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ATOM, the all-inclusive, nominal EAES classification of bile duct injuries during cholecystectomy

A. Fingerhut · C. Dziri · O. J. Garden · D. Gouma · B. Millat · E. Neugebauer · A. Paganini · E. Targarona

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Abstract
Background Several studies seem to indicate at least a 2-fold increase in bile duct injuries (BDI) since the inception of laparoscopic cholecystectomy. Moreover, injuries seem to be more proximal, seem to be revealed earlier, are expressed by leaks more often than by strictures, are repaired more frequently by nonspecialists (either during the index operation or soon after), and appear to be more often associated with loss of substance and ischemia. The plethora of prior classifications probably attests to the evolving clinical spectrum, the mounting wealth of ever-increasing diagnostic methods, and an acknowledgment of insufficiencies or lack of data in earlier classification reports. Previous attempts at uniformity remain incomplete. The purpose of this study was to devise a nominal classification, combining all existing classification items, taking into account the changing pattern of BDI.
Methods Extensive bibliographic research, analysis of each category within the individual classifications combined into one uniform classification.
Results Fifteen classifications were retained. All items were integrated into the European Association for Endoscopic Surgery (EAES) classification, using semantic connotations, grouped in three easy-to-remember categories, A (for anatomy), To (for time of), M (for mechanism): (1) the anatomic characteristics of the injury: NMBD for non-main bile duct or MBD for main bile duct (followed by a number 1–6, corresponding to the anatomic level on the MBD), followed by Oc (for occlusion) or D (division), P (partial) or C (complete), LS (loss of substance), VBI (vasculobiliary injury in general), and whenever known, the vessel; (2) time of detection: Ei (early intraoperative), Ep (early postoperative) or L (late); and (3) mechanism of injury: Me (mechanical) or ED (energy-driven).

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A. Fingerhut (✉)
First Department of Surgery, Hippokration Hospital, University of Athens Medical School, Athens, Greece
e-mail: abefingerhut@aol.com

A. Fingerhut
Section for Surgical Research, Department of Surgery, Medical University of Graz, Graz, Austria

C. Dziri
Surgical Department B, Charles Nicolle University Hospital, Tunis, Tunisia
e-mail: chadli.dziri@planet.tn

O. J. Garden
Clinical Surgery, Royal Infirmary, University of Edinburgh, Edinburgh EH3 9YW, UK
e-mail: ogarden@uun.ed.ac.uk

D. Gouma
Surgical Department, Academic Medical Center, Amsterdam, The Netherlands
e-mail: d.j.gouma@amc.uva.nl

B. Millat
Surgical Department, Hôpital St Eloi, University of Montpellier, Montpellier, France
e-mail: b-millat@chu-montpellier.fr

E. Neugebauer
IFOM FOM–Institut für Forschung in der Operativen Medizin
Lehrstuhl für Chirurgische Forschung Private Universität Witten/Herdecke, 51109 Cologne, Germany
e-mail: edmund.neugebauer@uni-wh.de

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Conclusions The EAES composite, all-inclusive, nominal classification ATOM (*a*natomic, *t*ime *o*f detection, *m*echanism) should allow combination of all information on BDI, irrespective of the original classification used, and thus facilitate epidemiologic and comparative studies; indicate simple, appropriate preventive measures; and better guide therapeutic indications for iatrogenic BDI occurring during cholecystectomy.

Keywords Bile duct injury · Biliary injuries · Cholecystectomy · Classification · Laparoscopic cholecystectomy · Laparoscopy · Vasculobiliary injury

Current data seem to point to at least a 2-fold increase in the iatrogenic bile duct injury (BDI) rate during laparoscopic cholecystectomy compared with that reported for open cholecystectomy [1–4]. Likewise, the pattern of such injuries has changed: BDI sustained during laparoscopic surgery appear to be more proximal [5, 6]; revealed earlier (by leaks, collections, or biloma more often than by strictures [7, 8]; associated more often with loss of substance [9, 10] and ischemia, whether related to concomitant vascular injuries [11, 12] or to energy-driven lesions of the bile duct [13–15]; and repaired more frequently by nonspecialists during the index operation, or soon afterward.

Numerous BDI classifications have been devised since the still widely used Bismuth classification [13, 15–24] (Online Supplementary Material). The cornucopia of classifications probably attests to the recognition of the evolving clinical spectrum, the mounting wealth of ever-increasing diagnostic methods as much as acknowledgment of insufficient descriptions or variations of injury, and in particular variation in the very definition of BDI in previous reports [11, 25]. Efforts at uniformization or combination of existing classifications have been made [15, 16] but remain incomplete. However, one of the major drawbacks is that most of these classifications attach specific BDI (occlusion, division, partial, or complete) with a specific anatomical level, while in fact these injuries can occur almost anywhere and in a variety of ways.

In view of these inconsistencies and variations, and at the occasion of the European Association for Endoscopic Surgery (EAES) consensus conference on iatrogenic BDI during the 19th EAES meeting in Turin, Italy, in June 2011 [26], several members of the consensus conference and three outside European experts in the field of biliary surgery (OJG, DG, and BM) thought that it would be timely to devise a new uniform classification with two goals: first, to take into account the changing pattern of injuries incurred since the introduction of laparoscopic cholecystectomy; and second, to combine all the existing items in the most widely used classifications to date into one all-inclusive, universally accepted classification [15]. This would allow collection of data useful for further epidemiological and comparative studies as a comprehensive classification that collates all types of injury, whether culled independently by endoscopists, radiologists, or surgeons, integrated into a user-friendly, anonymous, electronic registry. This may lead to a more precise determination of the true incidence of BDI incurred during laparoscopic cholecystectomy and thus to the creation of preventive measures.

A. Paganini
Divisione de II Clinica Chirurgica, Dipartemento de Rome, Rome, Italy
e-mail: alessandro.paganini@uniroma1.it

E. Targarona
Surgical Department, Sant Pau University Hospital, Barcelona, Spain
e-mail: etargarona@santpau.cat

Methods

An extensive bibliographic research was performed by querying PubMed, Medline, Embase, and Ovid SP (version OvidSP_UI03.02.04.102; Ovid Technologies, New York, NY, USA) databases from 1990 to 2013 with MeSH terms as follows: classification, biliary injuries, bile duct injury, vasculobiliary injury, laparoscopic cholecystectomy, laparoscopy, cholecystectomy, with the following Boolean operators: classification AND laparoscopic cholecystectomy AND cholecystectomy AND biliary injury AND bile duct injury AND biliovascular injury. Additional articles were searched by manual identification of references contained in the key articles. There were no language restrictions on our initial search, but only classifications either published in English or translated into English by the authors were included and analyzed. The search was limited to classifications involving BDI related to cholecystectomy or bile duct surgery for benign disease. We eliminated reports of BDI that resulted from trauma, malignant disease, liver, pancreatic or gastroduodenal ulcer disease, or surgery thereof.

All authors analyzed the strengths and weaknesses of each classification and then through a Delphi process composed an all-inclusive nominal EAES classification. An anonymous electronic database was set up on the EAES Web site (http://www.eaes.eu).

Results

Classification in the literature

Of 67 articles found with the above-mentioned search methodology, 18 articles contained classifications and/or modifications thereof [1, 8, 9, 11, 13, 15–17, 19–21, 23, 24, 27, 28], along with two English translations [29, 30]. All related to BDI occurring during cholecystectomy. The total number of classifications retained for analysis was 13; two additional items were derived from partial classifications [6, 22]. The Appendix provides more information about the classification systems.

The classifications [1, 8, 9, 11, 13, 15–17, 19–21, 23, 24, 27–30] have strong positive points but also weaknesses (Table 1).

EAES all-inclusive classification

Combining all the items found in these 15 classifications [1, 8, 9, 11, 13, 15–17, 19–21, 23, 24, 27–30], a composite classification was devised: the EAES all-inclusive classification, which divided the injuries into three easy-to-remember overall categories known by the mnemonic ATOM (*a*natomic, *t*ime *o*f detection, *m*echanism). Each is discussed in turn.

Anatomic characteristics of the injury

This includes the anatomic level on the biliary tree of the initial injury and concomitant vasculobiliary injury.

The biliary tree is divided into the main and nonmain biliary ducts. The main biliary duct (MBD in the EAES classification) (including the common biliary, the common hepatic, and the right and left hepatic ducts) derived from the Bismuth, Strasberg, Neuhaus, Connor class E, McMahon, and Lau classifications [6, 8, 9, 15, 18, 19, 24, 29]. Only the anatomic localization is given, not the associated lesions indicated in these cited classifications. The types are as follows: type 1, low main BDI $\geq$ 2 cm distal to inferior border of superior hepatic confluence; type 2, middle main BDI $<$ 2 cm distal to inferior border of superior hepatic confluence; type 3, high main BDI involving the superior hepatic confluence but the left–right communication is preserved, usually on the roof; type 4, high main BDI involving the superior hepatic confluence but left–right communication is interrupted, including the E6 injury of Connor and Garden [6]; type 5, left or right hepatic duct injuries without injury to the superior confluence; and type 6, isolated segmental hepatic duct injury (right anterior or posterior sectorial; Li type 1) [22].

The non-main biliary duct (NMBD in the EAES classification) includes the cystic aberrant and accessory (hepatic bed, subhepatic, or Luschka) ducts, corresponding to Strasberg types A and C, Neuhaus A, Lau 1, Amsterdam type A, and Li type 2 [9, 15, 19, 22, 24, 28, 29]. The type as well as the circumferential and longitudinal extent of injury depends on whether the injured bile duct was initially occluded (O) (ligation, clip, sealed) or divided (D) [11, 24] and leaked. In both of these, the lowercase letter "c" is added to stand for complete interruption (ligation, clip, sealing, or division), while a partial interruption (ligation, clip, sealing, or division) is labeled "p," followed by the percentage of the circumference involved whenever this detail is known, whether there was a loss of substance between two divisions, irrespective of whether one or both of the extremities was occluded or divided (LS; the length in centimeters, whenever known, is indicated in parentheses).

Concomitant vasculobiliary injury (VBI) is defined as an injury to both a bile duct and a nearby vessel [12]. Our definition also includes vascular injury that occurs alone in the index operation but results in injury, such as septic complications, stricture, or liver atrophy. The BDI may be caused by operative trauma, may be ischemic in origin, or may be both; and it may or may not be accompanied by various degrees of hepatic ischemia. When the injured (whether repaired, sealed off, or ligated) vessel is known, the following abbreviations can be added to VBI and included in the detailed electronic analysis: RHA, right hepatic artery injury, which is the most often involved [11]; LHA, left hepatic artery; CHA, common hepatic artery; and PV, portal vein.

Time of detection

The time of detection is classified as early (E) or late (L). Within the early detection group, a separation is made between the intraoperative (Ei) and the immediate postoperative detection groups (Ep) because the latter may be accompanied by inflammation and/or sepsis [31], whereas the former is usually discovered by the presence of bile in the operative field or at intraoperative cholangiogram [6, 7, 15, 18]. Pulitano et al. [32] defined the early postoperative period as fewer than 7 days because of the therapeutic implications of concomitant arterial injury. This period should allow detection of most bile leaks as well. In addition, the onset of liver abscess several days or weeks after, or discovery of hepatic atrophy [11, 32] several years after cholecystectomy would be an indication of a lesion to one of the main hepatic ducts—for instance, a Strasberg type B or type E IV lesion [24], or a vascular lesion (Stewart class D) [11].

Mechanism of injury

The mechanism of injury may be classified as mechanical (Me) (e.g., scissors, Dormia basket stone extraction) or energy driven (ED) (e.g., cautery or ultrasonic) injury.

The EAES classification label for BDI thus includes a series of acronyms: MBD for main bile duct (followed by a

Table 1 Bile duct injury classifications in the literature

Study		Anatomical characteristic								Time of detection			Mechanism of injury
		MBD/NMBD	Level of injury	Type and extent of injury of bile ducts					VBI	Ei	Ep	L	Me/ED
				Oc		D (leak)		LS					
				c	p	c	p						
Bismuth	[13, 18, 19]	+	+	d	d	d	d	−	−	−	−	+	i
Strasberg et al.	[24]	+	+	a	d	+	+	a	a	a	a	+	±I, k
McMahon et al.	[8]	+	a	a	−	+	+	a	−	a	a	+	a
AMA	[19, 28]	+	a	e	e	d	d	a	−	a	a	+	−
Neuhaus et al.	[9, 29]	+	+	+	+	d	+	f, g	a	±	−	+	j
Csendes et al.	[20]	−	b	−	−	d	d	+	+h	−	−	+	k
Stewart et al.	[11]	−	b	d	d	+	+	+	+h	−	−	k	+
Hanover	[16, 27]	+	+	+	+	+	+	g	+	a	a	+	±j
Lau and Lai	[15]	+	+	d	d	+	+	+	+h	+	+	−	−
Siewert et al.	[10, 30]	+	±a, b	d	d	+	+	g	a	−	+	+	−
Cannon et al.	[1]	+	c	−	−	−	−	−	+h	−	−	−	−
Kapoor	[21]	+	b	+	+	+	+	+	+h	j		−	−
Sandha et al.	[23]	a	b	−	−	−	−	−	−	−	−	−	−
EAES		+	+	+	+	+	+	+	+	+	+	+	+

a discussed but no clear explanation of how to include it in the classification; *b* no clear discriminator of level of injury; *c* Hanover classification for level of injury, but only for one category (III) of lesions (but also refers to Bismuth); *d* no distinction between partial (P) and complete (C) or this distinction is not indicted for all types or localizations; *e* no distinction between division left open (leak) and occlusion; *f* distinguishes between longitudinal partial lesions less than or more than 5 mm; *g* not clear what is meant by "defect" or "structural defect" (loss of substance?); *h* no indication of which vessel; *i* energy driven injury recognized but not indicated in the classification; *j* injury by clip recognized but no differentiation between mechanical and energy-driven injury; *k* recognizes mechanical and electric injury but no distinction between the 2 in the classification; *l* distinguishes between division left open (bile leak) and occlusion

Classification is according to whether and how the anatomical characteristics, time of detection, and mechanism of injury were included in the classification. The EAES classification includes: *MBD* main biliary duct or *NMBD* non-main biliary duct, a number (1–6, corresponding to the anatomic level according to Bismuth except for 5) followed by the letters C (complete) or P (partial). *Oc* occlusion; *D* division; *LS (cm)* loss of substance (length); *VBI* vascular biliary injury; *RHA*, *LHA*, *CHA*, *PV*, or *MV*, for vascular biliary injury to the right hepatic artery, left hepatic artery, common hepatic artery, portal vein, and marginal vessels, respectively, if the injured vessel is identified; *Ei, Ep, or L* early intraoperative, early postoperative, or late for time of detection; and *Me* mechanical or *ED* energy driven for the mechanism of injury

EAES European Association for Endoscopic Surgery, + yes, − not included or discussed

Table 2 EAES classification matrix for bile duct injuries

Anatomical characteristics							***Time of detection***			***Mechanism***	
Anatomic level	Type and extent of injury					Vasculobiliary injury (yes=VBI+) and name of injured vessel (RHA, LHA, CHA, PV, MV); (no = VBI-)	Ei (de visu, bile leak, IOC)	Ep	L	Me	ED
	occlusion		division								
	C	P*	C	P*	LS**						
MBD											
1											
2											
3											
4											
5											
6											
NMBD											

For each injury, the surgeon fills in the following matrix: (1) single injury (yes/no); (2) multiple injuries (yes/no). Then one matrix is filled in for each injury, as appropriate. For example, an injury made by an energy-driven (ultrasonic) dissector involving the superior biliary confluence with interruption of the right and left hepatic ducts, detected (intraoperatively) during the operation by the presence of bile would be classed as MBD 4 C VBI Ei, ED. The Connor Garden E6 injury is in fact a type 4 with LS: MBD 4 LS

EAES European Association for Endoscopic Surgery, *MBD* main biliary duct, *NMBD* nonmain biliary duct (Luschka duct, aberrant duct, accessory duct), *level 1* ≥ 2 cm from lower border of superior biliary confluent, *level 2* < 2 cm from lower border of superior biliary confluent, *level 3* involves the superior biliary confluent but communication right left is preserved, *level 4* involves superior biliary confluent but communication right left is interrupted, *level 5a* right or left hepatic duct, *level 5b* right sectorial duct but bile duct still in continuity, *C* complete, *P* partial, *LS* loss of substance, *Me* mechanical, *ED* energy driven, *VBI* vasculobiliary involvement, *RHA* right hepatic artery, *LHA* left hepatic artery, *CHA* common hepatic artery, *PV* portal vein, *MV* marginal vessels, *Ei* early intraoperative, *Ep* early postoperative, *L* late, *OC* intraoperative cholangiogram

[a] Indicate percentage of circumference, if known

[b] Indicate length, if known

number 1–6, corresponding to the anatomic level on the main bile duct), NMBD for nonmain bile duct, followed by the relevant acronyms (Table 2): O or D, each with the suffix c or p (%), LS (cm), VBI (RHA, LHA, CHA, PV, marginal vessel [MV]), Ei, Ep, or L, and Me or ED. If for some reason a parameter is unknown, the suffix "?" is added.

Discussion

The composite EAES all-inclusive classification enlaces all possible BDI described in the literature into one global classification, which we consider a possible universally accepted classification because of its exhaustive character. By dividing BDI into three simple categories (*a*natomic, *t*ime *o*f detection, *m*echanism), abbreviated ATOM, we tried to make it easy to remember.

Classifications are useful for several reasons. They can provide an anatomic picture of the lesion, help classify the lesions according to severity of prognosis or to complexity [15], provide insight to the mechanisms responsible and thus lead to preventive measures, serve as guidelines for therapy, and allow comparison of management and outcomes between different series.

There are several ways of setting up a classification: either letters or numbers are used in an ordinal (succession of letters or numbers) or even a cardinal fashion, or letters are used in a nominal fashion to signify the word they imply (i.e., semantics). Most of the classifications analyzed herein follow some logical order for some items, but not for the entire list. None of the classifications analyzed herein was scaled to note the progression in an ordinate fashion. Only a few classification schemes [18, 21, 27], including ours, use letters (usually the first letter of the corresponding word) and are based on the meaning or semantics behind the letters, thus making it easer to remember, but the words used in the previous classifications varied in meaning and in language (Appendix).

Advantages of the EAES classification

There are several advantages to the EAES classification. Because the EAES classification contains all the possible items found in the 15 other classifications, all reports of BDI can be integrated into the EAES matrix and then used

Table 3 EAES classification matrix for moment of occurrence of BDI

Item	Check if present
Before identification of cystic triangle elements	
During identification (dissection) of cystic triangle elements	
After identification of cystic triangle elements (clipping, energy-driven or ligation of cystic artery or duct, opening of the cystic duct for IOC); misinterpretation of above mentioned structures)	
Before cholecystectomy	
During cholecystectomy	
After cholecystectomy	
During dissection or maneuvers for stone extraction from main bile duct via cystic duct	
During dissection or maneuvers for stone extraction from main bile duct via common bile	
During IOC (opening the cystic duct or what is thought to be so), introduction of catheter or instrument for IOC)	
During other maneuvers (hepaticoenterostomy)	
After IOC (withdrawal of catheter or instrument)	
During mechanical or energy-driven injury for elective hemostasis or ligation	
Mechanical or energy-driven injury for unexpected bleeding	

From EAES (http://www.eaes.eu)

EAES European Association for Endoscopic Surgery, *BDI* bile duct injury, *IOC* intraoperative cholangiogram

for epidemiology studies and comparison between published series (Table 3).

We distinguished between main biliary duct injuries (MBD) and non-main biliary duct injuries (NMBD), i.e., the cystic duct, liver bed (including Luschka), and aberrant ducts. NMBD injuries were individualized in 7 of the 13 full classifications (Strasberg type A and C, Neuhaus A, Hanover A, Siewert type 1, Keulemans, Bergman A, Cannon 1, Lau) [1, 9, 10, 15, 16, 19, 24, 28–30], but not the 6 others [8, 11, 13, 16, 17, 20, 21, 23] (Table 1). Unlike several classifications, we made a distinction between segmental hepatic ducts (MBD type 5 and the other NMBD duct injuries)—again, because of the therapeutic consequences that they imply [15, 21, 22]. From a semantic point of view, this system (MBD and NMBD) was preferred to small [15, 20], major, and minor, as implied by the Amsterdam Academic Medical Center [19, 28] and Strasberg et al. [24] classifications, which may be confused with connotations of severity, as implied in the McMahon classification [8]; or peripheral [9, 18, 27, 29] and central [10, 30], or significant and insignificant, used by Kapoor [21].

There are two types of cystic duct leaks. First, either the cystic duct was identified, clipped, ligated, or eventually sealed with an ultrasonic or bipolar device but then leaked because the clip or ligation was insufficiently placed (i.e., not including the entire diameter); because the clip or sealing was ineffective (failed), or because the ligation or the clip fell off (Hanover A1 [16, 27], Neuhaus A1 [9, 29], Strasberg type A [24], Siewert type 1) [10, 30]; or because the sealing was insufficient. This is not, strictly speaking, a BDI, as injury is defined as harm or damage that is done or sustained, but rather is a biliary complication [6]. Moreover, it can be a sign of increased ductal pressure, due, for example, to a retained stone, with a rate as high as 12.3 % in one series [33]. Likewise, leakage from the cystic duct at the Hartmann pouch after subtotal cholecystectomy cannot be considered a BDI. Last, the Stewart class I (cholangiogram cystic duct incision that extends into the common bile duct [CBD]) [11] and Csendes type 2 (lesions of the cystic–choledochal junction due to excessive traction, section of the cystic duct very close or at the junction with the CBD [20], or a thermal injury to the cystic–choledochal junction, even when transmitted by metallic clips placed on the cystic ducts are CBD [MBD] injuries) are not, strictly speaking, cystic duct injuries.

The second, more correctly called a BDI, is when the cystic duct is opened unwillingly (e.g., because of obscure anatomy) because of an impacted stone or because of misidentification, but left untreated.

There are at least two arguments in favor of including cystic duct injuries in our classification. First is the classic Davidoff injury [34], where the cystic is ligated, clipped, or sealed proximally, near the gallbladder, but where the distal ligation, clip, or seal is placed on the CBD. The distal hepatic duct stump between these two sites is left open and bile flows freely into the peritoneal cavity. This lesion would be classed as both MBD and NMBD, Oc and D, and LS. Second is because it would include both leaks due to a clip placed on the cystic duct, at the junction with the CBD, that slides off and leaves what then appears to be a lateral defect in the CBD (Csendes type II [20], Strasberg type A [24]) and energy-driven ischemic secondary openings—for instance, enhanced by a metallic clip placed on the cystic duct.

The importance of the type of interruption (occlusion or division) and degree or extent of circumferential and longitudinal interruption derives from the differences between occlusion (closure of the bile duct by ligation or clip) and division (solution of continuity), with the latter either occluded or left open. Both occlusions and divisions can be complete (360°) or partial (less than 360°). Partial occlusion can be clinically silent but can result in stricture [35], or if ischemia occurs, secondary necrosis and leak. Complete occlusion of the MBD creates upstream retention with early (jaundice, sepsis) or late (atrophy) symptoms. Complete occlusion of NMBD (Strasberg type B [24], Csendes D [20]), depending on the extent of territory involved, can be clinically silent (slight perturbation of liver function tests) or symptomatic. The distinction between occlusions, either complete (Oc) or partial (O), with division (D) (also either Dc or Dp) leading to a leak is important to consider [9, 24, 29] because the diagnosis and treatment are often quite different [15]. Leaks are rarely diagnosed during the operation [31]; more often they result in early postoperative bile collections and sometimes in bile peritonitis. Several authors [8, 9, 15, 19, 20, 24, 28–30] have distinguished partial (tangential) from complete division, but, with the exception of McMahon et al. [8], without any precision as to the circumference involved. Although most incomplete injuries of the main biliary tract (MBT) are indeed lateral in the anatomic sense of the word—and are depicted as a such [9, 11, 20, 24, 29]—*partial* might be a better term because some injuries can be anterior, posterior, or more rarely median, or any combination thereof. This is captured by our classification.

When a loss of substance occurs, this is indicated as LS. The term *loss of substance* was preferred to the terms *defect* [16, 27], *structural defect* [9, 11, 29, 30], *excision* [19, 28, 36], or *tissue loss* [15]. In the so-called classical Davidoff injury [34], the CBD is mistaken for the cystic duct and is injured in two spots: when the surgeon secures what is believed to be distal portion of the cystic duct, and at the common hepatic duct that is believed to be the proximal segment of the cystic duct leading to the gallbladder. The E6 type injury of Connor and Garden [6] consists of complete excision of the extrahepatic biliary duct, including the confluence, and would be a combination (addition) of EAES types 3 and 4 with LS. Whenever known, the length of the loss of substance is indicated because the length of the loss of substance and the length of stricture when this complication occurs both have their importance for surgical treatment [19, 20, 24, 28], balloon dilatation, or stenting [37]. To the contrary of several classifications, strictures were not included in our classification because stricture is the result of an injury, not the injury itself.

The distinction between partial and complete division (with E6 [6] or without separation [B4] [13] or loss of substance) has its importance in repair. Partial BDI is easier to treat endoscopically or even surgically when bile duct continuity is respected [15].

We also included the timing of BDI detection intraoperatively, either by a bile leak or cholangiography, or the early consequences thereof, such as a biloma, abscess, or biliary peritonitis, or invariably late, resulting in stricture or hepatic atrophy. The importance of this categorization is because management is different according to what has already been done (artery ligation, opening of the bile duct) and the moment when the BDI is detected—for example, during the index operation, the immediate postoperative period (often with sepsis), or late (stricture). Although one recent report found that 17 of 19 (89.4 %) BDI were discovered intraoperatively in a series of 10,123 cholecystectomies [38], only up to one third of BDI were usually recognized during the operation [6, 7, 15, 18]. As pointed out by others [24, 38–40], the value of intraoperative cholangiogram is its ability to demonstrate the injury intraoperatively, leading to early discovery and ideally early repair, before inflammation and infection set in. Occlusion of a part of the biliary tree (Strasberg type B lesions [24], not individualized by either the McMahon et al. [8] or Bismuth [13, 18, 19] classifications) are rarely discovered early. These injuries may remain asymptomatic or present 10 or more years after the initial insult with pain or cholangitis [41] or liver atrophy [6].

Vascular injuries are essential to consider for several reasons: when vascular injuries occur during the operation, they are a potential source of blood loss, and blind hemostasis is often the cause of BDI; hemostasis of a terminal major biliary tract vessel means that downstream ischemia will ensue; vascular injuries can occur by mechanical division (scissors or electronic scalpel) or by secondary thrombosis, either through energy-driven propagation (diffusion) or accidental coagulation; the marginal arteries are cut at the same time as the duct; and concomitant vascular and ductal injury (even when the latter is repaired) increases the risk of long-term bile duct stricture [14] and liver atrophy [32], and perhaps equally stricture and restricture of a hepatoenterostomy performed too close to the initial injury [37].

We chose not to indicate whether the BDI was the consequence of an opening in the main bile duct with the intention of accomplishing or not accomplishing an action, such as inserting a catheter; removing a stone, parasite, or foreign body; or preparing an anastomosis. We had several reasons for this. First, we did not want to use the word *intentional,* as its definition is not universal. Second, the term has a medicolegal connotation. Finally, most often the opening (e.g., choledochotomy [11, 24]) is recognized and is closed, ideally or over a T tube. We recognize, however, that the closure of any opening in the bile duct can leak, reopen, and/or evolve to a later complication such as stricture. The term *purposeful* might be more appropriate.

All intraoperative BDI, especially when considered minor, whenever repaired immediately by the same surgeon, should be reported as injuries. Injuries treated endoscopically, injuries that result in intra-abdominal bile collection only, or injuries in strictures not seen or treated by surgeons (e.g., drained and/or treated by interventional radiologists) may be underreported in surgical series but may be more prevalent in endoscopic or interventional radiology. This is notably the case for NMBD injuries (e.g., Strasberg type A, McMahon minor, Neuhaus 1) [8, 9, 25, 29]. Combining surgical classifications with endoscopic classifications, such as the EAES endeavor, should lead to a more accurate account of the true incidence of BDI.

Study limitations

Although we have endeavored to make this classification comprehensive, it has several shortcomings. We recognize that this classification is complex. However, when dealing with BDI, surgeons familiar with this type of surgery should not be in any hurry to categorize these lesions. Rather, they should strive to be complete and precise. All reports using one or another of the existing classifications ought to be entered into a matrix (Table 2) that can then be used for universal reporting and comparisons.

Our classification does not provide an exact progressive picture of the intensity or severity of the lesion. Although there seems to be a progression in severity when one goes from Bismuth 1 to 4 [13, 18, 19], from partial to complete transection, or from closed to open duct leaks, the same is not true for the other grades of our classification or for the other classifications. Moreover, Bismuth 6 [13] is not always more severe than B5 [18, 19] (or E6 of Connor and Garden [6]).

As in other classification systems, there may be some overlap. For instance, the discovery of liver atrophy [11, 32] several years after cholecystectomy could attest to the presence of a lesion in one of the main hepatic ducts and/or a vascular lesion.

We did not distinguish between injuries experienced during the index cholecystectomy or at secondary repair, as suggested by Connor and Garden [6] and Stewart et al. [11]. The lesions are basically the same but admittedly probably more destructive, with additional vascular insult; detection and repair are far more complex.

The exact moment during the operation of when the BDI took place was not included. We do, however, believe that knowing the moment the BDI occurs means it can be prevented—or at least discovered early and repaired, again highlighting the value of intraoperative investigations, notably intraoperative cholangiogram [39, 40]. The matrix in Table 3 aims to classify the moment when the BDI occurs.

Conclusions

All surgeons practicing bile duct surgery ought to report all BDI, even those that they consider part of the operation or those repaired immediately. A second step, after reporting all injuries systematically in the operative note, is to validate this classification by a prospectively gathered cohort and to set up a registry. The EAES has devoted a specific part of its Web site to this endeavor and provides classification forms that can be downloaded (Table 2) (http://www.eaes.org/). Ideally, these data, as well as a specific table related to detection, patient-related data, and information about the type of repair, should be collected in a prospective European registry that ensures patient and surgeon anonymity.

This all-inclusive, semantics-based classification should enhance further research by helping determine the true incidence of BDI during laparoscopic cholecystectomy. It will help us understand the underlying mechanisms so preventive and adapted therapeutic measures may be proposed.

Disclosures A. Fingerhut, C. Dziri, O. J. Garden, D. Gouma, B. Millat, E. Neugebauer, A. Paganini, and E. Targarona have no conflicts of interest or financial ties to disclose.

Appendix: legend to Table 1

Bismuth's classification was originally proposed to catalog postoperative strictures and to stratify their treatment. Therefore, the emphasis was placed on the length of healthy distal bile duct mucosa proximal to the injury [18, 19]. A level 6 was added in to the original 5 levels of stricture in 2001 [13] to indicate isolated right duct or right branch strictures. Of note, the level of stricture (lower limit) does not always correspond to the level of injury [13] because of potential initial ischemic or thermal damage as well as the shortening that often accompanies upstream dilatation of the duct. This is why the initial site of the injury is indicated to define the injury level in the EAES classification. However, it is acknowledged that the length of stricture has direct therapeutic implications [37], and this parameter is found in the length of "loss of substance." The Bismuth classification does not account for acute injuries (e.g., transection) or leaks; there is no mention of vasculobiliary involvement.

The classification of Strasberg et al. [24] was specifically devised for laparoscopic injuries. It is comprehensive in that it includes a wide spectrum of injuries, including intra- and extrahepatic injuries. Strasberg et al. distinguished between occlusions (types B and E), occlusions leading to biliary obstruction, and divisions without occlusion (types A, C, and D), leading to leaks and bilomas. They also classified isolated occlusion of the right hepatic duct (missing from the Bismuth classification). Although the authors made the distinction between complete (type C) and partial division (type D), partial occlusion is missing. The classification insists on mechanisms and technical errors. It also includes the location (integrating the Bismuth classification). However, partial division can be located on the CBD, common hepatic duct (CHD), left hepatic duct, or right hepatic duct (RHD), and this anatomic distinction cannot be categorized. Also, included in type A injuries are cystic duct leaks that occur as a result of physical injury as well as insecure clips or ligatures, leading to the question of whether this latter mechanism truly represents a bile duct injury or, as stated by Connor and Garden [6], a biliary complication. Of note, type B and C injuries occur mainly when an aberrant right duct is mistaken for the cystic duct when the latter runs directly into the RHD (rather than the CHD), an anomaly that involves between 2 % [42] and 28 % [43] of the population. Types A, B, and C can occur in almost any location along the biliary tree, not only in an aberrant RHD. Strasberg et al. suggested that it would be interesting to subclassify injury according to whether there was a loss of substance and the length of the loss of substance; according to injury with devascularization but without division; and according to concomitant injury to the right hepatic artery (RHA) (in types E1 and E2). However, they did not include these injury profiles in their classification. Theoretically, types B, C, and D involve the main bile duct but do not indicate the level of injury. The varieties e, d, and f in type E lesions are in fact redundant with types B and C. Last, type E categorizes occlusion but not division of the bile ducts above the superior confluence. Adequate and complete use of this classification should therefore include a letter A to D for the type plus, an E number, for the location, which is rarely seen in the literature. All these variations were included in our classification.

McMahon et al. [8] divided lesions according the extent of damage to the main bile duct, including laceration, transection, or excision, or, later, as stricture, leading to a simple two-class separation, minor and major. Minor includes <25 % of circumference of the CBD, laceration of the cystic CBD junction, or both. Major includes >25 % of circumference, going all the way to full transection, and involves the common bile or hepatic ducts. This classification has several negative aspects. For example, minor injuries are described for the CBD only, while major injury involves the CBD and CHD, without mention of injury including or above the superior confluence. Another negative aspect is that the cutoff of 25 % is arbitrary: minor injury can encompass a variety of injuries (Strasberg types A, B, C, and D) and ultimately can result in stricture (a major injury). Both a lateral laceration of less than 25 % of the circumference and the laceration of the cystic CBD junction are in the same category, minor, whereas the same type of latter injury can involve more than 25 % of the circumference and thus be a major injury. Moreover, although the distinction had certain therapeutic implications at the time the classification was derived, today, a 30 % to 35 % circumference injury might still be quite easily repaired surgically or by stent insertion [31], whereas the treatment options are not the same when the injury involves 90–99 % of the circumference. However, in this classification, both types of injury are classed in the same "major" group. These authors made no distinction between division (laceration and transection) and occlusion, and they did not mention longitudinal loss of substance or vasculobiliary involvement. Similar to Strasberg et al. [24], and McMahon et al. [8] included the Bismuth classification to designate the length of proximal healthy bile duct. However, they describe a class 0, which is not mentioned in any other publication on the topic and which does indicate how to integrate "major/minor" or the anatomic level into the two-category classification other than by a full description.

The Amsterdam Academic Medical Center classification derives from two publications [17, 28]. Most of the diagnoses were made postoperatively, through endoscopic and/or percutaneous transhepatic cholangiography. Although mentioned and discussed, the classification itself does not indicate the location of the injury, except for A (cystic duct and aberrant or peripheral hepatic radicals); B I (main CBD); and B II (aberrant segmental extrahepatic branches). It is not clear what the authors mean by "minor" and "major"—whether this represents "not severe" and "severe," injury to the NMBD and MBD, or partial (B) versus complete (D) divisions. Bile leaks from the cystic duct, aberrant or peripheral hepatic radicals, and minor bile duct lesions are lumped together in type A. Type D injuries include complete transection, but nothing in the classification allows us to determine whether there has been a loss of substance. The classification does not provide insight into the mechanism of injury. There is no distinction between complete transection with (the bile ducts will dilate) or without (the bile duct will leak) occlusion (ligature, clip). Last, there is no mention of vasculobiliary involvement.

The classification of Neuhaus et al. [9] was originally published in German; an English translation can be found in Schmidt et al. [29]. This classification individualizes the nonmain BDI (type A), distinguishing between cystic duct (A1) and hepatic bed leaks (A2). However, it does not separate the physical cystic duct injuries from leaks due to slipped clips or ligatures. It incorporates vascular injuries, but these are not integrated into the figures, and there is no indication as to how to list them. The length of injury (type C) as well as loss of substance ("structural defect") are included. However, the 5-mm cutoff value for length of injury is arbitrary, with no explanation of why this was chosen. The level of injury is not indicated for acute injuries, only for stenosis. The word *stenosis* is used to designate stricture, which might mean any narrowing, not necessarily one that is the result of a BDI. Last, the extent of circumferential damage is binominal (partial and complete division only, without any quantification).

The classification of Csendes et al. [20], which is based on the analysis of three varied circumstances of recruitment (retrospective multicentric, prospective monocentric, and referrals) as well as etiologic and anatomic considerations, is restrictive in that there is no indication of the anatomical level and it does not include injury above the superior confluence. Thus, it is difficult to distinguish between partial and complete type III injuries, and there is no distinction between occlusion and division. The classification brings forth some of the possible mechanisms, but energy-driven injuries are not separated from mechanical (scissors) injury, and there is no mention of vasculobiliary involvement. It takes into consideration the therapeutic consequences of longitudinal loss of substance (Davidoff injury) [20]. Moreover, it implies that injury to the RHD can (always) be repaired during the index operation and that type I and II lesions can (always) be repaired by T-tube insertion.

The classification of Way et al. [43] was originally published in *Annals of Surgery*, but the Stewart et al. classification [11] is most often cited. Curiously, however, the two classifications differ somewhat because the subdivision of class III lesions is found only in the first article and is rarely used or cited. Subdivision of class III is based on the proximal extent of the injury as follows: class IIIa, remnant CHD; class IIIb, CHD transected at the bifurcation; class IIIc, bifurcation excised; and class IIId, proximal line of resection above the first bifurcation or of at least one of the lobar ducts. The classification is based on anatomy but also on the mechanism of the lesion. This classification also emphasizes the role played by vascular injury, but this is represented in class IV only, while this type of injury can occur in all four categories. The authors separate aberrant duct from RHD injuries. The subdivision of classes IIIa and IIIB differentiates between common BDI without and with loss of substance, but it does not describe the Davidoff lesion. Isolated injury (whether transection or resection) is described in the mechanism of injury but is not represented in the diagram. Moreover, this classification does not provide descriptors for simple bile leaks (from the cystic duct or the liver bed) or take into account the lesions evolving into bile duct leaks due to cautery or ischemic injuries. It does not describe late complications, such as strictures, or identify transections at or above the bifurcation (except the RHD in class IV), and it does not categorize injury to the right sectorial ducts. Last, the senior author published another classification in Wikisurgery [25] in which the author used the term *type* as opposed to *class.* Of note, types I and II are identical to classes I and II, but types III and IV are different from classes III and IV, which only adds to the confusion.

The Hanover classification [16, 27] has tried to combine several items included in other classifications and comes close to the goal of being all-inclusive, but some information is still missing. In particular, this classification does not distinguish between intraoperative and postoperative detection of the injury, or the mechanism of injury (except for the clip mechanism, type B). The authors used the term *stenosis* to designate an occluded duct; this might lead to confusion with *stricture*. Again, the 5-mm length of loss of substance was used [9, 29] without explanation of where this cutoff value came from. The letters used to designate the vascular injury are based on Latin and therefore might not be integrated easily—for example, d for dextra (right), s for sinistra (left), p for propria hepatic artery, and DHC for ductus hepatocholedochus. It is not clear what the authors mean by *defect* in type D, particularly whether this represents loss of substance; if this is so, then there is no clear difference between the two types of injury when they occur above the bifurcation. The level of injury is not indicated for acute injuries, only for "stenosis," which once again is a possible source of confusion with "stricture."

The classification of Lau et al. [5, 15], taking into account anatomic, etiologic, and vascular problems, mentions loss of substance but does not include the short-term cautery or ischemic injuries or the long-term septic consequences. It attempts to class BDI according to ascending order of severity as well as the date of appearance of the complication (early and late). However, it is not always true that vascular injury to the right hepatic artery (type V) is more severe than type IV. Moreover, vascular injuries are lumped together in one class. It does not distinguish between sectorial and main BDI. The level of acute injury is indicated as CBD, CHD, right/left hepatic, or sectorial duct.

Four other simple classifications were found, one by Siewert et al. [10] (reported in English by Weber et al. [30]) and another by Cannon et al. [1], both essentially based on economic considerations and severity; one by Sandha et al. [23] based on endoscopic findings; and one by Kapoor [21].

The Siewert classification [10, 30] divides acute BDI into two anatomic categories, peripheral and central (probably nonmain biliary tract and main biliary tract). Siewert and colleagues [10, 30] described four types of injury, noting that there was an increasing order of severity; surprisingly, late bile duct strictures, classified as type II, are found between the immediate biliary fistula group (type I) and the central lesions (types III and IV). This classification includes vascular injury, without any specific description for types III and IV. Derived from surgical series, it was used essentially to class injury before endoscopic-only treatment. Lesions that healed without consequences were apparently not recorded; this is perhaps one of the reasons that the incidence of BDI is probably higher than previously reported.

The classification of Cannon et al. [1] provides three grades of injury, I to III. Grade I consists of leaks from the cystic stump, duct of Luschka, or accessory right hepatic ducts; grade II includes all other levels of injury lumped together, without any clear distinction of level, from the CBD to the intrahepatic ducts; and grade III embraces all combined vascular and biliary injuries. Severity was indicated by an increased financial burden, referral decisions, and mortality (0, 1.4, and 15 %, respectively) as the grade went from I to III.

The goal of the endoscopic classification of Sandha et al. [23] was to distinguish between leaks discovered early or late in the postoperative period and according to their intensity. Low-grade (LG) leaks are those identified after opacification of intrahepatic radicals (extravasation of contrast material requires hyperpressure), and high-grade (HG) leaks are those detected before radicular opacification (spontaneous extravasation of contrast material). Although this classification was the result of identification by endoscopic retrograde cholangiopancreatography, it can also be applied to cholangiograms, with HG corresponding the spontaneous bile leaks and LG to those detected after opacification takes place. Other than this distinction, however, the classification is largely insufficient, including the lack of anatomic location, the absence of nonleaking lesions, the absence of vascular involvement, and bile volume dependence (drainage is not mandatory). It was therefore not included in the tables we present here.

Last, Kapoor [21], in a letter to the editor, published a classification similar to our own, in that letters pertaining to the type of injury were used (nominal), rather than a categorical sequence (ordinal or cardinal). However, the abbreviations Kapoor used did not always correspond to semantics; for instance, "By" was used for bile leak ("y" for "yes"), "Bn" for no bile leak, corresponding to ligation or clip, circumference involved ("Cf" for full circumference [transection or excision] or "Cp" for partial circumference [clip, cautery, hole, excision]) and duct injured ("Ds" for significant duct [CBD, CHD, RHD, right sectoral or segmental duct] and "Di" for insignificant duct [cystic duct, subsegmental duct, subvesical duct]). Missing is full-circumference occlusion. Vascular injury was included: the letter V is added when there is associated vascular injury. There was no clear indication as to how to describe the level of injury.

Two other partial classifications have their importance: one by Li et al. [22], which separates segmental from Luschka duct lesions, and the other by Connor and Garden [6], which added an E6 injury to the Strasberg classification to describe complete excision of the extrahepatic confluence.

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