Classification of Incidental Findings

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1 Introduction

Cross-sectional imaging, by means of CT and MR imaging, has evolved to play a major part in patient management as well for investigations on population-based cohorts. Due to continuous improvements in scanner and sequence technology, cross-sectional imaging has steadily advanced to provide excellent spatiotemporal resolution imaging, enabling the detection of complex disease processes as well as subclinical disease states (Bamberg et al. 2015). Apart from aiding to assess the target structures and sought medical issues, the increased application of cross-sectional imaging methods has resulted in an increased detection of incidental findings (IF). While some studies indicate that a high number of IFs derived from research studies result in important clinical benefits, such as earlier diagnosis to a small but significant minority of participants (Orme et al. 2010; Espinoza et al. 2014), the American College of Radiology pleads caution on the potential cascade of additional (noninvasive and invasive) investigations, anxiety and morbidity caused by the discovery of IFs (Berland et al. 2010). Hence, guidance on IF categorization and management is indispensable, yet difficult to allocate. While most population-based screening studies provide dedicated guidelines for IF management, the lack of clear-cut recommendations for IF management in the clinical setting results in high variations in practice among reporting radiologists.

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2 Classification of Incidental Findings in a Research Setting

The increasing application of imaging in population-based cohorts has helped to provide unbiased data to estimate the prevalence of certain diseases as well as to further understand complex disease processes, as well as the identification of novel imaging biomarkers (Schmermund et al. 2002; Bamberg et al. 2015). Numerous multicenter population-based studies have demonstrated the highly valuable integration of imaging and nonimaging modalities for risk assessment and prediction of diseases, such as cardiac events, investigated in the Heinz Nixdorf Recall Study (Erbel et al. 2010). While research imaging is designed to address specific questions regarding the population-based study set-up, its primary function is not a diagnostic test for clinical conditions, potentially lacking the standard of clinical diagnostic imaging (The Royal College of Radiologists 2011). A systematic review and meta-analysis on 16 population-based studies totaling 19,559 participants underlined the significant difference of IF detection rates due to the application of high-resolution versus low-resolution sequences in brain MRI, resulting in differing IF detection rates of 4.3 % (high-resolution) versus 1.7 % (low-resolution) (Morris et al. 2009). Furthermore, apart from the study protocols for research imaging being designed for epidemiologic use with specific protocol parameters, population-based cohort studies are accompanied by the additional defiance of the readers' blindness to information regarding the clinical status of the participants as well as the participants' associated risk for development of significant diseases (Bamberg et al. 2015). Apart from its important value to improved understanding of certain diseases, the wider use of research imaging has also led to an increased detection of incidental imaging findings of potentially unclear clinical relevance to the participant, raising awareness for the need for clarity and uniformity of IF categorization and management. Hence, there is a valid demand for the implementation of standardized protocols and guidelines for the correct handling of incidental findings in research to ensure that research procedures mirror the best interests of participants (Espinoza et al. 2014). These kind of universal agreements should take account ethical principles of medicine and consider the level of duty of care of a researcher to the research participant in regard of potentially harmful incidental findings, while preserve feasibility and practicability within the resourcing, workload and financial constraints of research studies.

Up to current status, there are no standardized guidelines established to cover all population-based research studies, instead most research trials determine study-based classifications and guidelines for IF management in accordance with appropriate ethical standards. While all guidelines are consent on the graduation of IFs according to their clinical relevance, there still is a wide diversity on the dedicated classification systems, modified in accordance with the investigated body region as well as age, gender, and body-mass-index of the studied cohort (Furtado et al. 2005; Orme et al. 2010). Well-accepted overall recommendations on IF classifications and indications on management, suggested by the Royal College of Radiologists (2011) and published by Wolf et al., comprise genetic- as well as imaging-based research studies (Wolf et al. 2008). These recommendations classify relevant imaging incidental findings into three categories:

Category 1: Strong net benefit, disclosure to participant suggested

- (a) Information revealing a condition likely to be life-threatening
- (b) Information revealing a condition likely to be grave that can be avoided or ameliorated

Category 2: Possible net benefit, may be disclosed to participant

- (c) Information revealing a nonfatal condition that is likely to be grave or serious but that cannot be avoided or ameliorated, when a research participant is likely to deem that information important

Category 3: Unlikely benefit, no disclosure to participant suggested

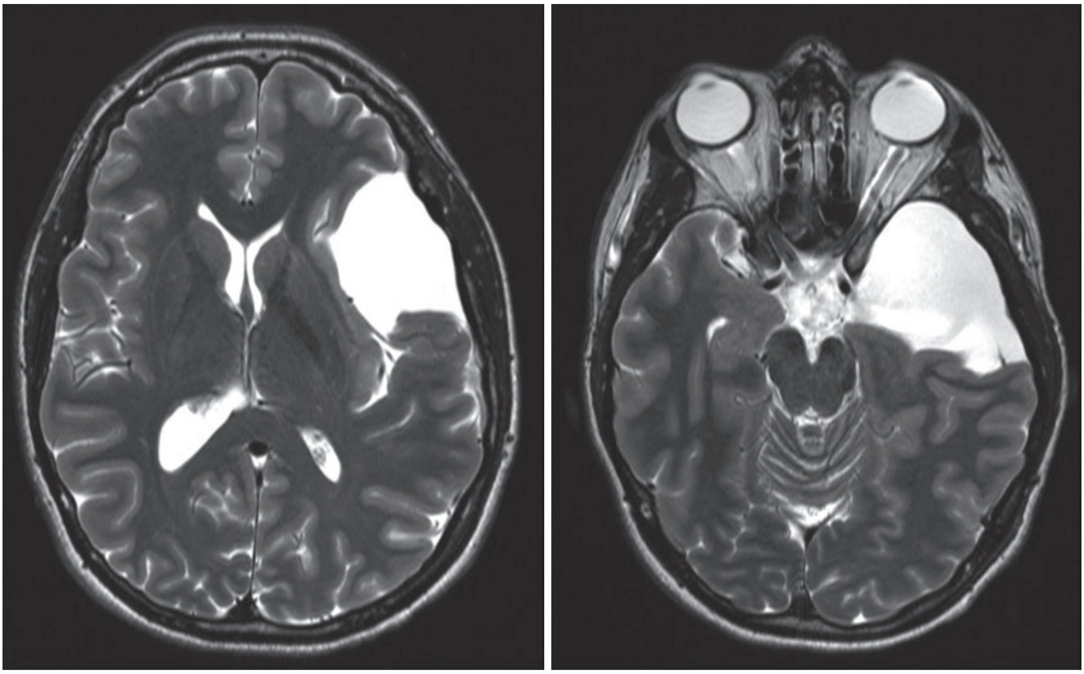

Fig. 1 Mega-arachnoid cyst in the left frontobasal lobe in a 38-year-old patient detected during an MR scan performed for exclusion of metastases of an extracranial primary

(d) Information revealing a condition that is not likely to be of serious health or reproductive importance
(e) Information whose likely heath or reproductive importance cannot be ascertained

More dedicated classification systems, subdivided into brain and body imaging and comprising imaging examples, will be given in the following section.

Brain imaging

While CT of the brain is typically performed in a clinical setting due to the utilization of ionizing radiation, MR imaging is commonly the diagnostic method of choice for screening purposes (Boutet et al 2016). Incidental brain findings include potentially symptomatic or treatable abnormalities such as neoplasms, cysts, structural vascular abnormalities or inflammatory lesions as well as potential markers of cerebrovascular disease such as white matter lesions or silent brain infarcts (Morris et al. 2009). While the classification of brain IFs remains comparable in accordance with the clinical significance in a majority of the studies, the overall prevalence and type of IFs may vary significantly according to the enrolled study population. Up to 20–50 % of IFs are known to be reported in adult research cohorts, with 2–8 % of the IFs being potentially clinically relevant, requiring follow-up (Malova et al. 2016). The reported IF incidence in children is shown to range from 7 to 36 % with even lower mean rates in preterm infants (10.1 %) (Malova et al. 2016). In addition to the different prevalence rates of IFs, the types of IFs are shown to significantly differ as well, revealing an increasing prevalence with age for white matter hyperintensities, silent brain infarcts, as well as neoplastic findings (Morris et al. 2009). Some of the most common IFs in brain MR imaging studies on the elderly include arachnoid cysts, aneurysms, meningiomas, cavernous malformations, or low-grade glioma (in descending prevalence) (The Royal College of Radiologists 2011). In a study on healthy young men with a mean age of 20.5 years (age range 17–35 years), the most common incidental findings were shown to be arachnoid cysts (Fig. 1) as well as Chiari I-malformation and dystope cere-

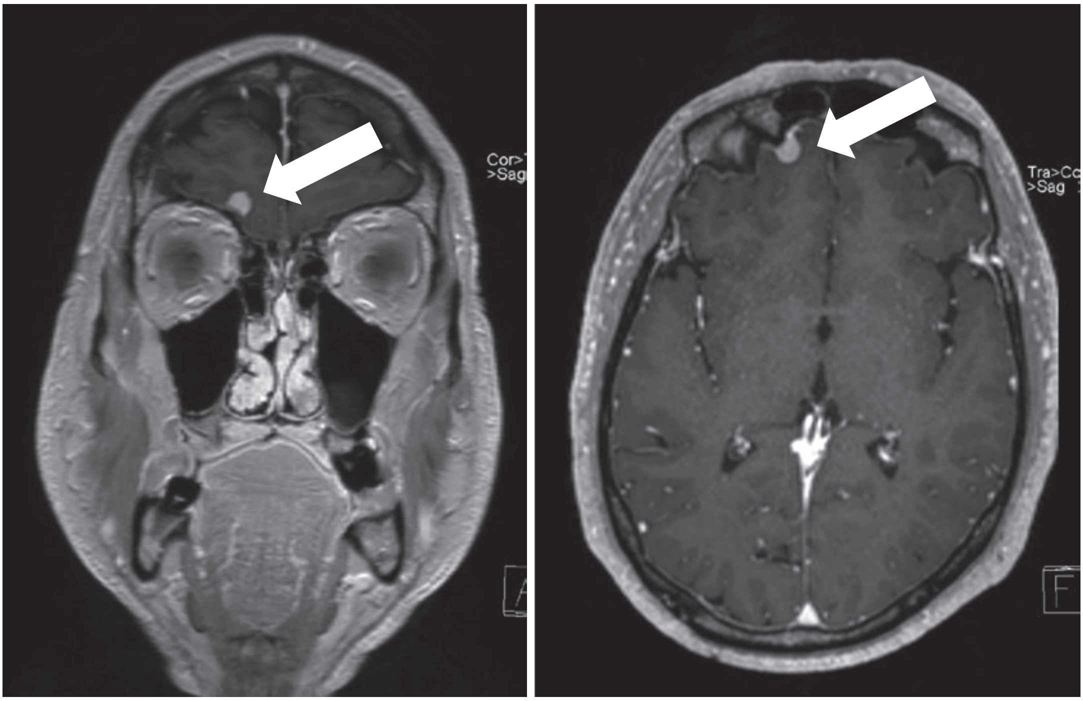

Fig. 2 An incidental finding of minor significance, by means of a very small meningeoma in the right frontal lobe

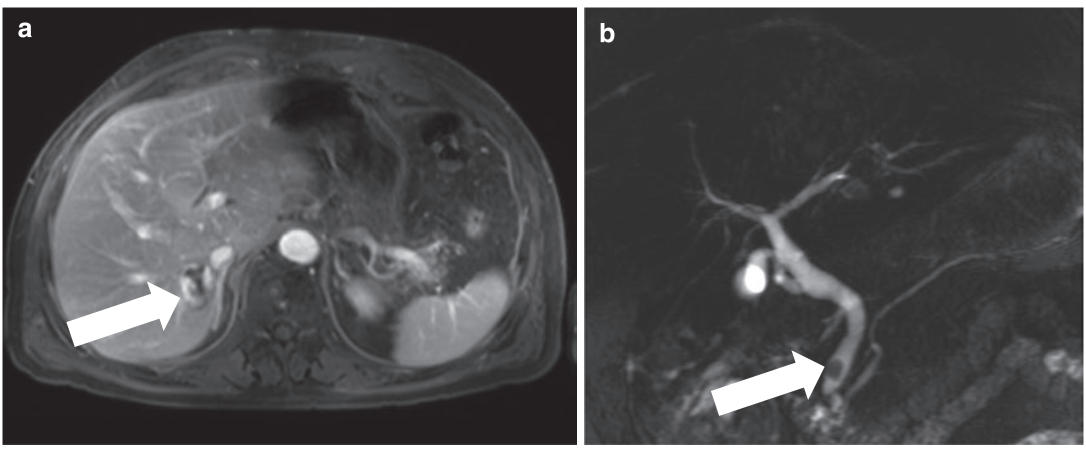

Fig. 3 Liver MR scan performed for further characterization of a CT-detected lesion in liver segment 7 (haemangioma marked with *arrow* in **a**). Incidental finding of moderate significance in the same patient, by means of a gall stone in the common bile duct (*arrow* **b**)

bellar tonsils (43 each out of a total of 166 abnormal findings) (Weber et al. 2006). As for tumor-type IFs, meningioma (Fig. 2) is the most common of all the incidental intracranial tumors, making up to 33 % of incidental tumors found at autopsy (Eskandary et al. 2005). With regard to vascular IFs, intracranial aneurysms (Fig. 3) are considered the most common incidental findings. Based on recent data derived from the population-based Rotterdam study, intracranial aneurysms were present in 134 out of the 5800 enrolled subjects (2.3 %), followed by 37 incidentally detected cavernous angiomas, dural fistulas, and arteriovenous malformations (Bos et al. 2016). While the detection of most incidental findings may be of little clinical significance, intracranial aneurysms bear the potential of acute bleeding, hence, demanding a clinical diagnostic work-up (contrast-enhanced CT or MR angiography and/or digital subtraction angiography). Of the above-named incidental aneurysms, 118 participants were enrolled in follow-up imaging and 16 were referred to a neurologist based on the size and location criteria of the aneurysms (as stated in the study protocol). Clinical management involved a wait-and-see policy in the vast majority of the participants, as well as endovascular treatment and surgery in a total of five subjects (Bos et al. 2016).

In terms of classification of IFs, the majority of studies are consent on the graduation of IFs according to their clinical relevance, mainly into three to four categories. Most studies stratify the incidental findings into three categories as follows (Teuber et al. 2016):

Category 1: Normal findings/Incidental finding without clinical significance, including anatomical variations within the normal range (cavum septi pellucidi), known pathologies or (common) findings without prognostic relevance (e.g., developmental venous anomalies)

Category 2: Incidental finding that requires further radiological or medical evaluation, for exampe, additional sequences or contrast-enhanced examinations (suspected neoplastic lesions)

Category 3: Incidental findings that require immediate medical referral (space-occupying lesion, suspected acute hemorrhagic stroke)

Some classification system put further emphasis on the timing of referral according to clinical relevance (Katzman et al. 1999):

Category 1: No referral necessary, normal or findings common in asymptomatic subjects (e.g., sinusitis)

Category 2: *Routine* referral; findings not requiring immediate or urgent medical evaluation, but should be reported to the referring physician (e.g., old infarction)

Category 3: *Urgent* referral required within weeks of study for any abnormality that will need further yet nonemergent evaluation (e.g., low-grade astrocytoma)

Category 4: *Immediate* referral required (e.g., subacute subdural hematoma)

The type of disclosure of the IF to the participant depends on its clinical relevance, differentiating between direct (phone) contact to the participant within a 24 h period in case of urgent IFs and a standardized letter within 10 days for reportable, yet not actionable IFs (Bamberg et al. 2015).

Body imaging

Similar to brain imaging, there is no universal classification system for incidental findings in body imaging either, leaving the dedicated classification of the IFs to study-based guidelines and ethical standards. Nevertheless, similar to brain imaging, there is a universal consent on graduation of the incidental findings according to their clinical relevance. One rather general classification system, that is, recommended by the Royal College of Radiologists, subdivides the common IFs on body imaging into three major categories according to their potential implications for medical management (The Royal College of Radiologists 2011):

Category 1: Major significance – always requiring further investigation and likely to have adverse health effects (e.g., aortic aneurysm >5 cm, aortic dissection, solid liver mass)

Category 2: Moderate significance – usually requires further investigation but health effects unclear; (e.g., gallstone in common bile duct (Fig. 3), splenomegaly, indeterminate liver lesion)

Category 3: Minor significance – rarely requires further investigation and unlikely to have adverse health effects (e.g., left-sided inferior vena cava, gallstones in gallbladder).

While this general classification system covers a majority of the most common IFs on body imaging, it provides rather little guidance on IF management, in terms of timing and type (letter, phone call) of disclosure of the IFs to the participants. Hence, to ensure correct IF and disclosure handling, most population-based studies on body imaging provide more detailed IF management guidelines.

In the National German cohort study, an expert panel categorized potential incidental findings into three groups, comprising "actionable," "reportable," and "nonreportable" IFs in accordance with clinical guidelines, recent research results and ethical considerations.

1. Actionable results are defined as incidental findings that bear a high likelihood to affect the participants' well-being within a short time and require urgent medical treatment. This group of IFs comprises, for example, pneumothoraces, aortic dissection. After detecting and reporting the IF, the reader is required to seek for direct participant contact and further guidance of clinical work-up (Fig. 4).
2. Reportable results involve findings that are associated with a reasonably high likelihood to alter the participants' well-being, such as aortic aneurysms with a diameter >5 cm or an abdominal mass >3 cm. In case of a "reportable result," the participant is informed via standardized letter within a time period of <10 working days.
3. All other IFs are categorized as nonreportable results without known clinical relevance, including renal cysts, gall bladder stones, etc. (Fig. 5) (Bamberg et al. 2015).

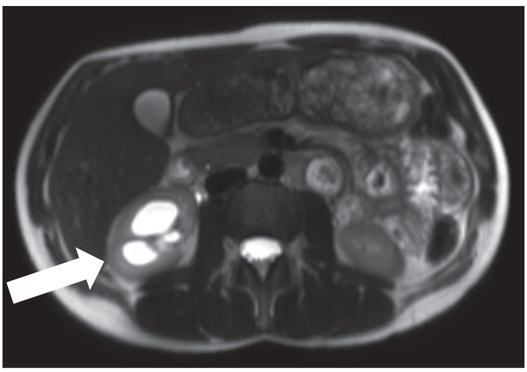

Fig. 4 Urinary congestion of the right kidney in a participant of a population-based cohort study. Immediate IF disclosure to the participant is required

3 Classification of Incidental Findings in a Clinical Setting

Within the last decades, imaging itself, and particularly cross-sectional imaging, has evolved to become an inevitable part of patient management, including assessment of acute and chronic benign diseases as well as staging, therapy monitoring, and aftercare of malignant diseases. While the aim of imaging in the clinical setting is set to address to sought the reason the study was ordered, the growing number of imaging examinations, particularly cross-sectional scans performed per patient, results in an increasing number of incidental findings. While IF classification and management is fairly settled in a research setting due to imposed study-based guidelines, the management of IFs detected in

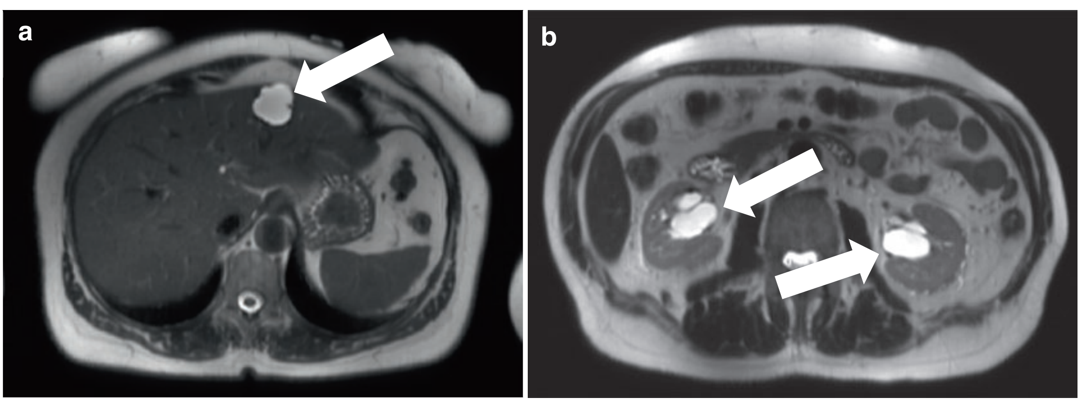

Fig. 5 Nonreportable IFs in two different participants of a population-based cohort study. The *arrows* mark a liver cyst (**a**) and bilateral parapelvin renal cysts (**b**)

clinical imaging is not guided by clear-cut recommendations, causing high variations in practice among reporting radiologists. An important difference between IFs detected in the clinical setting and IFs detected in a research environment, which may significantly influence patient management and is also reflected in most IF recommendations, is caused by the readers' knowledge of patient history, previous imaging studies, and potential comorbidities. Furthermore, in contrary to the predominantly MR-based research imaging studies, CT imaging plays an important role in clinical patient care, imposing a platform for other types of incidental findings that may not be detected by MRI, such as subsolid pulmonary nodules or atherosclerotic calcifications. In a systematic review by Lumbreras et al., the mean frequency of incidental findings was found to be as high as 23.6 % with an increased frequency of IFs in studies involving CT technology (mean 31.1 %) (Lumbreras et al. 2010). In a publication by Barrett et al., the reviewers analyzed the prevalence of incidental findings in trauma patients detected by computed tomography imaging, classifying the incidental findings into two categories: type 1 findings comprise findings that are potentially serious results and that demand further evaluation and close follow-up; type 2 findings comprise findings that require informing the patient but do not necessitate further follow-up. A third group of IFs comprise findings of little clinical consequence and did not necessitate patient notice, such as sinus mucuous retention cysts (Barrett et al. 2009). The analysis revealed a significant number of trauma patients diagnosed with potentially serious incidental findings, including 32.0 % of type 1 findings and 51.2 % of type 2 findings with the female sex showing a higher association to type 1 findings. While abdominal atherosclerosis (9.0 %), pulmonary nodules (7.4 %), and thoracic/mediastinal lymphadenopathy (5.6 %) constituted the most frequent type 1 IFs, a total of 631 incidental findings were considered suspicious of neoplastic foci (Barrett et al. 2009). Renal cysts, interstitial lung diseases, hepatic cysts, diverticulosis /-it is, and fatty liver were stated among the top five type 2 IFs, requiring patient information, yet no further follow-up investigations as proposed by the study protocol.

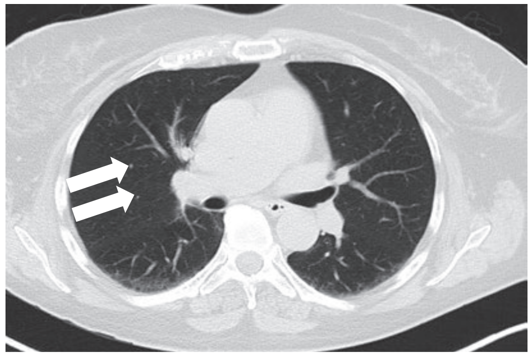

Fig. 6 Two pulmonary nodules (<4 mm) detected in a 52-year-old patient with no history of smoking or other risk factors. According to the Fleischner criteria no follow-up is needed

Numerous guidelines, mostly dedicated to organ-specific lesions such as the Fleischner classification for pulmonary nodules (Fig. 6), have been published over the years (MacMahon et al. 2005; Naidich et al. 2013). To provide a more comprehensive overview and management guidance, the American College of Radiology released conjoint recommendations, comprising pulmonary and abdominopelvic IFs as well as vascular findings (Berland et al. 2010; Heller et al. 2013; Khosa et al. 2013; Patel et al. 2013; Sebastian et al. 2013), including solid and subsolid pulmonary nodules, adrenal lesions, pancreatic cystic lesions, liver and renal lesions, splenic lesions, lymph nodes, as well as IFs of the biliary tract.

Examplatory organ-specific classification systems will be shown in the following section.

Lung

Incidental pulmonary nodules are encountered commonly in chest radiography and even more so in cross-sectional imaging due to its higher resolution and improved lesion-to-lung contrast. The incidental detection rates have been noted as low as 0.09– 0.2 % of all chest radiographs (Albert and Russel 2009) and as high as 31 %, for example, in a cohort study of patients undergoing CT scans for coronary calcium scoring (Burt et al. 2008). Overall, the estimated prevalence of solitary pulmonary nodules in the literature ranges from 8 to 51 % (Albert and Russel 2009). A solitary pulmonary nodule (SPN) is defined as a well-circumscribed, radiographic opacity measuring less than or equal to 30 mm in diameter, surrounded completely by aerated lung, and is not associated with adenopathy or atelectasis (Albert and Russel 2009; Gould et al. 2007). The differential diagnosis for pulmonary nodules comprises benign and malignant causes and demands further correlation regarding its radiologic features, patient history, as well as patient risk factors for cancer. Radiographic criteria utilized to estimate the probability of malignancy of a pulmonary nodule comprise potential calcification, nodule size, growth rate, as well as edge characteristics (Gurney et al. 1993; Cummings et al. 1986). While a lesion size <5 mm, smooth borders, solid density, and concentric or popcorn-like calcifications are considered suggestive for benign SPN, a lesion size >10 mm, spiculated borders, as well as a doubling time ranging from 1 month to 1 year are considered suggestive for malignancy (Albert and Russel 2009). Out of the above-named radiologic features, the size of the lesion seems to show the strongest link to the probability of malignancy at the time of detection as the prevalence of malignancy is 0–1 % for nodules <5 mm, 6–28 % for nodules 5–10 mm, and 64–82 % for nodules >20 mm in diameter (Wahidi et al. 2007). For nodules more than 3 cm in diameter, 93–97 % are malignant (Siegelman et al. 1986). After careful consideration of all clinical and radiographic criteria and estimation of probability of malignancy, further patient management regarding future (noninvasive) surveillance or potential invasive evaluation should be performed in accordance with the guidelines. A widely applied guideline for management of pulmonary nodules was introduced by the Fleischner society, categorizing solid and subsolid pulmonary nodules according to their size and patients' risk for malignancy and recommending follow-up imaging or PET/biopsy, accordingly (MacMahon et al. 2005; Naidich et al. 2013).

Kidney

With renal cysts being one of the most common incidental findings in abdominal imaging, renal lesions detected on CT imaging are categorized into solid and cystic lesions, including a more dedicated classification of the cystic lesions according to Bosniak (Berland et al. 2010). The Bosniak classification is a well-accepted means of triaging renal incidentalomas, subdividing renal cysts into five groups according to their morphologic features (Curry et al. 2000):

Category 1: Benign simple cyst with thin wall without septa, calcifications, or solid components; no contrast-enhancement, water-equal density.

Category 2: Benign cyst with a few thin septa, which may contain fine calcifications or small segments of mildly thickened calcification. This includes homogenous, high-attenuation lesions less than 3 cm with sharp margins but without enhancement. Hyperdense cysts must be exophytic with at least 75 % of its wall outside the kidney to allow for appropriate assessment of margins, otherwise they are categorized as IFs.

Category 2F: Up to 5 % of these cysts are malignant and as such they require follow-up imaging, though there is no consensus recommendation on the appropriate interval of follow-up. Well-marginated cysts with a number of thin septa, with or without mild enhancement or thickening of septa. Calcifications may be present; these may be thick and nodular. There are no enhancing soft tissue components. This also includes nonenhancing high-attenuation lesions that are completely contained within the kidney and are 3 cm or larger.

Category 3: Indeterminate cystic masses with thickened irregular septa with enhancement.

Category 4: Malignant cystic masses with all the characteristics of category III lesions as well as enhancing soft tissue components independent of but adjacent to the septa.

With increasing likelihood of malignancy, category 2F cysts show a risk of malignancy of up to 5 %, category 3 cysts of 50 %, and the majority of category 4 cysts are shown to be malignant, affecting patient management regarding follow-up and/or surgical procedures accordingly.

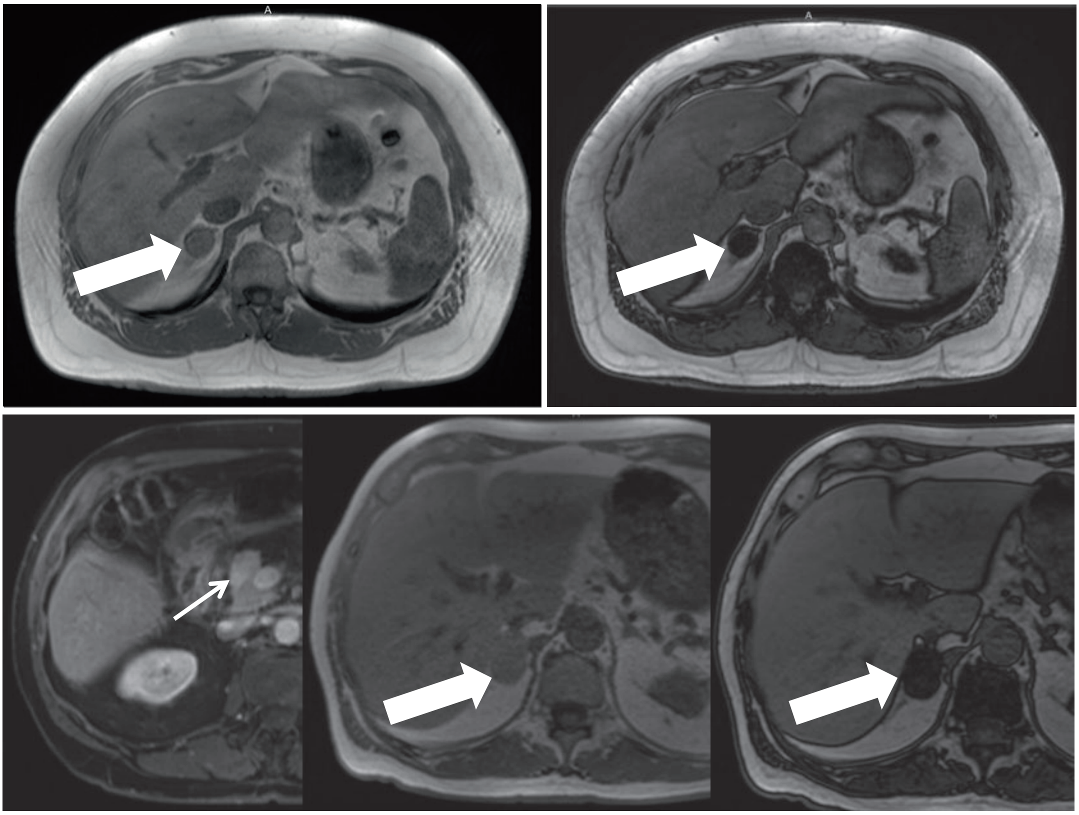

Fig. 7 The *upper row* shows In -(*left image*) and Opposed (*right image*) phase imaging of a participant in a population-based MRI study. The *arrows* point at an incidental adrenal adenoma. The images in the *bottom row* show an incidentaloma (*thick arrows* in the *middle and right image*) detected in a clinical study in a patient with a pancreatic tumor (*thin arrow left image*)

Adrenal gland
Adrenal incidentalomas are considered a disease of modern technology, as their detection as an incidental finding has significantly increased with improving technology and increasing application of cross-sectional imaging. The prevalence of adrenal incidentalomas has been reported as high as 8 % in autopsy series and 4 % in diagnostic imaging (Kapoor et al. 2008). Adrenal lesions can be categorized as primary or metastatic, benign or malignant, and functioning or nonfunctioning (Boland et al. 2008). Based on the significant association between the size of an adrenal incidentaloma and its likelihood of malignancy, adrenal masses are subdivided into two groups, by means of 1–4 cm in adrenal mass size and >4 cm. As approximately 70 % in adrenal masses >4 cm (85 % if larger than 6 cm) are known to be malignant, interventional investigations (biopsy/resection) are recommended accordingly (Berland et al. 2010). With nonfunctioning adrenal adenomas being the most common type of adrenal incidentaloma, recommendations on diagnostic procedures include CT densitometry and/or MR-based chemical shift imaging to detect a potential signal drop in Opposed-Phase-imaging, indicative for fatty adrenal tissue in adenomas (Boland et al. 2008). Recent recommendations also propose CT perfusion imaging to assess the washout kinetics of the adrenal lesions for further characterization (Boland 2011).

Furthermore, as in all clinical patient imaging studies, prior studies as well as patient history (e.g., history of lung cancer with a high likelihood of adrenal metastases; Fig. 7) should be taken into account when considering further diagnostic procedures/diagnoses.

Liver

Liver cysts are considered one of the most common incidental findings in abdominal imaging and do not need any further diagnostic work-up in the majority of the cases. In contrary, incidental liver masses, yielding a more potent risk of malignancy, require further evaluation and are categorized based on a combined analysis of size, morphologic features, as well as risk of malignancy in accordance with the patient history regarding hepatic dysfunction or known malignancy as well as age. As the patients' risk for malignancy based on prior hepatic diseases and age plays an important role for further liver IF management (apart from size and morphologic features of the lesions), the ACR recommends a separation into three groups:

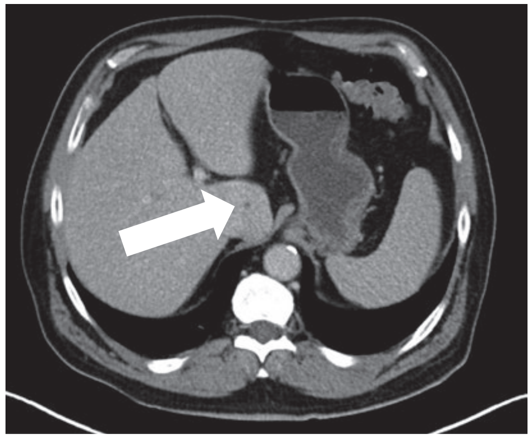

Fig. 8 Small lesion (<5 mm) detected in a low-risk individual, no follow-up needed according to ACR recommendations

1. Low risk individuals: Young patient (≤40 years old), with no known malignancy, hepatic dysfunction, hepatic malignant risk factors, or symptoms attributable to the liver.
2. Average risk individuals: Patient >40 years old, with no known malignancy, hepatic dysfunction, abnormal liver function tests, or hepatic malignant risk factors or symptoms attributable to the liver.
3. High risk individuals: Known primary malignancy with a propensity to metastasize to the liver, cirrhosis, and/or other hepatic risk factors. Hepatic risk factors include hepatitis, chronic active hepatitis, sclerosing cholangitis, primary biliary cirrhosis, hemochromatosis, hemosiderosis, oral contraceptive use, anabolic steroid use.

In terms of imaging-based classifications, the American College of Radiology recommends an initial classification of the liver IFs according their size into three subgroups: (1) <0.5 cm, (2) 0.5–1.5 cm and (3) >1.5 cm. As lesions <0.5 cm are commonly too small to be further characterized into benign or malignant lesions on CT imaging, patient management should be performed related to the patients' risk for malignancy (low and average risk individuals: no follow-up; high risk individuals: follow-up in 6 months) (Fig. 8). Lesions >0.5 cm should be further analyzed regarding their imaging characteristics (benign or malignant characteristics) as well as the patients' general risk for malignancy. A more dedicated algorithm for classification and management of liver lesions has been implemented for patients with cirrhosis or who are at risk for HCC, by means of the LI-RADS® criteria (Mitchell et al. 2015).

Spine

Incidental findings of the spine are commonly detected, regardless if the application field is dedicated to spine imaging, for example, for disk disease evaluation, or if the spine is unwittingly imaged as part of a cross-sectional cervical/thoracal or abdominal scan (Cieszanowski et al. 2014). Studies on incidental findings in dedicated lumbar spine MRI have reported mean detection rates of IFs of approximately 8.4 %, revealing mostly benign findings and associations with age and sex. In a publication by Park et al., 1268 patients' lumbar spine scans were re-investigated, yielding a total of 107 patients scans with lesion-type incidental findings, comprising fibrolipoma (3.2 %) as the most common IF, followed by Tarlov cysts (2.1 %) and vertebral hemangiomas (1.5 %) (Park et al. 2011). Naturally, age-related degenerative spine disease is one of the most common incidental findings, comprising a wide spectrum of degenerative abnormalities such as disk bulging or herniation, osteochondrosis, spondylosis deformans, spondylolysis, or spondylolisthesis. In a recent publication by Cieszanowski et al., a vast majority of the enrolled participants for whole-body screening MRI showed incidental degenerative spinal disease (86.7 % of the subjects <50 years and 98.1% of the subjects >50 years) (Cieszanowski et al. 2014). While the classification of incidental findings in a research setting is defined by the study set-up [e.g., type I: insignificant/low significance; type II: moderately or potentially significant; type III: further medical evaluation required; could cause clinical symptoms or require treatment; (Cieszanowski et al. 2014)], clinical imaging demands elaborate reporting of the radiologist to differentiate between IFs that should or should not be dedicatedly reported to prevent psychosocial distress. While clinical imaging lacks a universal classification for guidance of spinal IFs, a large number of classification systems for dedicated IFs have been established within time, comprising degenerative disk and osseous spine changes.

One classification to categorize disk degeneration was established by Pfirmann et al. Pfirmann et al. devised a widely used 5-point grading system for disk degeneration based on MR signal intensity, disk structure, distinction between nucleus and annulus, and disk height (Pfirrmann et al. 2001). Griffith et al. recently introduced a modified grading system referring to the Pfirrmann system to improve the discrimination of the severity of disk degeneration in elderly subjects (Griffith et al. 2007). While disk disease evaluation is considered one of the most common reasons to perform spine MRI, the causal relation between disk disease (e.g. protrusion) and back pain seems controversial. One of the first studies to evaluate the causal relation between abnormalities in the lumbar spine and low back bain was published in the early years of MR imaging by Jensen et al. (1994). Fifty-two percent of the enrolled 98 asymptomatic subjects in this study showed a bulge at least one level, 27 % a protrusion, and 1 % an extrusion. While the prevalence of bulges increased with ages, the findings did not show any gender-specific differences (Jensen et al. 1994). Considering the high prevalence of disk disease without associated back pain, disk disease may also be treated as an incidental finding, when the imaging is performed for other reasons than disk disease evaluation such as staging in oncologic patients. A commonly applied general classification of disk lesions subdivides the lesions into six categories:

Category 1: Normal (excluding aging changes)

Category 2: Congenital/developmental variants

Category 3: Degenerative/traumatic

- Anular tear
- Herniation:
  - Protrusion/extrusion
  - Intravertebral
- Degeneration:
  - Spondylosis deformans
  - Intervertebral osteochondrosis

Category 4: Inflammation/infection

Category 5: Neoplasia

Category 6: Morphologic variant of unknown significance

With lumbar discectomy being the most common surgical procedure performed in patients suffering from back pain and sciatica, the MSU (Michigan State University) classification was established to objectively measure lumbar disk herniation on MRI (Mysliwiec et al. 2010). The MSU classification of herniations according to size (1-2-3) and location (zone A-B-C) and correlation to appropriate clinical findings bears the potential to objectify criteria that may lead to improved surgery outcomes (Mysliwiec et al. 2010).

Even though a clear differentiation between disk-related spine disease and solely vertebrae-related spine disease is difficult to define, a number of classification systems focusing on osseous changes have been introduced over time. The Modic classification was first described and defined by Dr. Michael Modic in 1988, representing a classification for vertebral body end-plate changes on MRI (Modic et al. 1988) (Fig. 9).

- Modic type 1:
  - T1 low signal/T2 high signal
  - Represents bone marrow edema and inflammation (Fig. 10)
- Modic type 2:
  - T1 high signal/T2 iso to high signal
  - Represents normal red haemopoetic bone marrow into fatty marrow

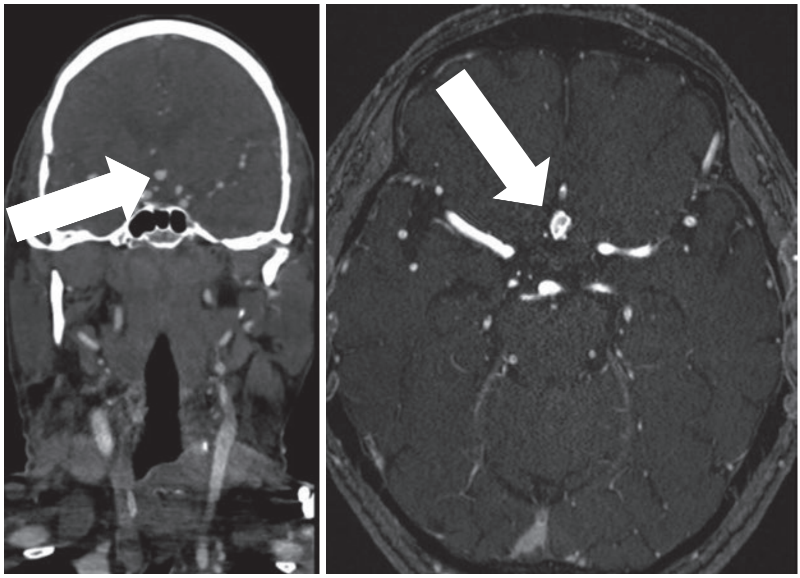

Fig. 9 Incidentally detected aneurysm of the anterior communicating artery in a 62-year-old patient (*arrows*). The initial CT angiography scan (*left*) was performed for exclusion of vessel occlusion after hemiparesis and hyposthesia. MRA was performed subsequently for verification of the IF (*right image* TOF MRA)

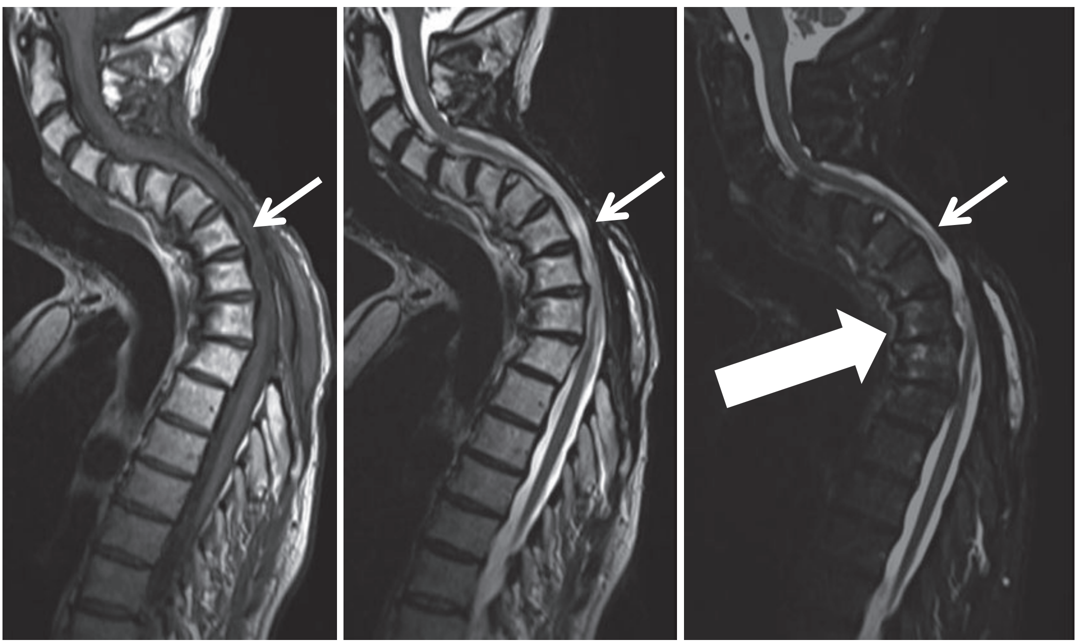

Fig. 10 T1 weighted (*left*), T2 weighted (*middle*), and STIR imaging (*right*) of the spine in a patient with known hyperkyposis (*thin arrows*). *Arrows* point at incidentally detected vertebral body end-plate changes of Modic type 1, representing bone marrow edema and inflammation

- Modic type 3:
  - T1 low signal/T2 low signal
  - Represents subchondral bony sclerosis

A commonly applied classification system for spondylolisthesis was introduced by Meyerding et al. This classification method grades spondylolisthesis according to the ratio of overhanging part of the superior vertebral body to the anteroposterior length of the adjacent inferior body into 5 grades, ranging from 0 to 25 % (grade 1) to grade 5 (spondyloloptosis: >100 %).

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