Chapter

Challenges for Intelligent Data Analysis Methods in Medical Image Analysis during Surgical Interventions of Aneurysms

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Abstract

Aortic aneurysms (AA) can be the primary cause of over 10,000 deaths and indirect cause for another 18,000 deaths annually in the USA as per the recent data released by the Centers for Disease Control and Prevention. Among the several factors related to high mortality, imaging methods and intervention procedures could be important. The commonly used diagnostic imaging methods of aneurysms are computed tomography (CT), magnet resonance imaging (MRI), ultrasound (US), digital subtraction angiography (DSA) and amalgamation of fluoro-D-glucose (FDG) integrated with positron emission tomography (PET) and/or CT and PET with CT or MRI. Several research findings indicate that diagnostic efficiency of different imaging methods differ. As intervention procedures depend upon diagnosis, the choice of appropriate diagnostic imaging method for a given case is very important. If the critical characteristics of the swelling are not detected due to the choice of unsuitable imaging method, interventions may not be very suitable. The American College of Radiologists (ACR) prescribed some appropriateness guidelines for diagnostic imaging. Not complying with them fully or partially may also be a mortality factor. This chapter is written with recent research findings in the field of intelligent data analysis for medical applications supported by case studies and practical examples.

Keywords: diagnosis, aneurysm, imaging modality, guidelines, mortality

1. Introduction

Aneurysm was the primary cause of more than 10,597 deaths and a contributing cause of over 17,215 deaths in the USA in 2009 [1], shown in **Figure 1**. Some essential details on aneurysm, its diagnosis, factors of influence and prevention and treatment are described by Nordqvist [2]. The author gives a more detailed description of aneurysm. The disease occurs when an artery or cardiac chamber swells. This results in the damage of artery or weakness of its walls. The swelling balloons out at its weakest point resulting from increasing blood pressure. This means there should be a threshold pressure above which only ballooning out

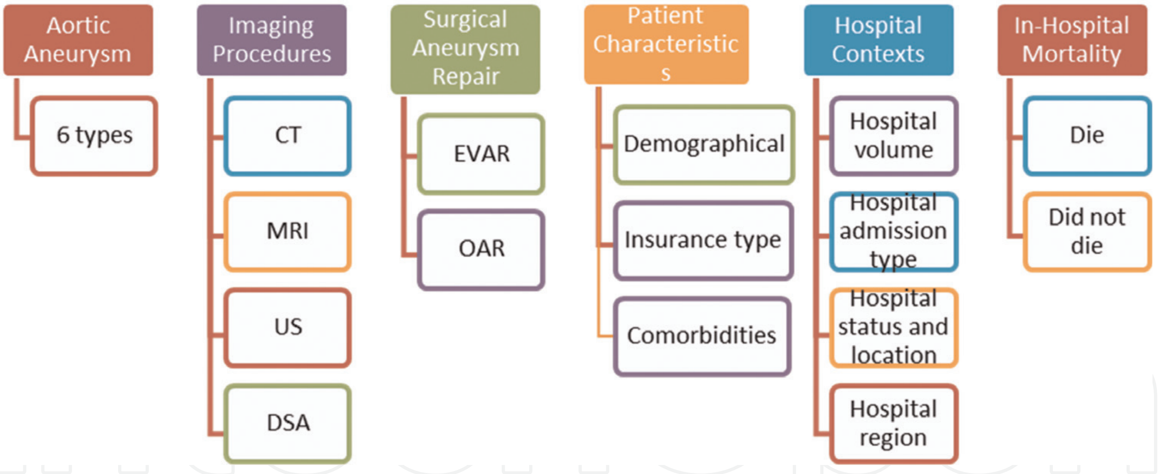

Figure 1.
Subcategorization of data elements used in this study.

happens. Although small swellings may be confined to a small area of the artery, large ones can extend along the whole length of the affected area. The balloon may become too large, and it may rupture when pressure build-up continues. Furthermore, a threshold point is indicated for the rupture. The rupture naturally leads to hemorrhage and other complications and even sudden death. Although aneurysm can occur in any part of the body, it is more common in the arteries, particularly in the aorta. True aneurysms can be atherosclerotic, syphilitic, congenital or ventricular following transmural myocardial infarctions and can occur in any of the three walls of the artery.

False aneurysm (pseudo-aneurysm) is also possible when there is complete leaking of blood out of an artery or vein confined to the tissue surrounding the vessel. Eventually, this blood-filled cavity may clot to seal the leak, or it may rupture out of the surrounding tissue. Trauma can be caused by punctures in the artery created by knife, bullet and so forth. Pseudo-aneurysms can be caused by percutaneous surgical procedures like coronary angiography or arterial grafting or an injection into the artery. Aneurysms are classified according to their morphology or by location. Morphologically, saccular aneurysms are spherical, 5–20 cm in diameter, partially or fully filled by thrombus and involve only a portion of the vessel wall. Fusiform types are spindle-shaped, with varying diameter up to 20 cm and with varying length, involving large portions of ascending and transverse aortic arch, abdominal aorta or iliac arteries.

Aneurysms, by location, could be arterial or venous, the former being more common. Aneurysms related to heart can be coronary artery aneurysms, ventricular aneurysms and aneurysms of sinus of Valsalva. Aneurysms following cardiac surgery also occur. Related to aorta, abdominal aortic aneurysm and thoracic aortic aneurysm can occur. Results of some studies show that about 25% of aneurysms occur in the thoracic area [3]. Related to the brain, cerebral, berry or Charcot-Bouchard aneurysms can occur. Cerebral aneurysm (intracranial or brain aneurysm) is more common at the base of the brain and more common in the anterior cerebral artery, especially in the internal carotid artery. Aneurysms can occur in the legs, especially in popliteal arteries. In the kidney, renal artery or intra-parenchymal aneurysms can occur. However, renal and leg aneurysms are rare. A comprehensive list of various types of aneurysms is given in **Table 1**.

Some studies show that mortalities vary with patient characteristics as well as the specific hospital contexts. Patient characteristics, such as gender, age, and comorbidities of some aortic aneurysm types, have been studied. Hospital contexts

Affected region	Aneurysm nomenclature
Aortic aneurysm	Thoracic aortic aneurysm Ruptured thoracic aortic aneurysm Thoracicoabdominal aortic aneurysm Ruptured thoracicoabdominal aortic aneurysm Abdominal aortic aneurysm Ruptured abdominal aortic aneurysm
Cranial and neck aneurysm artery	Cerebral artery aneurysm Ruptured cerebral artery aneurysm Ruptured syphilitic cerebral aneurysm Congenital cerebral artery aneurysm Carotid artery aneurysm Subclavian artery aneurysm
Intrathoracic aneurysm arteries	Heart aneurysm Coronary artery aneurysm Pulmonary artery aneurysm Mediastinal and spinal artery aneurysm
Intra-abdominal and pelvic aneurysm arteries	Renal artery aneurysm Splenic artery aneurysm Visceral artery aneurysm Iliac artery aneurysm
Upper extremity arteries	Brachial artery aneurysm Radial artery aneurysm
Lower extremity arteries	Femoral artery Popliteal artery

Table 1.
Comprehensive list of aneurysm types.

include type, location, educational qualifications and experience of health-care professionals and patient volume. However, not many studies have reported on the influence of using various types of imaging modalities and their capability to lead and guide aneurysm repair procedures to decrease the mortality rate of aortic aneurysm patients. One of the important aspects in hospital context is its adherence with the American College of Radiologists (ACR) guideline especially on medical imaging methods and patients safety aspects. The lack of protocols and costs have been cited as important reasons for not practising the most desirable or appropriate imaging methods in the case of aneurysm [4]. Obviously this affects the extent of compliance with ACR. However, not many studies have been reported on the influence of extent of compliance of medical imaging guidelines of ACR on the in-hospital mortality of aortic aneurysm patients.

Scientific knowledge is the basis of diagnostic and treatment procedures. It determines the diagnostic methods to be used for accurate assessment of the disease so that effective treatment procedure can be determined.

Imaging is a scientific method used for the diagnosis of aneurysm. If appropriate imaging methods are not used, the treatment outcome may be negative. The guidelines of ACR are relevant in this respect. Hospitals are rated according to their compliance with ACR, and its influence on in-hospital mortality is evaluated. The relationship between in-patient hospital mortality and aneurysm and the relationship between compliance with ACR and in-hospital mortality of aneurysm patients point to the importance of evidence-based diagnosis and treatment procedure. Thus, effectiveness of diagnosis using imaging techniques and its outcome in terms of mortality for hospitalized patients forms the most important components of the findings.

Patient safety is an important aspect of both diagnosis and treatment. Radiation exposure in terms of type, dose and duration and conditions under which imaging is done are of critical importance, and ACR has critical points on these aspects. This applies to treatment also. So, ACR compliance level and other hospital contexts determine the extent to which patient safety is cared for. This is an aspect derivable from the findings of this work. Thus, some of the six dimensions of heath-care quality are evaluated in this work.

So, the following questions are relevant:

1. How do the algorithms of these imaging methods determine the efficiency and effectiveness of diagnosis in the case of aneurysm?

2. Why is DSA preferred over other imaging methods for the diagnosis of aneurysm?

3. Is there any risk of higher mortality or reduction in mortality by not following/following ACR appropriateness guidelines for diagnostic imaging?

This chapter tries to answer the above questions based on our recent research findings.

2. Efficiency and effectiveness of diagnosis of imaging methods

Commonly used diagnostic imaging methods of aneurysms are computed tomography (CT), magnetic resonance imaging (MRI), ultrasound (US), digital subtraction angiography (DSA) and combinations of FDG with PET and/or CT and PET with CT or MRI. Many research findings indicate that diagnostic efficiency of different imaging methods differs. As intervention procedures depend upon diagnosis, the choice of appropriate diagnostic imaging method for a given case is very important. If the critical characteristics of the swelling are not detected due to the choice of unsuitable imaging method, interventions may not be very suitable. In this study, six types of aortic aneurysms are covered. These are ruptured and intact thoracic aortic aneurysms (rTA and TA), ruptured and intact abdominal aortic aneurysms (rAAA and AAA) and ruptured and intact thoracicoabdominal aortic aneurysms (rTAA and TAA). Surgical repairs by OAR and EVAR are the intervention procedures. The main imaging procedures are CT, MRI, ultrasound and DSA. The subcategorization of data elements is given in **Figure 1**.

Recent advances have made computed tomography angiography (CTA) and magnetic resonance angiography (MRA) as the most useful diagnostic tools for aortic aneurysm. These developments have helped to reduce the procedural risks of transarterial catheterization. Cross-sectional images provide information on the affected blood vessel and length of its affected part, total aortic diameter and diameter of the artery, true vascular diameter which includes patent lumen, the extent of formation of mural thrombus, the distance of diseased wall from critical aortic branches and extravascular pathology. This imaging method is used as a single procedure for diagnosis, procedure planning and post-operative monitoring. It has helped to reduce the rate of morbidity and mortality. Catheter-based angiography is used as an adjunct to treatment procedures. Integrated with contemporary cross-sectional imaging, this method includes uses of carbon dioxide angiography and intravascular ultrasound methods. Multiple imaging is done in which one pre-contrast imaging series and at least one contrast-enhanced imaging are included. Although contrast injection protocols include a number of parameters, the critical challenge is the optimal delivery of appropriate quantity of contrast to the volume of interest. These protocols need to be carefully determined for each specific situation. CTA has a definite edge over MRA in many respects. Renal impairment prevents the use of iodine contrast agents. Renal protective strategies are used for its mitigation, with a doubtful benefit at times.

CTA is a quick, reliable, simple and non-invasive diagnostic tool for aneurysms and can effectively replace conventional angiography [3]. Therefore, according to Prestigiacomo et al., 3-D CTA can be used as an initial screening tool in place of DSA. Sensitivity and predictive values of 100% were obtained by them. Sensitivity of 2D and 3D CTA to detect very small aneurysms was 98–100% compared to 95% for DSA [5]. CTA accuracy was also 99–100%. Based on these findings, Villablanca et al. recommended the use of CTA with commercial detectors to detect very small aneurysms [6]. Even without pre-operative angiography, pre-operative 3D CTA (instead of DSA angiography) can provide good anatomical information for microsurgical interventions of aneurysms, as was concluded by González-Darder et al. [7]. Forsting in 2005 concluded that CTA can effectively replace DSA and even MRA for diagnosis aneurysm [8]. Hoh et al. demonstrated the possibility of using only CTA instead of DSA for diagnosis and pretreatment planning in patients with ruptured and unruptured aneurysms in Massachusetts General Hospital [9]. In the findings of Karamessini et al., CTA had sensitivity, specificity, positive predictive, negative predictive and accuracy values of 88.7, 100, 100, 80.7, and 92.3%, respectively. The corresponding values for DSA were 87.8, 98, 97.7, 89.1, and 92.9%, respectively [10]. Based on these findings, the authors concluded that CTA and DSA were equally good for detection of aneurysms of 3 mm or more. With 100% detection accuracy, CTA is also useful to detect AcoA and MCA bifurcation aneurysms. According to Matsumoto et al., 3D CTA can effectively replace conventional catheter angiography in the diagnosis and surgery of most ruptured aneurysms [11]. Furthermore, a recent systematic review done by our group in 2015 also supports the use of CTA as an effective substitute for other imaging methods, at least to some extent, in the treatment and diagnosis of AAA [12]. In measuring the volume of aneurysms, CTA, MRA and rotational DSA produced statistically non-significant differences and hence can be considered equally as per the report of Piotin et al. [13].

On the other hand, in a comparative study, Biasi et al. found CTA inadequate to detect small aneurysms occasionally and therefore recommended DSA/3D rotational angiography [14]. Stavropoulos et al. also considered CTA inferior in detecting small aneurysms, and the use of DSA should be continued. Difficulty of detecting small aneurysms using CTA has been reported by many other workers [15]. According to latest study in 2015 by Chung et al., multi-slice 3D CTA offers better image resolution and is hence more useful than single-slice CTA to detect aortic aneurysms for post-EVAR [16]. In another finding, van Gelder [17] supported further investigation of small aneurysms detected by CTA if there is no pretest probability of ruptured aneurysm. Very low probability of clinically significant aneurysms can be detected by CTA when screening is done for unruptured aneurysms.

Some technological improvements include Sailer et al. in 2014 on using fluoroscopy image fusion guidance for CTA in endovascular interventions to reduce iodine contrast dose and procedure duration [18], Deák et al. on automated systems for detection of aortic aneurysms in CTA images [19] and Wada et al. 2014 on combining 3D CTA with 2D CT imaging guidance for clipping surgery [20].

2.1 Why is DSA preferred over other imaging methods for aneurysm detection?

Many research works and reports [21–24] indicate distinct preference for DSA over other imaging methods when diagnosing a variety of aneurysms. Specific reasons may be related to the availability of instruments, specifically trained staff, costs, convenience, etc. In the case of some specific types of aneurysms, DSA has been shown to be the most suitable one for maximum efficiency and effectiveness. These factors are discussed using scientific evidence.

High resolution makes conventional angiography the most desirable diagnostic tool for aortic aneurysm. It is done at the earliest opportunity of patient presentation after bleeding. With haemorrhage risk being high within the first 24 hours, an early angiogram is necessary for therapeutic decisions. Aortic angiography can locate lesions, reveal the size and shape of aneurysm, detect presence of multiple aneurysms, examine vascular anatomy and its collaterals and evaluate the presence of vasospasm and its intensity.

Comparisons of CTA and DSA done by many workers have been discussed above. Other works related to DSA are reviewed here. More often, DSA is used as a confirmatory or extended test of other imaging methods. For example, although 3D CTA compared very well with DSA, in the experiment, DSA was used for confirmation of the results obtained with 3D CTA in the work of Thurnher et al. [25]. The 3D rotational reconstructed DSA images can improve the assessment of aneurysms [26]. Although CTA can add value to DSA, it can never replace it [27]. In one finding by van Rooij et al., 3D rotational angiography (3DRA) was found superior to DSA, and hence they suggested it as the new gold standard [28]. However, according to Zhang et al. contrast-enhanced dual-energy CTA had better diagnostic image quality at lower radiation dose than 3D DSA. Based on their research [29], Defillo et al. concluded that indocyanine green video-angiography (ICGV) had distinct advantages over intraoperative catheter DSA with respect to rapid feedback and visualizing of local perforators [30]. DSA had better visualization of residual aneurysm and parent artery stenosis which did not limit flow. Based on these findings, they recommended the combined use of the two imaging tools. On the other hand, due to the absence of small neck remnants and some residual aneurysms by ICGV, DSA is necessary for quality of surgery assessment in complex aneurysms. Better image quality is possible with lower dose of radiation, according to the results obtained by Pearl et al. [31].

CO2-DSA gave better results than conventional DS in detecting Type I and Type II direct endoleaks in EVAR procedure. This is because CO2-DSA had higher sensitivity and specificity than conventional DSA [32]. In the studies of Wacker et al., in 2014, C-arm CT is used as a supplementary imaging tool with DSA for better localization and classification of endoleaks than DSA alone in EVAR repair [33].

When EVAR was done using single imaging methods, DSA was most preferred followed by US, CT, and MRI in the decreasing order. When two imaging methods were combined, DSA with US recorded the highest imaging frequency. This was followed by DSA + CT and DSA + MRI. The same trend was observed in the case of OAR also. OAR combinations recorded higher frequencies than EVAR combinations, as OAR was the preferred intervention procedure.

The trend was maintained for each aneurysm type as well. In **Table 2**, overall frequency was highest for AAA followed by TA, rAAA, and TAA in the decreasing order. This reflects the relative incidence and prevalence of aneurysm type rather than any preference of imaging for a specific aneurysm type. More than 70% of all imaging and interventions were done on AAA followed by about 21% for TAA, together accounting for about 90% of all aneurysm care.

Medical imaging modalities associated with interventional repair	Frequency	Valid percent	Cumulative percent
	n	%	%
EVAR + CT	38	0.1	0.1
EVAR + MRI	6	0.0	0.1
EVAR + US	259	0.7	0.8
EVAR + DSA	7718	20.2	21.0
EVAR + DSA + CT	95	0.2	21.2
EVAR + DSA + MRI	6	0.0	21.2
EVAR + DSA + US	676	1.8	23.0
OAR + CT	485	1.3	24.3
OAR + MRI	106	0.3	24.5
OAR + US	4620	12.1	36.6
OAR + DSA	20,865	54.5	91.1
OAR + DSA + CT	292	0.8	91.9
OAR + DSA + MRI	69	0.2	92.1
OAR + DSA + US	3028	7.9	100.0
Total	38,263	100.0	

Table 2.
Imaging frequencies for different aortic aneurysm types.

2.2 Is there a higher mortality risk if ACR appropriateness guidelines for diagnostic imaging are not complied with? Alternatively, can it be shown that compliance with ACR guidelines reduced mortality risks?

In Canada, ultrasound screening of 65–75-year-old men is done and is cost-effective. Relative risk of AAA-related mortality is 0.49 for this group compared to no screen. There is little benefit by screening of men beyond 75 years old. Screening of women over 75 years is not recommended. Individualized check-up of women over 65 years is adequate. No follow-up screening is required for AAA size less than 3 cm. Although annual screening of individuals with 3–4.4 cm is routinely done, evidence for this is weak. Screening every 2 years may be enough. Screening for popliteal aneurysm may be beneficial. There is no benefit by screening men or women less than 65 years. Physical examination can supplement screening wherever necessary. As advances in surgery techniques reduce AAA-related mortality rates, the cost-effectiveness of screening needs to be reviewed periodically.

A set of guidelines on clinical practices for endovascular AAA repair was given by Walker et al. [34]. The guidelines deal with endovascular repair, its indications and contradictions, EVAR requirements of patients, procedural assessment before repair containing detailed imaging methods and scoring systems, endograft types and their suitability, technical aspects of surgical procedure and post-operative management. Another set of guidelines on the same topic was published for European Society for Vascular Surgery [35]. There was also an earlier set of guidelines of Society for Vascular Nursing (SVN) Task Force published by Smith et al. [36]. This covers mostly the nursing and patient care aspects of pre-operative, intraoperative and post-operative stages. The guidelines use evidence-based best practice approach. A set of guidelines for peripheral arterial disease was published by Hirsch et al. on behalf of ACC/AHA (American College of Cardiology/American Heart

Association) and collaborated by many other related organizations. This contains information on classification of levels of evidence and standards of their acceptance. The diseases included are lower extremity, renal, mesenteric and abdominal aortic aneurysms [37].

The American College of Cardiology Foundation (ACCF) and American Heart Association (AHA) jointly published a set of guidelines for diagnosis and management of patients with TA [38]. This contains the following:

1. Recommendations for imaging and detection/identification/evaluation of genetic syndromes, familial TA and dissections and bicuspid aortic valve and associated congenital variants in adults.

2. Estimation of pretest risk of thoracic aortic dissection.

3. Initial evaluation and management of acute thoracic aortic disease.

4. Surgical intervention for acute thoracic aortic dissection and intramural hematoma without intimal defect and history.

5. Physical examination of thoracic aortic disease.

6. Medical treatment of patients with thoracic aortic diseases, asymptomatic patients with ascending aortic aneurysm and symptomatic patients with TA.

7. Open surgery for ascending aortic aneurysm, aortic arch aneurysms, descending thoracic aorta and thoracicoabdominal aortic aneurysm.

8. Counselling and management of chronic aortic diseases in pregnancy, aortic arch and thoracic aortic atheroma and athero-embolic diseases.

9. Periprocedural and perioperative management.

10. Surveillance of thoracic aortic disease and previously repaired patients and employment and lifestyle in patients with thoracic aortic disease.

Several guidelines are being published by a variety of organizations within countries internationally. It is appropriate to evaluate these guidelines with respect to their usefulness in routine clinical practices. Ferket et al. in 2012 reviewed the guidelines published on screening for AAA during 2003–2010. Of 2415 titles, 7 were included in this study. These were USPSTF2005, ACC2005, NSC2007, CSVS2007, CCS2005, SVS1 of 2004, and SVS2 of 2009 [39]. Unfortunately, some of the more recent ones discussed above were not included. Some changes in the classification systems of ICD in different years could also affect evaluation.

There was consensus across the guidelines regarding one-time screening of elderly men to detect and treat aneurysms of larger than 5.5 cm in size. For smaller aneurysms and other target groups, prediction models and effectiveness analysis are needed.

The American Image Management (AIM) guidelines on diagnostic imaging, known as AIM, 2010, contain imaging protocols for various parts of the body using CT, MRI, PET, CTA, MRA and other imaging methods including proton beam treatment. These have also been published in parts as updated versions later in 2014 [40].

The American College of Radiology (ACR) has also published appropriateness criteria for AAA interventional planning and follow-up [43, 44]. It contains rating for appropriateness for planning pre-endovascular repair or open repair and for follow-up after these repairs with a note by experts. Best practice guidelines on clinical decision support systems have been published by the ACR and Radiology Business Management Association (RBMA) jointly. This contains evidence-based best practices related to all heath-care service components aimed at best patient outcomes. Other ACR guidelines are on the development of evidence tables for diagnostic studies, literature search process, non-traumatic aortic disease, procedure information like contrast used and PET and topic review process. All these appropriateness criteria (as they are called) follow a standard format containing explanatory notes by experts. Recently a study was conducted [41] in Sweden, to estimate the effect of AAA screening on disease-specific mortality, incidence and surgery. It was found that AAA mortality in Swedish men has decreased from 36 to 10 deaths per 100,000 men aged 65–74 years between the early 2000s and 2015. Mortality decreased at similar rates in all Swedish counties, irrespective of whether AAA screening was offered. It was mentioned that AAA screening in Sweden did not contribute substantially to the large observed reductions in AAA mortality and such reductions were mostly caused by other factors, probably reduced smoking.

The National Guideline Clearinghouse is a database for evidence-based clinical practice guidelines prepared by various organizations for comparison, synthesizes guidelines prepared by different agencies on the same topic for similarities and differences and serves as an electronic platform for exchanging information on such guidelines and is also a source of annotated bibliography database. Two of these deal with cardiovascular diseases [42].

2.3 Hospital compliance of ACR guideline on abdominal aortic aneurysm

Huber et al. collected NIS data for 1994–1996 [43]. Most patients were white males. Majority of repairs were done at large, urban and non-teaching hospitals. The hospital mortality rate was 4.2%. There was 32.4% incidence of complications. Home discharge rate was 91.2%. Bad outcome was experienced in 12.6%. Bad outcome was related to age, gender, complications and comorbidities (patient classifications) and hospital size and year of procedure. The authors concluded that outcome after open repair of intact AAA in US was good. However, only white males visiting the hospitals and procedures done only at large, urban non-teaching hospitals show skewed behaviour of AAA detection and treatment. There may be a certain degree of not falling in line with ACR guidelines in some respects. However, this is not clear from the results as only short-term data were selected and the methods used were unable to detect this.

The extent of compliance with long-term surveillance recommendations following EVAR and type B aortic dissection was found poor due to lack of coordinated approach. Cases of 204 patients (171 EVAR, 33 type B dissection) were evaluated. Of 171 EVAR, 100 were AAA, 45 TA, 12 TAA and 7 iliac artery and 7 proximal graft extensions. Medium follow-up period was 28 $\pm$ 10.5 months. Overall, 56% were lost to follow-up, and 11% never returned after initial hospitalization [44]. Lakhani et al. reported an increase in nonroutine radiological communications especially of critical finings in a tertiary hospital during 1997–2005 due to increasing compliance with ACR guidelines [45]. According to Benjamin et al. [46], compliance of the radiologist with hospital guidelines for nonroutine communication of diagnostic imaging results gave better outcomes in a general hospital. Such communications were required most for CT, followed by MRI and ultrasound.

Good correlation was found by Gilk et al., [47] between 2013 updated ACR guidelines on MR safe practices and the Joint Commission's Sentinel Event Alert No 39 on MR safety as the Environment of Care standards. About 90% of US academic emergency departments deviated from ACR guidelines on contrast practices for abdominal and pelvic CT imaging, as observed by [48]. According to Abramson et al., there are wide variations with respect to compliance on ACR guidelines by different hospitals [49]. Some reports on compliance of hospitals with ACR guidelines on fluoroscopy and CT were cited and discussed [50]. Quality assurance protocols, tracking exposure time and direct measurement of patient exposure time all based on ACR guidelines have improved compliance in reducing radiation exposure in some hospitals.

Besides these reports on some factors related to compliance of hospitals with ACR guidelines, many individual hospitals have reported receiving awards and certificates of ACR imaging compliance.

In general, there are no direct studies on the effect of extent of ACR compliance on aneurysm deaths. The findings discussed above only indicate the lack of compliance on certain aspects of ACR guidelines but nothing to connect them with aneurysm mortality. The importance of this study is evident from this research gap.

2.4 Frequencies of aneurysm diagnostic imaging by different modalities

Aneurysm is a chronic disease usually affecting people towards the end of their lives. This makes detection and intervention procedures highly risky. A majority of aneurysm patients do not report to the hospitals. Among those reported, repair procedure is not done on a good majority. It is notable that imaging helps proper diagnosis eventually leading to the reduction of mortality. Abdominal aortic aneurysm is most common with roughly 73% accounted, followed by thoracic aortic aneurysm. All others occur in very low frequencies compared to these. Although EVAR is promising, OAR is still the choice method, probably as the best method to deal with emergency and urgent admissions of ruptured aneurysms. In spite of other more promising methods becoming increasingly available, DSA is still the gold standard for diagnostic imaging. Such techniques like MRI and CT were used very rarely.

The data related to different types of aortic aneurysm admissions in US hospitals are given in **Figure 2**.

Out of a total number of 32,434 cases, elective admission dominated with 48.8% of valid data, followed by about 33.3% for emergency admissions. The latter is alarming as emergency admissions are usually associated with ruptured aneurysms

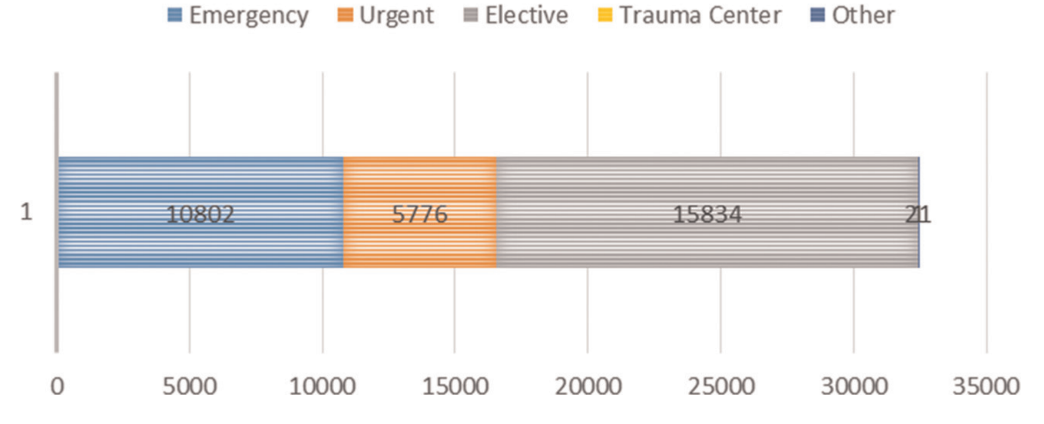

Figure 2.
Admission type of aortic aneurysm patients in US hospitals.

Hospital contexts		Medical imaging procedures				Total	P
		CT	MRI	US	DSA		
Admission type	Emergency	340	59	1084	9319	10,802	
	Urgent	53	10	469	5244	5776	
	Elective	73	20	2263	13,478	15,834	
	Trauma centre	0	0	2	19	21	
	Other	0	0	1	0	1	
Total		466	89	3819	28,060	32,434	<0.0001

Table 3.
Imaging frequencies using different methods of aortic aneurysm patients admitted in US hospitals.

and may lead to in-hospital mortality in spite of the best treatment given as it may be too late for any intervention to be successful. Urgent also is almost equally critical which accounted for about 17% of admissions. Emergency and urgent together constitute about 51% against 48.8% of elective admissions.

Different imaging methods may be used for different admission types. Thus more than 90% imaging was done with DSA in the case of emergency and urgent admissions compared to only about 79% for elective admissions (**Table 3**). Contrary to what was theorized, emergency plus urgent and elective admissions recorded almost equal 40–42% proportion of total patients for all imaging modalities. Overall, highest frequency (13,478) was observed for DSA in the case of elective admissions, and the lowest frequency of 10 was recorded by MRI for urgent admissions. On the other hand, US was highest in elective followed by emergency admissions. CT and MRI were highest in emergency followed by urgent admissions. Trauma centre and other admission types recorded very low frequencies to make any significant impact. Thus irrespective of admission type, DSA is the choice method followed by US.

This question is answered by reviewing research works in which two or more imaging methods are compared for their efficiency and effectiveness of aneurysm diagnosis, in which some specific aspect of the algorithms of one or more is enhanced. Several scientists have compared different imaging methods for diagnosis of aneurysms in which some algorithmic enhancements and support systems have been made for increasing their effectiveness and efficiencies of diagnosis. The parameters for efficiency are accuracy of diagnosis either by experimental comparisons of image readers or by relative quantitative or qualitative assessments. The measure of effectiveness is the relative merits of diagnosing some specific characteristics of the aneurysm under study like location, size, anatomy, etc.

This study utilized a series of processing methods on the NIS data, data mining techniques and statistical procedures to attain its goals. Data cleaning, recoding and extraction were used to arrange the raw data for the analysis. Statistical analyses such as frequencies, correlation, chi-square analysis, logistic regression and multinominal logistic test were applied. All of these different methodologies were used to analyse and process a big data set derived from multiple years from 2008 to 2012 and geographically collected from more than 4300 hospitals across the USA.

2.5 Objectives, variables and statistical analysis procedures

The NIS data set on different variables covering the period of 2008–2012 were used in this project. The variables required to fulfill different objectives are as given in **Table 4**.

No	Objective	Statistical tests applied
1	To study the relation between imaging modalities and in-hospital mortality among aortic aneurysm patients through US hospitals	Pearson chi-square test
		McNemar's test
		ANOVA test
		Logistic regression test
2	To compare in-hospital mortality of EVAR with OAR when different diagnostic imaging techniques are used in both cases	Pearson chi-square test
		McNemar's test
		ANOVA test
		Logistic regression test
3	To evaluate the effect of using ACR recommended imaging methods and extent of compliance on in-hospital mortality	Pearson chi-square test
		Gamma correlation test
		Logistic regression test
4	To determine among different patient characteristics and hospital context, those factors which can be used for prediction and thereby reduction of in-hospital mortality to desired levels	Logistic regression test
5	To determine among significant predictor factors, which type of diagnostic imaging performed is associated with in-hospital mortality	Multinominal logistic test

Table 4.
Relationship of objectives and statistical analysis procedures.

2.5.1 Data availability

Availability of the required data is a major factor in the ability to perform the above tests. In this project, all the required data are to be sourced from NIS data set. Hospitals may have not have given the cause of death properly. They may have automatically assumed that aneurysm patients died due to aneurysm only. Aneurysm as the specific cause of death may be absent. Even if it is possible to get data on a number of patients who underwent different repair procedures, records may not allow classification of repair procedures versus death data. A similar problem may arise with respect to imaging procedures also. Compliance percentage may not be indicative of a specific influence of ACR unless it is very high. At medium or low percentage values, the specific parameters on which there is compliance may also be important. Thus, the type of data available in NIS data set and its relationship with ACR guidelines is important. These are described below.

2.5.2 NIS dataset

There are two parts: the core file and the hospital file.

The core file has the data elements depicted in **Table 5**. The first core element of DXn and PRn deals with ICD-9 diagnostic and repair procedural codes, respectively. Other elements relate to mortality and patient classifications. The patient

Core file element	Variable in the study	Type	Description
DXn	Aortic aneurysm diagnosis	Nominal	ICD-9 diagnosis codes
DXCCSn	Comorbidities	Nominal	Clinical classification software
PRn	Interventional repair and imaging procedures	Nominal	ICD-9 procedure codes
DIED	In-hospital mortality	Ordinal	Died during hospitalization
AGE	Age group based on WHO standardization	Ordinal	Age in group at admission from 1 to 21 age groups
FEMALE	Gender	Nominal	The sex of the patient (male or female)
RACE	Race	Nominal	The race and ethnicity of patient
PAY1	Insurance type	Nominal	Indicates the expected primary payer
SOURCE	Admission type	Nominal	Source of admission to point of origin for admission or visit
LOS	Length of stay	Ratio	Length of stay from 0 day as same-day stays to greater than 365 days
YEAR	Year	Ratio	Calendar year (2008–2012)

Table 5.
The core file data element format.

classifications include age, gender, race, insurance type, admission type as source and the calendar year to which the data pertains.

In the hospital file in **Table 6**, information on location and type, bed size and geographical region are available. This is the core NIS file on hospital.

Results of a recent research by the authors are discussed here. ACR has nine rating scales of appropriateness criteria for different imaging methods and aneurysm types. For convenience of application for any imaging method and aneurysm type in our study, these were reduced to three appropriateness criteria by combining the same rating of different imaging methods and aneurysm types and making the ratings clearer. Hospital-wise data from NIS on mortality status (died/not died) to evaluate the effect of ACR compliance level on reducing mortality rate. The results showed that increasing levels of ACR compliance reduced mortality rates. More systematic research may be required for confirming the results. ACR appropriateness guidelines for diagnostic imaging have been developed by a large team of experts who examined available research works for the quality of evidence to prescribe these guidelines. The guidelines are reviewed and updated when new evidence becomes available. Hence, there is enough logic in contending that

Hospital file element	Variable in the study	Type	Description
H-LOCTCH	Hospital location	Nominal	Hospital's location and teaching status
H-BEDSZ	Hospital bed size	Ordinal	Hospital bed size
HOSP_REGION	Hospital region	Nominal	The hospital's census region was obtained from the AHA Annual Survey of Hospitals

Table 6.
Data elements in NIS hospital files.

compliance with ACR guidelines will improve the patient outcome especially on reducing mortality rate.

The details of the methodology and results are given and are discussed with the support of scientific evidence.

2.6 Effect of strictly and fully ACR compliant imaging procedures on in-hospital mortality rate

If compliance level is critical in determining mortality rate, the use of imaging methods in strict compliance with ACR should reduce mortality substantially. However, there can be variations among imaging methods to produce this effect. This aspect was studied, and the data are presented in **Table 7**.

CTA had a very few number of patients reported, and hence zero mortality obtained here is suspect. CT imaging of abdomen and pelvis as well as thoracic regions recorded similar mortality rate in the range of 10.5–12.0. The mortality rate was only 5.3% for US and was the lowest 2.6% for DSA. Based on length of stay, DSA was found undesirable in the earlier discussions. However, mortality rate itself is minimum for DSA, and this may be associated with a short period of hospital stay. All statistical tests were highly significant. Therefore, if ACR compliant procedures are used, DSA method is most effective followed by US in reducing mortality rate.

Earlier, in **Table 8**, mortality rate for different imaging methods (irrespective of ACR compliance) was presented. The mortality rates in both tables agree. Chi-square tests gave highly significant likelihood ratio and linear-by-linear values. Thus the model fitted better with predictors, and the relationship is strongly linear (**Table 8**).

Gamma test and other tests have relatively low negative value indicating a negative relationship between ACR compliance and mortality. Gamma = −0.328, which also indicates a strong degree of inverse correlation. Thus, the higher the compliance, the lower is the mortality rate (**Tables 2–12**).

ACR radiological procedures		Died during hospitalization		Total
		Did not die	Died	
CTA	Count	4	0	4
	%	100.0%	0.0%	100.0%
CT: abdomen and pelvis	Count	199	27	226
	%	88.1%	11.9%	100.0%
CT: thoracic	Count	224	26	250
	%	89.6%	10.4%	100.0%
US	Count	4619	259	4878
	%	94.7%	5.3%	100.0%
DSA	Count	31,881	865	32,746
	%	97.4%	2.6%	100.0%
Total	Count	36,927	1177	38,104
	% within ACR	96.9%	3.1%	100.0%

Table 7.
The effect of using strictly and fully ACR compliant radiological methods on frequencies of in-hospital mortality of aortic aneurysm patients in the USA.

Chi-square tests			
	Value	**df**	**Asymp. sig. (two-sided)**
Pearson chi-square	206.255[a]	4	0.000
Likelihood ratio	152.579	4	0.000
Linear-by-linear association	197.995	1	0.000
N of valid cases	38,104		

[a]*Two cells (20.0%) have expected count less than 5. The minimum expected count is 0.12*

Table 8.
Chi-square test results on effect of ACR compliant radiological procedures on frequency of in-hospital mortality among aortic aneurysm patients in the USA.

ACR compliance rating		**Died during hospitalization**		**Total**
		Did not die	**Died**	
Usually not appropriate	Count	4619	259	4878
	% within ACR compliance rating	94.7%	5.3%	100.0%
	% within died during hospitalization	12.5%	22.0%	12.8%
May be appropriate	Count	32,304	918	33,222
	% within ACR compliance rating	97.2%	2.8%	100.0%
	% within died during hospitalization	87.5%	78.0%	87.2%
Usually appropriate	Count	4	0	4
	% within ACR compliance rating	100.0%	0.0%	100.0%
	% within died during hospitalization	0.0%	0.0%	0.0%
Total	Count	36,927	1177	38,104
	% within ACR compliance rating	96.9%	3.1%	100.0%
	% within died during hospitalization	100.0%	100.0%	100.0%

Table 9.
Effect of ACR compliance levels of hospitals on frequencies of in-hospital mortality.

Compliance level	**In-hospital mortality percentage**
Usually not appropriate	5.3
May be appropriate	2.8
Usually appropriate	0

Table 10.
Mean effects of increasing compliance with ACR appropriateness criteria on in-hospital mortality rate of aortic aneurysm patients in the USA.

Accordingly, the odds relationship for ACR compliance with mortality rate is given by the following equation:

$$\text{Ln (Odds)} = -1.472 - 0.676 \times \text{ACR compliance rating}$$

As the equation will result in a negative estimate, odds for mortality decrease when ACR compliance of hospitals increase. Significant Wald test value indicates no interference of other predictors on the relationship (**Table 13**).

Chi-square tests			
	Value	df	Asymp. sig. (two-sided)
Pearson chi-square	92.255[a]	2	.000
Likelihood ratio	78.896	2	.000
Linear-by-linear association	92.252	1	.000
N of valid cases	38,104		

[a]*Two cells (33.3%) have expected count less than 5. The minimum expected count is 0.12*

Table 11.
Chi-square test results on effect of ACR compliance levels of hospitals on frequencies of in-hospital mortality of aneurysm patients in the USA.

Symmetric measures					
		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by ordinal	Gamma	−.328	.032	−7.617	.000
N of valid cases		38,104			

[a]*Not assuming the null hypothesis*
[b]*Using the asymptotic standard error assuming the null hypothesis*

Table 12.
Gamma test results on frequencies of in-hospital mortality of aneurysm patients as affected by ACR compliance levels of hospitals in the USA.

Variables in the equation									
		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
								Lower	Upper
Step 1[a]	ACR compliance rating	−.676	0.215	9.909	1	0.002	0.508	0.334	0.775
	Constant	−1.472	0.417	12.472	1	0.000	0.229		

[a]*Variable(s) entered on step 1: ACR compliance rating*

Table 13.
ACR compliance rating and various constants values.

3. Discussion

The aim of this chapter is to describe whether the extent of compliance with ACR diagnostic and interventional imaging guidelines by US hospitals influences in-hospital mortality rates of patients diagnosed with different types of aneurysms. The findings were expected to provide predictors of mortality outcomes under a given set of patient factors and hospital contexts. The need for any change in the guidelines or practices to reduce aneurysm mortality rates could be identified and recommended. Preliminary results had confirmed that out of the six main aortic aneurysm types, abdominal aortic aneurysm (AAA) was the most widespread type. About 75% of all aortic aneurysms was either AAA or rAAA. Another 21% of aneurysms belonged to thoracic aneurysm (TA). Thus, AAA and TA are the two types of aneurysms of specific concern. Although rupturing almost ensures death, only 3.4% of patients reported with ruptured aneurysm of any type. If only these patients die, overall mortality rate should be around 3.4%. Now the question arises:

which imaging methods were more commonly used in the case of ruptured aneurysms? Based on the findings, no specific imaging method was chosen for ruptured aneurysms. However, it is not certain that most of the mortalities occurred in the case of ruptured aneurysms only. It is also not certain that any other imaging method would have reduced mortality of patients with ruptured or intact aneurysms. As is evident from the above results, imaging methods were related to mortality rates: DSA recorded the lowest rate. All other imaging methods recorded higher than 3.4%.

The objectives of the study were specifically verified using various tests appropriate to the specific objective. The objectives were to establish that imaging methods had distinct influence on mortality rates, to compare the two intervention procedures in interaction with the imaging methods, to evaluate the impact of compliance with ACR guidelines on mortality rates, to examine the scope of using any patient factor or hospital context as predictors of mortality rates and to assess which imaging method is associated with mortality rate as affected by any of the significant predictors. The study relied on diagnosis and procedure of only the ICD-9 coding registered in NIS data set. NIS data does not include all the sophisticated diagnostic imaging procedure codes. Differentiation of pre- and post-operative imaging is not available in ICD-9 codes and is not indicated in NIS data also. This study was limited to the study of most common aneurysms and not all.

Only 5 years' data were included in this study. A more detailed study may need to be done for firm conclusions. Compatibility between NIS data and ICD codes need to be tested by using ICD-10 instead of ICD-9 to verify whether compatibility improves by this. Although several works reported increasing use of CT and MRI, this was not reflected in a data set as recent as 2008–2012. Similarly, increasing use of EVAR compared to OAR was also not reflected. This needs further investigation. How far probabilistic estimates of mortality based on predictors will be closer to actual figures is not clear either from published works or from this study. This aspect needs further study by developing such equations and comparing actual with estimates.

There is enough evidence that hospitals are less than fully compliant with ACR appropriateness criteria. However, their number is not known. A survey of US hospitals to evaluate numbers of fully compliant, partially compliant and non-compliant hospitals needs to be done. The latter two need to be persuaded to fully comply with the ACR criteria.

4. Conclusions

Recognizing the high mortality rates in certain aneurysm conditions, factors related to this were examined. Imaging methods have an important role in diagnosis and treatment interventions. ACR has published appropriateness criteria for diagnostic imaging. It was contended that if hospitals followed ACR guidelines, it would improve diagnosis and in turn intervention procedure also. The research was aimed at this aspect to develop predictors for mortality due to imaging methods and intervention procedures. Patient characteristics like age, gender, race, comorbidities and insurance type for medical reimbursement and hospital contexts like size, location, geographical region, type and admission types were included as variables for the study. The basic variables were four imaging methods and their combinations with EVAR and OAR upon which the patient characteristics and hospital contexts were superimposed. NIS data for the period of 2008–2012 from more than 4300 US hospitals were used. After prescribed data cleaning procedures, net sample size of 38,263 patients was obtained for detailed study. Apart from descriptive statistics, ANOVA, chi-square, logistic multiple regression, McNemar's and gamma tests were used for dealing with different objectives of the study. AAA and TA were most frequent aneurysm types. DSA and US were the most frequent imaging methods. OAR was much more frequently used than EVAR. Age group, male, and comorbidities had distinct effects on aneurysm frequency. More patients went to urban teaching and urban non-teaching, large-volume hospitals for emergency and elective admissions and were supported by medical reimbursement schemes. However, none of these patient characteristics or hospital contexts had any effect on frequency-based ranking of imaging methods or intervention procedures.

Results supported the view that imaging methods have a distinct effect on mortality. DSA recorded lowest and CT recorded highest mortality. Out of the intervention procedures, EVAR had lower mortality than OAR. However, in combination, OAR with DSA as the imaging method recorded lowest mortality. There was a distinct effect of hospital stay on these mortalities due to imaging methods with longer than 10 days for any imaging method increasing mortality risk. Definite effect of ACR compliance was observed. With increasing compliance, mortality rate reduced and became zero with full compliance. Thus, improving ACR compliance and patients selecting only compliant hospitals will reduce aneurysm mortality significantly. Results of logistic multiple regression were used for the development of probability equations for mortality with imaging methods alone and in combination with intervention procedures. From a detailed analysis of patient characteristics and hospital contexts, age group and comorbidities emerged as the most important predictors of mortality probability. Other factors were less important as they provided inconsistent results.

Overall, imaging methods affect mortality, and increasing compliance with ACR appropriateness criteria reduces mortality considerably. Probability of in-hospital mortality can be predicted using models with imaging methods with or without intervention procedures and adding age and comorbidity as predictors.

Conflict of interest

None declare conflict of interest.

List of abbreviations

TA	thoracic aortic aneurysm
rTA	ruptured thoracic aortic aneurysm
TAA	thoracicoabdominal aortic aneurysm
rTAA	ruptured thoracicoabdominal aortic aneurysm
AAA	abdominal aortic aneurysm
rAAA	ruptured abdominal aortic aneurysm
EVAR	endovascular aortic repair
OAR	open aortic repair
CT	computed tomography imaging
CTA	computed tomography angiography
MRI	magnetic resonance imaging
MRA	magnetic resonance angiography
US	ultrasound imaging
DSA	digital subtraction angiography imaging

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