The role of radiological imaging in the diagnosis of acute appendicitis

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Several strategies have been employed to improve the accuracy of the diagnosis of appendicitis and to reduce the associated perforation rate. Because clinical algorithms have been disappointing, many physicians resort to radiological modalities. Plain abdominal x-rays are nonspecific, barium enema examination has relatively low accuracy, scintigraphy scans require considerable time and are difficult to interpret, and magnetic resonance imaging is relatively unstudied. The most promising modalities are graded compression sonography and computed tomography. In expert hands, these techniques can achieve a high degree of accuracy. Nevertheless, most published studies have been marred by methodological difficulties. Moreover, ultrasound is more useful in detecting than in ruling out appendicitis. The radiological criteria for acute appendicitis, the accuracy of various imaging modalities and the limitations of the available research are described.

Key Words: Appendicitis; Computed tomography; Diagnosis; Magnetic resonance imaging; Scintigraphy; Ultrasonography

Le rôle de l'imagerie radiologique dans le diagnostic d'appendicite aiguë

RÉSUMÉ : Plusieurs stratégies ont été utilisées pour améliorer la précision du diagnostic d'appendicite et réduire le taux de perforation concomitante. Puisque les algorithmes cliniques se révèlent décevants, de nombreux médecins ont recours à des modalités radiologiques. Les rayons-X simples de l’abdomen ne sont pas spécifiques, les examens au lavement baryté présentent une précision relativement faible, la scintigraphie est très longue à exécuter et difficile à interprêter et l’imagerie par résonance magnétique est relativement non étudiée. Les modalités les plus prometteuses sont la sonographie avec compression dosée et la tomodensitométrie. Exécutées par des mains expertes, ces techniques peuvent assurer un taux de précision élevé. Néanmoins, la plupart des études publiées sont gâchées par des problèmes méthodologiques. De plus, les ultrasons sont plus utiles pour déceler l’appendicite que pour en écarter la possibilité. Les critères radiologiques d’appendicite aiguë, la précision des diverses modalités d’imagerie et les limites des recherches disponibles sont décrits.
Appendicitis is a common and important clinical problem that affects 8.6% of male and 6.7% of female Americans. There are 250,000 to 300,000 appendectomies, including 60,000 to 80,000 involving children, and more than one million patient-days of hospitalization for appendicitis, each year in the United States (1-3).

There are problems with the current methods of diagnosis, which are based mainly on the clinical history, physical examination and simple laboratory tests. The classic presentation includes vague midabdominal pain, anorexia and nausea, followed by localized right lower quadrant (RLQ) abdominal pain and guarding, and leukocytosis. Up to 45% of cases, however, have atypical symptoms and/or signs (4).

The clinical diagnosis of acute appendicitis is accurate only 70% to 80% of the time (5-9). Delays in diagnosis often lead to perforation (5,10,11), which occurs in 8% to 39% of cases (2,7,8,12-14). To prevent perforation, the surgeon may adopt liberal criteria for surgery, which results in negative appendectomy rates of 15% to 22% (7,9,15). Unnecessary surgery causes pain and inconvenience for patients, wastes precious health care resources and can lead to serious complications (15-17). Appendicitis is especially difficult to diagnose, and the consequences of error are greater in children, pregnant women and elderly patients (18-23). These difficulties are due to physiological factors, variations in clinical presentation and, in some cases, problems with communication.

Most surveys have found an inverse relationship between rates of perforation and rates of negative appendectomy (1,7,24-26). Therefore, attempts to reduce the rate of unnecessary surgery often lead to unacceptable perforation rates, while a reduction in the latter is generally achieved at the expense of diagnostic accuracy. For example, Law et al (13) reviewed 216 patients with a preoperative diagnosis of appendicitis, and reported a high rate of diagnostic accuracy (89%), together with a high perforation rate (29%). In contrast, Andersen et al (14) reviewed 454 patients and reported a much lower perforation rate (8%) at the expense of a lower accuracy rate (67%).

This dilemma has been addressed in four ways:

- adoption of standardized diagnostic criteria;
- observation in hospital of patients with equivocal clinical presentations;
- application of diagnostic tests, including radiological imaging; and
- use of diagnostic laparoscopy.

Of the many standardized scoring systems for the diagnosis of acute appendicitis, the Alvarado criteria (27), which generate the MANTRELS score (Table 1), appear to be the most effective (28). A score of more than seven points has a relatively high sensitivity (88% to 90%), but the specificity is generally no better than 80%, and is especially low in women (28-30). Modifications have included removing the leukocyte count criteria or reducing the threshold to five points, but these modifications further impair the specificity of the system, particularly in pediatric patients (29-32). While these and other criteria may assist junior staff and nonsurgical personnel in identifying patients with appendicitis, they are not likely to be helpful for experienced surgeons who possess astute clinical judgement.

Several authorities have suggested that close observation of patients with atypical presentations improves diagnostic accuracy without causing inordinate delays in treatment (9,33,34). Early, appropriate referral to a surgeon appears to be the most important way of producing a successful outcome.

With the exception of leukocytosis, laboratory markers of inflammation have not proved to be of much value in early diagnosis. The use of radiological imaging techniques – plain x-rays, barium enema, ultrasonography, computed tomography (CT), nuclear imaging (scintigraphy) and magnetic resonance imaging (MRI) – is the subject of this review.

Several groups advocate the use of diagnostic laparoscopy (35-39). It has a high sensitivity and specificity, and may be especially valuable in women of child-bearing age, because gynecological diseases that might be confused with appendicitis can be readily diagnosed. Appendectomy can be carried out safely and quickly with this technique (40-43). The normal-appearing appendix can be left in situ, thus reducing the rate of negative appendectomy (35,39,41-46). Some authorities recommend that the appendix be removed in all cases, however, because a normal macroscopic appearance does not exclude the presence of histological appendicitis with certainty (47-49). Moreover, it has been suggested that recurrent pain can arise from appendices that have neurochemical or immunological abnormalities even in the absence of overt inflammation (50-56).

A substantial proportion of patients report a history of recurrent episodes of pain before appendectomy (recurrent appendicitis) or of prolonged pain, which may or may not

### Table 1

**Alvarado scoring system**

<table>
<thead>
<tr>
<th>Clinical or laboratory feature</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Migration of pain from the midabdomen to right lower quadrant</td>
<td>1</td>
</tr>
<tr>
<td>Anorexia or acetonuria (a surrogate marker of food avoidance)</td>
<td>1</td>
</tr>
<tr>
<td>Nausea and vomiting</td>
<td>1</td>
</tr>
<tr>
<td>Tenderness in the right lower quadrant</td>
<td>2</td>
</tr>
<tr>
<td>Rebound tenderness</td>
<td>1</td>
</tr>
<tr>
<td>Elevated temperature (≥38°C)</td>
<td>1</td>
</tr>
<tr>
<td>Leukocytosis (&gt;10,400 cells/mm³)</td>
<td>2</td>
</tr>
<tr>
<td>Shifted white blood cell count (&gt;75% neutrophils)</td>
<td>1</td>
</tr>
<tr>
<td>Total possible points</td>
<td>10</td>
</tr>
</tbody>
</table>

*Data from reference 27*
be accompanied by histological evidence of fibrosis or of chronic inflammation (chronic appendicitis) (57-66).

**PLAIN ABDOMINAL X-RAYS**

Except for the presence of an appendicolith (fecalith) and possibly of a sentinel loop, the findings of acute appendicitis on plain radiographs (Table 2) are nonspecific and generally appear only in advanced disease (67-70). Appendicolithiasis is said to be the most specific of the common findings of appendicitis but is identified in only 10% to 15% of all cases (71,72) – a considerably lower rate than those quoted in studies of ultrasonography and CT (vide infra). Plain x-rays are thus of little value in the early diagnosis of appendicitis (70,73-75) and are actually less cost effective than either ultrasonography or CT (76,77). They are more helpful in detecting nonappendiceal causes of acute abdominal pain, including bowel obstruction, ureteral calculi and basal pneumonia (78).

**BARIUM ENEMA**

The diagnosis of acute appendicitis by barium enema examination is based on nonfilling of the inflamed appendix and on the presence of an extrinsic defect in the wall of the cecum, due to appendiceal and periappendiceal inflammation (79). The examination can result in complications, however, including perforation (79,80), and its diagnostic accuracy is variable and often poor (81-83). Technical failures occur in 16% of examinations; 10% to 23% of normal appendices fail to fill, and up to 20% of inflamed but nongangrenous appendices fill completely (82,84-86). It may be difficult to be certain that the entire appendix, including its bulbous tip, has been filled (87). Therefore, cases of distal appendix, in which the proximal part of the organ could be opacified, might easily be missed (88). Diagnostic confusion can also occur in patients with chronic or recurrent appendicitis (79,89,90).

**ULTRASONOGRAPHY**

The usefulness of ultrasonography in the diagnosis of appendicitis has been known since the early 1980s. It is safe (including during pregnancy) and relatively inexpensive, and can be performed quickly and repeatedly, using portable equipment. The patient can indicate the point of maximal tenderness, to which the transducer can be applied. This can facilitate the diagnosis when the appendix is in an atypical location. Children, because of the relative paucity of intra-abdominal fat, and young women, who are susceptible to gynecological disorders, are especially good candidates for sonography.

Sonography has, however, several limitations. Some of the limitations are nonspecific: obesity, intestinal gas, patient cooperation, quality of equipment, and the skill and experience of the technician. Other limitations are particularly relevant to acute appendicitis (Table 3).

Some of these limitations have been circumvented by using graded compression, a technique by which the transducer is applied with gradually increasing pressure to the area of McBurney’s point. Continuous, steadily increasing pressure from the transducer, unlike intermittent application of the device, is tolerated relatively well by patients with acute appendicitis (91). Gas artifacts are reduced, because the transducer either compresses or displaces unflamed loops of bowel. Specifically, compression can expel intraluminal contents from the normal appendix, but not if it is distended and thickened due to inflammation. This technique also brings the transducer closer to the area of the appendix, which allows the use of high-frequency transducers with short focal ranges (such as 5.0 or 7.5 MHz linear-array transducers).

Obesity is still a major problem for sonography. Because it is difficult to approximate the transducer to the appendix, low-frequency transducers (which have long focal ranges but poor resolution) must be used, and it is difficult to apply sufficient pressure to compress the bowel adequately. Furthermore, cases of retrocecal appendicitis can easily be overlooked because of the inability to see through the cecum. Special techniques, such as oblique imaging from a laterally placed transducer (92), may be required in such cases. Pelvic (transvaginal) sonography is also helpful in distinguishing appendicitis from gynecological disorders, especially if transabdominal approaches are inconclusive (93,94). Disease is confined to the tip of the appendix (dis-
appendicitis) in 5% to 8% of cases, and can be missed if the entire length of the appendix is not visualized (95-97).

In most normal appendices, ultrasonography can demonstrate an echogenic layer (arising from the submucosa) surrounded by a hypoechoic layer (the muscularis propria) (95). In some cases, additional luminal, epithelial, subepithelial and serosal structures can be identified and give rise to a 'target' appearance. The definition of these layers, especially that of the echogenic submucosal layer, is lost with transmural extension of edema, inflammatory infiltrate and necrosis (95,98). The normal appendix resembles the terminal ileum sonographically, except that the former generally lacks peristalsis, has a blind end, is less than 6 mm in diameter, is round instead of oval in cross-section, and does not change in configuration with time (92).

The key sonographic finding of acute appendicitis is a dilated and noncompressible appendix with a thickened wall. An appendicolith, which can be identified by its acoustic shadow, is found in up to 29% to 36% of cases (95). The loss of the submucosal echogenic layer, as well as the presence of hyperechoic periappendiceal fat and of a loculated pericecal fluid collection, are said to be indicative of perforation (99-101). The inflamed appendix is less likely than the normal appendix to contain luminal air (102). Mesenteric lymphadenopathy is sometimes apparent but can be confused with mesenteric adenitis in children (91,95,100). Most authorities have stated that the normal appendix can be visualized by ultrasonography less than 5% of the time (103-105); therefore, it is easier to establish the diagnosis of appendicitis than to exclude it.

There has been considerable discussion about appendiceal diameter, the most widely used diagnostic criterion. Most authorities use a threshold of 6 or 7 mm for appendicitis (91,95,98,99,101,104,106,107), and dilation is often quite obvious (108). A dilated appendix is not, however, a specific sign of appendicitis (109), because the healthy appendix can dilate in the presence of metabolic disturbances or inflammatory processes elsewhere in the abdomen or pelvis. An appendiceal wall diameter of 3 mm or greater may be more predictive, but effacement of the wall of a very dilated appendix may occur just before rupture (97,98,110). Moreover, a dilated noncompressible appendix is much less frequently seen after perforation (101,111), probably because of collapse or even disintegration. For this reason, sonography is actually less able to detect perforated than nonperforated acute appendicitis, although the recent use of more refined techniques has partially overcome this problem (103,111-114).

Many investigators have studied the diagnostic accuracy of ultrasonography for patients suspected of having appendicitis. Some of the largest and best designed of the prospective studies are summarized in Table 4. In most cases, graded compression technique was used, but the use of pelvic ultrasonography was usually not discussed specifically. Diagnostic accuracy seems to be similar in women and men (98,115), although most investigators have not reported their results separately according to sex. It is also accurate in pregnant women (116). Comparable performance characteristics are observed with adult and pediatric patients (Table 4), but it is less sensitive in patients with a body mass index of 25 or greater than in lean patients (107,117).

Some investigators have stated that ultrasonography is more accurate than clinical assessment in diagnosing acute appendicitis (118-123), while others have found that it offers no advantage (110,124). It has been suggested that the use of ultrasonography would reduce the negative appendectomy rate to 7% or even lower, but the perforation rate is not decreased (78,110,111,113,119,125-128). Many studies may have been biased in favour of sonography. The radiological tests were performed after the initial clinical

<table>
<thead>
<tr>
<th>Author, year (reference)</th>
<th>n</th>
<th>Acute appendicitis (%)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
<th>Accuracy (%)</th>
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<td>Puylaert et al, 1987 (103)</td>
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<td>95</td>
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<td>68</td>
<td>37</td>
<td>80</td>
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<td>Jeffrey et al, 1988 (104)</td>
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<td>96</td>
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<td>Vignault et al, 1990 (207)*</td>
<td>70</td>
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<td>Rioux, 1992 (208)</td>
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<td>26</td>
<td>93</td>
<td>94</td>
<td>86</td>
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<td>Sivit et al, 1992 (141)*</td>
<td>180</td>
<td>29</td>
<td>88</td>
<td>82</td>
<td>90</td>
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<tr>
<td>Chen et al, 1998 (209)</td>
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<td>90</td>
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<tr>
<td>Hahn et al, 1998 (114)*</td>
<td>3859</td>
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<td>97</td>
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<td>Schulte et al, 1998 (210)*</td>
<td>1285</td>
<td>9</td>
<td>92</td>
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<tr>
<td>Sivit et al, 2000 (158)*</td>
<td>315</td>
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<td>78</td>
<td>93</td>
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<td>92</td>
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<tr>
<td>Douglas et al, 2000 (125)</td>
<td>129</td>
<td>46</td>
<td>95</td>
<td>89</td>
<td>88</td>
<td>95</td>
<td>91</td>
</tr>
</tbody>
</table>

*Studies comprised exclusively pediatric patients (other studies comprised mainly adults). NPV Negative predictive value; PPV Positive predictive value
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Diagnosis of acute appendicitis

Assessment with which they were compared, and thus after the illness had progressed. Not all patients underwent surgery, and it was not always clear that the ultrasound results did not influence the decision to operate. These factors introduce possible verification bias. The interactive nature of sonography could also have introduced additional biases, in that patients with localized pain and tenderness (ie, those with a high pretest probability of a surgical condition) would be more likely to have a definitive ultrasound result than those without localizing symptoms or signs (129,130).

Ultrasound was generally performed and interpreted by experts in the field, whereas clinical assessments were often performed by junior surgeons, surgical residents or others using clinical scoring systems (118,123,124,128,131). Sonography is highly dependent on technical expertise and the nature of the equipment, however, and it is unlikely to perform as well in non-specialized centers as in research centers (92,132-136).

A shortcoming that is common to all of these investigations is the failure either to apply strict histological criteria for the diagnosis of appendicitis or to estimate the interobserver variability for pathologists or for the radiologists. Variability in the histological criteria can affect the sensitivity and specificity of the tests (137). Moreover, entry criteria are often vague, and patients with a wide range of pretest likelihood of having acute appendicitis may be included.

Most surgeons urgently operate on patients with typical clinical findings of appendicitis, and do not appreciate the delay caused by obtaining a sonogram (125,127,138,139). It appears that a substantial minority (8% to 26%) of patients with clinically typical appendicitis have false-negative ultrasonography scans (113,127,140-143). Sonography may be more useful in equivocal cases. Orr et al (144) undertook a meta-analysis of 17 studies (including 3358 patients) published between 1986 and 1995, and categorized patients according to their likelihood of appendicitis – high, intermediate and low (with disease prevalences of 80%, 40% and 2%, respectively). They found that, in the high-risk group, the positive predictive value of ultrasonography was 97.6% but the negative predictive value was only 59.5%; in the intermediate group, on the other hand, the negative predictive value was 99.7% but the positive predictive value was only 19.5%. They concluded that sonography was most useful for patients with intermediate clinical risk of appendicitis. Other investigators have found that ultrasonography is cost effective only for patients with equivocal clinical findings (145-147).

Another fundamental weakness of most ultrasonography studies is the failure to address inconclusive test results adequately. Sometimes, the failure to visualize the appendix is regarded as evidence against the diagnosis of appendicitis (110); however, this assumption may not be valid. In other studies, inconclusive results (such as an appendix of 5 to 7 cm in diameter) lead to further radiological investigation (eg, CT scanning or Doppler ultrasonography). It would be preferable if investigators acknowledged the proportion of indeterminate tests. In one study, the kappa scores for intra- and interobserver variability among radiologists were only 0.39 to 0.42 and 0.15 to 0.20, respectively (148).

Another problem occurs when the sonogram suggests the presence of appendicitis (ie, a dilated, noncompressible appendix), but the patient's illness resolves spontaneously (97,111,149,150). Are these cases of self-limited acute appendicitis, or do they represent false-positive ultrasonography results? Such patients generally are not subjected to immediate surgery, although some have further episodes of pain and ultimately undergo appendectomy. It has been suggested that the risk of eventual recurrence is higher in patients with previous episodes of typical pain and in those with appendicolithiasis (149). When surgery is not performed in patients who have undergone radiological investigation, it is crucial for the investigator to ensure sufficient follow-up to detect cases of recurrent or chronic appendicitis. Studies vary in the extent to which this has been done. Even if symptoms do not recur, the failure to operate on all patients with positive (or negative) scans interferes with the ability to determine the true sensitivity and specificity of the imaging modality.

**COLOUR DOPPLER SONOGRAPHY**

Colour Doppler ultrasonography identifies areas of hypervascularity in the wall of the inflamed (but not the normal) appendix and in the wall of a periappendiceal abscess, and may be helpful if the appendix has a diameter of 5 to 7 mm (151-154). The absence of either a visible appendix or strong Doppler signals is said to be strong evidence against the diagnosis of acute appendicitis (155). Doppler signals may not be detectable, however, if gangrenous appendicitis supervenes (152). This technique can also reveal other inflammatory and even neoplastic conditions in the abdomen and pelvis, some of which can cause false-positive results on conventional (gray scale) ultrasonography scans (151). Doppler ultrasonography is slightly more accurate than conventional techniques, although the differences may not be clinically significant (156). A further refinement, power Doppler sonography, may more precisely evaluate local blood flow (157), but some authorities question its benefit (92).

**CT**

The past decade has witnessed the increasing use of CT in the assessment of patients with acute appendicitis. Advantages of CT over ultrasonography include enhanced ability to detect the normal appendix (and thus rule out the diagnosis of appendicitis), appendicoliths (especially when using helical CT), retrocecal appendicitis, perforation and its complications, and alternative diagnoses. Disadvantages are the increased cost of CT; the use of ionizing radiation; the frequent need for contrast material; and the time required to prepare the patient, and to perform and interpret the scan. Unlike ultrasonography, CT is more effective for obese patients. Overall, the diagnostic accuracy of CT is
superior to that of ultrasonography (115,158-161), and CT is often able to establish the diagnosis when sonography is inconclusive (162,163). Radiologists generally have more confidence in CT (148,164), and surgeons are more likely to trust a negative CT than a negative ultrasonography result (162). There is less dependence on operator technique, and the images are more easily interpreted by trainees, by radiologists without special training and even by clinicians.

Some of the criteria for the diagnosis of appendicitis with the use of CT are similar to those for diagnosis with the use of ultrasonography, including appendiceal dilation, wall thickening and appendicolithiasis. Periappendical changes are more readily identified by CT and include blurred pericecal fat, mesenteric fat stranding, phlegmon, abscess, abnormal collections of air and fluid accumulations (165-167). Inflammatory thickening of the wall of the cecum is also often seen, and gives the appearance of an arrowhead or of a 'cecal bar' when the cecum is opacified by contrast material.

It is not possible to assess the compressibility or motility of the appendix, but the ability of the appendix to fill with enteric contrast material can be evaluated by CT. This is most rapidly and effectively done using rectal contrast agents. The alternative use of oral contrast material is more time consuming (by at least 30 to 60 min) and is limited by nausea, vomiting and disturbance of gastrointestinal motility. Failure to use enteric contrast material substantially reduces the ease of interpretation of the images, because the inflamed appendix might easily be mistaken for a loop of distal ileum. The use of intravenous contrast material introduces more risk, but it can reveal increased blood flow in the wall of the inflamed appendix or in periappendiceal tissues, and may be especially useful in thin patients (whose internal organs are not well separated by abdominal fat) and in those with periappendiceal abscesses. The relative merits of various contrast materials have been extensively debated (92,168-172).

Accuracy in evaluating the appendix can be enhanced if 5 mm instead of 10 mm sections are taken during scanning – a procedure known as thin collimation (173). Scanning times can be reduced by narrowing the field to the area of the appendix alone. This technique, called focused appendiceal CT (FACT), may, however, miss disease elsewhere in the abdomen or pelvis, or even atypically situated appendices. Therefore, quick preliminary scanning of the abdomen and pelvis is recommended, together with rectal instillation of contrast material (171). The best results have been obtained using helical CT, a technique that is costly and is available at only a small minority of radiology facilities (174). Advantages include the high speed of the technique, which allows rapid scanning of relatively large areas (even with thin collimation) and a reduction in image distortion due to respiration, but the images are somewhat less sharp than those obtained with conventional techniques (175).

Some of the largest and most well designed prospective studies of CT in acute appendicitis are summarized in Table 5. Most have employed helical CT with thin collimation, enhanced by rectal and/or oral contrast agents. Only one of the studies described in Table 5 did not use helical CT (176). Retrospective studies have yielded similar results (177-181). It is difficult to find differences between performance characteristics of helical and conventional CT in these studies. A study that directly compared these techniques seemed to reveal a significant advantage for helical CT, but there was wide and uncontrolled variation in other aspects of the scanning technique (163). It has been claimed that CT is more accurate than clinical assessment (163,182), and that it reduces the negative laparotomy rate
without increasing the perforation rate (183-186). It also seems to have a greater positive impact on clinical care than does ultrasonography (115,162,186,187). Another study, however, found that CT scanning significantly prolonged the diagnostic evaluation and increased the perforation rate (188).

Many of the methodological deficiencies that have been described in ultrasonography studies also apply to CT studies. For example, strict histological criteria have not been employed, not all patients underwent surgery, CT was compared with initial (and not later) clinical assessment and most studies were carried out by a relatively small number of enthusiastic radiologists. One study found that only 5% of CT scan results were not definitive, but many of the patients had prolonged symptoms and presumably fairly advanced disease (182). A different conclusion was reached by other investigators, however, who found that 12% of CT scans were interpreted as equivocal (189). The proportion of nondiagnostic results might actually increase if the decision to operate were based predominantly on the results of CT scans, as some investigators have advocated (182,190).

One study found a relatively low agreement between radiologists in the interpretation of helical CT scans with 5 mm and 10 mm collimation (kappa values were 0.58 and 0.69, respectively) (173). In another study, the kappa statistics for intraobserver and interobserver variability were only 0.76 and 0.36, respectively, for FACT without contrast and only 0.85 and 0.45, respectively, for FACT with rectally administered contrast (148).

Several groups have evaluated the cost effectiveness of CT scanning. The results of such an analysis depend on the relative costs of the test itself, hospital admission, surgery and care of patients with complications, and may not be easily translated across jurisdictions. Garcia Peña et al (191) undertook a decision analysis based on a retrospective review of 609 cases over 20 months, and found that a policy of performing helical CT (with oral and intravenous contrast), followed by observation in hospital, would be the most cost effective in the management of children with intermediate clinical likelihood for appendicitis. The brief admission to hospital would reduce the rate of missed appendicitis and thus reduce the expenses related to the treatment of complications. The authors recommended immediate surgery for patients with classic symptoms. The same group also found that ultrasonography, followed by CT in equivocal cases, was more cost effective than clinical assessment alone (192).

Rao et al (182) and Rhea et al (190) have argued that cost savings can be realized by performing FACT with rectal contrast in patients with an estimated high likelihood of appendicitis, because a significant minority of these patients would otherwise undergo negative appendectomies. These arguments assume that a high degree of accuracy (in the range of 98%) can be achieved with CT, and that all patients with radiological signs of appendicitis actually require surgery, rather than have self-limited disease. This latter assumption may not be valid. Moreover, CT scanning must be performed and interpreted rapidly and definitively (they report a total time from request to final report of less than 1 h); otherwise the perforation rate is likely to increase.

NUCLEAR IMAGING

Nuclear imaging techniques detect accumulations of white blood cells (or of immunoglobulins) in areas of inflammation. Other causes of RLQ inflammation are also detected, not all of which require surgery. Disease in atypical locations can be detected but may be misdiagnosed. Because the liver, spleen, bone marrow and large blood vessels take up radionuclide, the scans are limited in their anatomic scope. The available techniques differ in the length of time required for a positive scan and in the need for preliminary in vitro labelling of the patient's leukocytes.

Due to the availability and relatively low cost of the isotope, $^{99m}$technetium-labelled hexamethylpropylene amine oxime (HMPAO) scans are most commonly performed. A 2 h preparation time is required, during which the patient's blood is labelled with the radionuclide before the scan can be commenced. Scanning is then undertaken for up to 3 h, although most positive results occur before then. The per-

### TABLE 6

Prospective studies of the use of $^{99m}$technetium hexamethylpropylene amine oxime scans for the diagnosis of appendicitis

<table>
<thead>
<tr>
<th>Author, year (reference)</th>
<th>n</th>
<th>Acute appendicitis (%)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
<th>Accuracy (%)</th>
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NPV Negative predictive value; PPV Positive predictive value
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formance characteristics of this technique have been cal-
culated in several studies (Table 6), but these impressive
results may not be easily achieved in nonspecialized centres,
because of difficulty in interpreting the images. Although
the studies summarized in Table 6 found that the accuracy
of this technique was similar in all demographic groups,
another team reported poor results in children, as well as
poor interobserver agreement in the interpretation of
\(^{99m}\)technetium-labelled HMPAO scans (193).

A newer technique involves in vivo targeting of leukocytes
by a specific antileukocyte antibody (anti-CD15 immuno-
globulin M monoclonal antibody, or LeuTech [Palatin
Technologies, USA] that is labelled with \(^{99m}\)technetium.
Thus, no preparatory time is required. Furthermore, most
positive images are apparent within 15 min (194,195). The
two published trials of this technique (194,195) came from
the same institution, and found that the sensitivities were
close to 100%, but the specificities were only 83% to 84%
when approximately one-half of the study patients had appen-
dicitis.

Other radiolabelled antigranulocyte antibodies have also
been investigated but do not seem to be superior to
\(^{99m}\)technetium-labelled HMPAO scanning (196,197).
Immunoglobulin G antibody scans may offer more promise,
but only the results of preliminary trials have been reported
(198,199). Other scintigraphic modalities have been studied,
but they have been limited by prolonged preparation
times, inferior sensitivity and/or specificity, high frequen-
cies of uninterpretable images or high cost of the radionu-
clide (200-203).

MRI
The MRI diagnosis of acute appendicitis is generally based
on the demonstration of an abnormal appendix (204). The
presence of periappendiceal fluid collections, appendiceal
phlegmon, pericecal inflammatory changes or abscesses
(with or without visualization of an inflamed appendix) sig-
nifies perforation. The appendix is often curved, and thus
may be seen as two round structures on a given image.
Specific findings and technical details have been described
(204,205). In the only two studies that have assessed its
diagnostic accuracy, MRI seemed to be superior to ultra-
soundography, especially in cases of retrocecal and pelvic
appendicitis, in obese patients and if perforation had
occurred (204,205). In one study, however, MRI (unlike ultrasoundography) was performed only in patients with
appendicitis (205). Because the normal appendix cannot be
identified with the use of MRI, the diagnosis of appendici-

tis cannot easily be excluded. Moreover, appendicoliths
cannot be distinguished from air bubbles or avascular zones.
Even though this modality is operator-independent, radi-
ological expertise in assessing the appendix by MRI is lim-
ited. Other disadvantages of this technique are its high cost,
the relatively long time needed for the examination, the
need for intravenous contrast material (in some applica-
tions), the need to immobilize the patient (which might be
problematic when dealing with children) and difficulties
with claustrophobic patients. It is, therefore, unlikely that
MRI will supplant ultrasoundography or CT as the preferred
imaging modality for the diagnosis of appendicitis.

SUMMARY
The timely diagnosis of acute appendicitis is still mainly
determined by the clinical acumen of attending physicians
and surgeons. Diagnostic algorithms – including scoring
systems, leukocyte counts and radiological imaging – may
have adjunctive roles. Patients with classical clinical pre-
sentations should be operated on urgently, without resort-
ing to prior imaging, unless complications that might affect
the course of surgery are suspected. Plain abdominal radi-
ographs are of little value, except if certain nonappendic-
disorders are considered likely. Barium enema examinations
are cumbersome and have been supplanted by cross-
sectional imaging techniques. Nuclear imaging has been disap-
pointing, because most techniques require long periods of
time and the scans are often indeterminate. MRI remains
unproven, and resources are unlikely to be readily available
for this indication.

Ultrasoundography is safe and relatively inexpensive.
Good diagnostic accuracy can be achieved by expert per-
sonnel who employ graded compression, but the technique
is highly dependent on the skill, experience and persistence
of the operator. It may be especially useful when evaluating
children (because of their low body mass) and women
(because of their proclivity to gynecological disorders). The
inability to identify the normal appendix, and the high
false-negative rate in retrocecal appendicitis are important
drawbacks. Its sensitivity is too low for it to be of value in
patients who are clinically likely to have appendicitis, but it
does seem to be beneficial in equivocal cases. Colour
Doppler ultrasonography may offer a small advantage when
conventional techniques yield inconclusive results.

CT is highly accurate, especially when conducted by
experienced personnel. Highly refined techniques, such as
helical CT, thick collimation and the use of rectal contrast,
seem to enhance its effectiveness. It is superior to ultra-
soundography in obese patients and in those with perforation
or other complications. Because the normal appendix can
usually be identified, appendicitis can be ruled out with
more confidence. For it to be valuable as a diagnostic tech-
nique without causing important delays in management,
however, the equipment and specialized radiology staff need
to be continuously available.

Unfortunately, studies of radiological techniques in
acute appendicitis have been marred by the lack of stan-
dardized radiological or even histological criteria for the
diagnosis of appendicitis. There are also methodological
limitations, including comparison of imaging with initial
clinical assessments, lack of blinding, failure to confirm
(either by surgery or by thorough and prolonged follow-up)
the diagnosis in all patients, lack of acknowledgement of
indeterminate test results and failure to measure interob-
server variability. Finally, most studies have been conducted
by investigators with a high degree of interest and expertise
in appendiceal imaging. The applicability of their results to other settings is unclear.

Some investigators have reported very high degrees of diagnostic accuracy with advanced radiological techniques, such as graded compression ultrasonography, colour Doppler ultrasonography, and focused helical CT with enteric and/or intravenous contrast. It has even been suggested that all patients with suspected appendicitis should undergo CT scanning (182). Such a strategy can be effective only if the radiological investigations are undertaken rapidly, are interpreted accurately and definitively, and are used to guide treatment. It seems that such high standards could be achieved only in centres in which emergency medicine, radiology and surgery services are well coordinated, and in which equipment and highly trained personnel are committed to the management of appendicitis [206]. Unfortunately, these conditions are difficult to meet.

**REFERENCES**

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Diagnosis of acute appendicitis


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