Cholangiocarcinoma (CCA) is a heterogeneous group of malignancies that can emerge at every point of the biliary tree, from the canals of Hering to the main bile duct. According to their anatomical location, CCAs are classified as intrahepatic (iCCA), perihilar (pCCA) and distal CCA (dCCA), which have particular similarities but also important inter-tumour and intra-tumour differences that can affect the pathogenesis and outcome. CCAs, taken together, represent the second most frequent type of primary liver cancer and ~3% of all gastrointestinal neoplasias. However, the epidemiological profile of CCA and its subtypes displays enormous geographical variation, reflecting the exposure to different risk factors. Although in most countries CCA is a rare cancer (incidence <6 cases per 100,000 people), its incidence is exceptionally high in some countries and regions, including Chile, Bolivia, South Korea and North Thailand. In general, a progressive increase in iCCA incidence worldwide was reported up to the end of the past century, reaching a plateau in the past 10 years. By contrast, the incidences of both pCCA and dCCA seem to be decreasing. Late diagnosis compromises the effective therapeutic options, which are based on surgical resection and/or liver transplantation, whereas chemotherapies are virtually palliative given the marked chemoresistance of this cancer.
pathogenesis, prognosis and chemosensitivity, thus indicating the best therapeutic options for each patient as well as new potential targets for therapy.

In sum, CCA represents a global health problem that warrants considerable attention and thorough investigation (BOX 1). In this respect, the European Network for the Study of Cholangiocarcinoma (ENS-CCA) was created in May 2015 (www.enscca.org or www.cholangiocarcinoma.eu) to promote and boost collaborative research projects on CCA at basic, translational and clinical levels. In this Consensus Statement, the ENS-CCA aims to provide knowledge on novel classifications, genetics, epigenetics, pathogenesis, signalling pathways, current emerging therapies and future directions in basic and translational research as well as clinical medicine for CCA.

Methods

The ENS-CCA is constituted by active research groups of nine European countries (Austria, Denmark, France, Germany, Italy, Norway, Spain, Switzerland and the UK) and also involves distinguished International Advisors and/or Collaborators (see Acknowledgements). These research teams have contributed to generate many of the key advancements in the pathophysiology of the biliary tree and development and/or onset of CCA.

To write this Consensus statement, relevant articles were found by searching PubMed with the term “cholangiocarcinoma” in combination with the following terms: “diagnosis”, “progression”, “survival”, “growth factors”, “neuroendocrine peptides”, “estrogen”, “inflammation”, “cancer-associated fibroblasts”, “myofibroblasts”, “hepatic stellate cells”, “macrophages”, “tumour-associated macrophage”, “endothelial cells”, “vascular cells”, “inflammation”, “classification”, “histology”, “cell of origin”, “cancer stem cell”, “therapy”, “chemoresistance”. No specific search dates were used.

Classification and pathological features

The classification of CCA has become a matter of intense debate. Considering different aspects of these tumours, several classifications have been proposed [1,2]. On the basis of anatomical location, the latest system classifies CCA into iCCA, pCCA and dCCA (FIG. 2A).

On the basis of gross appearance, the iCCA can present three different patterns of growth (FIG. 2B): mass-forming (MF-iCCA), periductal infiltrating (PI-iCCA), and intraductal growing (IG-iCCA), in which the MF-iCCA largely represents the most frequent form [3–6]. For pCCA and dCCA, growth patterns similar to PI-iCCA or IG-iCCA can also be seen; however, pCCA can adopt a nodular plus periductal infiltrating growth pattern that represents the most frequent form (>80%) [5,6,10]. MF-iCCA usually occurs in chronic non-biliary liver diseases and arises in peripheral small bile ducts, whereas PI-iCCA and IG-iCCA types exclusively involve large (segmental and area) intrahepatic bile ducts [11]. These differences can be also linked to the bile duct heterogeneity (that is, small versus medium and large bile ducts) [12]. The PI-iCCA type grows longitudinally along the bile duct, typically determines biliary strictures and, in some cases, invades the liver parenchyma adopting combined features of periductal infiltrating and mass-forming types (PI+MF-iCCA). The IG-iCCA type shows papillary growth towards duct lumina [11,13] but at present the American Joint Cancer Committee/Union for International Cancer Control (AJCC/UICC) does not recognize this growth pattern [11,14]. Similar to pCCA and dCCA, PI-iCCA emerging from large intrahepatic bile ducts is often preceded by preinvasive lesions classified as biliary intraepithelial neoplasm, intraductal papillary neoplasm, mucinous cystic neoplasm or intraductal tubular neoplasm [11,13,14]. By contrast, preinvasive lesions of the MF-iCCA are not well known.

Histologically, the vast majority of pCCA and dCCA are mucinous adenocarcinomas. Conversely, iCCAs are highly heterogeneous tumours and several classifications have been proposed [11,13,17,18]. However, despite differences in nomenclature, iCCAs show two main histological subtypes, reflecting their anatomical origin along the intrahepatic biliary tree: bile ductular type (mixed) (FIG. 3A), arising from small intrahepatic bile ducts, and bile duct type (mucinous) (FIG. 3B), arising...
from large intrahepatic bile ducts\textsuperscript{11,13,17,18}. Interestingly, this histological subclassification corresponds to different clinicopathological features. The bile ductular type (mixed) iCCAs display an almost exclusively mass-forming growth pattern\textsuperscript{11,13,17,18}; are frequently associated with chronic liver diseases (viral hepatitis or cirrhosis)\textsuperscript{19} and are not preceded by pre-neoplastic lesions such as biliary intraepithelial neoplasm or intraductal papillary neoplasm\textsuperscript{11,13,17,18}. Notably, bile ductular type (mixed) iCCAs share clinicopathological similarities with cytokeratin (CK) 19-positive hepatocellular carcinoma (HCC)\textsuperscript{17,20}. On the other hand, bile duct type (mucinous) iCCAs might appear grossly as mass-forming, periductal infiltrating or intraductal growing types; they are more frequently associated with primary sclerosing cholangitis (PSC) than bile ductular type (mixed) iCCAs, and can be preceded by preneoplastic lesions such as biliary intraepithelial neoplasm or intraductal papillary neoplasm\textsuperscript{11,13,17,18}. Interestingly, the bile duct type (mucinous) iCCAs share phenotypic traits with pCCA and pancreatic cancers\textsuperscript{21}. In our opinion, this histological subtyping should be taken into serious consideration because it underlines different cell of origin, aetiology, risk factors, molecular profile, clinical outcome and response to treatment.

**Risk factors**

Although most CCAs are considered de novo without apparent cause, there are also well-established risk factors\textsuperscript{22,23} (BOX 2). Infection with liver flukes (Opisthorchis viverrini and Clonorchis sinensis) is a common risk factor in East Asia where iCCA represents a large proportion (~85\%) of primitive liver cancers\textsuperscript{24-26}. The association between CCA (mainly pCCA) and PSC is well established especially in Europe, but PSC is a rare disease\textsuperscript{27}. More relevant from epidemiological and clinical points of view is the association with HBV-related and HCV-related liver diseases that have been identified as definitive risk factors, with a stronger association for iCCA than pCCA\textsuperscript{28}. In general, HCV-related diseases show an increased association with CCA in Europe and other Western countries; the association with HBV is more statistically significant where the prevalence of HBV infection is high, including Asian countries\textsuperscript{29,30}. Occult HBV infection is an emerging risk factor for iCCA\textsuperscript{31}. The increased incidence of iCCA, registered at the end of the past century, has been linked with the burden of HCV infection\textsuperscript{29,30}. Other studies also demonstrate an association between metabolic syndrome and CCA, which could lead to increased incidence in Western countries given the rising prevalence of obesity\textsuperscript{31,32}. Hepatolithiasis, as well as congenital biliary tract malformations such as Caroli disease and bile duct cysts, also predisposes to the development of CCA\textsuperscript{33,34}. All these risk factors share, as a putative pathogenic mechanism, chronic inflammation involving the biliary tract\textsuperscript{33,34}. This process might be favourised by local intrahepatic accumulation of bile acids, even in the absence of net cholestasis\textsuperscript{35}. Several toxic and environmental factors are known or suspected to be

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**Figure 1 | Worldwide incidence of CCA.** Worldwide incidence (cases per 100,000) of cholangiocarcinoma (CCA)\textsuperscript{36}. Data refer to the period 1971–2009. Green colour identifies countries with lower incidence (<6 per 100,000 cases, rare cancer), whereas pink colour indicates countries in which CCA is not a rare cancer (>6 per 100,000 cases). Diagnoses have been classified according to international classification of disease (ICD) codes (ICD-O-1, ICD-O-2, ICD-O-3, ICD-10, ICD-V9, ICD-V10, ICD-O). When available, the more incident form (intrahepatic (IH) versus extrahepatic (EH)) CCA and the temporal trend of incidence (↑ increasing trend; ↓ stable trend; ↓ decreasing trend) have been reported.
related to CCA development, among them nitrosamine-contaminated food, asbestos, dioxins, vinyl chlorides and thorotrast. Heavy smoking and possibly alcohol consumption represent relevant cofactors.

**Cells of origin**
The cell of origin, or cancer-initiating cell, is considered to be the normal cell that receives the first cancer-causing mutation. On the other hand, cancer stem cells (CSCs) are the cells that sustain tumour growth and propagation. The phenotype of cell of origin and CSCs might therefore be substantially different.

CCAs of different locations exhibit pronounced heterogeneity, raising the question of potential diverse cellular origins in every type of CCA. Possible cells of origin are hepatic stem cells, immature neural cell adhesion molecule positive (NCAM+) cholangiocytes, mature (NCAM-) interlobular cholangiocytes and peribiliary gland cells. According to different observations, pCCAs are thought to originate from mucin-secreting cholangiocytes and/or peribiliary glands located in hilar bile ducts. First, pCCAs are associated with preneoplastic lesions emerging in surface epithelium and peribiliary glands. Second, immunohistochemistry and gene-expression profiling of pCCA have shown a strong similarity to the cylindrical, taller, mucin-producing cholangiocytes (or peri- biliary glands) lining hilar bile ducts. iCCAs show inter-tumour heterogeneity, leading to the classification into two main different histological subtypes, with both probably having a different cell of origin. The bile duct (mucinous) type iCCAs arise in large intrahepatic bile ducts that share anatomical (mucin-secreting cholangiocytes and peribiliary glands) and embryological similarities with the extrahepatic biliary tree and pancreatic duct systems. This iCCA subtype displays immunohistochemistry, gene expression and a clinicopathological profile that can be superimposed on pCCA and, in addition, shows (together with pCCA) large similarities to pancreatic ductal adenocarcinoma. Consistently, the pattern of growth and the presence of preneoplastic lesions in cholangiocytes and peribiliary glands lining large intrahepatic bile ducts seem to indicate that these cells are candidate cells of origin. The bile ductular (mixed)-type iCCAs show an immunohistochemical and gene expression profile corresponding to mucin-negative cuboidal cholangiocytes that line the smaller bile ducts (interlobular bile ducts and ductules). In addition, the phenotypic and genotypic profiles are similar to cholangiolocellular carcinoma, thought to originate from hepatic progenitor cells. A number of observations suggest that bile ductular (mixed)-type iCCAs together with cholangiolocellular carcinoma and CK19+ HCC represent a group of primitive liver cancers originating from hepatic progenitor cells, the different phenotype depending on the step of hepatic progenitor cell differentiation toward cholangiocytes or hepatocytes, in which neoplastic transformation occurs.

**Cancer stem cells**
CSCs are defined as the cells within a tumour that possess the capacity for self-renewal and generation of heterogeneous lineages. CSCs are highly tumorigenic and responsible for chemoradioresistance and for tumour recurrence.

Several CSC markers are expressed in human CCAs, including CD133, CD44, CD13, SOX2, CD90, and Nanog, the entity of expression correlating with the worst prognosis. Although in most solid cancers CSCs represent <3% of the total cell population, in CCAs >30% of the tumour mass express CSC markers, pointing to the potential role of CSCs in CCA. Indeed, all CSC markers characterize normal stem cells located in canals of Hering or bile ductules and/or peribiliary glands, further indicating these structures as the site of origin of most CCAs. On the other hand, the absence of specific markers limits selective strategies targeting CSCs in CCAs. Consistently, also in liver-fluke-associated CCAs, the vast majority of neoplastic cells co-express CK19 and albumin, a feature characterizing hepatobiliary stem or progenitor cells. Interestingly, the CSC profile is similar between pCCA and the bile duct (mucinous) type iCCA with high representation.
of the intestinal CSC marker LGR5, whereas, at variance, CD133+ CSCs characterized bile ductular (mixed)-type iCCA. Notably, the original human CCA can be reproduced by injecting selected human CSCs into liver of a mouse model of cirrhosis. Most CCA-associated CSCs co-express epithelial and mesenchymal features and display markers of EMT (epithelial to mesenchymal transition) trait, therefore justifying many typical CCA properties including desmoplastic features, morphopathological heterogeneity, aggressiveness and resistance to chemotherapeutic agents.

The CSC model is also involved in tumour heterogeneity. Specifically, genetically distinct subclones together with developmental pathways and epigenetic modifications can contribute to functional heterogeneity and chemoresistance. Furthermore, the tumour microenvironment, composed of cancer-associated macrophages, fibroblasts and vascular cells and functioning as a specialized CSC niche, contributes to the maintenance of stemness and chemoresistance.

Genomic and epigenetic alterations

Genomic heterogeneity

The genomic heterogeneity of CCA (Table 1) is not only related to the diverse anatomical location of the tumour (that is, intrahepatic, perihilar or distal) but also to the various risk factors and associated pathologies. The most prevalent genetic alterations identified in CCA affect key networks such as DNA repair (TP53), the WNT–CTNNB1 pathway, and the SWI/SNF complex (PBRM1, BAP1). Intrahepatic CCA is characterized by activating mutations in the IDH1 and IDH2 genes, which are involved in the production of the enzyme isocitrate dehydrogenase, a key enzyme in the Krebs cycle. These mutations inhibit the enzyme from oxidizing isocitrate to α-ketoglutarate, leading to the production of oncometabolites that are associated with the development of cancer.

FGFR2 gene fusions

Fusion gene products between the kinase receptor FGFR2 and multiple other genes have been described in CCA. This alteration is not currently identified in other liver cancers, and is targetable and relevant for use in diagnosis of the disease. FGFR2 fusion gene products are FGFR2–BICC1, FGFR2–KIAA1598, FGFR2–TACC3, FGFR2–AHCYL1, FGFR2–MGEA5, FGFR2–KCTD1 and FGFR2–TXLNA. FGFR2–BICC1 and other selected FGFR fusions have been shown to facilitate oligomerization and FGFR kinase activation, which result in altered cell morphology and increased cell proliferation. The in vitro and in vivo oncogenic ability of FGFR2 fusion proteins has effectively been suppressed by treatment with FGFR kinase inhibitors such as BGJ398 and PD173074, as well as PD173074 and pazopanib, suggesting that FGFR fusion kinase
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In the epigenetic landscape, frequent mutations have been found in both IDH1 and IDH2 in CCA\textsuperscript{84,85}. Mutations in IDH are associated with hypermethylation of CpG shores, which suggests global deregulation within the transcriptional programme\textsuperscript{86}. IDH1 was emphasized as an epigenetic rheostat that when mutated was proposed to reshape the genomic landscape with a global consequence on the transcriptional machinery, triggering an altered state in the cellular process of differentiation\textsuperscript{86}. Importantly, mutations in IDH were shown to cause the deregulation of hepatocyte nuclear factor 4α (HNF4α), blocking hepatocytic differentiation and thus promoting bile duct cancer\textsuperscript{87}.

The contribution of chronic liver inflammation alongside an aberrant epigenetic landscape provides survival signals to the tumour (for example, IL-6–STAT3)\textsuperscript{88,89}. Marked reduction in DNA hydroxymethylation characterizes CCA tissue when compared with non-neoplastic tissue and a DNA mCyt content of ≥5.59% in peripheral blood mononuclear cells relates to a favourable outcome in primary liver cancers\textsuperscript{90}. On the other hand, several promoters of genes involved in Wnt signalling are hypermethylated in CCA tissue\textsuperscript{86}. A number of publications strongly suggest that epigenetic changes are early events in the malignant process, linking the tumour epigenetics to the microenvironment\textsuperscript{92} and opening up opportunities for early detection of CCA\textsuperscript{93}.

In particular, overexpression of histone deacetylase 6 (HDAC6) was reported in CCA, which promotes the shortening of the primary cilium and subsequent hyperproliferation\textsuperscript{94}. Molecular and pharmacological targeting of HDAC6 restores the primary cilium and decreases CCA cell growth\textsuperscript{95}. These data suggest that restoration of primary cilia in CCA cells by HDAC6 targeting is a potential therapeutic approach.

Molecular pathways and interactions

Endocrine and neuroendocrine factors

Several hormones and growth factors promote proliferation and exert anti-apoptotic effects on reactive and neoplastic cholangiocytes (FIG. 4)\textsuperscript{96}. CCAs are estrogen-sensitive tumours and the expression of both estrogen receptors (ER-α and ER-β) is generally increased\textsuperscript{97}. Although ER-α activation stimulates proliferation of CCA cells\textsuperscript{98}, the selective stimulation of the ER-β has antineoplastic effects \textit{in vitro} and \textit{in vivo} via induction of apoptosis\textsuperscript{99}. Commonly, estrogen-sensitive cancers lose ER-β expression with disease progression; however, the expression of ER-β is maintained in CCA at advanced stages, representing a potential therapeutic target\textsuperscript{100}. Indeed, administration of the ER antagonist, tamoxifen, or a selective ER-β-selective agonist, KB9520, inhibits CCA growth \textit{in vivo}\textsuperscript{101}. Moreover, estrogens stimulate the expression of IL-6 and vascular endothelial growth factor (VEGF), both crucial mediators of CCA biology\textsuperscript{102,103}.

Several other mediators have also been shown to regulate biliary proliferation in CCA (FIG. 4)\textsuperscript{104}, either by stimulating cell growth or affecting survival. Examples of factors promoting proliferative effects in CCA cells include serotonin, dopamine, leptin, opioids and the endocannabinoid 2-arachidonoylglycerol\textsuperscript{105–109}.

is a promising candidate for targeted therapy for CCA. Accordingly, the beneficial effect of FGFR2 inhibition in patients with CCA who have FGFR2–MGEA5 and FGFR2–TACC3 fusions after treatment with ponatinib and pazopanib, respectively, has been highlighted\textsuperscript{110}.

Finally, an integrative RNA-sequencing and exome-sequencing analysis revealed the presence of another novel fusion product, FGFR2–PPHLN1 [REF. 74]. This study demonstrated that FGFR2 fusions might represent the most recurrent targetable alteration in CCA. Importantly, FGFR2 fusions could also represent a diagnostic marker as these rearrangements are almost exclusively found in iCCA\textsuperscript{111–113}.

Epigenetic modifications

The mechanisms involved in gene regulation controlled by epigenetics include histone modification, DNA methylation and noncoding RNAs. Information related to the effect of altered histone modifications in CCA and to the response of CCA to epigenetic-based therapies is limited\textsuperscript{114–116}.

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Histological subtypes of intrahepatic CCA. a | Bile ductular (mixed)-type intrahepatic cholangiocarcinomas (iCCAs) are composed of areas with small tubular cord-like structures (yellow arrows) with irregular lumina (arrowheads) and cordonial areas expressing hepatocyte markers such as Hep-Par1 (hepatocyte-like areas, yellow arrows). The proportion of each area is largely variable. In general, mucin production is low or absent. Scale bars = 200 μm and 100 μm as indicated. b | Bile duct (mucinous)-type iCCAs are well-to-moderately differentiated adenocarcinoma with abundant stroma (asterisks); these tumour subtypes are composed of tubular, acinar or papillary structures; tumour cells are columnar with abundant clear, eosinophilic or mucinous cytoplasm; mucin production is also present in the glandular lumen (arrowheads). CK7, cytokeratin-7; H&E, haematoxylin and eosin; PAS, periodic acid–Schiff.

Figure 3
Interestingly, some of those mediators, such as serotonin or endogenous opioid peptides, limit cholangiocyte hyperplasia in response to damage. However, such a function is lost in the course of CCA development, in which they stimulate cell growth and survival.

Among neuroendocrine factors that either inhibit proliferation or induce apoptosis secretin, gastrin, α-aminobutyric acid, endothelin-1 and the endocannabinoid anandamide have been described. Although the activation of histamine H₁ and H₂ receptors (HRH₁ and HRH₂) inhibits CCA growth, histamine itself is considered proliferative as it sustains CCA growth by forming an autocrine loop. The proliferative effects of histamine are in part mediated through HRH₁, as shown by in vitro blocking experiments using a HRH₁ antagonist.

**Growth factors**

Immunohistochemistry studies have shown that the epidermal growth factor receptor (EGFR) is overexpressed in CCA human samples. EGFR activation triggers the oncogenic MAPK–ERK signalling pathway in cholangiocytes, making this receptor a potential target for therapy. To this extent, mutations and amplifications in the EGFR gene have been found in up to 15% and 5% of CCAs, respectively.

The expression level of hepatocyte growth factor (HGF) receptor (HFGFR, also known as c-Met) is also increased in CCA. In iCCA, HGF overexpression is associated with poor prognosis. Moreover, the activation of the EGF and HGF pathways has been shown to influence the metastatic potential of CCA. Indeed, EGFR activation contributes to the EMT of CCA cells, which has been implicated in tumour invasiveness and poor differentiation, and HGF stimulates in vitro cell invasiveness and motility via AKT and ERK pathways.

**Biliary compounds**

Cholestatic conditions are well-known risk factors for CCA development. Bile acids are able to activate the EGFR via a transforming growth factor (TGF) α-dependent mechanism, thereby stimulating cholangiocyte proliferation. Moreover, conjugated bile acids such as glycochenodeoxycholic acid downregulate the expression of the bile acid receptor farnesoid X-activated receptor (FXR, also known as bile acid receptor) and promote CCA growth in vivo; this event is inhibited by the administration of FXR agonists. Moreover, growth-promoting effects of conjugated bile acids via the activation of sphingosine 1-phosphate receptor 2 have been reported. In sum, in experimental models, bile acid accumulation during cholestatic conditions seems to facilitate carcinogenesis via the induction of biliary proliferation and inflammation rather than by direct mutagenic effects.

**Developmental pathways**

Deregulation of developmental pathways is involved in CCA pathophysiology. Cell-fate tracing experiments have demonstrated that combined activation of Notch and AKT can lead to iCCA arising from mature hepatocytes in mice. The expression of the intracellular domain of Notch2 upregulates proliferative genes that sustain the dysplastic proliferation of cholangiocytes in vivo. Notch2 and the Notch ligand Jagged1 seem to be particularly important, as their inhibition almost eliminates CCA development in a mouse model of liver cancer driven by transfection of activated forms of AKT and Ras oncogenes. Activation of Notch signalling has also been shown to induce EMT and increase the migration of CCA cells. An additional developmental pathway involved in CCA is the Hedgehog (Hh) signalling pathway. The Hh ligand Sonic hedgehog protein is overexpressed in human CCA and the inhibition of its receptor Smoothened by cyclopamine reduces the proliferation and invasion of CCA cells. CCA cells also exhibit a non-canonical G protein-coupled Hh signalling, which does not require cilia expression and controls chemotaxis and metastasis formation. Moreover, Hh signalling is a potent survival pathway in CCA. Activation of Hh pathway by myofibroblast-derived PDGF-BB is essential in protecting CCA derived PDGF-BB is essential in protecting CCA cells.

**Risk factors for cholangiocarcinoma**

<table>
<thead>
<tr>
<th>General</th>
<th>Age &gt;65 years</th>
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<td>Obesity</td>
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<td>Diabetes mellitus</td>
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<td>Inflammatory diseases</td>
<td>Primary sclerosing cholangitis</td>
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<td>Hepatolithiasis (Oriental cholangiohepatitis)</td>
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<td></td>
<td>Biliary tract stone disease</td>
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<td></td>
<td>Biliary–enteric anastomosis</td>
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<td>Liver cirrhosis</td>
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<tr>
<td>Infectious diseases</td>
<td>Opisthotrichis viverrini (liver flukes)</td>
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<td></td>
<td>Clonorchis sinensis (liver flukes)</td>
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<td>Hepatitis C</td>
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<td>HIV infection</td>
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<td>Drugs, toxins or chemicals</td>
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<td>Nitrosamines</td>
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<td>Asbestos</td>
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<td>Oral contraceptive pills</td>
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<td>Isoniazid</td>
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<tr>
<td>Congenital</td>
<td>Choledochal cysts (type I, solitary, extrahepatic; type IV, extrahepatic and intrahepatic)</td>
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<td></td>
<td>Caroli disease</td>
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<td>Congenital hepatic fibrosis</td>
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at least in part, via modulation of the cell-cycle kinase serine/threonine-protein kinase PLK2 (also known as polo-like kinases 2)\(^{1,41}\). As such, the fine-tuning of developmental pathways seems to be a promising therapeutic tool for CCA. A number of modulators and inhibitors of Notch and Hh signalling have been described and certainly warrant further investigation\(^{1,41}\).

**Inflammatory mediators**

CCA often arises in the context of biliary inflammation. Integrative molecular analysis of iCCA identified two different biological subtypes of the tumour, namely the proliferation and inflammation classes\(^7,6\). The latter is specifically characterized by activation of inflammatory pathways and overexpression of different cytokines. IL-6, which is constitutively secreted by CCA cells, has crucial paracrine stimulatory effects on cholangiocyte growth via the activation of the MAPK pathway or the epigenetic control of gene expression\(^1,2,12,13\). IL-6 also modulates the survival of CCA cells through the induction of induced myeloid leukaemia cell differentiation protein Mcl-1 (MCL1), an anti-apoptotic member of the Bcl2 family responsible for resistance to TRAIL\(^1,2,12,13\). MCL1 expression is induced by IL-6 via the modulation of the MAPK, JAK–STAT and AKT pathways\(^1,2,14,15\). Along the same lines, suppressor of cytokine signalling 3, which normally controls IL-6–STAT-3 signalling pathway by a negative feedback loop, is epigenetically silenced in CCA\(^1,18\). Malignant cholangiocytes also overexpress TGFβ and TGFβ receptor II\(^1,19,130\). TGFβ has been shown to induce EMT in CCA cells via modulation of epithelial and mesenchymal markers expression, and thereby promotes invasion and migration of CCA\(^1,131,132\).

The enzyme cyclooxygenase-2 (COX2), responsible for prostaglandin synthesis, also has a role in CCA development. COX2 expression is induced in CCA by both bile acids and oxysterols, oxidation products of cholesterol that are increased in bile during biliary inflammation\(^13,13,134\). The inhibition of COX2 by celecoxib has been shown to reduce proliferation and to increase apoptosis of CCA cells in different studies\(^13,135,139\). The microsomal prostaglandin E synthase-1, which is coupled with COX2 and mediates the synthesis of prostaglandin E2, is also crucial for cholangiocarcinogenesis in vitro and in vivo\(^16,169\).

Inflammatory cytokines might also induce the expression of inducible nitric oxide synthase (iNOS) in CCA\(^1,161\). Nitric oxide (NO) promotes DNA damage directly and also by inhibiting DNA repair mechanisms, thereby promoting carcinogenesis\(^1,161,162\). iNOS activation also stimulates the expression of COX2 [REF. 163]. In this complex scenario, in an integrated mouse model of CCA based on constitutively active AKT and YAP, cholestasis induced by bile duct ligation and IL-33 administration largely recapitulates the molecular pathogenesis of human CCA\(^1,164,165\).

**Tumour microenvironment**

CCA is characterized by a prominent desmoplastic stroma\(^1,60\), which is composed primarily of cancer-associated fibroblasts (CAFs) and a lesser proportion of tumour-associated macrophages (TAMs) and vascular cells. Through reciprocal interactions with malignant cells, stromal cells potentially contribute to the hallmarks of cancer and therapeutic responses\(^166,167\). Extracellular vesicles such as microvesicles and exosomes are emerging as important carriers involved in the intercellular communication of cancer cells with tumour microenvironment\(^168\). The presence of microRNA-laden extracellular vesicles in human bile has been described in patients with CCA\(^169,170\). CCA-cell derived extracellular vesicles are able to modulate fibroblast differentiation of mesenchymal stem cells, which in turn can enhance CCA growth in vitro by releasing proinflammatory factors, such as IL-6 [REF. 171].

The stroma of CCA undergoes profound changes in its composition during cholangiocarcinogenesis with upregulation of genes related to the cell cycle, extracellular matrix, TGFβ pathway and inflammation\(^172,173\). Stromal signature was found to be significantly associated with poor CCA prognosis (enrichment score = 0.52), consistent with a major contribution of the microenvironment to tumour progression\(^173\).

**Cancer-associated fibroblasts**

Although their origin has not been formally proven, CAFs are probably derived from activated hepatic stellate cells and/or portal (or periductal) fibroblasts in the liver\(^174\). CAFs, which express α-smooth muscle actin, are able to modulate several processes (that is, proliferation, migration, invasion and EMT) in CCA tumour cells\(^175,176,177,178\). Accordingly, patients with high levels of α-smooth muscle actin expression in CCA tissue samples exhibit worse prognosis\(^178,179\).

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**Table 1 | Genetic and epigenetic alterations found in cholangiocarcinoma**

<table>
<thead>
<tr>
<th>Molecular target</th>
<th>Functional role</th>
<th>Possible clinical features</th>
<th>Refs</th>
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<tr>
<td><strong>Genetic alterations</strong></td>
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<tr>
<td>TERT</td>
<td>Telomere stability</td>
<td>Activation (associated with Wnt signalling in HCC)</td>
<td>70</td>
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<tr>
<td>TPS3</td>
<td>Cell cycle</td>
<td>Inhibition (DNA damage response)</td>
<td>72,73,75</td>
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<tr>
<td>WNT or CTNNB1</td>
<td>Development and differentiation</td>
<td>Activation (genomic stability)</td>
<td>67</td>
</tr>
<tr>
<td>KRAS, BRAF, SMAD4, FGFR2</td>
<td>Tyrosine kinase receptor signalling</td>
<td>Activation (survival and proliferation)</td>
<td>29,68,70, 73–75, 78–80</td>
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<tr>
<td><strong>Epigenetic alterations</strong></td>
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<tr>
<td>IDH1, IDH2</td>
<td>Genome maintenance (epigenetic, DNA methylation)</td>
<td>Altered methylation status, survival</td>
<td>69,70,72, 74,75, 84–87</td>
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<tr>
<td>SWI–SNF complex (ARID1A, PBRC1, BAP1)</td>
<td>Chromatin remodelling</td>
<td>Activation (poor prognosis)</td>
<td>69,70,72, 74,75</td>
</tr>
<tr>
<td>Mixed-lineage leukaemia 3 (MLL3 or KMT2C)</td>
<td>Methyltransferase or chromatin remodelling</td>
<td>Activation</td>
<td>73</td>
</tr>
<tr>
<td>HDAC6</td>
<td>Regulate primary cilium morphology or functionality</td>
<td>Overexpressed</td>
<td>91</td>
</tr>
</tbody>
</table>

HCC, hepatocellular carcinoma.
Experimental *in vitro* models of CCA–stromal cell co-cultures have shown that the major signalling axes identified so far involving CAFs are: PDGF–PDGFR, SDF-1–CXCR4 (REFS 176, 177), HB–EGF–EGFR, CXCL5–CXCR2–IL-1β and Hh (178).

Regarding therapeutic implications, a study has demonstrated how the unique properties of CAFs can be used in tumour treatment (183). Activation or transdifferentiation of hepatic stellate cells to myofibroblasts enhances their susceptibility to apoptosis, which makes them exceptional targets to impair their reciprocal communication with cancer cells. By using the cytotoxic drug navitoclax (an inhibitor of Bcl-2, Bcl-X<sub>L</sub> and Bcl-w) apoptosis was induced only in CAFs in a syngeneic rat model of CCA, with the concomitant reduction of desmoplastic extracellular matrix proteins, suppressing tumour growth and improving host survival. Thus, these data strongly support the possibility of targeting CAFs from the tumour stroma as a therapeutic strategy.
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necessary in the context of a nodule in non-cirrhotic liver, biopsy is still a challenge and combined HCC–CCA — by imaging procedures is primitive liver cancers — such as HCC with stem cell enhancement (CT) (around 5ʹ) phase (MRI, CT) or an arterial peripheral-rim progressive homogeneous contrast uptake until the delayed similar to HCC pattern of contrast medium wash-in and wash-out nodules (>3 cm) as smaller nodules frequently show a hallmarks (such as contrast medium wash-in in the arte HCC is obligatory sion of a metastatic lesion, differential diagnosis with MF-iCCA occurs in context of cirrhotic liver, after exclu

Presentation, diagnosis and staging

Clinical presentation and diagnosis

CCAs are usually asymptomatic in early stages. When symptomatic, the clinical onset of iCCA is heterogenee with malaise, cachexia, abdominal pain, night sweats, fatigue and/or jaundice, associated or not with systemic manifestations. In 20–25% of cases, however, diagnosis of iCCA is an incidental finding. For pCCA, by contrast, jaundice (typically painless) is the most frequent clinical onset. In patients with PSC, CCA can emerge as a rapid deterioration of clinical conditions, dominant stricture during follow-up, during transplantation work-up or waiting list, or as an incidental finding at transplantation. As aforementioned, iCCA occurs more frequently in patients with chronic liver disease (HBV or HCV infection) or parasitic infestation than pCCA. Nonetheless, the majority of CCA cases occur in the absence of an evident chronic liver disease or other risk factors. In general, the mass-forming type represents the most frequent macroscopic presentation of iCCA (>90%) appearing, at imaging, as a nodule. If MF-iCCA occurs in context of cirrhotic liver, after exclusion of a metastatic lesion, differential diagnosis with HCC is obligatory. In this context, contrast-enhanced MRI studies on patients with iCCA show a lack of HCC hallmarks (such as contrast medium wash-in in the arterial phase followed by wash-out in the late phase) in all cases; however, by CT, this finding occurs only in large nodules (>3 cm) as smaller nodules frequently show a pattern of contrast medium wash-in and wash-out similar to HCC. The most frequent imaging patterns displayed by iCCA in the cirrhotic liver are a progressive homogeneous contrast uptake until the delayed (around 5ʹ) phase (MRI, CT) or an arterial peripheral-rim enhancement (CT). Currently, identification of rare primitive liver cancers — such as HCC with stem cell features (CK19+ HCC), cholangiocellular carcinoma and combined HCC–CCA — by imaging procedures is still a challenge. After excluding HCC in cirrhosis, or in the context of a nodule in non-cirrhotic liver, biopsy is necessary. According to most guidelines, biopsy should be avoided in case of surgical resectability because of the risk of tumour seeding; however, this statement lacks supporting evidence.

At histology, differential diagnosis of iCCA versus HCC or metastasis represents an unsolved problem, and no specific markers have been validated. A panel of immunohistochemistry markers is required to exclude metastasis, and the cytokeratin profile (CK7-, CK19+, CK20-) in combination with immunohistochemistry for Hep-Par1 is sufficient to exclude HCC. The positivity for N-cadherin, the study of IDH1 and IDH2 mutations, and the evaluation of albumin expression by in situ hybridization have been proposed for iCCA differential diagnosis.

Radiologically, pCCA usually appears as a bile duct stricture. In this instance, MRI plus magnetic resonance cholangiopancreatography represents the imaging procedure with the highest diagnostic accuracy for localizing and sizing the stricture; thus, the challenge is the definitive demonstration of malignancy. For a definitive diagnosis, these patients usually undergo endoscopic retrograde cholangiopancreatography and a number of procedures (cytology, brushing, FISH (fluorescence in situ hybridization)-polysomy, biopsy, intraductal ultrasonography, choledochoscopy, cholangioscopy, chromoendoscopy, confocal endoscopy, narrow-band imaging and so on) can be applied for microscopic confirmation, albeit with unsatisfactory sensitivity. Indeed, at least 40% of patients are sent to surgery without definitive diagnosis and, in 10% of cases after surgery, no evidence of cancer is seen in resected tissues.

Even more challenging is the diagnosis of CCA in patients with PSC. Biliary strictures, occurring at the time of PSC presentation in 15–20% of patients, might be of malignant nature in 10–15% of the cases. MRI, CT, endoscopic ultrasonography or FDG PET-CT cannot definitively demonstrate the neoplastic nature of the stricture. The only condition (either in patients with or without PSC) that does not require histological confirmation is biliary stricture associated with perihilar mass, hypertrophy–atrophy complex and vascular encasement, but this presentation is very rare. Endoscopic ultrasonography-guided fine-needle aspiration demonstrated a good diagnostic performance for discriminating benign versus malignant biliary strictures and without apparent risk of tumour seeding linked with the procedure. For iCCA, the risk of tumour seeding after transperitoneal biopsy of pCCA is based on limited evidence. The role of FISH-polysomy in detecting CCA in patients with PSC has been questioned by a meta-analysis, due to its limited sensitivity. Better markers are therefore required for early CCA detection. In this regard, serum CA19-9 levels >130 U/ml in PSC had sensitivity and specificity of 79% and 98% for the detection of CCA, respectively. However, the CA19-9 serum level is biased by elevation due to cholangitis and cholestasis and, is undetectable in Lewis-antigen-negative patients (average 7%). Correction of CA19-9 serum levels for fucosyltransferase (FUT2) and FUT3 genotype has been proposed to improve sensitivity in patients with CCA and PSC, as individuals lacking FUT3 activity
are unable to express the CA19-9 epitope\textsuperscript{235}. A number of biomarkers in serum (trypsinogen-2, serum IL-6, MUC5AC, trypsinogen-2, CYFRA21-1, progranulin), urine (volatile organic compounds, proteomic profiles) and bile (IGF1, microRNA-laden vesicles, proteomic profile, \textit{Wisteria floribunda} agglutinin-positive mucin 1, molecular profiling on cell-free DNA of bile supernatant) have been proposed, but none have reached clinical application\textsuperscript{81,226–230}. In summary, diagnosis of CCA still requires a combination of clinical, radiological and nonspecific histological and/or biochemical markers.

**Staging systems**

The goals of CCA management are to determine the surgical resectability and outcomes, and for this purpose correct staging is crucial. Different staging systems have been proposed for iCCA and pCCA. For years, iCCA has been staged by using the same tumour-node metastasis (TNM) system of HCC. In 2010, the 7\textsuperscript{th} edition of the AJCC/UICC staging manual\textsuperscript{231} proposed a staging system for iCCA based on specific criteria including the number of tumours, vascular invasion, direct invasion of adjacent structures histology and lymph node metastasis. Notably, tumour size was removed as a prognostic factor. This staging system was independently validated for iCCA in France in 2011 (REF. 14) with the evidence of a better discriminating capacity in predicting survival than with the 5\textsuperscript{th} and 6\textsuperscript{th} editions. The upcoming 8\textsuperscript{th} edition of the AJCC/UICC staging manual (set for publication in 2016) should further improve iCCA staging thanks to new insights on pathology and the relative importance of the different lymph node stations eventually involved. According to European Association for the Study of the Liver guidelines published in 2014 the 7\textsuperscript{th} edition of the AJCC/UICC staging system is preferred for staging iCCA\textsuperscript{3,15}.

As far as pCCA staging is concerned, in 1975, Bismuth and Corlette described their criteria for classifying bile duct involvement by pCCA and this staging system has been used for years to categorize pCCA\textsuperscript{231}. However, the lack of information concerning vascular encasement and distant metastasis makes this classification scarcely helpful for management decisions. By specifically focusing on predicting resectability and outcomes, the Memorial Sloan Kettering Cancer Center group proposed a staging system that classifies pCCA on the basis of the local tumour extension, site of bile duct involvement, portal vein invasion and hepatic lobar atrophy, although the size of the remnant liver is not specified\textsuperscript{233}. In 2011, the Mayo Clinic proposed a staging system comprising the tumour size, the extent of the disease in the biliary system, the involvement of the hepatic artery and portal vein, the involvement of lymph nodes, distant metastasis and the volume of the putative remnant liver after resection\textsuperscript{233}. Although complex, this classification has the merit of finely defining surgical options, standardizing prospective reporting of pCCA and discriminating between prognostic classes. The AJCC/UICC 7\textsuperscript{th} Edition that incorporates the TNM staging system is simple and is the most widely used postoperatively, but it cannot allow evaluation of local resectability of the tumour and, therefore, does not help with the decision about the various surgical options. In comparison with the 6\textsuperscript{th} edition, the 7\textsuperscript{th} edition of the AJCC manual allows improved prediction of survival and stratification of prognostic classes of patients who have undergone resection\textsuperscript{234}.  

**Therapies and treatment strategies**

**Surgery**

Surgery with complete resection represents the only treatment for CCA with curative intent\textsuperscript{236}. Resection of affected segments or lobe is usually performed in iCCA, pancreatoduodenectomy in dCCA and, depending on the extent of the tumour, resection of the involved intrahepatic and extrahepatic bile ducts, the associated ipsilateral liver, the gallbladder and regional lymph nodes in pCCA\textsuperscript{14}. Survival after resection mainly depends on the presence of tumour-negative margins, absence of vascular invasion and lymph node metastasis, and adequate functional liver remnant\textsuperscript{236}. Overall, 5-year survival after resection has been reported in the range 22–44% for iCCA, 11–41% for pCCA and 27–37% for dCCA\textsuperscript{14}. Traditionally, less than one-third of the patients have been classified as having a resectable tumour at the time of diagnosis owing to advanced local tumour infiltration or peritoneal or distant metastasis, lack of biliary reconstruction options and inadequate future liver remnant\textsuperscript{14}. However, differing resectability criteria and surgical strategies have been applied between regions, in particular between Western (USA and Europe) and Eastern centres, and a more aggressive surgical approach (including extended hepatic resection and combined vascular resection in early-stage pCCA) has led to increased rates of actual resection and improved outcomes in the East Asia\textsuperscript{237,238,238}.

Liver transplantation has been associated with rapid tumour recurrence and low survival (10–25%), and has historically not been recommended as treatment for unresectable CCA\textsuperscript{239}. However, in selected patients with early stage (I–II) pCCA, the rate of recurrence-free survival after 5 years has been reported in the range 65–68% after liver transplantation following protocols using neoadjuvant therapy (including external beam radiotherapy combined with radiosensitizing chemotherapy, endoluminal brachytherapy and maintenance chemotherapy)\textsuperscript{239–242}. Notably, the patient selection criteria used in these transplantation series have been rigorous, therefore survival outcomes after transplantation are not directly comparable to that observed in historical resection series, including a less-selective patient group\textsuperscript{243}. Indeed, in similar-staged patients, performance of extended hepatic surgery in pCCA has demonstrated survival comparable to that observed after liver transplantation (the disease-specific survival: 67.1% at year 5)\textsuperscript{237}.

**Chemotherapy**

For patients presenting with unresectable or metastatic CCA, systemic chemotherapy remains the mainstay palliative treatment modality. A meta-analysis combining the results from two randomized trials (ABC-02, phase III and BT22, phase II; see BOX 3 and
A systematic review published in 2014 of second-line gemcitabine and cisplatin failure, no established standard has demonstrated in several phase II studies. Capecitabine in combination with oxaliplatin have been evaluated in renal insufficiency, safety and efficacy using gemcitabine alone, the median overall survival (median 13.2 months) between these two groups. In addition, Y-TARE has provided partial response (27%) or stable disease (68%) in patients with iCCA. Hepatic arterial infusion includes a catheter-based intra-arterial infusion of chemotherapeutic agents, without embolization. This method has also been reported to be of benefit in cases of iCCA, but involves implantation of an infusion port or pump and might predispose to more complications than TACE and TARE.

Radiofrequency ablation seems to prolong survival in inoperable iCCA. Intraductal radiofrequency ablation has been shown to be safe and feasible in the treatment of extrahepatic CCA and seems to be a safe way of improving stent patency. On the other hand, photodynamic therapy can improve survival in patients with unresectable CCA. The role of radiation therapy in CCA is still not clearly outlined, but radiation with concurrent chemotherapy has been recommended in margin-positive and node-positive iCCA and pCCA, and in unresectable pCCA ineligible for liver transplantation. Thus, although results have been promising from the various locoregional types of therapy, conclusive evidence for efficacy in patients with CCA is still lacking and larger prospective randomized studies are warranted.

**Biliary stenting**

Although debated, guidelines recommend that routine biliary drainage should be avoided before staging and assessment of resectability of CCA and preoperatively. Preoperative drainage is indicated in cases of cholangitis, jaundice in conjunction with preoperative antineoplastic therapy, severe malnutrition, hepatic or renal insufficiency, and in patients undergoing portal vein embolization. A multidisciplinary approach is important to select the best approach in each case. Biliary drainage might be beneficial as a palliative treatment in patients with unresectable CCA, with longer survival (19 months for the endoscopic group versus 16.5 months for the surgical group) and less cost than surgical treatment.
Both plastic stents and self-expandable metallic stents can be utilized, but self-expandable metallic stents seem to offer several advantages, including higher patency duration than plastic stents284.

**Targeted therapy**

Several clinical trials are evaluating the effect of specific molecular agents targeting various signalling pathways in CCAs, for example tyrosine kinase inhibitors (for example, erlotinib, bevacizumab, cetuximab, panitumumab and lapatinib) (BOX 3 and Supplementary information S2 and S3 (tables)). Existing data demonstrate no or only very modest survival benefits of the agents tested. Larger clinical CCA studies, and also improved patient selection based on localization as well as molecular alterations, are needed29.

Novel molecular alterations have been identified in CCA267,274, and a large comprehensive study published in 2015 demonstrates that nearly 40% of the patients harbour genetic alterations that are potentially targetable27. Several preclinical (Supplementary information S4 (table)) and clinical phase I studies have been initiated27, evaluating some of these novel targets for therapy, including IDH280, microRNAs268,272,296 and fusion genes268,74,79,296. Targeted anti-fibrotic therapy is also under investigation296. In addition, the expression in tumour cells of the specific uptake transporter for bile acids, the apical sodium-dependent bile acid transporter (ASBT), has suggested the possibility of using cytostatic bile acid derivatives, such as the urso-deoxycholic acid–cisplatin conjugate BAMET-UD2, in targeted chemotherapy for CCA270.

In 2015, the rationale for immunotherapy with checkpoint-molecule-specific monoclonal antibodies in patients bearing ICCA without defects in HLA class I antigen expression has been provided271 but, so far, no clinical trial has been performed. Crucially, it must be underscored that the management of CCAs should only be undertaken in dedicated tertiary units with access to multidisciplinary approaches.

**Mechanisms of chemoresistance**

CCAs are highly chemoresistant tumours, which means that pharmacological therapies are generally unsuccessful. One of the goals of modern pharmacology is the identification and overcoming of the mechanisms of chemoresistance (MOC) by addressing the marked multidrug resistance phenotype of different tumours, including CCA, which usually becomes exacerbated in response to chemotherapy (TABLE 2). Most MOC are already present in healthy cholangiocytes, where they are involved in defense against toxic compounds from blood and/or bile.

In lowering the intracellular amount of drug (MOC-1)4, an important part is played by reduced uptake (MOC-1a) through solute carrier (SLC) transporters, such as organic anion-transporting polypeptides (OATPs). Substrates of OATP1A2, which is highly expressed in cholangiocytes, include methotrexate, taxanes and imatinib, whose uptake by CCA cells in vitro can be impaired by OATP1A2 downregulation272 or the expression of less active genetic variants273. Uptake of cationic drugs (for example, platinum derivatives and tyrosine kinase inhibitors) is mediated in part by organic cationic transporters (OCT), which are downregulated (OCT3)274 or very poorly expressed (OCT1)275 in CCA. Gemcitabine and 5-fluorouracil are taken up through nucleoside transporters, equilibrative nucleoside transporters (ENT) and concentrative nucleoside transporters (CNT). In CCA cells, low expression of ENT1 is associated with poor response to these drugs276–278, and CNT1 expression is also impaired279. Lack of sensitivity to cisplatin is due, in part, to reduced uptake through the copper transporter CTR1, whose expression in CCA is decreased279.

Export pumps of the ATP-binding cassette (ABC) superfamily of proteins are key elements determining the intracellular concentration of drugs (MOC-1b). Multidrug resistance protein 1, highly expressed in healthy cholangiocytes280, is able to export a large variety of anticancer drugs (for example, doxorubicin, etoposide, paclitaxel and vinblastine)281,282, hence reducing their efficacy in CCA283,284. Members of the ABCG family, MRP1, MRP3, MRP4 and MRP5, might also be involved in CCA chemoresistance285,286,287.

Intracellular mechanisms account for decreased drug precipitation or enhanced inactivation of active agents (MOC-2). Downregulation and/or impaired activity of enzymes involved in gemcitabine and 5-fluorouracil activation, such as thymidine phosphorylase, uridine phosphorylase 1 and uridine monophosphate synthetase, reduce the sensitivity of CCA to these drugs286,288. The phase II enzyme glutathione S-transferase P is highly expressed in CCA, which might have an important role in inactivating drugs by conjugation with glutathione289,290.

Changes in molecular targets could also affect the response to chemotheraphy (MOC-3). Thymidylate synthase has a key role in the sensitivity of CCA to 5-fluorouracil291. Although some controversy exists279,288,290, simvastatin has been shown to boost the 5-fluorouracil effect in CCA cells by suppressing thymidylate synthase expression292. Expression of ERs in CCA29 justifies its sensitivity to tamoxifen293 and KB9520, which activates apoptosis in experimental CCA284. Decreased ER expression might account for a weaker response to this type of drug than CCAs with a high ER expression. Upregulation of EGFR decreases the sensitivity of CCA cells to erlotinib294. Insulin-like growth factor type 1 receptor (IGF1R) contributes to tumour angiogenesis through upregulation of VEGF. Given the upregulation of IGF1R in CCA295, antibodies against the IGF1R or against its ligands might have limited therapeutic applications296,297.

Different repair strategies permit cancer cells to tackle different types of drug-induced DNA lesions (MOC-4). In 5-fluorouracil-resistant CCA cells, uracil-DNA glycosylase is upregulated, which activates base-excision repair, the major route to repair 5-fluorouracil-induced misincorporation of fluoronucleotides273. The endonuclease involved in nucleotide-excision repair, DNA excision repair protein ERCC-1 (ERCC1), removes a wide variety of bulky DNA adducts. ERCC1 has been associated with the response to cisplatin of several tumours, including CCA298. RAD51, upregulated in most CCA299, is a recombinase involved in repairing DNA
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double-strand breaks and is associated with poor sensitivity to cyclophosphamide, epirubicin and docetaxel. The DNA mismatch repair system recognizes and repairs erroneous insertion of nucleotides as well as short insertions and deletions. Downregulation of MutS (MSH2, MSH3 and MSH6) and MutLa (hMLH1 and PMS2) protein complexes involved in DNA mismatch repair results in genetic instability, poorer prognosis and higher chemoresistance in CCA in comparison with tumours without MutS and MutLa downregulation. Under the direct control of Tp53, upregulation of ribonucleotide reductase p53R2 increases the supply of nucleotides for repairing DNA damage. p53R2 expression is suggested as a predictive marker for resistance to gemcitabine in CCA. Serine/threonine-protein kinase tousled-like kinase 1 is highly expressed in CCA, regulating chromatin assembly and the repair of cisplatin-induced DNA damage.

As the final goal of most anticancer drugs is to induce apoptosis, downregulation and/or inactivation of pro-apoptotic mediators (MOC-5a) or enhanced expression and/or activity of anti-apoptotic factors (MOC-5b) resulted in decreased efficacy of chemotherapy. NK4 is a fragment of hepatocyte growth factor (HGF) that blocks its binding to HGF-receptor (HGF/R), which enhances 5-fluorouracil-induced activation of caspases 3 and 9. Downregulation of NK4 in response to 5-fluorouracil treatment constitutes an intrinsic mechanism of CCA resistance to this drug. In addition, CCAs are frequently resistant to TRAIL-mediated apoptosis. Interaction of Fas cell surface death receptor with calmodulin leads to the inhibition of Fas-induced apoptosis and might be involved in CCA chemoresistance. Moreover, mutations in the pro-apoptotic tumour suppressor TP53 have been suggested as predictors of CCA outcome. Among anti-apoptotic factors,

Table 2 | Most relevant proteins involved in MOC in cholangiocarcinoma

<table>
<thead>
<tr>
<th>Protein</th>
<th>Gene</th>
<th>Type of MOC</th>
<th>Generic mechanism</th>
<th>Role in multiple drug resistance phenotype of CCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>OATP2A1</td>
<td>SLCO2A1</td>
<td>MOC-1a</td>
<td>Drug uptake</td>
<td>Reduced uptake of anionic drugs</td>
</tr>
<tr>
<td>OCT3</td>
<td>SLC22A3</td>
<td>MOC-1a</td>
<td>Drug uptake</td>
<td>Reduced uptake of cationic drugs</td>
</tr>
<tr>
<td>ENT1</td>
<td>SLC29A1</td>
<td>MOC-1a</td>
<td>Drug uptake</td>
<td>Reduced uptake of nucleoside analogues</td>
</tr>
<tr>
<td>CNT1</td>
<td>SLC28A1</td>
<td>MOC-1a</td>
<td>Drug uptake</td>
<td>Reduced uptake of nucleoside analogues</td>
</tr>
<tr>
<td>CTR1</td>
<td>SLC31A1</td>
<td>MOC-1a</td>
<td>Drug uptake</td>
<td>Reduced uptake of cisplatin</td>
</tr>
<tr>
<td>MDR1</td>
<td>ABCB1</td>
<td>MOC-1b</td>
<td>Drug export</td>
<td>Enhanced drug efflux</td>
</tr>
<tr>
<td>MRP1, 3, 4 &amp; 5</td>
<td>ABCCC1, ABCC3, ABCC4 &amp; ABCC5</td>
<td>MOC-1b</td>
<td>Drug export</td>
<td>Enhanced drug efflux</td>
</tr>
<tr>
<td>TYMP</td>
<td>TYMP</td>
<td>MOC-2</td>
<td>Drug metabolism</td>
<td>Reduced gemcitabine and 5-fluorouracil activation</td>
</tr>
<tr>
<td>UPP1</td>
<td>UPP1</td>
<td>MOC-2</td>
<td>Drug metabolism</td>
<td>Reduced gemcitabine and 5-fluorouracil activation</td>
</tr>
<tr>
<td>UMP5</td>
<td>UMP5</td>
<td>MOC-2</td>
<td>Drug metabolism</td>
<td>Reduced gemcitabine and 5-fluorouracil activation</td>
</tr>
<tr>
<td>GSTP1</td>
<td>GSTP1</td>
<td>MOC-2</td>
<td>Drug metabolism</td>
<td>Inactivation by conjugation with glutathione</td>
</tr>
<tr>
<td>TYMS</td>
<td>TYMS</td>
<td>MOC-3</td>
<td>Change in drug target</td>
<td>Enhanced expression of target</td>
</tr>
<tr>
<td>ER-α or ER-β</td>
<td>ESR1 or ESR2</td>
<td>MOC-3</td>
<td>Change in drug target</td>
<td>Reduced expression of target</td>
</tr>
<tr>
<td>EGFR</td>
<td>EGFR</td>
<td>MOC-3</td>
<td>Change in drug target</td>
<td>Enhanced expression of target</td>
</tr>
<tr>
<td>IGF-1R</td>
<td>IGF1R</td>
<td>MOC-3</td>
<td>Change in drug target</td>
<td>Enhanced expression of target</td>
</tr>
<tr>
<td>UNG</td>
<td>UNG</td>
<td>MOC-4</td>
<td>DNA repair</td>
<td>Enhanced ability to activate base-excision repair</td>
</tr>
<tr>
<td>ERCC1</td>
<td>ERCC1</td>
<td>MOC-4</td>
<td>DNA repair</td>
<td>Removal of DNA adducts by nucleotide-excision repair</td>
</tr>
<tr>
<td>RAD51</td>
<td>RAD51</td>
<td>MOC-4</td>
<td>DNA repair</td>
<td>Repair of DNA double-strand breaks</td>
</tr>
<tr>
<td>MutS</td>
<td>MSH2, MSH3 &amp; MSH6</td>
<td>MOC-4</td>
<td>DNA repair</td>
<td>Enhanced ability to carry out mismatch repair</td>
</tr>
<tr>
<td>MutLa</td>
<td>MLH1 &amp; PMS2</td>
<td>MOC-4</td>
<td>DNA repair</td>
<td>Enhanced ability to carry out mismatch repair</td>
</tr>
<tr>
<td>p53R2</td>
<td>RRM2B</td>
<td>MOC-4</td>
<td>DNA repair</td>
<td>Supply of nucleotides to repair DNA damage</td>
</tr>
<tr>
<td>TLK1</td>
<td>TLK1</td>
<td>MOC-4</td>
<td>DNA repair</td>
<td>Repair of cisplatin-induced DNA damage</td>
</tr>
<tr>
<td>NK4 or HGFR</td>
<td>NK4 or MET</td>
<td>MOC-5a</td>
<td>Reduced apoptosis</td>
<td>Antagonist of HGF or reduced HGF activation</td>
</tr>
<tr>
<td>TRAIL</td>
<td>TNFSF10</td>
<td>MOC-5a</td>
<td>Reduced apoptosis</td>
<td>Downregulation of the pro-apoptotic protein</td>
</tr>
<tr>
<td>FAS</td>
<td>FAS</td>
<td>MOC-5a</td>
<td>Reduced apoptosis</td>
<td>Inactivation by binding to calmodulin</td>
</tr>
<tr>
<td>p53</td>
<td>TP53</td>
<td>MOC-5a</td>
<td>Reduced apoptosis</td>
<td>Inactivating mutations</td>
</tr>
<tr>
<td>Bcl-2</td>
<td>BCL2</td>
<td>MOC-5b</td>
<td>Enhanced survival</td>
<td>Up-regulation of the anti-apoptotic protein</td>
</tr>
<tr>
<td>XIAP or BIRC4</td>
<td>XIAP</td>
<td>MOC-5b</td>
<td>Enhanced survival</td>
<td>Up-regulation of the anti-apoptotic protein</td>
</tr>
<tr>
<td>Survivin</td>
<td>BIRC5</td>
<td>MOC-5b</td>
<td>Enhanced survival</td>
<td>Up-regulation of the anti-apoptotic protein</td>
</tr>
<tr>
<td>AKT</td>
<td>AKTI</td>
<td>MOC-5b</td>
<td>Enhanced survival</td>
<td>Promotion of anti-apoptotic pathways</td>
</tr>
</tbody>
</table>

HGF, hepatocyte growth factor; HGFR, hepatocyte growth factor receptor; MOC, mechanisms of chemoresistance.

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several members of the Bcl-2 protein family are upregulated in CCA cell lines, causing chemoresistance to cisplatin and 5-fluorouracil. The E3 ubiquitin protein ligase (XIAP, IAP3 or BIRC4), which inhibits caspases 3 and 9 and TRAIL pathway, shows increased activity in CCA-enhancing chemoresistance in vitro. Likewise, the anti-apoptotic protein survivin is also highly expressed in CCA. Finally, inhibition of the AKT signalling pathway in CCA cells leads to apoptosis via Bcl-2 downregulation and Bax upregulation, and sensitizes cells to cisplatin.

The demonstration that high numbers of CSCs are present in iCCA and pCCA is an additional explanation for the marked chemoradioresistance and for the high rate of recurrence of this cancer.

**Future perspectives**

CCAs display pronounced inter-tumoural and intra-tumoural heterogeneity caused, among others, by the inter-relationships between cancer cells, CSCs and the tumour microenvironment, clonal evolution and molecular (genetic and epigenetic) abnormalities. Indeed, studies on different cohorts described an extreme heterogeneity of molecular profiling with subclassification of CCAs in different molecular subtypes, associated with potential therapeutic targets and prognostic indicators. Unfortunately, most clinical trials have been performed without accurate molecular profile analyses and, therefore, the evaluation of outcomes for specific subgroups of patients with CCA is absolutely inadequate. For the future, it should be desirably that clinical studies on CCA will take into consideration the clinical–pathological subtyping (mixed versus mucin, CCAs associated with HCV, HBV, PSC or liver fluke) and the relative genetic background. With these considerations in mind, a major mission of the ENS-CCA is to support and coordinate a roadmap of future translational works to fill the gap between basic science and clinical studies exploring biomarkers for screening and surveillance of populations at risk, early diagnosis, prognosis and targeted therapies.

From a clinical point of view, the regulatory authorities should consider that CCA must be managed by dedicated centres provided with multidisciplinary expertise where personalized diagnostic work-up and management can be performed. This approach is fundamental given the heterogeneity and complexity of the disease. From a scientific point of view, a number of key issues need to be considered in mind, a major mission of the ENS-CCA is to support and coordinate a roadmap of future translational works to fill the gap between basic science and clinical studies exploring biomarkers for screening and surveillance of populations at risk, early diagnosis, prognosis and targeted therapies.

**Conclusions**

CCAs comprise a group of cancers with different locations and pronounced inter-tumoural and intra-tumoural heterogeneity. Apart from the anatomical location, CCA heterogeneity is caused by different variables including the inter-relationships between cancer cells, CSCs and the tumour microenvironment, clonal evolution and molecular (genetic and epigenetic) abnormalities. Specific efforts have been undertaken in the past to classify CCAs on the basis of anatomical location, genetic background, pathology, risk factors and molecular profile. However, a lot of work still remains to update clinical-pathological classification and to investigate biomarkers and/or imaging hallmarks specific for each CCA subtype. Studies, focused on molecular profiling, described different CCA subtypes and this should represent the background for clinical trials addressing targeted therapies against specific CCA subgroups. Waiting for these future acquisitions, surgery with complete resection, including liver transplantation in highly selected cases, is still the only curative therapy for CCA. Unfortunately, curative surgical resection is applicable in a minority of cases and therefore a main challenge is to increase the number of resectable cases by expanding early diagnosis. As a worldwide accepted statement, a personalized CCA diagnostic work-up and therapeutic approach must be managed by dedicated centres with multidisciplinary expertise and where translation from basic science to clinic can rapidly take place.


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Consensus Statement


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Competing interests statement
The authors declare no competing interests.

Further information
ENS-CCA: www.emsccan.org

Supplementary information
See online article: S1 (table) | S2 (table) | S3 (table) | S4 (table)

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