Review Article

K-ras Mutational Status in Cytohistological Tissue as a Molecular Marker for the Diagnosis of Pancreatic Cancer: A Systematic Review and Meta-Analysis

Jing Yang, Jingjing Li, Rong Zhu, Huawei Zhang, Yuanyuan Zheng, Weiqi Dai, Fan Wang, Miao Shen, Kan Chen, Ping Cheng, Yan Zhang, Chengfen Wang, Junshan Wang, Yujing Xia, Jie Lu, Yingqun Zhou, and Chuanyong Guo

Department of Gastroenterology, Shanghai Tenth People’s Hospital, Tongji University School of Medicine, Shanghai 200072, China

Correspondence should be addressed to Chuanyong Guo; guochuanyong@hotmail.com

Received 12 April 2014; Revised 22 June 2014; Accepted 30 June 2014; Published 16 July 2014

Academic Editor: Lance A. Liotta

Copyright © 2014 Jing Yang et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Background. More clinically meaningful diagnostic tests are needed in pancreatic cancer (PC). K-ras mutations are the most frequently acquired genetic alteration. Methods. Original research articles involving the diagnostic accuracy of K-ras mutation detection in PC were selected. Data were presented as forest plots and summary receiver operating characteristic (SROC) curve analysis was used to summarize the overall test performance. Results. We assessed 19 studies from 16 published articles. The summary estimates for detecting K-ras status using an invasive method (fine needle aspiration (FNA), endoscopic retrograde cholangiopancreatography (ERCP), or surgery) were better than cytology: the pooled sensitivity was 77% (95% confidence interval (CI): 74–80%) versus 54% (95% CI: 47–61%); specificity was 88% (95% CI: 85–91%) versus 91% (95% CI: 83–96%); and diagnostic odds ratio (DOR) was 20.26 (95% CI: 11.40–36.03) versus 7.52 (95% CI: 2.80–20.18), respectively. When two procedures were combined, the diagnostic accuracy was markedly improved. Conclusions. The analysis of K-ras mutations in pancreatic tissue has a promising diagnostic significance in PC. Further valuable studies are needed.

1. Introduction

Pancreatic cancer (PC) is one of the most aggressive malignancies, with an overall 5-year survival rate of only 3% [1]. The reasons for this poor prognosis are due to its early dissemination, its lack of early specific symptoms, and its late diagnosis. At the time of diagnosis, patients with PC usually have locally advanced disease and even metastases, precluding curative surgery, which is currently the only possible curative method for PC in the very early stage [2]. Early detection of PC is therefore extremely important to improve patient survival. Imaging methods are not accurate enough to detect early lesions, assess tumor stage or resectability, and even discriminate between benign and malignant lesions [3]. Currently, CA 19-9 is considered the best-validated serum marker in patients with PC, but it has limited use in the early diagnosis of PC and in monitoring progression of the disease.

More clinically meaningful and efficient diagnostic strategies such as molecular markers capable of identifying PC during the curative stage of the disease are urgently needed.

The K-ras gene encodes a protein that acts as a mediator in intracellular processes and has an important role in cell proliferation and differentiation [4]. Present in 75%–90% of tumors, activating point mutations in the K-ras oncogene is the most frequently acquired genetic alteration in PC [5, 6], the most common of which is substitution of the wild-type glycine residue (codon 12) by cysteine, arginine, valine, or aspartic acid. K-ras mutations can be detected—with substantially different accuracy—in pancreatic tissue, pancreatic juice, bile, plasma, and stools. K-ras tests may thus have different diagnostic properties. In plasma or stools, K-ras mutations are detected at a much lower frequency than in cytohistological materials (pancreatic juice, pancreatic duct brushings, duodenal aspirates, or tissue) [7–9]; therefore,
we mainly identified studies that evaluated the diagnostic accuracy using these methods. In fact, the detection of K-ras mutation could not only be useful in the diagnosis, but also in staging, prognosis, evaluation of response to therapy, and follow-up of PC.

Numerous studies have been carried out to determine the diagnostic utility of K-ras mutation detection; however, results are heterogeneous and conflicting. The objective of the present review was to analyze the results from a systematic selection of research papers that evaluated the utility of detecting K-ras mutational status in different cytohistological materials for the diagnosis of PC using an invasive method.

2. Methods

2.1. Inclusion and Exclusion Criteria. Articles were preselected based on the following criteria. Original research articles that evaluated the diagnostic accuracy of K-ras mutation detection for the diagnosis of PC in at least 30 patients were included. Studies that evaluated the diagnostic validity of K-ras in combination with other diagnostic procedures were included. The method used to retrieve samples for DNA extraction and K-ras determination was limited to invasive techniques (FNA, ERCP, or surgery). Studies which did not provide exact raw data on sensitivity or specificity were excluded. Abstracts, letters, editorial, expert opinions, reviews without original data, case reports, and studies lacking control groups were also excluded. No restriction was set on the study design, year of publication, or publication status.

2.2. Identification of Studies. A comprehensive systematic literature review of original research assessing the diagnostic accuracy of K-ras was performed by searching the following electronic databases up to March 2014: PubMed/ Medline, Embase, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Science Citation Index (ISI Web of Science), Chinese Biomedical Literature Database (CBM), and Chinese National Knowledge Infrastructure (CNKI) [10, 11]. In addition, references from the included articles and relevant published reports were hand searched. Subject headings and keywords used in the search process were as follows: (1) K-ras, kirsten-ras, and ki-ras; (2) PC, pancreatic neoplasms, pancreatic cancer, adenocarcinomas of the pancreas, and pancreatic adenocarcinomas. We did not use keywords or indexing terms for diagnostic accuracy to avoid missing relevant studies.

2.3. Study Selection. All the studies were reviewed by two reviewers (Jing Yang and Jingjing Li) independently based on titles and abstracts, and then the full texts of potentially eligible studies were retrieved for further assessment. Disagreements between the reviewers were resolved by consensus. The authors were contacted for further study details when necessary.

2.4. Data Extraction. Using a structured form, the following data were extracted from the included studies by two reviewers (Jing Yang and Jingjing Li) independently: author, year of publication, journal, study design, number of patients initially included in the study, number of patients that contributed to the evaluation of K-ras, assay type for markers, and raw data on analysis of sensitivity and specificity (the number of true positive, false negative, true negative, and false positive results) to compare patients diagnosed with PC versus all other patients included and to determine whether the study evaluated the diagnostic accuracy of another marker in addition to K-ras mutation. According to the sample type and the method used to obtain the material, we divided the studies into three groups: minimally invasive (FNA), moderately invasive (ERCP), and very invasive (surgery).

When the articles described two different types of samples or presented two separate patient populations, the text referring to the clinical application of each setting was extracted, and the results were recorded as two separate studies. Overall, the agreement between the two reviewers for data extraction was 87.5%. Discrepancies were resolved by consultation with the third reviewer (Rong Zhu).

2.5. Assessment of Methodological Quality. The quality of each study was assessed according to the adapted quality criteria from the QUADAS-2 checklist recommended by the Cochrane Collaboration [12, 13]. The QUADAS-2 tool comprises four domains: patient selection, index test, reference standard, and flow and timing. Each domain is assessed in terms of risk of bias, and the first three domains are also assessed in terms of concerns regarding applicability. Signaling questions are included to help judge risk of bias. This revised checklist allows for more transparent rating of bias and applicability of primary diagnostic accuracy studies.

2.6. Representative Patient Spectrum. Patients with upper abdominal pain, development or worsening of diabetes mellitus, elevated serum pancreatic enzymes and/or tumor markers, and abnormal imaging findings including the dilated pancreatic/biliary duct and suspicious pancreatic masses were selected as being at high risk for PC. It is in these target populations that molecular markers are most urgently needed.

Histopathology is the currently accepted reference standard recommended for PC. If histopathology is not available, PC diagnosis is usually established by various imaging methods (such as ERCP, US, MRI, CT, and EUS), and a compatible clinical course (when death occurred within the first year after diagnosis, with clinical evolution compatible with disseminated cancer disease). Other types of neoplasia were diagnosed on the basis of pathological findings. The diagnosis of chronic pancreatitis was usually based on standard clinical criteria and ERCP findings.

2.7. Data Analysis. Using MetaDisc (version 1.4; Clinical Biostatistics Unit, Ramon y Cajal Hospital, Madrid, Spain), the Spearman correlation coefficient was calculated to estimate if there was a threshold effect. The overall sensitivity, specificity, and diagnostic odds ratio (DOR) were then calculated. Data were presented as forest plots with RevMan5.2 (The Nordic Cochrane Centre, The Cochrane Collaboration, 2012), which
3. Results

We searched suitable articles published from 1985 through 2014 (30 years), and a total of 275 articles were found, of which 47 publications were considered to be eligible for inclusion in the analysis. After full-text review, 31 articles were excluded: 26 articles were excluded because they did not allow the calculation of sensitivity or specificity; two were excluded because of a suspected overlap study population or a duplicate publication; and three were excluded because of insufficient patient size. In total, 19 studies from 16 published articles were used to evaluate the quality of all the 19 studies from 16 published articles (Figure 2). However, the quality was unsatisfactory. Only four studies used a perspective design. Notably, the selection criteria were not clearly described in nine articles (56.25%), and various studies did not report sociodemographic or clinical details of the final patient population. Less than half of the studies (seven, 43.75%) stated that the K-ras mutational status of patients was interpreted blinded to the definitive diagnosis. Both situations may lead to reviewer bias and inflated estimates of diagnostic accuracy. One study recruited healthy subjects in the control group. All the studies reported the diagnostic standard of PC. Of 16 studies that did not report K-ras results in all patients who entered the study, four (25%) failed to explain why this had occurred. Of the 12 that did explain, common reasons were failure of DNA amplification and problems with sample collection.

3.1. Quality of the Studies Identified. QUADAS-2 criteria were used to evaluate the quality of all the 19 studies from 16 published articles (Figure 2). However, the quality was unsatisfactory. Only four studies used a perspective design. Notably, the selection criteria were not clearly described in nine articles (56.25%), and various studies did not report sociodemographic or clinical details of the final patient population. Less than half of the studies (seven, 43.75%) stated that the K-ras mutational status of patients was interpreted blinded to the definitive diagnosis. Both situations may lead to reviewer bias and inflated estimates of diagnostic accuracy. One study recruited healthy subjects in the control group. All the studies reported the diagnostic standard of PC. Of 16 studies that did not report K-ras results in all patients who entered the study, four (25%) failed to explain why this had occurred. Of the 12 that did explain, common reasons were failure of DNA amplification and problems with sample collection.

3.2. Summary Diagnostic Accuracy of K-ras Mutation Using an Invasive Method (FNA, ERCP, and Surgery) for PC. The DerSimonian-Laird (random effects) model was used to calculate the pooled value. The sensitivity of K-ras mutation levels in these studies ranged from 72% to 83%, 26% to 100%, and 72% to 92% using FNA, ERCP and surgical tissues in the diagnosis of PC, respectively, while the specificity ranged from 85% to 100%, 86% to 100%, and 65% to 93%, respectively. We included the paired sensitivity and specificity with 95% CIs for each study in the forest plot, and significant heterogeneity was observed (Figure 3).

We also calculated the summary positive likelihood ratio (PLR), negative likelihood ratio (NLR), diagnostic odds ratio (DOR), and the area under the SROC for each group (Table 2). The PLR in FNA group was 7.87, indicating that patients with PC had more than a 7.8-fold higher chance of a positive K-ras mutation in FNA sample compared to patients without PC. The NLR in ERCP was 0.34, which indicated that if the K-ras mutation in ERCP sample was negative, the probability of these patients developing PC was approximately 34%. Thus ERCP-negative results may not be used to exclude PC.

The SROC approach is the standard method in the meta-analysis of diagnostic reporting pairs of sensitivity and specificity [30]. This approach uses DOR as the main outcome measure which removes the effect of a possible threshold [31]. Therefore, we included the SROC curves obtained using the parameters of the hierarchical model to obtain an overall summary of moderately invasive methods and surgery. As shown in Figure 4, the SROC curve of paired data of moderately invasive methods and surgery indicated that the former curve falls above the surgery curve. Thus, it seems reasonable to conclude that K-ras mutation in cytohistological material obtained from ERCP or EUS-FNA may...
Table 1: Main characteristics of the studies included.

| Study                  | Country     | TP/FP/FN/TN | Number | Invasive | Assay type                        |
|------------------------|-------------|-------------|--------|----------|-----------------------------------|
| Trümpser et al., 1994  | Germany     | 16/0/0/11   | 1      | Moderate | PCR-SSCP + enriched PCR-RFLP      |
| Watanabe et al., 1998  | Japan       | 19/1/0/36   | 2      | Moderate | PCR-HPA                           |
| Mora et al., 1998      | Spain       | 22/5/6/32   | 3      | Very     | PCR-RFLP                          |
| Wengen et al., 1999    | Germany     | 28/3/8/12   | 5      | Very     | PCR + hybridization               |
| Castells et al., 1999  | Spain       | 28/4/11/22  | 6      | Minimal  | Enriched RFLP-PCR + SSCP         |
| Okai et al., 1999      | Japan       | 14/2/5/15   | 7      | Moderate | PCR-RFLP                          |
| Futakawa et al., 2000  | Japan       | 8/4/10/24   | 8      | Moderate | PCR-RFLP                          |
| Tada et al., 2002a     | Japan       | 20/0/6/8    | 9      | Minimal  | Enriched PCR and enzyme linked minisequence assay |
| Dianxu et al., 2002    | China       | 33/1/3/13   | 11     | Very     | PCR-RFLP                          |
| Tada et al., 2002b     | Japan       | 10/5/28/57  | 12     | Moderate | PCR-PHFA                          |
| Zheng et al., 2003     | China       | 45/0/9/12   | 14     | Minimal  | PCR-RFLP                          |
| Liu et al., 2003       | China       | 14/1/6/14   | 15     | Moderate | PCR-SSCP                          |
| Talar-Wojnarowska et al. | Poland     | 20/8/6/15   | 16     | Very     | PCR-RFLP                          |
| Shi et al., 2008       | USA         | 16/1/1/8    | 17     | Moderate | LigAmp strategy                   |
| Parker et al., 2011    | Spain       | 94/20/27/71 | 18     | Very     | PCR-RFLP                          |
| Ogura et al., 2012     | Japan       | 266/0/40/47 | 19     | Moderate | PCR-direct sequence assay         |

TP: true positive; FP: false positive; FN: false negative; and TN: true negative.

* According to how the material was obtained, the types of sample used for K-ras analysis were divided into three groups: fine needle aspiration (FNA) was considered minimally invasive, endoscopic retrograde cholangio-pancreatography (ERCP) moderately invasive, and surgery very invasive.

have better diagnostic value than that obtained from surgery. The difference may be caused by the different assays used to detect K-ras mutation. The materials obtained from ERCP or FNA usually have higher tissue specificity and can be sent for analysis immediately, while the intraoperative measurements of K-ras mutations in resection margins are far too complex. However, due to the limited number of studies in FNA and surgery group, this difference may have occurred by chance.

3.3. Diagnostic Accuracy of Serum K-ras Mutation Level for PC. The diagnostic value of serum K-ras mutation for detecting PC was reported in two articles [18, 22] in the same patient population, from which we sort out three individual studies. As shown in Table 3, K-ras mutation detection in cytohistological material had better value for early diagnosis due to its high sensitivity. However, detection of plasma K-ras mutations shows a high specificity, which may become a confirmatory tool in those cases in which a more invasive approach is contraindicated.

3.4. Summary Diagnostic Accuracy of K-ras Mutation versus Cytology for PC. Cancer is a diverse class of diseases that differ widely in their causes and biology; therefore, it is unlikely that a single marker will detect all cancers in a particular organ with high specificity and sensitivity. The diagnostic value of cytology for detecting PC was reported in seven studies, four of which also reported the diagnostic accuracy of K-ras in combination with cytopathology. The raw data for the two markers are shown in Figure 5. The pooled sensitivity and specificity for cytology were inferior to K-ras mutation detection: sensitivity 54% (95% CI: 47–61%); specificity 91% (95% CI: 83–96%); and DOR 7.52 (95% CI: 2.80–20.18). When two procedures were combined, the diagnostic accuracy was significantly improved with a pooled sensitivity of 83% (95% CI: 76–89%), specificity 100%, and DOR 79.46 (95% CI: 17.89–352.92).

3.5. Metaregression for Heterogeneity. The heterogeneity within the studies can also be observed in the SROC diagram. To investigate this heterogeneity, we attempted to explore the following study characteristics using metaregression: population characteristics (gender, ethnicity, age, disease types, and stage distribution), study design (prospective or retrospective and year of publication), and test characteristics (test type and number of tests per screening round). However, because of the unsatisfactory methodological quality of the studies, assay type and country were the only two features examined. The accuracy measure used was DOR, as it is a unitary measure of diagnostic performance that encompasses both sensitivity and specificity. However, due to the limited number of studies, the differences for assay type and country did not have a statistically significant effect on DOR (Table 4), suggesting that the influencing factors are complex.

3.6. Publication Bias. A Deeks funnel plot was obtained using the "metafunnel" command for Stata (version 12.0, StataCorp, College Station, TX, USA). As shown in Figure 6, the funnel plot was asymmetric, which indicated that publication bias existed in our study.
Figure 2: Summary of the methodological quality of included studies on the basis of review authors’ judgments on the four domains of the QUADAS-2 checklist for each study.
Table 2: Summary of the diagnostic accuracy of K-ras mutation level in different materials in the same patient group using MetaDisc (Version 1.4).

| Study              | FNA               | ERCP              | Surgery            |
|--------------------|-------------------|-------------------|--------------------|
| SEN                | 79 (95% CI: 72–85%) | 76 (95% CI: 72–79%) | 80 (95% CI: 74–85%) |
| SPE                | 94 (95% CI: 84–98%) | 92% (95% CI: 89–95%) | 79% (95% CI: 73–85%) |
| PLR                | 7.87 (95% CI: 2.95–20.97) | 6.83 (95% CI: 3.40–13.73) | 3.64 (2.42–5.47) |
| NLR                | 0.24 (95% CI: 0.18–0.32) | 0.34 (95% CI: 0.19–0.58) | 0.26 (0.20–0.36) |
| DOR                | 34.26 (95% CI: 10.01–117.2) | 23.92 (95% CI: 8.20–69.77) | 14.88 (95% CI: 7.51–29.47) |
| AUC                | 0.6957            | 0.9541            | 0.8540             |

SEN: sensitivity; SPE: specificity; PLR: positive likelihood ratio; NLR: negative likelihood ratio; DOR: diagnostic odds ratio; and AUC: area under curve.

Table 3: Summary of the diagnostic accuracy of K-ras mutation level in different materials in the same patient group using MetaDisc (version 1.4).

| Summary | Serum       | Cytohistological material |
|---------|-------------|---------------------------|
| Sensitivity | 41% (95% CI: 33–50%) | 77% (95% CI: 74–80%) |
| Specificity  | 95% (95% CI: 90–99%) | 88% (95% CI: 85–91%) |
| DOR            | 17.36 (95% CI: 6.61–45.59) | 20.26 (95% CI: 11.40–36.03) |

Table 4: Metaregression of the effects of methodological characteristics on diagnostic accuracy.

| Var.   | Coeff. | Std. Err. | P value | DOR   | 95% CI  |
|--------|--------|-----------|---------|-------|--------|
| Assay type | 0.212  | 0.8041    | 0.7954  | 1.24  | 0.22–6.94 |
| Country  | 0.431  | 0.9861    | 0.6690  | 1.54  | 0.19–12.75 |
PC in 19 studies from 16 published articles. The results of the independent application of a diagnostic tool for PC. Over half of the studies stated that K-ras is a valuable molecular marker and an independent predictor of PC. We assessed the diagnostic accuracy of K-ras detection in stool does not appear to be appropriate for clinical practice, and inactivation of tumor suppressor genes (e.g., p16, p53, DPC4, and BRCA2) [35, 36]. Members of the epidermal growth factor receptor (EGFR) family are transmembrane receptors with tyrosine kinase activity and are overexpressed in 20% to 90% of ductal adenocarcinomas [37]. The TGF-b signalling pathway, which inhibits growth, is deregulated in a large proportion of pancreatic cancers and associated with underexpression of TGF-b receptors and mutation of the SMAD4/DCP4 gene [38]. p53, which functions in a variety of pathways to control the G1 and S phases of the cell cycle and to initiate DNA repair or apoptosis [39], is inactivated in at least 60% of pancreatic cancers. Many of the mutations result in production of a protein which has a greater stability and half-life than the wild type, p16, which binds to cdkks 4 and 6 and prevents their association with the D-type cyclins, thus inhibiting the catalytic activity of the cdk-cyclin complex, is inactivated in over 80% of pancreatic cancers [40]. The relevance of these

Figure 4: Summary receiver-operating characteristic curves for detecting K-ras mutation using FNA/ERCP/surgical methods from the hierarchical summary receiver operating characteristic model.

4. Discussion

We assessed the diagnostic accuracy of K-ras mutation for PC in 19 studies from 16 published articles. The results demonstrated that K-ras mutation in cytohistological tissue is a valuable molecular marker and an independent diagnostic tool for PC. Over half of the studies stated that the independent application of K-ras was favorable, while some other studies concluded that K-ras mutations could be useful in the diagnosis of PC when combined with cytohistopathology. Only a limited number of studies allowed us to evaluate the combined sensitivity and specificity of K-ras and other techniques; in these studies, we observed higher values of diagnostic sensitivity, which may have been the result of selective reporting bias. However, the studies showed numerous methodological limitations, a broad range of diagnostic accuracy values, and heterogeneity.

As has been concluded, the mean accuracy of K-ras detection is higher in cytohistological material than in serum. K-ras mutations can be detected in pancreatic tissue, pancreatic juice, bile, plasma, and stools. The sensitivity of K-ras detection in stool does not appear to be appropriate for diagnostic use. Plasma K-ras mutations can potentially be used as a screening method in asymptomatic patients, but these mutations have mainly been detected in patients with distant metastasis; thus, this marker is not useful for the early diagnosis of PC [32]. Collection of pancreatic juice during ERCP is technically easier than EUS-FNA. However, there was one drawback to the analysis of pancreatic juice. When there were even small cystic lesions in the pancreas, the mutant gene was also detected at very high frequency and amounts in these cases, which was comparable with cases of pancreatic neoplasms [33]. EUS-FNA has the advantage of targeting a solid mass lesion directly. On the other hand, pancreatic juice might reflect migrating tumor cells from a mass lesion, but actually cells with mutant K-ras gene from either malignant or benign cystic lesions are collected in it. Therefore, analysis of aspirates obtained by targeting under EUS should be superior to pancreatic juice.

Besides, different K-ras analysis systems are also shown in our meta-analysis. Several assays are available to detect K-ras mutation, such as PCR-ASO-DBH, PCR-RFLP, hybridization protection assay, PCR-SSCP, and PCR-denaturing gradient gel electrophoresis. Each of them has a different analytical sensitivity, which can be an important source of heterogeneity. Since these assays use different technologies, it is likely that there are differences in the accuracy between them. Watanabe et al. detected K-ras mutation in their study with a method (the mutant allele specific amplification (MASA) method) declared to be most sensitive for detecting point mutations for K-ras among various other methods [34]. Their results suggest that the detection of K-ras mutation can be achieved even in bile samples by using a highly sensitive method, such as MASA. Unfortunately, there is currently no standard test that has been approved by the US Food and Drug Administration in this regard.

Different incidence of K-ras mutations among distinct geographical areas is another reason to affect the diagnostic accuracy. In Japan, the prevalence of K-ras mutation ranged from 90 to 100%, whereas in the West it was relatively low, ranging from 65 to 70% in Europe and 85% in USA. In the present meta-analysis, the effects of this factor were not evaluated successfully because of lack of necessary data in the original studies.

The development of PC consists of multiple steps which include progression from intraepithelial proliferation with dysplasia to carcinoma in situ and finally to invasive cancer [35]. During the disease process, various genetic disorders occur which lead to loss of mechanisms that control cell differentiation, growth, and apoptosis [36]. These genetic alterations include point mutation in K-ras, overexpression of oncogenes (e.g., EGFR, c-erbB-2, c-erbB-3, and c-erbB-4), and inactivation of tumor suppressor genes (e.g., p16, p53, DPC4, and BRCA2) [35, 36].
The implications of therapeutic approaches. In general, studies on the prognostic implications of K-ras mutations point towards a worse prognosis, but the findings have been inconsistent. Previous research has demonstrated a relationship between K-ras mutation and the presence of lymph node metastases. Niedergethmann et al. have reported that para-aortic lymph nodes diagnosed for K-ras mutation were independent pancreatic cancer prognostic markers in multivariate analysis [43]. All of the patients with the K-ras mutation in lymph nodes had recurrence after surgery and a significantly poorer survival than those without mutated K-ras. K-ras is now also widely accepted as a predictor of poor response to antiepidermal growth factor receptor (EGFR) monoclonal antibodies in metastatic colorectal cancer and testing for K-ras mutation has been incorporated into treatment [44]. Whether the importance for specific effector pathways of K-ras is different in different tumor types or whether findings from other malignancies can be translated to pancreatic cancer will have to be addressed in the future.

One of the major goals of meta-analysis is to explore reasons for heterogeneity rather than computation of a single summary measure [45]. In our meta-analysis, we failed to find a reason for the heterogeneity observed. Statistical analysis of the sources of heterogeneity may have been hampered due to the following reasons. First, many studies on diagnostic accuracy lacked information on key elements of design and conduct. Without complete and accurate reporting, we cannot correctly identify potential sources of bias and variability. Second, few studies using direct comparisons were available. The small numbers in this analysis also made subgroup analysis less accurate. Third, the diagnostic meta-analysis was also threatened by publication bias. The investigation of publication bias in diagnostic tests is problematic.

5. Conclusions

In conclusion, our meta-analysis found that the detection of K-ras mutation in cytohistological tissue is a valuable molecular marker and independent diagnostic tool for PC due to its high sensitivity and specificity. The detection of K-ras mutations may improve the diagnosis and treatment of one of the most aggressive malignancies worldwide. More studies are needed to further elucidate the combined value of K-ras mutation detection and cytology.

Conflict of Interests

The authors declare that they have no competing interests.
Authors’ Contribution

Jing Yang and Jingjing Li contributed equally to this paper.

Acknowledgment

This study was supported by the National Natural Science Foundation of China (Grant no. 81172312).

References

[1] A. L. Warshaw and C. Fernandez-del Castillo, “Pancreatic carcinoma,” New England Journal of Medicine, vol. 326, no. 7, pp. 455–465, 1992.
[2] C. Rosty and M. Goggins, "Early detection of pancreatic carcinoma," Hematology/Oncology Clinics of North America, vol. 16, no. 1, pp. 37–52, 2002.
[3] A. Oto, M. A. Eltorky, A. Dave et al., “Mimicks of pancreatic malignancy in patients with chronic pancreatitis: correlation of computed tomography imaging features with histopathologic findings,” Current Problems in Diagnostic Radiology, vol. 35, no. 5, pp. 199–205, 2006.
[4] L. C. Fry, K. Mönkemüller, and P. Mallertheiner, “Molecular markers of pancreatic cancer: development and clinical relevance,” Langenbeck’s Archives of Surgery, vol. 393, no. 6, pp. 883–890, 2008.
[5] C. Almoquera, D. Shibata, K. Forrester, J. Martin, N. Arnheim, and M. Perou, “Most human carcinomas of the exocrine pancreas contain mutant c-K-ras genes,” Cell, vol. 53, no. 4, pp. 549–554, 1988.
[6] N. Malats, M. Porta, and J. M. Corominas, “Ki-ras mutations in exocrine pancreatic cancer: associations with clinicopathological characteristics and with tobacco and alcohol consumption,” International Journal of Cancer, vol. 70, pp. 661–667, 1997.
[7] M. Goggins, “Molecular markers of early pancreatic cancer,” Journal of Clinical Oncology, vol. 23, no. 20, pp. 4524–4531, 2005.
[8] R. Talar-Wojnarowska and E. Malecka-Panas, "Molecular pathogenesis of pancreatic adenocarcinoma: potential clinical implications," Medical Science Monitor, vol. 12, no. 9, pp. RA186–RA193, 2006.
[9] K. Mizumoto and M. Tanaka, “Genetic diagnosis of pancreatic cancer,” Journal of Hepato-Biliary-Pancreatic Surgery, vol. 9, no. 1, pp. 39–44, 2002.
[10] Y. Zhang, J. Lu, W. Dai et al., “Combination therapy of ursodeoxycholic acid and corticosteroids for primary biliary cirrhosis with features of autoimmune hepatitis: a meta-analysis,” Gastroenterology Research and Practice, vol. 2013, Article ID 490731, 9 pages, 2013.
[11] P. Whiting, A. W. S. Rutjes, J. B. Reitsma, P. M. M. Bossuyt, and J. Kleijnen, “The development of QUADAS: a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews,” BMC Medical Research Methodology, vol. 3, article 25, 2003.
[12] P. F. Whiting, A. W. S. Rutjes, M. E. Westwood et al., “Quadas-2: a revised tool for the quality assessment of diagnostic accuracy studies,” Annals of Internal Medicine, vol. 155, no. 8, pp. 529–536, 2011.
[13] Review Manager (RevMan) [Computer program]. Version 5.2, The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark, 2012.
pancreatic cancer: a prospective study in a clinically-relevant spectrum of patients,” European Journal of Epidemiology, vol. 26, no. 3, pp. 229–236, 2011.

[29] T. Ogura, K. Yamao, A. Sawaki et al., “Clinical impact of K-ras mutation analysis in EUS-guided FNA specimens from pancreatic masses,” Gastrointestinal Endoscopy, vol. 75, no. 4, pp. 769–774, 2012.

[30] J. J. Deeks, “Systematic reviews in health care: systematic reviews of evaluations of diagnostic and screening tests,” British Medical Journal, vol. 323, no. 7305, pp. 157–162, 2001.

[31] S. D. Walter, “Properties of the summary receiver operating characteristic (SROC) curve for diagnostic test data,” Statistics in Medicine, vol. 21, no. 9, pp. 1237–1256, 2002.

[32] T. Yamada, S. Nakamori, H. Ohzato et al., “Detection of K-ras gene mutations in plasma DNA of patients with pancreatic adenocarcinoma: correlation with clinicopathological features,” Clinical Cancer Research, vol. 4, no. 6, pp. 1527–1532, 1998.

[33] K. Tateishi, M. Tada, M. Yamagata et al., “High proportion of mutant K-ras gene in pancreatic juice of patients with pancreatic cystic lesions,” Gut, vol. 45, no. 5, pp. 737–740, 1999.

[34] H. Watanabe, A. Ha, and Y. X. Hu, “K-ras mutations in duodenal aspirate without secretin stimulation for screening of pancreatic and biliary tract carcinoma,” Cancer, vol. 86, pp. 1441–1448, 1999.

[35] R. H. Hruban, M. Goggins, J. Parsons, and S. E. Kern, “Progression model for pancreatic cancer,” Clinical Cancer Research, vol. 6, no. 8, pp. 2969–2972, 2000.

[36] D. Li, K. Xie, R. Wolff, and J. L. Abbruzzese, “Pancreatic cancer,” The Lancet, vol. 363, no. 9414, pp. 1049–1057, 2004.

[37] P. A. Hall, C. M. Hughes, S. L. Staddon, P. I. Richman, W. J. Gullick, and N. R. Lemoine, “The c-erbB-2 proto-oncogene in human pancreatic cancer,” Journal of Pathology, vol. 161, no. 3, pp. 195–200, 1990.

[38] E. Rozenblum, M. Schutte, M. Goggins et al., “Tumor-suppressive pathways in pancreatic carcinoma,” Cancer Research, vol. 57, no. 9, pp. 1731–1734, 1997.

[39] M. Hollstein, D. Sidransky, B. Vogelstein, and C. C. Harris, “p53 Mutations in human cancers,” Science, vol. 253, no. 5015, pp. 49–53, 1991.

[40] A. Kawesha, P. Ghanem, and A. Andren-Sandberg, “K-ras oncogene subtype mutations are associated with survival but not expression of p53, p16(INK4A), p21(WAF-1), cyclin D1, erbB-2 and erbB-3 in resected pancreatic ductal adenocarcinoma,” Cancer, vol. 86, pp. 1441–1448, 1999.

[41] C. M. Croce, “Oncogenes and cancer,” New England Journal of Medicine, vol. 358, no. 5, pp. 502–511, 2008.

[42] M. Porta, M. Crous-Bou, P. A. Wark et al., “Cigarette smoking and K-ras mutations in pancreas, lung and colorectal adenocarcinomas: etiopathogenic similarities, differences and paradoxes,” Mutation Research—Reviews in Mutation Research, vol. 682, no. 2–3, pp. 83–93, 2009.

[43] M. Niedergethmann, M. Rexin, R. Hildenbrand et al., “Prognostic implications of routine, immunohistochemical, and molecular staging in resectable pancreatic adenocarcinoma,” American Journal of Surgical Pathology, vol. 26, no. 12, pp. 1578–1587, 2002.

[44] C. Clancy, I. P. Burke, and J. C. Coffey, “KRAS mutation does not predict the efficacy of neo-adjuvant chemoradiotherapy in rectal cancer: a systematic review and meta-analysis,” Surgical Oncology, vol. 22, no. 2, pp. 105–111, 2013.

[45] D. B. Petitti, “Approaches to heterogeneity in meta-analysis,” Statistics in Medicine, vol. 20, no. 23, pp. 3625–3633, 2001.