenesis and gain high experimental reproducibility mainly due to their long-term growth ability,  
467 short replication doubling time, and low maintenance costs. However, several significant weaknesses  
468 have been described, such as long-term serum-based culture conditions favouring the accumulation of  
469 new genomic alterations <sup>123-126</sup>. Furthermore, *in vitro* maintenance often supports the selection of cell  
470 clones that are not representative of the genetic heterogeneity of the original tumor. In addition, cell  
471 cultures grown as a monolayer may lack polarization and realistic cell-cell contacts within the tumour  
472 bulk. Finally, the absence of cancer stromal cells and cell-matrix interactions do not recreate the  
473 fundamental interaction with the tumour microenvironment <sup>3,123</sup>.

474 In addition to immortalized 2D cell lines, primary cultures of CCA tissue were established <sup>127-130</sup>. The  
475 overall success rate for CCA cell line isolation and establishment is relatively low (around 10%), partly  
476 due to insufficient numbers of tumour cells in resected tissues. Notably, contaminating non-tumour cells  
477 (*i.e.*, fibroblasts) must be removed. Primary cultures are grown under serum-free and growth factor-  
478 enhanced conditions, which better resemble the *in vivo* tumour condition. Also, primary CCA cultures  
479 can be used shortly after derivation, retaining more of the morphological and functional characteristics  
480 of their tissue of origin <sup>131</sup>. Primary cultures constrain cell differentiation and partially preserve the stem-  
481 like component, thus reflecting tumour heterogeneity. However, the short time window to reach  
482 senescence hampers long-term experiments and their reproducibility.

483 A major limitation, independently of whether cell lines or primary CCA cultures are used, is the absence  
484 of components of the tumour microenvironment. To address this problem <sup>132,133</sup>, different strategies have  
485 emerged in 2D cell culture, including conditioned media experiments, indirect co-culture through porous  
486 membrane cell culture inserts <sup>134</sup>, and direct co-culture <sup>135</sup>. In some cases, these experiments are  
487 performed with primary cultures of tumour and stromal cells (i.e., cancer-associated fibroblasts, CAFs;  
488 monocytes/macrophages) <sup>5,136</sup>. In other cases, CCA cell lines are made to interact with immortalized  
489 stromal cell lines (**Table 3**) <sup>132,134,137</sup>. Although these systems do not fully recapitulate the complex  
490 tumour microenvironment, they enable the study of the crosstalk between CCA cells and other cell types,  
491 deepening our understanding of the role of different stromal cell types in tumour progression and drug  
492 response mechanisms <sup>132,133,136</sup>.

493 Based on statements on histological assessment (Table 1) and a unanimous agreement, the expert  
494 panel (Box 1) strongly suggests to state in publication the origin of any cell line (previously established  
495 or new) according to the new CCA classification (intrahepatic, perihilar, distal). In addition, information  
496 regarding cell culture conditions should be provided in the publication to standardize the procedures  
497 (choice of plastic support and cell culture medium, level of confluence, isolation procedure for primary  
498 culture, passaging and sub-culturing methods, etc.).

### 499 **3D-culture recapitulating tumour organization**

500 To facilitate personalized/precision medicine, patient material is used to study treatment responses.  
501 While 2D CCA models are a step closer to the *in vivo* situation in the patient compared to the established  
502 CCA cell lines, 3D culture models, including spheroids and organoids, resemble physiological conditions  
503 even more thoroughly. Spheroids are 3D aggregates of cells grown without a predefined culture  
504 substrate to adhere to <sup>5,138</sup>, while organoids self-organize in a matrix-rich 3D environment with which  
505 they interact <sup>139,140 6,141</sup>. While traditional organoids represent an epithelial cell culture, there is a  
506 consensus that 3D models should ideally be upgraded to include epithelial stem cells, cells from the  
507 tumour microenvironment (e.g., fibroblasts and/or immune cells), and extracellular matrix components  
508 to enable the analysis of cell-cell and cell-matrix interactions.

### 509 **Spheroids**

510 Tumour spheroids, mostly generated as 3D multicellular aggregates from 2D-grown adherent cells,  
511 sometimes including stromal cells such as fibroblasts and endothelial cells, are used to model tumour  
512 biology <sup>5,138</sup>. They can be grown in natural and/or synthetic hydrogels <sup>141,142</sup>, and the increased

513 complexity of the model enhances the understanding of tumour pathobiology, including tumour  
514 homeostasis and organization. In contrast to 2D cultures, tumour spheroids inherently recapitulate the  
515 gradient of oxygen supply and drug diffusion occurring within the tumour. However, their use as high-  
516 throughput, robust platforms is still limited.

### 517 **Organoids**

518 Robust protocols for deriving biliary organoids from both mouse and human primary tissue explants or  
519 biopsies have been established <sup>6,140</sup>, and complemented by methods that allow for the derivation and  
520 propagation of organoids from iPS cells <sup>143</sup>, or cells collected from bile <sup>144,145</sup>. Apart from organoids  
521 derived from healthy donors, the successful establishment of organoid cultures from tumour tissues  
522 <sup>6,7,9,146,147</sup> can substantially add to the toolbox of preclinical and translational CCA research. The overall  
523 consensus in the field is that the efficiency of establishing these CCA organoids (CCAOs) from different  
524 patient tumours should be at least 25%. Efficiency should reach over 50% to guarantee the applicability  
525 of organoids to personalized medicine. Working with CCAOs inevitably has limitations, including the  
526 overgrowth by non-malignant cholangiocyte organoids. Using specific tumour enrichment medium <sup>148</sup>,  
527 resort to hand picking non-malignant or tumour organoids to clean up the culture, and  
528 xenotransplantations are ways to address this challenge. It is agreed upon that tumorigenicity needs  
529 to be confirmed for all CCAO lines, preferably done by mutation analysis (stand-alone or as part of whole  
530 genomic profiling). Proof of organoid tumorigenicity in immunocompromised mice and  
531 histopathological analysis are additional tests that can be performed. A shortcoming of CCAOs is that  
532 an established line does not fully reflect the polyclonal nature of the original tumour. This might hamper  
533 insights into drug sensitivity or clonal regrowth of treated CCA tumours.

534 In addition to fully transformed CCAOs, non-malignant cholangiocyte organoids can be a genetically  
535 flexible platform to functionally annotate the influence of specific genetic alterations on CCA  
536 pathobiology. Thus, recurrent iCCA genetic alterations (such as *BAP1*, *NF1*, *SMAD4*, *PTEN*, *KRAS*,  
537 *AKT*, and *IDH1/2* mutations, as well as *FGFR2* fusions and *MYC* overexpression) were engineered *in*  
538 *vitro* in either human <sup>149,150</sup> or mouse <sup>151</sup>. Collectively, these studies provided convincing evidence that  
539 liver organoids, in which few genetic hits were introduced to recapitulate recurrent patterns of putative  
540 iCCA driver mutations, gave rise to CCA upon sub-cutaneous or orthotopic transplantation in mice. This  
541 approach is therefore suitable for modelling genetically-defined cholangiocarcinogenesis in bipotent  
542 liver precursors and generating models for precision oncology research <sup>10</sup>.

543

544 Based on the available data and a unanimous agreement, the expert panel strongly suggests:

- 545 - The use of a specific tumour « enrichment » medium (i.e., tumour initiating medium as  
546 described by Broutier et al., 2017, DOI: 10.1038/nm.4438) to minimize contamination in non-  
547 tumour organoids.
- 548 - To perform mutation and phenotypic analyses to confirm the malignant origin of established  
549 organoid lines and to report them in publication.
- 550 - To characterize every organoid culture before clinical applications such as drug screening.

551

### 552 **Complex 3D culture systems**

553 Although a hydrogel-based extracellular matrix (ECM) is used to support the 3D growth of cells for both  
554 spheroids and organoids, this is typically a mouse tumour-derived basement membrane extract  
555 (Matrigel or BME) not fully comprising human or tumour ECM. Moreover, additional stromal cells such  
556 as fibroblasts and immune cells are generally lacking in these cultures. The tumour microenvironment  
557 plays a crucial role in the initiation, progression, and invasion of CCA through a complex interaction  
558 between tumour cells, stromal cells, and the extracellular matrix<sup>152</sup>. Targeting this desmoplastic, stroma-  
559 rich tumour microenvironment might be essential to overcome chemoresistance<sup>153-155</sup>. Thus, including  
560 the CCA extracellular environment *in vitro* seems vital to mimic tumour composition, cell-cell and cell-  
561 matrix interaction<sup>156</sup>, morphology, and tumour architecture more closely.

562 Current efforts is focussed on the generation of future complex models (assembloids) that integrate the  
563 epithelial CCA component with 3D bio-printed scaffolds that recapitulate the anatomy of the biliary  
564 system; immune cells that shape tumour growth and drug sensitivity through direct- or paracrine-  
565 interaction; stromal cells that create a physical barrier for drug delivery in addition to a pro-tumorigenic  
566 microenvironment. The challenges reside in the co-culture of autologous cell types derived from the  
567 same patient, as each cell type will have a peculiar growth dynamic and timeline. The use of  
568 cryopreservation protocols and human iPSC-derived generation of cell types from the same background  
569 cell may overcome these issues.

570

### 571 **How can clinical needs be addressed using currently available experimental models**

572 The experimental models described here will facilitate the translation from experimental and preclinical  
573 work to the clinical setting. While some models provide relevant insights into the basic mechanisms of  
574 cancer progression, unraveling pathway and cell signaling analysis, cell-cell, or tumour-  
575 microenvironment interactions, others provide results that can be cautiously translated into the design  
576 of more effective treatments for CCA or the development of new human clinical trials. A few recent  
577 studies indicate that genetically defined cellular and animal models can advance the discovery of  
578 actionable vulnerabilities associated with druggable iCCA oncogenic drivers. Specifically, three  
579 independent studies reported that a) RAS-ERK signalling is necessary and sufficient to support the  
580 oncogenic activity of FGFR2 fusions in PDX <sup>157</sup>, GEMMs <sup>158</sup>, and organoid-based iCCA models <sup>151</sup>; b)  
581 combination therapies capable of providing for more robust and durable suppression of RAS-ERK,  
582 improved the therapeutic efficacy of clinically approved FGFR tyrosine kinase inhibitors <sup>151,157,158</sup>.  
583 Likewise, Idh1/Kras-driven models revealed that pharmacological targeting of mutated Idh1 sensitized  
584 iCCA to host-mediated immune responses, which could be enhanced by concomitant administration of  
585 immune checkpoint inhibitors <sup>107</sup>.

586 The increasing availability of novel circulating biomarkers beyond the conventional serum tumour  
587 markers warrants validation for specific uses. Additional prognostic biomarkers may allow for a more  
588 accurate patient risk assessment and stratification in clinical trials. Predictive biomarkers for selecting  
589 the optimal therapy, such as ctDNA-based assays for FGFR2 fusions and IDH-1 mutations <sup>159,160</sup>, are  
590 already in clinical use and will push the field forward. Finally, additional pharmacodynamic biomarkers  
591 able to track disease evolution more accurately than the carbohydrate antigen (CA) 19-9 and that can  
592 reveal the emergence of drug resistance are warranted <sup>161</sup>, as shown for FGFR2 resistance <sup>162</sup>.

593 CCA organoids have proven helpful for understanding fundamental mechanisms of cancer progression  
594 and biomarker discovery <sup>7</sup>. Though successful derivation of CCA organoids has lagged behind some  
595 other tumour types, organoids hold high potential as tools for improving CCA research and therapy <sup>163</sup>.  
596 With further improvement of clinical applicability, through continued advances in stem cell biology,  
597 organoid culture, and single-cell sequencing, a possible golden era for CCA organoids in personalized  
598 medicine is within reach. A common limitation of experimental models is their inability to fully mimic all  
599 aspects of the tumour biology and personalized cancer features of individual patients. For example, the  
600 tumour microenvironment is a complex mix of cancerous and non-cancerous cells. The ECM dynamics  
601 constantly remodeled by tumour cells, CAFs, and tumor-associated macrophages create a desmoplastic

602 environment. In addition, there is considerable heterogeneity within and between tumours. It is  
603 challenging to capture this in experimental models but essential in assessing drug resistance and  
604 tumour progression. Due to the lack of the tumour microenvironment, drug screenings performed *in vitro*  
605 do not fully reflect the *in vivo* efficacy, resulting in newly developed drugs failing in phase I-III clinical  
606 trials <sup>164</sup>. Finally, common risk factors and co-existing diseases characterizing human CCA (primary  
607 sclerosing cholangitis, liver flukes, chronic viral hepatitis, liver cirrhosis, etc.) are generally absent in the  
608 existing models. Thus, generating new models that combine established risk factors and concomitant  
609 morbidities for the human tumour with specific genetic alterations such as those reported above might  
610 recapitulate human CCA more accurately.

### 611 **Consensus strengths and limitations**

612 The Delphi method was applied to reach a consensus on the criteria required to establish valid  
613 preclinical models for the study of CCA. For this purpose, we built a task force of 45 renowned experts.  
614 Although we recognized that a more extensive panel could be preferred, we believe that the number of  
615 experts, their relevance in the CCA field, and the variety of backgrounds represented, including basic  
616 scientists, pathologists, and clinicians, strengthened the validity of the consensus. During the process,  
617 the experts raised numerous comments, suggestions, and questions, which were openly and rigorously  
618 discussed and incorporated into the study. This interactive and dynamic approach and the absence of  
619 dominant voices, which often inhibit the expression of minority viewpoints, resulted in fair and balanced  
620 contributions and the achievement of the final consensus statements and recommendations.

621  
622 Experimental models are essential for a better understanding of carcinogenesis and tumour  
623 progression, testing anti-tumour therapies, and deciphering therapeutic resistance mechanisms. The  
624 panoply of CCA experimental models is wide, from simple, practical, and inexpensive to more complex  
625 models resembling human cancer biology, with a more challenging implementation and higher costs.  
626 The choice of the model depends on what is requested of it, its accessibility, and, most importantly, its  
627 ability to answer a well-defined scientific question. 2D cultures and engrafted subcutaneous murine  
628 models are the most used to dissect signalling pathways, identify therapeutic targets, and investigate  
629 drug resistance mechanisms. Depending on the type of research, *in vivo* orthotopic implantation models  
630 are preferred over ectopic CCA models. Both have advantages and limitations, as reviewed above.  
631 GEMMs appear to mimic pathobiological features of human tumourigenesis more closely, despite being

632 complex and expensive. Regarding *in vitro* models, tremendous progress has been made in better  
633 recapitulating the tumour 3D structure. The difficulty in employing these models includes not only the  
634 relatively high costs to set up the culture but also the availability of starting material (human CCA tissue).

---

635 In addition to providing an inventory, including evaluating (dis)advantages, of the most accurate  
636 experimental models currently available to the CCA scientific community, we present recommendations  
637 on minimal criteria for using these models. Using a Delphi-based process, a panel of experts in the field  
638 reached a consensus on these criteria as proposed herein. Obviously, disease models should ultimately  
639 lead to knowledge transfer from (basic) laboratory research to the clinic, to better understand the disease  
640 and offer innovative therapies. As the choice of model is highly dependent on the research question, to  
641 provide a comprehensive tumour mimic, results gathered using different models are highly  
642 recommended. This fosters the consolidation of scientific data with well-defined minimal criteria before  
643 validating them on humans by manipulating *ex vivo* samples or clinical trials.

644

#### 645 **Conclusions [Au: please provide a short concluding paragraph]**

646 Biomedical research relies entirely on *in vitro* and *in vivo* experimental models, a prerequisite for  
647 research in basic and applied sciences. In this Consensus Statement, an international group of experts  
648 developed and endorsed a set of consensus statements and recommendations on CCA experimental  
649 models, and provided guidance on the models proposed to the scientific community and the information  
650 that should be specified in publications on these models. As a complement, the experts provided the  
651 scientific community with a brief overview of currently available models to the scientific community,  
652 highlighting the advantages and disadvantages that scientists should be aware of. Importantly, This  
653 Consensus Statement has been prepared based on the expertise of both researchers and clinicians  
654 from different specialties (cell biologists, molecular biologists, oncologists, hepatologists, pathologists),  
655 thus ensuring the relevance of these statements and recommendations for a broad range of scientific  
656 public, from medical healthcare to scientists who are directly investigating this fatal cancer.

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672

673 **Author contributions**

674 LF coordinated the workgroups and the process of generating the manuscript, the review, MV and RC  
675 coordinated the Delphi questionnaire, and all authors contributed equally to the redaction and final  
676 revision of the manuscript.

677

678 **Competing interests**

679 CB receives honoraria from Incyte and Servier. AF received consultancy fees from Bayer, AstraZeneca,  
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684

685 **Consortium Authorship**



686 Diego F Calvisi, Institute of Pathology, University of Regensburg, Regensburg, Germany (author), Luke  
687 Boulter, MRC-Human Genetics Unit, Institute of Genetics and Molecular Medicine, University of  
688 Edinburgh, Edinburgh, UK (author), Javier Vaquero, TGF- $\beta$  and Cancer Group, Oncobell Program,  
689 Bellvitge Biomedical Research Institute (IDIBELL), Barcelona, Spain & National Biomedical Research  
690 Institute on Liver and Gastrointestinal Diseases (CIBEREHD), Instituto de Salud Carlos III, Madrid,  
691 Spain (author), Anna Saborowski, Department of Gastroenterology, Hepatology and Endocrinology,  
692 Hannover Medical School, Hannover, Germany (author), Luca Fabris, Department of Molecular  
693 Medicine, University of Padua School of Medicine, Padua, Italy & Digestive Disease Section, Yale  
694 University School of Medicine, New Haven, CT, USA (author), Pedro M Rodrigues, National Biomedical  
695 Research Institute on Liver and Gastrointestinal Diseases (CIBEREHD), Instituto de Salud Carlos III,  
696 Madrid, Spain & Department of Liver and Gastrointestinal Diseases, Biodonostia Health Research  
697 Institute - Donostia University Hospital, University of the Basque Country (UPV/EHU), San Sebastian,  
698 Spain & Ikerbasque, Basque Foundation for Science, Bilbao, Spain (author), Cedric Coulouarn, Inserm,  
699 Univ Rennes 1, OSS (Oncogenesis Stress Signaling), UMR\_S 1242, Centre de Lutte contre le Cancer  
700 Eugène Marquis, Rennes, France (author), Rui E Castro, Research Institute for Medicines  
701 (iMed.Ulisboa), Faculty of Pharmacy, Universidade de Lisboa, Lisbon, Portugal (author), Oreste  
702 Segatto, Unit of Oncogenomics and Epigenetics, IRCCS Regina Elena National Cancer Institute, Rome,  
703 Italy (author), Chiara Raggi, Department of Experimental and Clinical Medicine, University of Florence,  
704 Florence, Italy (author), Luc JW van der Laan, Department of Surgery, Erasmus MC Transplantation  
705 Institute, University Medical Center Rotterdam, The Netherlands (author), Guido Carpino, Department  
706 of Movement, Human and Health Sciences, Division of Health Sciences, University of Rome "Foro  
707 Italico", Rome, Italy (author), Benjamin Goepfert, Institute of Pathology and Neuropathology,  
708 Ludwigsburg, Germany (author), Stephanie Roessler, Institute of Pathology, Heidelberg, Germany  
709 (author), Timothy Kendall, Centre for Inflammation Research, University of Edinburgh, Edinburgh, UK  
710 (author), Matthias Evert, Institute of Pathology, University of Regensburg, Regensburg, Germany  
711 (author), Ester Gonzalez-Sanchez, TGF- $\beta$  and Cancer Group, Oncobell Program, Bellvitge Biomedical  
712 Research Institute (IDIBELL), Barcelona, Spain & National Biomedical Research Institute on Liver and  
713 Gastrointestinal Diseases (CIBEREHD), Instituto de Salud Carlos III, Madrid, Spain & Department of  
714 Physiological Sciences, Faculty of Medicine and Health Sciences, University of Barcelona, Spain  
715 (author), Juan W Valle, Department of Medical Oncology, The Christie NHS Foundation Trust,

716 Manchester, UK & Division of Cancer Sciences, University of Manchester, Manchester, UK (author),  
717 Arndt Vogel, Department of Gastroenterology, Hepatology and Endocrinology, Hannover Medical  
718 School, Hannover, Germany (author), John Bridgewater, Department of Medical Oncology, UCL Cancer  
719 Institute, London, UK (author), Mitesh J Borad, Mayo Clinic Cancer Center, Mayo Clinic, Phoenix, AZ,  
720 USA (autor), Gregory J Gores, Division of Gastroenterology and Hepatology, Mayo Clinic College of  
721 Medicine and Science, Rochester, MN, USA (author), Lewis Roberts, Division of Gastroenterology and  
722 Hepatology, Mayo Clinic College of Medicine and Science, Rochester, MN, USA (author), Jose JG Marin,  
723 National Biomedical Research Institute on Liver and Gastrointestinal Diseases (CIBEREHD), Instituto  
724 de Salud Carlos III, Madrid, Spain & Experimental Hepatology and Drug Targeting (HEVEPHARM),  
725 IBSAL, University of Salamanca, Salamanca, Spain (author), Jesper B Andersen, Biotech Research  
726 and Innovation Centre (BRIC), Department of Health and Medical Sciences, University of Copenhagen,  
727 Copenhagen, Denmark (author), Domenico Alvaro, Department of Precision and Translational Medicine,  
728 Sapienza University of Rome, Rome, Italy (author), Alejandro Forner, National Biomedical Research  
729 Institute on Liver and Gastrointestinal Diseases (CIBEREHD), Instituto de Salud Carlos III, Madrid,  
730 Spain & Liver Unit, Barcelona Clinic Liver Cancer (BCLC) Group, Hospital Clinic Barcelona, IDIBAPS,  
731 University of Barcelona, Barcelona, Spain (author), Jesus M Banales, National Biomedical Research  
732 Institute on Liver and Gastrointestinal Diseases (CIBEREHD), Instituto de Salud Carlos III, Madrid,  
733 Spain & Department of Liver and Gastrointestinal Diseases, Biodonostia Health Research Institute -  
734 Donostia University Hospital, University of the Basque Country (UPV/EHU), San Sebastian, Spain &  
735 Ikerbasque, Basque Foundation for Science, Bilbao, Spain & Department of Biochemistry and Genetics,  
736 School of Sciences, University of Navarra, Pamplona (author), Vincenzo Cardinale, Department of  
737 Medico-Surgical Sciences and Biotechnologies, Sapienza University of Rome, Rome, Italy (author),  
738 Rocio IR Macias, National Biomedical Research Institute on Liver and Gastrointestinal Diseases  
739 (CIBEREHD), Instituto de Salud Carlos III, Madrid, Spain & Experimental Hepatology and Drug  
740 Targeting (HEVEPHARM), IBSAL, University of Salamanca, Salamanca, Spain (author), Silve Vicent,  
741 University of Navarra, Centre for Applied Medical Research, Program in Solid Tumours, Pamplona,  
742 Spain & IdiSNA, Navarra Institute for Health Research, Pamplona, Spain & Centro de Investigación  
743 Biomédica en Red de Cáncer (CIBERONC, Instituto de Salud Carlos III), Madrid, Spain (author), Xin  
744 Chen, Department of Bioengineering and Therapeutic Sciences and Liver Center, University of  
745 California, San Francisco, USA (author), Chiara Braconi, Institute of Cancer Sciences, University of

746 Glasgow, Glasgow, UK (author), Alexander Scheiter, Department of Pathology, University Regensburg,  
747 Regensburg, Germany (consortium member), Florin M Selaru, Division of Gastroenterology and  
748 Hepatology and Sidney Kimmel Cancer Center, Johns Hopkins University, Baltimore, USA (consortium  
749 member), Katja Evert, Institute for Pathology, University Regensburg, Regensburg, Germany  
750 (consortium member), Kirsten Utpatel, Institute of Pathology, University of Regensburg, Regensburg,  
751 Germany (consortium member), Laura Broutier, Childhood Cancer & Cell Death, Centre de Recherche  
752 en Cancérologie de Lyon (CRCL), Lyon, France (consortium member), Massimiliano Cadamuro,  
753 Department of Molecular Medicine - DMM, University of Padova, Padova, Italy (consortium member),  
754 Meritxell Huch, Max Planck Institute of Molecular Cell Biology and Genetics, Dresden, Germany  
755 (consortium member), Rob Goldin, Centre of Pathology, Imperial College London, London, UK  
756 (consortium member), Sergio A Gradilone, The Hormel Institute, University of Minnesota, Austin, USA,  
757 Masonic Cancer Center & University of Minnesota, Minneapolis, USA (consortium member), Yoshimata  
758 Saito, Division of Pharmacotherapeutics, Keio University Faculty of Pharmacy, Tokyo, Japan & Division  
759 of Gastroenterology and Hepatology, Department of Internal Medicine, Keio University School of  
760 Medicine, Tokyo, Japan (consortium member), Monique MA Verstegen, Department of Surgery,  
761 Erasmus MC Transplantation Institute, University Medical Center Rotterdam, The Netherlands (author),  
762 Laura Fouassier, Sorbonne Université, Inserm, Centre de Recherche Saint-Antoine (CRSA), Paris,  
763 France (author).

764

765 Alexander Scheiter, <sup>37</sup> Florin M Selaru, <sup>38</sup> Katja Evert, <sup>39</sup> Kirsten Utpatel, <sup>39</sup> Laura Broutier, <sup>40,41</sup>  
766 Massimiliano Cadamuro, <sup>42</sup> Meritxell Huch, <sup>43</sup> Rob Goldin, <sup>44</sup> Sergio Gradilone, <sup>45,46</sup> Yoshimata Saito, <sup>47</sup>

767

768 <sup>37</sup> Institute of Pathology, University of Regensburg, Regensburg, Germany

769 <sup>38</sup> Division of Gastroenterology, Department of Medicine and Sidney Kimmel Comprehensive Cancer  
770 Center, Johns Hopkins University, Baltimore, MD

771 <sup>39</sup> Institute of Pathology, University of Regensburg, Regensburg, Germany

772 <sup>40</sup> Childhood Cancer & Cell Death (C3), Université Claude Bernard Lyon 1, INSERM 1052, CNRS  
773 5286, Centre Léon Bérard, Centre de Recherche en Cancérologie de Lyon (CRCL), Lyon, France

774 <sup>41</sup> The Wellcome Trust/CRUK Gurdon Institute, University of Cambridge, Cambridge, UK

775 <sup>42</sup> University of Padua, Dept of molecular medicine (DMM), Padua, Italy

776 <sup>43</sup> Max Planck Institute of Molecular Cell Biology and Genetics (MPI-CBG), Dresden, Germany

777 <sup>44</sup> Division of Digestive Sciences, Imperial College, London, UK

778 <sup>45</sup> The Hormel Institute, University of Minnesota, Austin, MN, USA.

779 <sup>46</sup> Masonic Cancer Center, University of Minnesota, Minneapolis, MN, USA

780 <sup>47</sup> Division of Pharmacotherapeutics, Keio University Faculty of Pharmacy, Tokyo, Japan

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910 suppressor in cholangiocarcinoma. *J Hepatol* **67**, 72-83 (2017).
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**Box 1. Benefits and limitations of cholangiocarcinoma experimental models and recommendations.**

	<b>Benefits</b>	<b>Limitations</b>
<b><i>In vivo</i> models</b>		
Engrafted models		
Xenograft	<ul style="list-style-type: none"> <li>- Engraftment of human cells or tissue</li> <li>- Ectopic engraftment inexpensive and easy to implement</li> <li>- Easy-to-measure ectopic tumours</li> <li>- Commonly used for drug testing</li> </ul>	<ul style="list-style-type: none"> <li>- Defective immune system</li> <li>- Ectopic allograft poorly relevant</li> <li>- Rate of human CCA tissue ectopic engraftment (PDX) very low</li> <li>- Orthotopic engraftment difficult to perform</li> </ul>
Allograft	<ul style="list-style-type: none"> <li>- Full immune system</li> <li>- Ideal to study tumour-stroma interplay</li> <li>- Fully compatible for testing immunotherapy-based therapies</li> </ul>	<ul style="list-style-type: none"> <li>- Ectopic allograft poorly relevant</li> <li>- Orthotopic engraftment difficult to perform</li> </ul>
Chemically-induced	<ul style="list-style-type: none"> <li>- Recapitulate development of CCA (TAA) with pre-cancerous disease history</li> <li>- Long-term furan treatment induces 100% of tumour incidence</li> </ul>	<ul style="list-style-type: none"> <li>- Highly variable</li> <li>- Control tissue: isolated bile duct and not whole liver</li> </ul>
GEMM	<ul style="list-style-type: none"> <li>- Design to mimic genetic alterations of human CCA</li> <li>- Model of advanced CCA</li> <li>- Valuable tool for testing targeted therapies</li> </ul>	<ul style="list-style-type: none"> <li>- Fast tumour development</li> <li>- Origin of CCA multiple</li> <li>- Appearance of mixed HCC/CCA tumour</li> <li>- Costly</li> </ul>
<b>RECOMMENDATIONS</b>		
<b>Histological assessment (all <i>in vivo</i> models)</b>		
<ol style="list-style-type: none"> <li>1. Invasion of the basement membrane and tumorigenic capacity of isolated cells engrafted subcutaneously in immune-deficient mice are the most important malignant features of CCA (97% and 91%, A).</li> <li>2. Immunohistochemistry of at least one biliary cytokeratin should always be performed to characterize an early-stage tumour in a preclinical CCA model (90%, A).</li> <li>3. A classification of preclinical CCA models as intrahepatic, perihilar, and distal CCA is recommended. (93%, A).</li> <li>4. Focal desmoplastic stroma is a morphological feature required to classify a lesion as CCA in a preclinical model (100%, U).</li> <li>5. Three histopathological features of human CCA must be assessed in a preclinical model: intratumoral heterogeneity (high stroma, inflammatory response, epithelial phenotype) (90%, A), the pattern of growth (mass-forming, periductal infiltration, intraductal growth) (90%, A), and immunopositivity for CK7 or CK19 (100%, U).</li> </ol>		
<b>Xenograft models, Genetically Engineered Mouse Models (GEMM)</b>		
<ol style="list-style-type: none"> <li>6. The type of CCA should be specified for patient-derived xenograft models (92%, A).</li> <li>7. Drugs should be tested in more than one model (95%, A).</li> </ol>		
<b><i>In vitro</i> models</b>		
2D-culture with cell lines or primary cells	<ul style="list-style-type: none"> <li>- Easy and low maintenance costs</li> <li>- High experimental reproducibility</li> <li>- Large panels of cell lines commercially available</li> </ul>	<ul style="list-style-type: none"> <li>- Absence of stromal cells</li> <li>- Cultures grown as a monolayer</li> </ul>

	- Cells available with genetic alteration(s)	
3D-culture recapitulating a tumour organization		
Spheroids	<ul style="list-style-type: none"> <li>- Can be patient-derived</li> <li>- Increased complexity through 3D multicellular aggregates of epithelial cells and stromal cells</li> <li>- Recapitulate the gradient of oxygen supply and drug diffusion</li> <li>- Increased complexity</li> </ul>	<ul style="list-style-type: none"> <li>- Limited use for high-throughput analysis</li> <li>- Often made from cell lines</li> <li>- Do not fully reflect the polyclonal nature of a CCA tumour</li> </ul>
Organoids	<ul style="list-style-type: none"> <li>- Increased complexity by 3D tumour cell growth in ECM <ul style="list-style-type: none"> <li>- Well established protocol</li> </ul> </li> <li>- Specific mutations can be introduced in non-tumour organoids to analyse CCA driver mutations</li> </ul>	<ul style="list-style-type: none"> <li>- Low initiation efficiency from human tumours</li> <li>- An established line does not fully reflect the polyclonal nature of the original tumour</li> <li>- Overgrowth of non-tumour cells in culture initiation <ul style="list-style-type: none"> <li>- Absence of stromal cells</li> </ul> </li> </ul>
<p><b>RECOMMENDATIONS</b></p> <p><b>2D cultures</b></p> <p>8. Cell culture procedures should be standardised in experiments with cell lines or primary 2D cultures and be reported in publications. Procedures include the choice of plastic support, cell culture medium, and the level of confluence when performing the experiments should be mentioned (88%, 85%, 82%, B). The isolation protocol for primary cells, including passaging and sub-culturing methods, should be reported in publications (i.e., enzymatic vs. mechanical dissociation, etc.) (89% and 85%, B). The origin of any cell line (previously established or new) should be stated for publication according to the new CCA classification (i.e., intrahepatic, perihilar, distal) (90-99, A)</p> <p>9. The origin of any cell line (previously established or new) should be presented in a publication according to the new CCA classification (i.e., intrahepatic, perihilar, distal) (97%, A).</p> <p><b>3D cultures</b></p> <p>10. A specific tumour "enrichment" medium (i.e., tumour initiating medium as described by Broutier et al., 2017, DOI: 10.1038/nm.4438) is recommended to minimize contamination in non-tumour organoids (94%, A).</p> <p>11. Mutation analysis (targeted genomic profiling using a diagnostic panel) (90%, A), and phenotypic analysis should be done to confirm the malignant origin of established organoid lines and reported in publications (93%, A).</p> <p>12. Every organoid culture should be characterized before clinical applications such as drug screening (92%, A).</p> <p>13. The shorter period for patient-organoids initiation, expansion, and analysis has to be less than 3 months (57%, C).</p>		

1164 Grading system: U, denotes unanimous (100%) agreement; A, 90–99% agreement; B, 70–89%  
1165 agreement; C, 50-69% agreement; and D, <50% agreement.  
1166 ECM, extracellular matrix; HCC/CCA, hepatocellular carcinoma; TAA, thioacetamide.

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[Au: please add details of the grading system used as a footnote as each display item must be understood as a standalone item]

**Table 1. Consensus statements.**

#	Statement	Response yes / total responders	Grade
<b>Histological assessment</b>			
1	Which of the following ones are malignant features of biliary tumours?		
	1. Invasion of the basement membrane	31/32	A
	2. Increased nucleus/cytoplasm ratio	18/31	C
	3. Distant metastasis	27/32	B
	4. Tumorigenic capacity of isolated cells after subcutaneous injection in immune-deficient mice	29/32	A
2	What type of histological investigation(s) should always be done to characterize an early-stage tumour in a preclinical CCA model?		
	1. Morphological examination of H&E	32/32	U
	2. Immunohistochemistry	27/30	A
	3. Immunohistochemistry for at least one biliary cytokeratin (e.g., CK19, CK7, pan CK, etc.)	16/25	C
	4. Markers for inflammatory cells and CAFs	12/26	D
	5. PAS reaction for highlighting mucin	13/26	C
	6. A broad panel of markers for hepatobiliary malignancies and metastasis	12/24	C
3	To allow correlation with the anatomical classification of human tumours, a preclinical model of CCA should specifically classify tumours induced as:		
	1. Intrahepatic CCA, perihilar CCA, and distal CCA	25/30	B
	2. Intrahepatic CCA and extrahepatic CCA	12/25	D
	3. No need for such classification	1/23	D
4	Which of the following morphological and/or immunophenotypic features must be present to classify a lesion as CCA in a preclinical model?		
	1. Location within the liver or extrahepatic biliary tree	24/28	B
	2. Absence of an extrahepatic bile duct primary lesion	14/28	C
	3. Epithelial cytological features (cohesive groups or structures and/or pan-cytokeratin immunopositivity)	25/28	B
	4. At least focal gland formation	9/25	D
	5. Absence of hepatocellular differentiation (bile production and canalicular CD10 or BSEP)	14/24	D
	6. Immunopositivity for CK7 or CK19	31/31	U
	7. Focal desmoplastic stroma	22/30	B
	8. Presence of precursor lesions	4/24	D
	9. Primary origin within the intra- or extra-hepatic biliary tree	19/28	D
	10. Absence of primary hepatobiliary lesions	0/28	U
5	What histopathological features of human CCA must be verified in a preclinical model of CCA?		
	1. Intra-tumoral heterogeneity (high stroma, inflammatory response, epithelial phenotype)	27/30	A

	2. Inter-tumoral heterogeneity (large versus small bile duct tumour in iCCA)	20/26	B
	3. Growth pattern (mass-forming, periductal infiltration, intraductal growth)	25/28	A
	4. Proportion of tumour showing gland formation	17/25	C
	5. Immunopositivity for CK7 or CK19	32/32	U
	6. Focal desmoplastic stroma	26/30	B
	7. Presence of precursor lesions	16/24	C
6	It has been proposed that iCCA may originate from several cells of origin. Which of the following cell types may be the cells-of-origin for iCCA?		
	1. Mature hepatocytes	27/32	B
	2. Mature cholangiocytes	23/32	B
	3. Hepatic progenitor/oval cells	32/33	A
	4. Peribiliary glands	29/30	A
<b>In vivo and in vitro models</b>			
<b>Xenograft models, Genetically Engineered Mouse Models (GEMM)</b>			
7	Concerning newly developed patient-derived xenograft models		
	1. Should the model(s) be validated by an expert pathologist and the histology of the tumour shown in publications?	37/37	U
	2. Should immune profiling also be reported?	20/31	C
	3. Should the model(s) be validated in more than one mouse strain?	8/34	D
	4. Should the expert pathologist specify what type of CCA is found in the model?	33/36	A
	5. Do orthotopic xenograft models represent the most disease-relevant tumour environment in which to test a drug, compared to ectopic xenograft models?	27/35	B
	6. Should a drug be tested in more than one model?	35/37	A
<b>2D culture models</b>			
8	Which cell culture procedures should be standardised in experiments with cell lines or primary 2D cultures and be reported in publications?		
	1. Choice of plastic support (i.e., TPP, Falcon, Corning, +/- ECM layer, etc.)	30/34	B
	2. Choice of cell culture medium	29/34	B
	3. Level of confluence when performing the experiments	27/33	B
	4. Isolation protocol for culture of primary cells	31/35	B
	5. Passaging and sub-culturing methods (i.e., enzymatic vs. mechanical dissociation, etc.)	29/34	B
9	The origin of any cell line (previously established or new) should be stated for publication according to the new CCA classification (i.e., intrahepatic, perihilar, distal)	37/38	A
<b>3D cultures</b>			

10	Contaminating non-tumour organoids often grow in CCA organoid cultures. How should selection for tumour organoids be performed?		
	1. Specific tumour "enrichment" medium (i.e., tumour initiating medium (as described by Broutier <i>et al.</i> , 2017, DOI: 10.1038/nm.4438)	29/31	A
	2. Hand-picking of organoids with a different phenotype / removing the 'normal-looking' organoids	21/30	B
	3. Xenotransplantation in mice to select for tumour clones	22/30	B
11	Which analyses should be done to confirm the malignant origin of established organoid lines and be reported in publications?		
	1. Full genomic profiling	8/28	D
	2. Mutation analysis (targeted genomic profiling using a diagnostic panel)	28/31	A
	3. Phenotypic analysis	28/30	A
	4. Histological analysis (immunohistochemistry of EpCAM, CK7)	28/32	B
	6. Xenotransplantation in mice	26/32	B
12	Should every organoid culture be characterized (as proposed in Q 11) before clinical applications such as drug screening?	33/36	A
13	Personalized medicine applications such as drug screenings to find the best treatment for the patient, will cost time. How much time is acceptable to initiate, grow and expand the organoids for these analyses? In other words, what is the maximum time acceptable to be relevant to the clinics?		
	<1 month	9/35	D
	<3 months	20/35	C
	<6 months	4/35	D
	Other; the less as possible / <1 mo 1st line treatment and <3 mo 2 <sup>nd</sup> line treatment	2/35	D

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Grading system: U, denotes unanimous (100%) agreement; A, 90–99% agreement; B, 70–89% agreement; C, 50–69% agreement; and D, <50% agreement.

1187 **Table 2. Carcinogen-based rodent models of cholangiocarcinoma.**

<b>Carcinogenic agent</b>	<b>Animal</b>	<b>Mechanism of action</b>	<b>Biliary lesions</b>	<b>Ref.</b>
TAA	Rat and mouse	Membrane protein and phospholipid modifications	Intense fibrosis with dysplasia	91,92
Furan	Rat	DNA adduct generation	Chronic inflammation, proliferation of bile duct cells	98
DEN, DMN (even combined with BDL)	Hamster and mouse	DNA adduct generation	Desmoplasia, cystic hyperplasia of bile ducts	94-96,165
Opisthorchis viverrini	Hamster	DNA oxidative damage	Alterations of oxidative metabolism and proliferation of bile ducts	97

1188 BDL, bile duct ligation; DEN, diethylnitrosamine; DMN, dimethylnitrosamine; TAA, thioacetamide.

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**Table 3. Summary of the most representative in vivo CCA models based on genetically-engineered mice.**

<b>Genetic strategy</b>	<b>Key features</b>	<b>Advantages and Disadvantages</b>	<b>Ref.</b>
<i>Alfp-Cre, Trp53<sup>flf</sup></i>	Advanced HCC/CCA (from LPCs)	A: <i>Trp53</i> mutation found in human CCA D: Long latency (14- to 20-month-old mice), tumours of bilinear origin (mixed HCC/CCA)	166
<i>Alb-Cre, Smad4<sup>flf</sup>, Pten<sup>flf</sup></i>	Multistep progression involving hyperplasia, dysplasia, carcinoma <i>in situ</i> , and well-established iCCA (from LPCs)	A: 100% tumour penetrance D: Cre activation during embryogenesis, long tumour latency (4-5 months) and lack of metastasis	100
<i>Alb-Cre, Kras<sup>L5LG12D/+</sup>, Pten<sup>flf</sup></i>	Invasive iCCA with an abundant desmoplasia, primarily showing glandular morphology resembling well-differentiated human CCA (from LPCs)	A: 100% penetrance, rapid development (7 weeks of age), abundant desmoplastic stroma, iCCA exclusive D: Cre activation during embryogenesis, no apparent metastases or invasion to other organs	103 104
<i>Alb-Cre, Idh2<sup>L172</sup>, Kras<sup>L172-G12D</sup></i>	Multifocal liver masses of iCCA (from LPCs)	A: 100% penetrance, splenic invasion and peritoneal metastases D: Cre activation during embryogenesis, long tumour latency (33-58 weeks)	105
<i>Alb-Cre, Notch1<sup>CD</sup></i>	Development of transplantable CCA, likely progenitor cell-derived (transplantation of cells from 8 months-old mice in immunodeficient animals gives rise to CCA) (from LPCs)	A: Notch expression is characteristic of human disease D: Cre activation during embryogenesis, no obvious cancer development after 8 months in transgenic mice, requires additional transplantation model	167
<i>Alb-Cre, Trp53<sup>flf</sup>, Notch1<sup>CD</sup></i>	Development of iCCA abortive glandular pattern (moderate to high pleomorphic nuclei with some atypic mitoses) and dense fibrous tissue with inflammatory cells (from LPCs)	A: 100% penetrance, development of fibrous/inflammatory microenvironment D: Long tumour latency (>8-9 months), no metastases	168
<i>Alb-Cre, Kras<sup>L5LG12D/+</sup>, Fbxw7<sup>L5LR468C</sup></i>	Dysplastic dust-like structures surrounded by fibrosis in all mice (only bile duct dilation and hyperplasia in some heterozygous <i>Fbxw7<sup>L5LR468C</sup></i> mice at the age of 8 months) (from LPCs)	A: Low latency (2 months of age) D: Cre activation during embryogenesis, homozygous <i>Fbxw7</i> mutations not occurring in human disease	169
<i>Alb-Cre, Hspd1<sup>flf</sup></i>	Cholangiocellular lesions, characterized by irregular glands, loss of polarity, multilayering of cells, and frequent mitosis resembling human BIN	A: Low latency, possibility of transplanting cholangiocellular lesions, activation of human CCA pathways D: Not related to known oncogenic drivers of human disease, no metastases, not established iCCA	109
<i>Alb-Cre, Jnk1<sup>flf</sup>, Jnk2<sup>-/-</sup></i>	JNK deletion causes changes in cholesterol and bile acid metabolism that foster cholestasis, bile duct proliferation, and iCCA	A: iCCA exclusive D: ~95% penetrance, long tumour latency (14 months)	170
<i>Alb-Cre, NEMO<sup>flf</sup>, Jnk1<sup>flf</sup>, Jnk2<sup>-/-</sup></i>	Hyperproliferative ductular lesions with atypia compatible with CCA	A: Elevated ROS associated with cholangiocellular proliferation D: Not full penetrance, long latency (50 weeks)	171
<i>Alb-Cre, Kras<sup>L5LG12D/+</sup>, Trp53<sup>flf</sup></i>	Multistage progression including stroma-rich tumours and premalignant biliary lesions (IPBN and) (from LPCs)	A: 100% penetrance, average latency 16 weeks, metastatic lesions D: Cre activation during embryogenesis, wide latency range, CCA in ~80% of mice	101

<i>Kras</i> <sup>LSLG12D/+</sup> , <i>Trp53</i> <sup>ff</sup> infected with AAV8-TBG- Cre	Development of ICC (40%), HCC (40%), mixed HCC/CCA (20%) (from hepatocytes)	A: Recombination event in adult mice, higher CCA frequency in combination with DCC diet (all tumours ICC or mixed HCC/CCA) D: Cre-recombinase administration via adeno-associated virus (AAV), large tumour latency range (12-66 weeks post-AAV infection)	102
<i>AhCre</i> <sup>ERT</sup> , <i>Kras</i> <sup>G12V/+</sup> , <i>Pten</i> <sup>ff</sup>	Multifocal non-invasive papillary neoplasms in the intrahepatic biliary tract (from major interlobular bile ducts to small bile duct radicles in portal tracts)	A: 100% penetrance, low latency (43 days), tumour development starts in adult mice D: Not specific to liver tissue, lack of invasive tumour or metastasis	172
<i>Sox9-Cre</i> <sup>ERT2</sup> , <i>Kras</i> <sup>LSL-G12D/+</sup> , <i>Trp53</i> <sup>ff</sup>	iCCA tumours accompanied by adjacent extensive ductular reactions and desmoplasia, with areas resembling BIN (from cholangiocytes)	A: 100% penetrance, iCCA exclusive, recombination in mature cholangiocytes D: 30 weeks average latency	102
<i>Ck19-Cre</i> <sup>ER</sup> , <i>Kras</i> <sup>LSL- G12D</sup> , <i>Tgfb2</i> <sup>fllox/fllox</sup> , <i>Cdh1</i> <sup>fllox/fllox</sup>	Markedly thickened EHBD wall with a swollen gallbladder involving invasive periductal infiltrating-type eCCA and lymphatic metastasis (from biliary cells)	A: Low latency (4 weeks), eCCA exclusive B: Concurrent development of lung adenocarcinomas leads to mice asphyxiation	110
<i>Pdx1-Cre</i> , <i>Pik3ca</i> <sup>LSLH1047R/+</sup>	Adult mice develop enlarged extrahepatic bile duct and BIN with complete penetrance leading to eCCA (from well-differentiated, stroma-rich ductal adenocarcinomas to more undifferentiated)	A: eCCA exclusive, only one genetic hit driving CCA B: ~40 weeks average latency, 90% penetrance, wide tumour latency range	173
<b>GEM-based implantation models</b>			
LPCs from <i>Alb- Cre</i> , <i>Kras</i> <sup>LSL-G12D</sup> , <i>Trp53</i> <sup>LSL-R172H/lox</sup> +/- FIG-ROS fusion	Allografted tumours resemble advanced CCA	A: Quick model, orthotopic implantation in the liver, iCCA exclusive, stroma presence D: Requires technical training to isolate LPC	88
LPCs or cholangiocytic progenitor cells or hepatocytes from <i>Trp53</i> <sup>-/-</sup> mice	Tumours exhibit a high stromal content and a mixed hepatocellular and cholangiocellular differentiation	A: Quick model D: Not CCA exclusive	166
Adult liver organoids from <i>Kras</i> <sup>LSL-G12D</sup> , <i>Trp53</i> <sup>ff</sup> mice	<i>Kras</i> driven organoids lead to CCA while c-Myc expression in wild-type organoids induces HCC formation	A: Tumours latency of 6-8 weeks for <i>Kras</i> mut and <i>Trp53</i> ko organoids D: Requires training in organoid isolation, growth and manipulation	10
Cholangiocytes from <i>Kras</i> <sup>LSL-G12D</sup> , <i>Trp53</i> <sup>ff</sup> mice	Tumours with a high stromal component expressing CCA markers	A: Quick and reproducible model, orthotopic implantation in the liver, iCCA exclusive, stroma presence D: Requires technical training to isolate mouse cholangiocytes	64
<b>GEM-based carcinogenic models</b>			
<i>Alb-Cre</i> <sup>ERT2</sup> , <i>R26</i> <sup>RlacZ/+</sup> or <i>Ck19- Cre</i> <sup>ERT2</sup> , <i>R26</i> <sup>RlacZ/+</sup> mice treated with TAA	Macronodular liver cirrhosis containing cells the typical histology of CCA	A: 100% penetrance, iCCA exclusive D: Long latency (30 weeks)	174
<i>Ck19-Cre</i> <sup>ERT/eYFP</sup> ; <i>Trp53</i> <sup>ff</sup> mice treated with TAA	Treatment with TAA generates oncogenic stress yielding multifocal invasive iCCA	A: iCCA exclusive D: 80% penetrance, long latency (>6 months)	111
<i>Trp53</i> <sup>-/-</sup> mice treated with CCl <sub>4</sub>	Bile duct injury/necrosis, proliferation and fibrosis development triggered by CCl <sub>4</sub>	A: Exclusive iCCA D: 50% mice develop tumours, metastatic lesions rarely observed	112

GSTA3 <sup>-/-</sup> mice treated with aflatoxin B1	Macro- and microscopic liver cysts, hepatocellular nodules, cholangiomas, iCCA and oval cell proliferation	D: Long latency (12 and 24 weekly AFB1 injections followed by a rest period of 12 and 6 months)	<sup>175</sup>
<i>Alb-Cre</i> , <i>Jnk1<sup>fl/fl</sup></i> , <i>Jnk2<sup>-/-</sup></i> treated with DEN	Cystogenesis and cholangioma-like structures in liver parenchyma with strong infiltration of immune cells	A: Participation of inflammatory insult D: No established CCA, long latency	<sup>171</sup>

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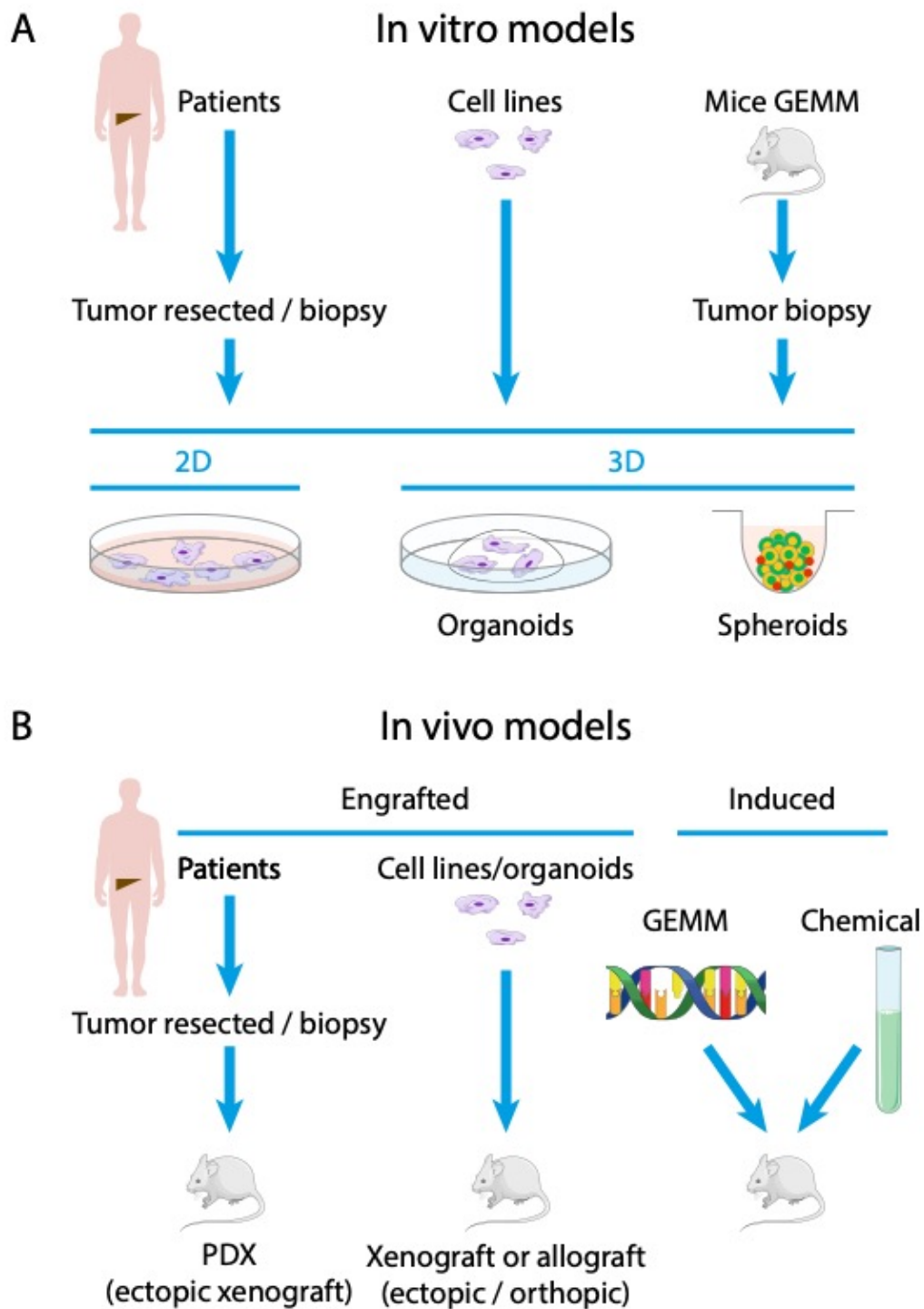
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A: Advantages; BIN: biliary intraepithelial neoplasia; CCl<sub>4</sub>: carbon tetrachloride; D: disadvantages; DEN: diethylnitrosamine; GSTA3: glutathione-S-transferase A3; IPBN: intraductal papillary biliary neoplasms; LPCs: bipotent liver progenitor cells; ROS: reactive oxygen species; TTA: tetradecylthioacetic acid; VMC Von Meyenburg complexes.



**Table 4. Experimental model sheet.**

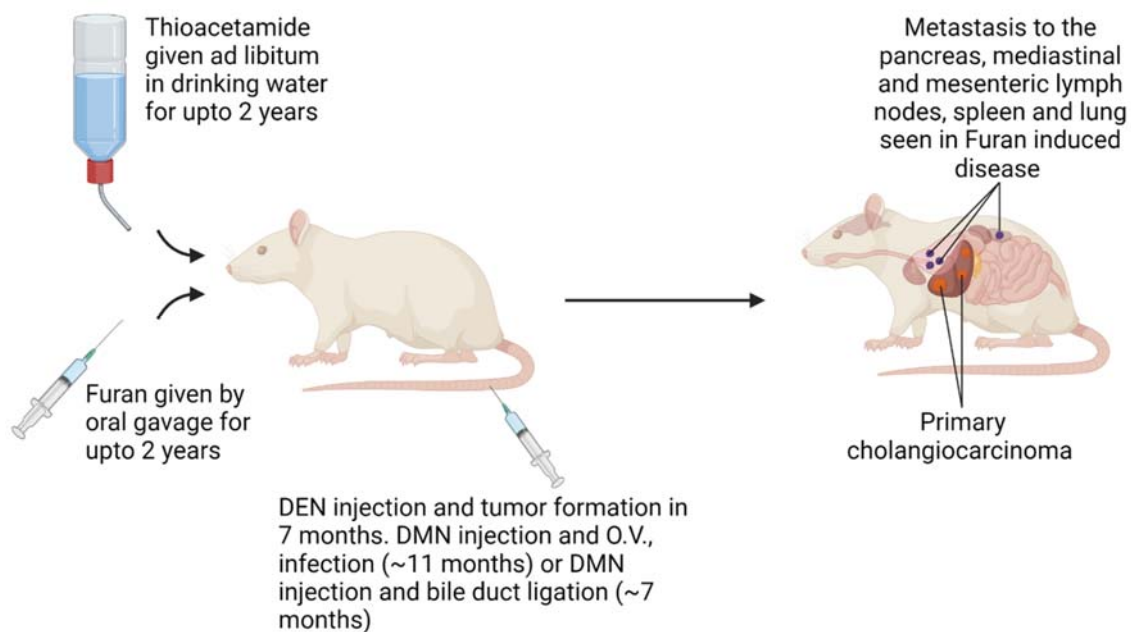
<b>Experimental model sheet</b>	
1. <b>Type of model:</b> ( <i>in vitro</i> , <i>ex vivo</i> , <i>in vivo</i> )	
2. <b>Species:</b> (mouse, rat, hamster, human, etc.)	
3. <b>Gender:</b> (male, female, both)	
4. <b>Strain:</b>	
5. <b>Condition of the surrounding liver</b> (apparently healthy, cirrhosis, fibrosis, etc.) :	
6. <b>Method of generation:</b> (spontaneous, carcinogenic, chronic injury, infectious, transgenic, knockout, transposon-mediated, patient-derived xenograft, organoids, isolated from animal tumours, isolated from human tumours, etc.):	
7. <b>Tumour development:</b> (fast, slow)	
8. <b>Metastasis:</b> (yes, no, locations,...)	
9. <b>Anatomical location of the lesions (when applicable):</b> (intrahepatic, extrahepatic, both)	
10. <b>Cell of origin (if available):</b> (cholangiocyte, stem/progenitor cell, hepatocyte)	
11. <b>Types of samples and storage conditions for future analyses</b>	
12. <b>Presence of preneoplastic lesions:</b> (yes/no)	
13. <b>Type of preneoplastic lesions:</b> (IPNB, IPMN, BillIN, etc.)	
14. <b>Type of cholangiocarcinoma:</b> (iCCA, pCCA, dCCA, combined HCC/CCA)	
15. <b>Histology of tumours:</b> (large duct type, small duct type, CCA, lymphoepithelioma-like CCA, etc.)	
16. <b>Microenvironment features:</b> (presence of stroma/desmoplastic reaction, absence of stroma, immune infiltration yes/no)	
17. <b>Phenotype of the lesions:</b> (CK7, CK19, MUC1, MUC2, MUC5AC, MUC6, HNF4A, AFP, markers of stemness, markers of EMT, etc.)	
18. <b>Control samples used if applicable</b> (bile duct freshly isolated from liver or cell line)	



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**Figure 1.** Panel of experimental *in vitro* (A) and *in vivo* (B) models provided for cholangiocarcinoma preclinical studies.

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**Figure 2.** Schematic summary of available chemical models to initiate cholangiocarcinoma in rodents and induce metastatic dissemination.