Received:
25 January 2018

Revised:
20 March 2018

Accepted:
28 March 2018

<https://doi.org/10.1259/bjr.20180115>

Cite this article as:

Suyama Y, Yamada Y, Yamaguchi H, Someya G, Otsuka S, Murayama Y, et al. The added value of tomosynthesis in endoscopic retrograde cholangiography with radiography for the detection of choledocholithiasis. *Br J Radiol* 2018; **91**: 20180115.

FULL PAPER

The added value of tomosynthesis in endoscopic retrograde cholangiography with radiography for the detection of choledocholithiasis

^{1,2,3}YOSUKE SUYAMA, MD, ^{1,2}YOSHITAKE YAMADA, MD, PhD, ²HIDEKI YAMAGUCHI, RT, ⁴GOU SOMEYA, MD, ⁴SEIJI OTSUKA, MD, ²YOSHITAMI MURAYAMA, RT, ³HIROSHI SHINMOTO, MD, PhD, ¹MASAHITO JINZAKI, MD, PhD and ²KENJI OGAWA, MD, PhD

¹Department of Radiology, Keio University School of Medicine, Shinjuku-ku, Tokyo, Japan

²Department of Radiology, Nippon Koukan Hospital, Kawasaki-shi, Kanagawa, Japan

³Department of Radiology, National Defense Medical College, Tokorozawa-shi, Saitama, Japan

⁴Department of Gastroenterology and Hepatology, Nippon Koukan Hospital, Kawasaki-shi, Kanagawa, Japan

Address correspondence to: Dr Yoshitake Yamada

E-mail: yamada@rad.med.keio.ac.jp

Objective: The diagnostic performance of endoscopic retrograde cholangiography (ERC) with radiography is imperfect. We assessed the value of adding tomosynthesis to ERC with radiography for the detection of choledocholithiasis.

Methods: This study included 102 consecutive patients (choledocholithiasis/non-choledocholithiasis, $n = 57/45$), who underwent both radiography and tomosynthesis for ERC in the same examination and were not diagnosed with malignancy. The reference standard for the existence of choledocholithiasis was confirmed by endoscopic stone extraction during ERC, intraoperative cholangiography, or follow up with magnetic resonance cholangiopancreatography ($n = 78, 11$, and 13 , respectively). A gastroenterologist and a radiologist independently evaluated the radiographs and the combination of tomosynthesis and radiographic images in a blinded and randomised manner. Receiver operating

characteristic analysis was used for statistical analysis.

Results: The areas under the receiver operating characteristic curve for combined tomosynthesis and radiography were significantly higher than those for radiography alone for both readers: Reader 1/Reader 2, $0.929/0.956$ [95% confidence interval (CI), $0.861-0.965/0.890-0.983$] vs $0.803/0.769$ (95% confidence interval, $0.707-0.873/0.668-0.846$), respectively ($p = 0.0047/< 0.0001$).

Conclusion: Adding tomosynthesis to radiography improved the diagnostic performance of ERC for detection of choledocholithiasis.

Advances in knowledge: Adding tomosynthesis to radiography improves detection of choledocholithiasis and tomosynthesis images can be obtained easily after radiographs and repeated immediately.

INTRODUCTION

Choledocholithiasis is a common disease that can be detected using imaging techniques, such as endoscopic retrograde cholangiography (ERC) with radiography and magnetic resonance cholangiopancreatography (MRCP).^{1,2} However, the diagnostic performance of ERC with radiography is imperfect, and choledocholithiasis is sometimes detected only during endoscopic stone extraction.³⁻⁷ Therefore, if choledocholithiasis is not detected by ERC with radiography, but is highly suspected, endoscopic stone extraction may be performed.³⁻⁵ Endoscopic stone extraction requires endoscopic sphincterotomy or endoscopic papillary balloon dilatation,⁸ which can cause complications such as pancreatitis, cholangitis, cholecystitis, sepsis, liver abscess,

perforation, haemorrhage, recurrence of stones, new gall-stone formation, and biliary carcinoma.⁹⁻¹³

Digital tomosynthesis allows for determination of depth and reconstruction of multiple image planes from a set of projection data acquired over a finite range of movements of the X-ray tube.¹⁴⁻¹⁶ The advantage of tomosynthesis images is that they provide better contrast of local structures at specific depths by removing the visual interference associated with the overlying anatomy.^{17,18} If adding tomosynthesis to radiography for ERC would improve the diagnostic performance for choledocholithiasis, clinicians could avoid unnecessary endoscopic sphincterotomy or endoscopic papillary balloon dilatation.

The purpose of this study was to assess the value of adding tomosynthesis to ERC with radiography for the detection of choledocholithiasis.

METHODS AND MATERIALS

Patients

We performed a retrospective review of patients who underwent both radiography and tomosynthesis for ERC in the same examination, on the same day, and who were not diagnosed with malignancy, at our hospital (Nippon Koukan Hospital) between July 2009 and June 2014. This study was approved by Institutional Review Board and waived the requirement for informed consent after Institutional Review Board review.

Imaging protocol

For radiography and tomosynthesis, the SONIALVISION Safire radiography/fluoroscopy system (Shimadzu Co, Kyoto, Japan), which has a direct-conversion digital flat panel detector, was used.

Radiography for ERC was performed at 80–85 kVp, 320 mA, and 60–80 ms with automatic control of the patients' exposure. The effective dose for an average American male (height, 176 cm; weight, 86 kg) was estimated to be approximately 0.064 mSv for the posteroanterior view, using the PCXMC 2.0 computer software tool, which is based on the Monte Carlo program¹⁹ and the International Commission on Radiological Protection publication 103.²⁰

Tomosynthesis was performed with the direct-conversion digital flat panel detector, which provided a 24 × 24 cm field of view in the 15 frames per second mode. The anatomical range and the imaging depth were adapted to the patients' body up to 30 cm in the anteroposterior direction. With these settings, the tube performed a continuous movement within $\pm 20^\circ$ for 2.5 s, and the reconstruction time was 12 s. The other acquisition parameters used for tomosynthesis were 90 kVp, 160 mA, and 16 ms. The effective dose for an average American male was estimated (as described above) to be approximately 0.60 mSv. Approximately, 20 coronal images with a thickness of 5 mm were generated by reconstructing tomosynthesis images covering the entire common bile duct in all patients.

Detection study

(1) Radiographs, (2) tomosynthesis images, and (3) a combination of tomosynthesis images and radiographs were evaluated for the presence of choledocholithiasis by a gastroenterologist with 6 years of clinical experience in gastroenterology and hepatology and 4 years of tomosynthesis experience, and a radiologist with 7 years of clinical experience in diagnostic radiology and no experience with tomosynthesis.

The readers were blinded to any clinical information and the ratio of choledocholithiasis to non-choledocholithiasis cases. They could change the window width and window level, and use the pan/zoom functions and greyscale inversion on the workstation. Each image was scored from 0 to 4 in terms of the diagnosis of choledocholithiasis, according to the reader's degree

of confidence. A rating of 4 represented the highest degree of confidence (definitely choledocholithiasis), that of 1 represented the lowest degree of confidence (possible choledocholithiasis), and that of 0 represented definitely no choledocholithiasis. The readers were also advised to ignore gallstones. To eliminate systematic bias in the reading of the images, the order of reading the radiographs and tomosynthesis images was random in the first two reading sessions; *i.e.* in the first and second session, each case occurred only once in each session (*i.e.* if the tomosynthesis image was included in the first session, the respective radiograph was included in the second session), allowing independent evaluation of the tomosynthesis images and radiographs. In the third session, all cases were included and tomosynthesis images and radiographs were evaluated in combination, in a blinded and randomised manner. The interval between each session was more than 1 month.

Reference method

The reference standard for the existence of choledocholithiasis was confirmed by endoscopic stone extraction during ERC (identified by a gastroenterologist with approximately 20 years of clinical experience), intraoperative cholangiography²¹ (identified by surgeons with over 20 years of clinical experience), or follow up with MRCP (performed less than 2 months after ERC and confirmed by a radiologist with approximately 30 years of clinical experience).

The diagnoses made on (1) radiographs, (2) tomosynthesis images, and (3) a combination of tomosynthesis images and radiographs by the readers were compared with the diagnosis made using the reference standard. The possible causes of false-negative and false-positive diagnoses were evaluated retrospectively. Causes of false-positive diagnoses and false-negative diagnoses were defined by consensus among two gastroenterologists and a radiologist.

Gradation of contrast media, which was the possible cause of false-positive diagnoses, was defined as relatively low contrast medium concentrations that resembled bile duct stones. Small stones were defined as those that measured less than 5.0 mm on tomosynthesis and were not detected by radiography.

Statistical analysis

Receiver operating characteristic analysis was used to compare the diagnostic performance among radiography, tomosynthesis, and combined tomosynthesis and radiography; the main analysis was the comparison between radiography and combined tomosynthesis and radiography. The Bonferroni correction was used for all multiple comparisons among radiography, tomosynthesis, and combined tomosynthesis and radiography. The area under the curve (AUC) and its 95% confidence interval (CI) were calculated for each diagnostic test. The sensitivity, specificity, accuracy, positive-predictive value (PPV), and negative-predictive value (NPV) of (1) radiographs, (2) tomosynthesis images, and (3) combined tomosynthesis images and radiographs were estimated by treating a rating of greater than 0 as a positive test result in each session. Interobserver agreement between the two readers was assessed using the kappa statistic.

Figure 1. Area under the receiver operating characteristic curve for the detection of choledocholithiasis. Area under the curve of (a) Reader 1 and (b) Reader 2.

The significance level for all tests was 5% (two-sided). All data were analysed using a commercially available software program (SPSS v. 21; IBM SPSS, Armonk, New York).

RESULTS

Patient characteristics

We performed a retrospective review of 102 consecutive patients [males/females, $n = 59/43$; age, $68.8 \pm 12.6/68.3 \pm 15.6$ years; height, $164.2 \pm 6.5/151.6 \pm 6.1$ cm; weight, $62.5 \pm 17.9/50.7 \pm 10.0$ kg; body mass index (BMI), $22.9 \pm 6.5/21.8 \pm 3.9$ kg m⁻²]. None of the 102 subjects were excluded from this study.

Consequently, of 102 patients, 57 patients ($n = 54$, confirmed by endoscopic stone extraction; $n = 3$, confirmed by intraoperative cholangiography) were diagnosed with choledocholithiasis (males/females, $n = 34/23$; age, $69.2 \pm 12.7/72.9 \pm 13.2$ years; height, $164.3 \pm 6.2/150.3 \pm 5.8$ cm; weight, $60.9 \pm 14.8/48.7 \pm 7.4$ kg; BMI, $22.4 \pm 4.3/21.5 \pm 2.7$ kg m⁻²), and 45 patients ($n = 24$, confirmed by endoscopic stone extraction; $n = 8$, confirmed by intraoperative cholangiography; $n = 13$, confirmed by MRCP) were diagnosed as having no choledocholithiasis (males/females, $n = 25/20$; age, $68.2 \pm 12.5/63.0 \pm 16.5$ years; height, $164.0 \pm 6.8/152.9 \pm 6.0$ cm; weight, $64.8 \pm 21.3/52.7 \pm 11.8$ kg; BMI, $24.1 \pm 8.6/22.5 \pm 4.8$ kg m⁻²). The 13 non-choledocholithiasis cases confirmed by follow-up MRCP had no recurrence of symptoms during a minimum follow up of 12 months.

AUCs, sensitivity, specificity, accuracy, PPV, and NPV for each diagnostic technique

The AUCs for each diagnostic technique are shown in Figure 1. Non-parametric AUC values for the techniques are summarised in Table 1. The AUC for combined tomosynthesis and radiography was significantly higher than that for radiography for both readers [Reader 1, 0.929 [95% CI (0.861–0.965)] vs 0.803 [95% CI (0.707–0.873)], $p = 0.0047$; Reader 2, 0.956 [95% CI (0.890–0.983)] vs 0.769 [95% CI (0.668–0.846)], $p < 0.0001$]. Figures 2 and 3 show examples of cases in which choledocholithiasis was correctly diagnosed on tomosynthesis images, but not on radiographs.

The sensitivity, specificity, accuracy, PPV, and NPV for each technique are summarised in Table 2.

False-positive diagnosis

For radiography, the causes of false-positive diagnoses (Reader 1, $n = 20$; Reader 2, $n = 35$) were the presence of air in the common bile duct ($n = 7$ and $n = 15$, respectively), which entered the common bile duct during performance of ERC, and bowel gas ($n = 13$ and $n = 20$, respectively). For tomosynthesis, the causes of false-positive diagnoses ($n = 24$ and $n = 27$, respectively) were the presence of air in the bile duct ($n = 17$ and $n = 18$, respectively) and graduation of contrast media ($n = 7$ and $n = 9$, respectively; Figure 4).

Table 1. Area under the receiver operating characteristic curve and its 95% confidence interval for the detection of choledocholithiasis on radiography, tomosynthesis, and combined radiography plus tomosynthesis for endoscopic retrograde cholangiography

Reader	Area under the ROC curve(95% CI)			<i>p</i> -value		
	Radiography	Tomosynthesis	Radiography + Tomosynthesis	Radiography vs Tomosynthesis	Radiography vs Radiography + Tomosynthesis	Tomosynthesis vs Radiography + Tomosynthesis
1	0.803 (0.707–0.873)	0.876 (0.794–0.928)	0.929 (0.861–0.965)	0.1474	0.0047 ^a	0.1008
2	0.769 (0.668–0.846)	0.907 (0.823–0.952)	0.956 (0.890–0.983)	0.0004 ^a	<0.0001 ^a	0.0129 ^a

CI, confidence interval; ROC, receiver operating characteristic.

^aSignificant by Bonferroni's method ($p < 0.0167$).

Figure 2. A 34-year-old male with choledocholithiasis. (a) radiography; (b) tomosynthesis. Stones were missed on the radiographs (a), but were detected on the tomosynthesis images (b). The stones (arrows) in the common bile duct are difficult to differentiate from air in the bowel on the radiograph (a) but are easy to differentiate from the air in the bowel on the tomosynthesis image (b).

For combined tomosynthesis and radiography, the causes of false-positive diagnoses ($n = 22$ and $n = 15$, respectively) were the presence of air in the common bile duct ($n = 18$ and $n = 14$, respectively) and gradation of contrast media ($n = 4$ and $n = 1$, respectively). There were no false-positive diagnoses due to gradation of contrast media with radiography alone, and no false-positive diagnoses due to bowel gas with tomosynthesis or with combined tomosynthesis and radiography. In contrast, the number of false-positive diagnoses due to the presence of air in the common bile duct was higher with tomosynthesis and combined tomosynthesis and radiography than with radiography alone (tomosynthesis, Reader 1, $n = 17$ and Reader 2, $n = 18$; combined tomosynthesis and radiography, $n = 18$ and $n = 14$, respectively; radiography, $n = 7$ and $n = 15$, respectively).

Figure 3. A 66-year-old female with choledocholithiasis. (a) radiography; (b) tomosynthesis. A stone (arrow) was missed on the radiograph (a), but was detected on the tomosynthesis image (b). Tomosynthesis (b) can detect the stone hidden by the contrast media and endoscope on the radiograph (a).

False-negative diagnosis

For radiography, the causes of false-negative diagnoses (Reader 1, $n = 10$; Reader 2, $n = 4$) were oversight ($n = 3$ and $n = 0$, respectively) and small stones ($n = 7$ and $n = 4$, respectively). For tomosynthesis and combined tomosynthesis and radiography, the cause of false-negative diagnoses (tomosynthesis, $n = 2$ and $n = 3$, respectively; combined tomosynthesis and radiography, $n = 1$ and $n = 2$, respectively) was oversight. In all cases of false-negative diagnoses with tomosynthesis and combined tomosynthesis and radiography, choledocholithiasis could be detected by retrospective assessment.

Interobserver variability

The κ values were 0.416 [95% CI (0.241–0.592)] for radiography, 0.595 [95% CI (0.404–0.785)] for tomosynthesis, and 0.707 [95% CI (0.555–0.859)] for combined tomosynthesis and radiography.

DISCUSSION

Our study demonstrated that combined tomosynthesis and radiography had a significantly higher AUC and a higher NPV than ERC with radiography alone for the detection of choledocholithiasis. These findings are important because adding tomosynthesis with an effective dose of less than 1 mSv to ERC with radiography could be useful in a clinical setting to: (1) prevent unnecessary endoscopic sphincterotomy or endoscopic papillary balloon dilatation and their potential life-threatening complications; (2) make it easy to find the location of the stones in the common bile duct, thereby facilitating endoscopic stone extraction; and (3) rule out any remaining stones if there were no shadows present in the bile duct on the tomosynthesis images after ERC. Although combined tomosynthesis and radiography has more risk compared with MRCP, MRCP is sometimes difficult to perform immediately,

Table 2. The sensitivity, specificity, accuracy, positive-predictive value, and negative predictive value for the detection of choledocholithiasis on radiography, tomosynthesis, and combined radiography plus tomosynthesis for endoscopic retrograde cholangiography

Reader	Performance	Radiography	Tomosynthesis	Radiography + Tomosynthesis
1	Sensitivity	0.825 (47/57)	0.965 (55/57)	0.982 (56/57)
	Specificity	0.556 (25/45)	0.467 (21/45)	0.511 (23/45)
	Accuracy	0.706 (72/102)	0.745 (76/102)	0.775 (79/102)
	PPV	0.701 (47/67)	0.696 (55/79)	0.718 (56/78)
	NPV	0.714 (25/35)	0.913 (21/23)	0.958 (23/24)
2	Sensitivity	0.930 (53/57)	0.947 (54/57)	0.965 (55/57)
	Specificity	0.222 (10/45)	0.400 (18/45)	0.666 (30/45)
	Accuracy	0.618 (63/102)	0.706 (72/102)	0.833 (85/102)
	PPV	0.602 (53/88)	0.667 (54/81)	0.786 (55/70)
	NPV	0.714 (10/14)	0.857 (18/21)	0.938 (30/32)

NPV, negative-predictive value; PPV, positive-predictive value.

depending on the situation, typically due to low accessibility. Combined tomosynthesis and radiography could be effective in cases where choledocholithiasis is highly suspected by CT or ultrasound, but the stones are not found by radiography on ERC.

Tomosynthesis is used for the detection of pulmonary nodules,^{15–17} urinary stones,¹⁸ and breast cancer,²² and in musculoskeletal radiography.^{23–25} To the best of our knowledge, this is the first study to use and evaluate the diagnostic performance of tomosynthesis for the detection of choledocholithiasis. Tomosynthesis images can be obtained quite easily after radiographs for ERC and can be repeated immediately within a minute or two (this includes reading the images), since both tomosynthesis and radiography can be performed by the same device. Although adding tomosynthesis to ERC with radiography increases radiation exposure, the effective dose of tomosynthesis is equivalent to 0.6 times

that of reference conventional abdominal X-ray,²⁶ which may be within acceptable limits.

In our study, the specificity of radiographs for ERC was numerically lower than that described in previous studies.^{3–5,7} False-positive diagnoses in this study were caused mainly by the presence of air in the common bile duct. It was difficult to discriminate the air in the common bile duct from stones both on tomosynthesis and on radiography. One possible reason for this is that the readers performed this detection study without clinical information and not at the same time that ERC was being performed. That is, if our detection study had been performed at the same time as ERC was being performed, and the readers could observe the injection of air into the common bile duct during ERC, the readers may have been able, at least to some extent, to distinguish stones from air correctly in the common bile duct.

In our study, in all cases of false-positive diagnoses due to bowel gas on radiographs, the bowel gas could be discriminated by tomosynthesis in the other two sessions (*i.e.* by tomosynthesis and by combined tomosynthesis and radiography). A possible reason for this is that tomosynthesis could determine a focus depth and could provide better contrast of local structures at a specific depth than radiographs, thereby allowing the readers to distinguish choledocholithiasis from bowel gas.

In contrast, gradation of contrast media was one of the causes of false-positive diagnoses on tomosynthesis, but not on radiography. Additionally, the number of false-positive cases due to gradation of contrast media on combined tomosynthesis and radiography was lower than that of tomosynthesis alone. This could be because gradation of the contrast medium was unclear on radiographs and was only visible on tomosynthesis images. Additionally, gradation of the contrast medium was likely to occur at the beginning of the cystic duct and the bifurcation of the intrahepatic bile duct. Therefore, if readers were aware of the

Figure 4. A 50-year-old male without choledocholithiasis (a) radiography; (b) tomosynthesis. Gradation of contrast media appeared as stones on the tomosynthesis image (b). Note that the gradation (arrows) is caused by bifurcation of the intrahepatic bile duct.

frequent sites of gradation of the contrast medium, the number of false-positive cases due to gradation of contrast medium on combined tomosynthesis and radiography and on tomosynthesis alone could be decreased.

In terms of experience in reading tomosynthesis images, one of the readers (Reader 2), a radiologist, had never performed ERC previously and was not accustomed to interpreting ERC images on a frequent basis. However, the diagnostic performance of Reader 2 in combined tomosynthesis and radiography was similar to that of Reader 1, who is a gastroenterologist with 6 years of clinical experience and 4 years of tomosynthesis experience. The interobserver agreement was good ($\kappa = 0.707$) for combined tomosynthesis and radiography. Therefore, this study also showed that less-experienced operators are able to detect stones in the common bile duct with confidence when performing tomosynthesis for ERC.

Our study had several limitations. First, the size of the patient group was relatively small, and further studies with larger

numbers of patients must be performed. Second, the image readers in this study were provided with no clinical information. If our detection study was performed concurrently with ERC, and the readers could observe the injection of air into the common bile duct during ERC, there may have been fewer false-positive cases caused by the presence of air in the common bile duct. Third, although this study demonstrated the diagnostic performance of radiographs, tomosynthesis images, and a combination of tomosynthesis images and radiographs, further investigations are needed to understand how tomosynthesis for ERC would impact clinical management.

CONCLUSION

Adding tomosynthesis to radiography improved the diagnostic performance of ERC for the detection of choledocholithiasis.

FUNDING

KO received a grant from Shimadzu.

REFERENCES

- Kaltenthaler E, Vergel YB, Chilcott J, Thomas S, Blakeborough T, Walters SJ, et al. A systematic review and economic evaluation of magnetic resonance cholangiopancreatography compared with diagnostic endoscopic retrograde cholangiopancreatography. *Health Technol Assess* 2004; **8**: 1–89. doi: <https://doi.org/10.3310/hta8100>
- Kim TK, Kim BS, Kim JH, Ha HK, Kim PN, Kim AY, et al. Diagnosis of intrahepatic stones: superiority of MR cholangiopancreatography over endoscopic retrograde cholangiopancreatography. *AJR Am J Roentgenol* 2002; **179**: 429–34. doi: <https://doi.org/10.2214/ajr.179.2.1790429>
- Ney MV, Maluf-Filho F, Sakai P, Zilberstein B, Gama-Rodrigues J, Rosa H. Echo-endoscopy versus endoscopic retrograde cholangiography for the diagnosis of choledocholithiasis: the influence of the size of the stone and diameter of the common bile duct. *Arq Gastroenterol* 2005; **42**: 239–43. doi: <https://doi.org/10.1590/S0004-28032005000400009>
- Pasanen P, Partanen K, Pikkarainen P, Alhava E, Pirinen A, Janatuinen E. Ultrasonography JE. Ultrasonography, CT, and ERCP in the diagnosis of choledochal stones. *Acta Radiol* 1992; **33**: 53–6. doi: <https://doi.org/10.1177/028418519203300111>
- Canto MI, Chak A, Stellato T, Sivak MV. Endoscopic ultrasonography versus cholangiography for the diagnosis of choledocholithiasis. *Gastrointest Endosc* 1998; **47**: 439–48. doi: [https://doi.org/10.1016/S0016-5107\(98\)70242-1](https://doi.org/10.1016/S0016-5107(98)70242-1)
- Palazzo L, Girollet PP, Salmeron M, Silvain C, Roseau G, Canard JM, et al. Value of endoscopic ultrasonography in the diagnosis of common bile duct stones: comparison with surgical exploration and ERCP. *Gastrointest Endosc* 1995; **42**: 225–31. doi: [https://doi.org/10.1016/S0016-5107\(95\)70096-X](https://doi.org/10.1016/S0016-5107(95)70096-X)
- Das A, Isenberg G, Wong RC, Sivak MV, Chak A. Wire-guided intraductal US: an adjunct to ERCP in the management of bile duct stones. *Gastrointest Endosc* 2001; **54**: 31–6. doi: <https://doi.org/10.1067/mge.2001.115006>
- Lai KH, Chan HH, Tsai TJ, Cheng JS, Hsu PI. Reappraisal of endoscopic papillary balloon dilation for the management of common bile duct stones. *World J Gastrointest Endosc* 2015; **7**: 77–86. doi: <https://doi.org/10.4253/wjge.v7.i2.77>
- Hammarström LE, Stridbeck H, Ihse I. Long-term follow-up after endoscopic treatment of bile duct calculi in cholecystectomized patients. *World J Surg* 1996; **20**: 272–6. doi: <https://doi.org/10.1007/s002689900043>
- Tanaka M, Takahata S, Konomi H, Matsunaga H, Yokohata K, Takeda T, et al. Long-term consequence of endoscopic sphincterotomy for bile duct stones. *Gastrointest Endosc* 1998; **48**: 465–9. doi: [https://doi.org/10.1016/S0016-5107\(98\)70086-0](https://doi.org/10.1016/S0016-5107(98)70086-0)
- Freeman ML, Nelson DB, Sherman S, Haber GB, Herman ME, Dorsher PJ, et al. Complications of endoscopic biliary sphincterotomy. *N Engl J Med* 1996; **335**: 909–19. doi: <https://doi.org/10.1056/NEJM199609263351301>
- Schreurs WH, Juttman JR, Stuijbergen WN, Oostvogel HJ, van Vroonhoven TJ. Management of common bile duct stones: selective endoscopic retrograde cholangiography and endoscopic sphincterotomy: short- and long-term results. *Surg Endosc* 2002; **16**: 1068–72. doi: <https://doi.org/10.1007/s00464-001-9104-8>
- Sugiyama M, Atomi Y. Risk factors predictive of late complications after endoscopic sphincterotomy for bile duct stones: long-term (more than 10 years) follow-up study. *Am J Gastroenterol* 2002; **97**: 2763–7. doi: <https://doi.org/10.1111/j.1572-0241.2002.07019.x>
- Grant DG. Tomosynthesis: a three-dimensional radiographic imaging technique. *IEEE Trans Biomed Eng* 1972; **19**: 20–8. doi: <https://doi.org/10.1109/TBME.1972.324154>
- McAdams HP, Samei E, Dobbins J. 3rd, Tourassi GD, Ravin CE. Recent advances in chest radiography. *Radiology* 2006; **241**: 663–83.
- Yamada Y, Jinzaki M, Hashimoto M, Shiomi E, Abe T, Kuribayashi S, et al. Tomosynthesis for the early detection of pulmonary emphysema: diagnostic

- performance compared with chest radiography, using multidetector computed tomography as reference. *Eur Radiol* 2013; **23**: 2118–26. doi: <https://doi.org/10.1007/s00330-013-2814-1>
17. Yamada Y, Jinzaki M, Hasegawa I, Shiomi E, Sugiura H, Abe T, et al. Fast scanning tomosynthesis for the detection of pulmonary nodules: diagnostic performance compared with chest radiography, using multidetector-row computed tomography as the reference. *Invest Radiol* 2011; **46**: 471–7. doi: <https://doi.org/10.1097/RLI.0b013e318217b838>
 18. Mermuys K, De Geeter F, Bacher K, Van De Moortele K, Coenegrachts K, Steyaert L, et al. Digital tomosynthesis in the detection of urolithiasis: diagnostic performance and dosimetry compared with digital radiography with MDCT as the reference standard. *AJR Am J Roentgenol* 2010; **195**: 161–7. doi: <https://doi.org/10.2214/AJR.09.3075>
 19. Servomaa A, Tapiovaara M. Organ dose calculation in medical X ray examinations by the program PCXMC. *Radiat Prot Dosimetry* 1998; **80**: 213–9. doi: <https://doi.org/10.1093/oxfordjournals.rpd.a032509>
 20. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Ann ICRP* 2007; **37**: 1–332. doi: <https://doi.org/10.1016/j.icrp.2007.10.003>
 21. Jamal KN, Smith H, Ratnasingham K, Siddiqui MR, McLachlan G, Belgaumkar AP. Meta-analysis of the diagnostic accuracy of laparoscopic ultrasonography and intraoperative cholangiography in detection of common bile duct stones. *Ann R Coll Surg Engl* 2016; **98**: 244–9. doi: <https://doi.org/10.1308/rcsann.2016.0068>
 22. Houssami N, Skaane P. Overview of the evidence on digital breast tomosynthesis in breast cancer detection. *Breast* 2013; **22**: 101–8. doi: <https://doi.org/10.1016/j.breast.2013.01.017>
 23. Fujii M, Aoki T, Okada Y, Mori H, Kinoshita S, Hayashida Y, et al. Prediction of femoral neck strength in patients with diabetes mellitus with trabecular bone analysis and tomosynthesis images. *Radiology* 2016; **151657281**: 933–. doi: <https://doi.org/10.1148/radiol.2016151657>
 24. Geijer M, Gunnlaugsson E, Götestrand S, Weber L, Geijer H. Tomosynthesis of the thoracic spine: added value in diagnosing vertebral fractures in the elderly. *Eur Radiol* 2017; **27**: 491–497. doi: <https://doi.org/10.1007/s00330-016-4392-5>
 25. Ottenin MA, Jacquot A, Grospretre O, Noël A, Lecocq S, Louis M, et al. Evaluation of the diagnostic performance of tomosynthesis in fractures of the wrist. *AJR Am J Roentgenol* 2012; **198**: 180–6. doi: <https://doi.org/10.2214/AJR.11.6374>
 26. Radiation and your patient: a guide for medical practitioners. *Ann ICRP* 2001; **31**: 5–31.