Second reading of coronary angiograms by radiologists

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BACKGROUND: In many hospitals in the provinces of Quebec and Nova Scotia, as well as in some hospitals in the rest of Canada, coronary angiograms are performed and interpreted by invasive cardiologists, and are later reinterpreted and reported by radiologists.

OBJECTIVE: To evaluate the value of second readings of coronary angiograms by radiologists.

METHODS: Cardiology and radiology reports of a total of 160 consecutive coronary angiograms were compared from patients at three hospitals. Ten segments of the coronary tree were considered and 1582 segments were included. Agreement between cardiology and radiology interpretations was evaluated using per cent agreement, Pearson correlation and Bland-Altman limits of agreement. Agreement was calculated for each arterial segment and for each hospital.

RESULTS: Excellent agreement was found between cardiology and radiology interpretations of coronary angiograms. Per cent agreement ranged from 94.9% to 100%, Pearson correlation ranged from 0.83 to 0.97 and Bland-Altman limits of agreement ranged from -18.1 to 19.4. Agreement was similar for each segment and for each hospital. Agreement remained excellent after exclusion of normal angiograms (n=348 segments), with a per cent agreement of 96.3%. Secondary analyses demonstrated a mean time delay of 13 days between angiograms and the subsequent radiology reports.

CONCLUSIONS: There are minimal differences between the cardiology and radiology interpretations of coronary angiograms. Routine second reading by a radiologist may be redundant.

Key Words: *Coronary angiography; Inter-interpreter agreement; Radiography*

The number of coronary angiograms performed each year in Canada is substantial. In Ontario alone, more than 100,000 coronary angiograms are performed each year (1). Angiograms are generally performed and interpreted by invasive cardiologists. However, in some hospitals, coronary angiograms are performed by invasive cardiologists, and are later reinterpreted and reported by radiologists. Although this practice of second reading has been abandoned by hospitals in many provinces, it continues regularly in the provinces of Quebec and Nova Scotia, as well as in some hospitals in the rest of Canada (Canadian Association of Radiologists, personal communication). Second readings significantly increase health care costs. In Quebec, for example, more than one million dollars is spent each year on remuneration to radiologists for the interpretation and reporting of coronary angiograms (2,3). Considering the additional costs associated with second

Une deuxième lecture des angiogrammes coronaires par les radiologues

HISTORIQUE : Dans de nombreux hôpitaux des provinces de Québec et de Nouvelle-Écosse, ainsi que dans certains hôpitaux du reste du Canada, les angiogrammes coronaires sont effectués et interprétés par des cardiologues effractifs, puis interprétés de nouveau par des radiologues.

OBJECTIF : Évaluer la valeur de la deuxième lecture des angiogrammes coronaires par les radiologues.

MÉTHODOLOGIE : On a comparé les rapports de cardiologie et de radiologie de 160 angiogrammes coronaires consécutifs chez des patients de trois hôpitaux. Dix segments de l'arbre coronaire ont été pris en compte, et 1 582 segments ont été inclus. On a évalué la concordance entre l'interprétation cardiologique et radiologique au moyen du degré de concordance, de la corrélation de Pearson et des limites de concordance de Bland-Altman. On a calculé la concordance de chaque segment artériel et de chaque hôpital.

RÉSULTATS : On a constaté une excellente concordance entre les interprétations cardiologique et radiologique des angiogrammes coronaires. Le degré de concordance oscillait entre 94,9 % et 100 %, la corrélation de Pearson, entre 0,83 et 0,97 et les limites de concordance de Bland-Altman, entre -18,1 et 19,4. La concordance était similaire pour chaque segment et chaque hôpital. Elle demeurait excellente après l'exclusion des angiogrammes normaux (n = 348 segments), le degré de concordance s'élevant alors à 96,3 %. Les analyses secondaires ont démontré un retard temporisé de 13 jours entre les angiogrammes et les rapports radiologiques subséquents.

CONCLUSIONS : On remarque des différences minimales entre les interprétations cardiologique et radiologique des angiogrammes coronaires. La deuxième lecture systématique par les radiologues pourrait être redondante.

readings of angiograms, routine second readings should be evaluated. In particular, in an era of percutaneous coronary interventions (PCI), when decisions regarding patient management are almost always made and implemented at the time of the angiogram, the necessity of second, delayed readings should be assessed. Although many studies have examined the inter-interpreter agreement of angiographic readings (4-13), little is known about the usefulness of routine second reading by radiologists. The objective of the present study was to evaluate the value of routine second reading of coronary angiograms by radiologists.

METHODS

Selection of angiograms

A total of 160 coronary angiograms from three hospitals were examined. Angiograms were identified from the coronary

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TABLE 1
Distribution of coronary disease among 160 coronary angiograms

Radiologist interpretation	Cardiologist interpretation			
	Normal	Single-vessel	Double-vessel	Triple-vessel
Normal	38	2	0	0
Single-vessel	0	45	0	0
Double-vessel	0	0	37	2
Triple-vessel	0	0	0	36

A vessel was considered diseased when any of its corresponding arteries contained significant ($\geq 50\%$) stenosis. Single-vessel disease corresponds to significant stenosis in any one of the three major epicardial arteries. Double-vessel disease corresponds to stenosis in two of the major epicardial arteries or of the left main artery and triple-vessel disease corresponds to stenosis in all three major epicardial arteries. In 156 of 160 angiograms, both specialists agreed on the number of diseased arteries. In four angiograms in which the specialists disagreed on the number of diseased vessels, the cardiologist identified a segment as diseased that was not identified as such by the radiologist. In one angiogram, the cardiologist identified a left main artery as significantly stenosed, but the artery was not mentioned in the radiology report and was thus assumed to have no stenosis. In the three other angiograms in which the specialists disagreed, the cardiologist thought a segment was 50% stenotic, while the radiologist thought it was 40% stenotic (proximal right coronary artery and middle left anterior descending artery) or 30% stenotic (distal right coronary artery)

catheterization laboratory log books that record all angiograms performed. Fifty to 60 consecutive angiograms from each hospital were examined, beginning on three arbitrary dates in 2001 (January 1, September 1 and December 1). When multiple angiograms from a single patient were available ($n=2$), all angiograms were included. Angiograms were excluded if a report was missing, insufficiently completed or illegible ($n=23$). Angiograms of patients with previous coronary bypass surgery were also excluded ($n=37$). Ethics approval for this study was obtained from the McGill Faculty of Medicine Research Ethics Board (Montreal, Quebec).

Interpretation of angiograms

The cardiology and radiology reports for each angiogram were reviewed. A study investigator who was not involved in patient management reviewed each report. Reports from 10 cardiologists and five radiologists were examined. For each angiogram, 10 segments of the coronary tree were considered, so 1600 segments were potentially available for analysis. These segments were the proximal, middle and distal portions of the right coronary artery (RCA), the left anterior descending coronary artery (LAD) and the circumflex coronary artery, as well as the left main coronary artery (LM). These 10 segments correspond to the major epicardial arteries, not including branch arteries. Branch arteries were not included in the present study because reporting on branch vessels was inconsistent in the study's angiogram sample. The organization of arterial segments was in keeping with models used in previous studies (11). In eight angiograms, radiologists used descriptive words instead of percentages to describe the degree of arterial narrowing in some segments. These segments ($n=18$) were excluded from agreement analyses, so a total of 1582 segments was included in the final analyses.

Statistical analysis

The primary analysis consisted of two phases: the descriptive phase and the analytic phase. In the descriptive phase, the extent of coronary disease was evaluated. An artery was considered diseased when any of its corresponding segments contained

significant (at least 50%) stenosis. Single-vessel disease corresponds to significant stenosis in any one of the major epicardial arteries: the RCA, the LAD or the circumflex coronary artery. Double-vessel disease corresponds to stenosis in two of the major epicardial arteries or of the LM and triple-vessel disease corresponds to stenosis in all three of the major epicardial arteries. In the descriptive phase, reports that used words instead of percentages to describe arterial lumen calibre were included ($n=8$ angiograms), and words were converted into estimations of per cent stenosis. For example, arterial segments that were described as 'patent' or 'mild' were included as 50% stenosis or less, whereas segments described as 'significant' or 'severe' were included as greater than 50% stenosis. In the descriptive phase, the possible tendency of one specialist over- or under-rating stenosis severity was also explored. For these analyses, segments deemed significantly stenosed by one specialist were reviewed to evaluate whether the other specialist had also identified the presence of a significant stenosis.

The second phase of the primary analysis, the analytic phase, evaluated the agreement between cardiology and radiology interpretations of 1582 coronary segments. Measures of agreement included per cent agreement, Pearson correlation and Bland-Altman limits of agreement. The per cent agreement represents the proportion of arterial segments on which both readers agreed as to the presence or absence of stenosis. Per cent agreement was calculated for two thresholds. The threshold defines the degree of arterial lumen narrowing to be considered stenotic. For a given threshold, any reading above this value is considered stenotic and any one below is considered nonstenotic. Any two readings above or below the threshold were considered to agree, whereas one reading below the threshold and one reading above the threshold were not. A primary threshold of 50% and a secondary threshold of 75% were used for analysis in the present study. Pearson correlations were calculated to investigate the strength of the relation between cardiology and radiology reports. Agreement between cardiologist and radiologist interpretations were also examined using Bland-Altman limits of agreement. Bland-Altman limits of agreement measure the mean difference between two values while incorporating uncertainty, or random error (14). It can be interpreted as a CI of the difference. The primary analyses were calculated for each segment of the coronary tree and for each hospital. Analyses were repeated for abnormal angiograms alone, where abnormal was defined as stenosis greater than zero on either the cardiology or radiology report, such that entirely normal angiograms were excluded.

The secondary analysis consisted of a review of angiograms from patients in whom a percutaneous intervention was performed at the time of the angiogram to determine whether the second reader had agreed to the presence of a significantly (at least 50%) stenosed artery. Finally, the dates of the angiogram, the cardiology and radiology reports were examined. The date of the angiogram was compared with the date of each report to determine the time delay between the angiogram and subsequent reports.

RESULTS

Extent of coronary disease

In the study sample of 160 coronary angiograms, both readers agreed on the number of diseased vessels in 98% of cases (156 of 160). Among the 156 angiograms, 38 were normal, 45 had single-vessel disease, 37 had double-vessel disease and 36 had triple-vessel disease (Table 1). In four angiograms in which the specialists disagreed as to the number of diseased

TABLE 2
Agreement between cardiology and radiology reports by coronary artery segment

Artery segment	Number of segments	Pearson correlation	Per cent agreement threshold $\geq 50\%$	Per cent agreement threshold $\geq 75\%$	Bland-Altman limits of agreement
Left main coronary artery	160	0.83	99.4	99.4	-15.8, 18.1
Proximal left anterior descending artery	158	0.95	98.1	97.5	-21.6, 23.5
Middle left anterior descending artery	159	0.97	97.5	96.8	-17.3, 18.3
Distal left anterior descending artery	158	0.94	98.7	99.4	-13.6, 15.3
Proximal circumflex artery	156	0.91	97.4	98.1	-26.7, 28.0
Middle circumflex artery	159	0.99	100	99.4	-8.7, 11.3
Distal circumflex artery	159	0.96	100	99.4	-9.6, 11.5
Proximal right coronary artery	156	0.96	98.7	98.7	-20.1, 21.7
Middle right coronary artery	157	0.96	98.1	98.1	-21.0, 18.7
Distal right coronary artery	160	0.95	97.5	98.1	-20.4, 21.0

Pearson correlations varied by artery segments, but reflect the excellent concordance between cardiology and radiology interpretations. The per cent agreement represents the proportion of angiogram segments where both specialists agreed as to the presence or absence of stenosis. All per cent agreement results were excellent, indicating that cardiology and radiology interpretations are alike. Per cent agreement is similar regardless of threshold. Bland-Altman limits of agreement measure the mean difference between two values and can be interpreted as a CI of the difference. All Bland-Altman limits of agreement include 1, indicating that no statistical difference was present between the cardiology and radiology interpretations

vessels, the cardiologist identified a segment as 'diseased' that had not been identified as such by the radiologist. In one of these angiograms, the cardiologist identified an LM as 'significantly stenosed', but the artery was not mentioned in the radiology report and was thus assumed to have no stenosis. In the three other angiograms on which the specialists disagreed, the cardiologist thought a segment was 50% stenotic, while the radiologist thought it was 40% stenotic (proximal RCA and middle LAD) or 30% stenotic (distal RCA).

Descriptive agreement

Both readers agreed on the presence or absence of significant stenosis in almost all cases (1515 of 1582 [95.8%]). Of the segments in which the cardiologist thought there was significant stenosis, 271 of 280 (96.8%) were also identified by the radiologist. Similarly, among the segments in which the radiologist thought there was significant stenosis, 271 of 286 (94.8%) were also identified by the cardiologist. Only nine of 280 segments that were considered to be significantly stenotic by the cardiologist were not identified as such by the radiologist, and only 15 of 286 segments that were considered to be significantly stenotic by the radiologist were not identified as such by the cardiologist. Therefore, there was little evidence that one specialist tended to over- or under-read angiograms compared with the other.

Measures of agreement

The agreement between cardiologist and radiologist interpretations of 160 angiograms was excellent using several measures of agreement. Per cent agreement was nearly perfect when considering all segments, ranging from 97.4% to 100% (Table 2). When evaluating agreement by hospital, per cent agreement ranged from 94.9% to 99.4% (Table 3). Per cent agreement was similar regardless of threshold. The Pearson correlation reflected the excellent concordance between cardiology and radiology interpretations, ranging from 0.83 to 0.99 for 10 arterial segments and from 0.94 to 0.96 for three hospitals (Tables 2 and 3). The lowest correlation was found for the LM ($r=0.83$), reflecting one angiographic report in which the

cardiologist described the artery as being 85% stenotic, while the artery was not mentioned in the radiology report and was assumed to have no stenosis. There were six angiograms with significant left main disease, and in the remaining five angiograms, reports of left main arterial stenosis were identical between the specialists. All Bland-Altman limits of agreement included 1, indicating that no statistical difference was present between the cardiology and radiology interpretations (Tables 2 and 3). Agreement remained excellent after exclusion of normal angiograms ($n=348$ segments), with per cent agreement of 96.3% and 93.9% using 50% and 75% thresholds, respectively.

Although the precise per cent stenoses reported by specialists varied somewhat by specialist, there were essentially no disagreements in terms of significant or nonsignificant stenoses when thresholds of 50% and 75% were used (Figure 1, $r=0.95511$ and $P<0.0001$). When using a 50% threshold, in each segment in which the cardiologist thought there was significant stenosis but the radiologists did not ($n=9$ segments), the radiologists thought there was 30% to 40% stenosis, except in four segments, in which the per cent stenosis was assumed to be zero because radiology reports did not comment on these segments. When the radiologist thought there was a significant (at least 50%) stenosis but the cardiologist did not ($n=15$ segments), the cardiologist thought there was 40% to 45% stenosis in six cases, 20% stenosis in three cases, and stenosis was assumed to be zero in the remaining six cases because cardiology reports did not comment on these segments. When using a 75% threshold, in each segment in which the radiologists thought there was significant stenosis and cardiologists did not ($n=6$ segments), the cardiologist thought there was 60% to 70% stenosis. When cardiologists thought there was significant (at least 75%) stenosis but radiologists did not ($n=7$ segments), radiologists thought there was 50% to 70% stenosis, except in two cases in which there was thought to be zero stenosis because radiology reports did not comment on these segments.

Secondary analyses

In the sample of 160 angiograms in the present study, 24 PCIs were performed at the same sitting. For these angiograms, the

TABLE 3
Agreement between cardiology and radiology reports by hospital

	Number of segments	Pearson correlation	Per cent agreement threshold $\geq 50\%$	Per cent agreement threshold $\geq 75\%$	Bland-Altman limits of agreement
Hospital A	500	0.94	97.6	97.6	-21.3, 21.7
Hospital B	600	0.96	94.9	98.7	-18.1, 16.4
Hospital C	482	0.96	99.4	99.3	-13.8, 19.5
All hospitals	1582	0.96	98.5	98.5	-18.1, 19.4

Pearson correlations varied by hospital, but reflect excellent concordance between cardiology and radiology interpretations. Per cent agreement varied by hospital, but was excellent for all hospitals, indicating that cardiology and radiology interpretations are comparable. Per cent agreement was similar regardless of threshold. All Bland-Altman limits of agreement include 1, indicating that no statistical difference was present between the cardiology and radiology interpretations

Figure 1) Variability in angiographic interpretations among cardiologists and radiologists. Although the precise per cent stenoses reported by specialists varied somewhat by specialist, there were essentially no disagreement in terms of significant or nonsignificant stenoses when thresholds of 50% and 75% were used. When using a 50% threshold, in each segment in which the cardiologists thought there was a significant stenosis but the radiologists did not ($n=9$ segments), the radiologists thought there was 30% to 40% stenosis, except in four segments, in which the per cent stenosis was assumed to be zero because radiology reports did not comment on these segments. When the radiologist thought there was a significant ($\geq 50\%$) stenosis but the cardiologist did not ($n=15$ segments), the cardiologist thought there was 40% to 45% stenosis in six cases, 20% stenosis in three cases and stenosis was assumed to be zero in the remaining six cases because the cardiology reports did not comment on these segments. When using a 75% threshold, in each segment in which the radiologists thought there was significant stenosis and cardiologists did not ($n=6$ segments), cardiologists thought there was 60% to 70% stenosis. When cardiologists thought there was significant ($\geq 75\%$) stenosis but radiologists did not ($n=7$ segments), radiologists thought there was 50% to 70% stenosis, except in two cases in which there was thought to be zero stenosis because radiology reports did not comment on these segments

radiology report always agreed on the presence of a significantly stenosed artery. No time delay was found between the angiogram and the cardiology report, which was invariably reported on the same day as the angiogram was performed. However, there was a mean time delay of 13 days between the angiograms and the radiology reports. The minimum average time delay was 2.3 days at one hospital and the maximum was 23.1 days at another hospital.

DISCUSSION

Our study was designed to assess the value of routine second readings of coronary angiograms by radiologists. We found minimal differences between the reports issued by cardiologists and radiologists. Both specialists agreed on the number of diseased vessels in more than 95% of cases. Both specialists also agreed on the presence of significantly stenosed arterial segments in more than 95% of cases. Agreement was excellent when assessed by per cent agreement, Pearson correlation and Bland-Altman limits of agreement. The results were consistent across 10 artery segments and among three hospitals. Our results suggested that cardiologists and radiologists issue angiographic interpretations that are essentially indistinguishable.

Questioning the value of routine radiology reading of angiograms is reasonable, particularly given the cost burden of routine second readings (2,3). In a health care system with limited resources, costly practices must be logically justifiable. The hypothesis that a second reading is useful in confirming the presence of a significant lesion before an intervention is performed, while theoretically plausible, is unlikely given the results of the present study. We found that the second reader was virtually always in agreement on the presence of significant stenosis in patients who underwent PCI. More importantly, radiology reports were usually dated many days after the angiogram was performed, at which point the reports are unlikely to be relevant to clinical practice because cardiologists make decisions about PCI or bypass surgery at the time of the angiogram. Therefore, there appears to be little, if any, advantage offered by routine second reading of coronary angiograms.

Previous studies

To our knowledge, no previous studies have evaluated the inter-interpretation agreement between cardiologists and radiologists. However, several studies have evaluated inter-interpretation agreement for coronary angiograms. These studies have, for the most part, compared readings by the same interpreter performed at different times. These studies have found variable results, with agreement ranging from 45% to 95% (4-13). There are a number of reasons to explain why the results of this study show consistently positive agreement, whereas previous studies of inter-interpretation agreement have found variable results. One potential explanation is that previous studies of inter-interpretation agreement used blinded interpreters, whereas in our study, radiologists may have had access to the cardiology report at the time of their interpretation. In addition, the

radiologists were not blinded to the PCI procedures, which were done at the same sitting, and this could have affected their interpretations.

Limitations

Several possible limitations of the present study should be noted. First, we examined the major epicardial arteries, but not the branch arteries. Inclusion of branch arteries may have affected our agreement, but we were unable to examine this issue because of inconsistent reporting. Second, the number of angiograms in the present study was relatively small for a study of inter-interpreter agreement. However, we used 10 segments from each angiogram, so that more than 1500 individual arterial segments were included in our analyses. Finally, we only examined three hospitals, which may have limited the applicability of our results.

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CONCLUSIONS

Our study examined the use of routine second reading of coronary angiograms by radiologists. We found there to be excellent agreement between the interpretations of cardiologists and radiologists. We also found that second readings usually occur many days after the angiogram is performed, by which time decisions regarding interventions have already been made and implemented. Thus, the routine second reading of coronary angiograms appears to be redundant and likely has little impact on patient management.

CONFLICT OF INTEREST AND DECLARATION OF SUPPORT:

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