Original Article

A Synoptic Reporting System to Monitor Bone Marrow Aspirate and Biopsy Quality

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Abstract

Objectives: Bone marrow evaluation plays a critical role in the diagnosis, staging, and monitoring of many diseases. Although there are standardized guidelines for assessing bone marrow specimen quality, there is a lack of evidence-based tools to perform such assessments. The objective was to monitor bone marrow sample quality in real time by standardizing the basic components of a synoptic report and incorporating it into a bone marrow report template. **Materials and Methods:** A relational database of bone marrow quality parameters was developed and incorporated into our laboratory information system bone marrow report template, with data entry completed during specimen sign out. Data from multiple reports created within a date range were extracted by Structured Query Language query, and summarized in tabular form. Reports generated from these data were utilized in quality improvement efforts. **Results:** The synoptic reporting system was routinely used to record the quality of bone marrow specimens from adult patients. Data from 3189 bone marrow aspirates, 3302 biopsies, and 3183 biopsy touch imprints identified hemodilution as the principal issue affecting bone marrow aspirate quality, whereas aspiration artifact and fragmentation affected bone marrow biopsy quality. **Conclusions:** The bone marrow synoptic reporting process was easy to use, readily adaptable, and has proved a useful component of the overall quality assurance process to optimize bone marrow quality.

Keywords: Bone marrow specimen quality, laboratory information management system, pathology informatics, synoptic reporting

Introduction

Bone marrow evaluation plays a critical role in the diagnosis, staging, and monitoring of many diseases involving the hematolymphoid system. The bone marrow procedure involves the aspiration of liquid marrow and acquisition of a core of bone marrow tissue using special needles. The specimens are usually obtained from the posterior iliac crest, with the anterior iliac crest and sternum providing alternate collection sites. Aspirates are used for the preparation of Wright-Giemsa-stained smears and special studies, such as flow cytometry, while the core biopsy is fixed in formalin, embedded in paraffin, sectioned, and stained with H and E and other stains. However, accurate morphologic interpretation and reliable information from special studies are possible only if enough bone marrow cells and an adequate biopsy core specimen are collected during the procedure. Inadequate bone marrow specimens may delay or compromise patient care or require expensive and painful repeat procedures. For these reasons, bone marrow specimen quality is a major concern to hematopathologists.

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Detailed guidelines for standardization of the procurement, processing, interpretation, and reporting of bone marrow specimens have been published by the International Society for Laboratory Hematology (ISLH), the College of American Pathologists (CAP), and other expert groups.[1-4] These guidelines define adequate bone marrow smears as containing multiple particles with "trails" of well-stained, morphologically well-defined bone marrow cells. Inadequate aspirate specimens are often the result of hemodilution, excessive thickness, poor staining, or crushed, unrecognizable cells from excessive pressure during smear preparation. The

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bone marrow core biopsy should be of adequate length, intact, well-fixed, uniformly sectioned, and well-stained. Common problems affecting bone marrow core biopsies include: Inadequate length (subcortical specimens), aspiration artifact, fragmentation, and poor fixation, sectioning, or staining.[5] Operator technique and experience, needle type, and the use of a specimen preparation checklist have been identified as factors that affect bone marrow specimen quality.[3,6,7] A summary of the causes of suboptimal bone marrow specimen quality is presented in Table 1.

There are relatively few published studies evaluating the quality of bone marrow specimens. Bearden *et al*. considered 1% of bone marrow biopsies and 14% of bone marrow aspirates to be inadequate.[8] Based on the criterion of a minimal biopsy length of 1.5 cm or 5 intertrabecular marrow spaces advocated by Frisch and Bishop *et al*. considered 59% of their 232 biopsy specimens to be of inadequate length, while Reid and Roald found up to 50% of bone marrow biopsy specimens from children were inadequate.[9-11] In contrast, a recent study of 6374 marrow specimens from 32 academic centers showed only 4% of the bone marrow biopsies and 2% of the bone marrow biopsy/bone marrow aspirate samples inadequate for diagnosis.[12]

Synoptic reporting, using standardized checklists and data elements, is widely accepted to improve the accuracy and completeness of pathology reports[13] and this format has been facilitated by the cancer checklists and guidelines developed by the CAP.[12,13] Based on the CAP checklist, Murari and Pandey proposed synoptic reporting system for bone marrow specimens, in 2006, and a similar synoptic system for hematological and lymphoid neoplasms was devised by Mohanty *et al*.[14,15] Detailed guidelines for the application of the checklist in synoptic bone marrow reporting were subsequently published by the CAP Pathology and Laboratory Quality Center.[4] However, these guidelines do not specifically address the reporting of bone marrow quality parameters.

Materials and Methods

A reliable, appropriate, and measurable care initiative identified bone marrow specimen quality as one of the several opportunities for improving the quality of care for patients with leukemia and other hematologic malignancies at our institution. A bone marrow quality improvement committee was formed, and a number of changes were implemented, including the use of a specimen preparation checklist, similar to that developed by Odejide *et al*., and the establishment of a process for continuous monitoring of bone marrow quality.[3] This process involved the development of specific evidence-based criteria for bone marrow specimen quality, based on the recommendations of the ISLH and CAP, and the incorporation of these criteria into a synoptic reporting system. The synoptic reporting system required bone marrow quality data to be entered into the record of each bone marrow specimen, and data reports to be generated from multiple reports to show location-specific data for a chosen period. The data reports were used by the bone marrow quality improvement committee to identify and implement further changes in the system.

The majority of the bone marrow procedures in adult and pediatric outpatients at our institution are performed by specially trained nurse practitioners, while inpatient bone marrow specimens are routinely obtained by the hematology/

Table 1: Factors that compromise bone marrow specimen quality

Specimen	Artifact	Cause
Bone marrow aspiration	Suboptimal staining	Old or contaminated staining solution, inadequate staining time
	Inadequate particles	Poor aspiration technique, "dry tap"
	Cell crushing and distortion	Inadequate training, improper procedure
	Thick smears	Clotted specimen, inadequate training, improper procedure
	Uneven cell distribution	Clotted specimen, inadequate training, improper procedure
	Clotted specimen	Poor technique, multiple aspiration attempts with local activation of coagulation system, hyperactive coagulation system
Bone marrow biopsy	Aspiration artifact	Biopsy of aspiration site, failure to obtain aspirate and biopsy specimens from different areas
	Suboptimal staining	Inadequate fixation of processing, expired or contaminated staining solution
	Biopsy of previous aspiration or biopsy site	Failure to reorient biopsy needle at a proper angle or to a proper site
	Crushed or fragmented specimen	Harsh handling during touch imprint preparation or processing, inadequate microtomy
	Inadequate fixation	Inadequate volume of fixative solution, inadequate fixation time
	Excessive decalcification	Poor tissue fixation, excessive time in decalcification solution
	Inadequate decalcification	Poor tissue fixation, insufficient time in decalcification solution, inadequate volume of decalcification solution
	Uneven section thickness, "thick and thin" sections, "chatter," "Venetian blind effect"	Inadequate decalcification, inadequate microtomy (dull knife blade, improper handwheel tension, improper clearance angle, improper pressure plate or spring balance tension, loose cassette clamp, inadequate decalcification, worn equipment)
	Compressed or wrinkled sections	Inadequate microtomy (dull knife blade, warm specimen block, improper clear angle, loose cassette clamp, worn equipment)
	"Scratched" or "split" sections	Defective cutting blade, inadequate decalcification, worn or improperly adjusted microtome

oncology fellows. A minority of patients with significant obesity or pain sensitivity are referred to interventional radiology for ultrasound-guided procedures under moderate sedation. A few specimens are referred from extramural sources affiliated with our institution. Two or more aspirate smears, two biopsy imprints, and three sections of the trephine biopsy and/or clot were reviewed in all patients, including a few patients who had bilateral biopsies.

A major part of the quality improvement initiative was the development of the synoptic method for reporting bone marrow quality during bone marrow specimen sign out. This was done by storing the specimen quality parameters [Table 2] in a relational database integrated into our laboratory information system (Cerner Millennium, Kansas City, MO). In this database, each data item was stored as a predetermined text value referred to as a term, and the collection of such terms constituted the synoptic report. The synoptic report, with convenient drop-down entry boxes to select and record data, was added to our bone marrow report template. Specimen quality data entry was completed during specimen sign out by selecting the appropriate choice from the drop-down box or typing into a text field [Table 3].

Bone marrow quality summary reports were prepared using a Structured Query Language (SQL) query to extract the data from multiple synoptic reports within a specified date range. The extraction process used a proprietary programming language developed by Cerner Corporation called Cerner Command Language (CCL). The CCL compiler converts the program into pure Procedural Language SQL for an Oracle database (Oracle Corporation, Redwood Shores, CA). The entire report is stored as predetermined "terms" in a set of relational tables in the Oracle database as shown in the list as follows:

- PATHOLOGY_CASE
- CASE_REPORT
- AP_CASE_SYNOPTIC_WS
- SCD_STORY
- SCD_TERM
- SCR_TERM
- SCR_TERM_TEXT
- SCD_TERM_DATA.

The pathology case table contains information about the case. It is used as the starting point in the process of identifying and summarizing the specimen quality criteria.

The case report table contains all the reports related to a case. It is joined to the pathology case table using the unique case identifier. The other remaining synoptic-related tables in the list store all of the interrelated terms. There are multiple types of synoptic reports, but the specimen quality report is generated by filtering the AP_CASE_SYNOPTIC_WS table with the ID associated with the specimen quality report. The remaining terms are interrelated and stored in the form of stories. Each of these terms are predetermined and assigned an ID. When a synoptic report is created and completed, the stories and terms are identified and stored in the database.

After all the relevant information is identified and extracted, a postextraction process is iterated through each row of the database. Each specimen quality criterion and its scale (term

Table 2: Bone marrow quality assurance grading parameters

Parameter	Inadequate	Suboptimal	Adequate
Bone marrow aspirate			
#spicules	No spicules	1-3 spicules	>3 spicules or adequate cells without spicules
Hemodilution	Moderately to severely diluted with blood, compromising interpretation	Minimal to mild hemodilution, not compromising interpretation	Clear background
Cell preservation	Poorly preserved, most cells ruptured	Focal areas of preserved cells	Well preserved cells
Staining quality	Extensively blurred cellular details	Focal areas of adequate staining	Crisp nuclear and cytoplasmic detail
Bone marrow biopsy touch imprints			
#spicules	No spicules	1-3 spicules	>3 spicules or adequate cells without spicules
Hemodilution	Moderately to severely diluted with blood, compromising interpretation	Minimal to mild hemodilution, not compromising interpretation	Clear background
Cell preservation	Poorly preserved, most cells ruptured	Focal areas of preserved cells	Well preserved cells
Staining quality	Extensively blurred cellular details	Focal areas of adequate staining	Crisp nuclear and cytoplasmic detail
Bone marrow biopsy			
Total biopsy length	No intact marrow tissue	<1.6 cm	>1.6 cm
Length of interpretable marrow	No intact marrow tissue	<1.2 cm	>1.2 cm
Aspiration artifact	Extensive, moderate to severe, compromising interpretation	Focal, minimal to mild, not compromising interpretation	None
Other artifacts (fragmentation, poor sectioning)	Extensive, compromising interpretation	Focal artifacts, not compromising interpretation	No other artifacts
Decalcification	Extensive undecalcification	Focal underdecalcification	Well decalcified
Staining quality	Extensively blurred cellular details	Focal areas of adequate staining	Crisp nuclear and cytoplasmic detail

Table 3: Bone marrow quality report components, with terms and available selection choices for each specimen type

Specimen type	Terms	Selection choices
Bone marrow aspirate	#spicules	Inadequate, suboptimal, adequate
	Hemodilution	Moderate/severe, minimal/mild, none
	Cell preservation	Inadequate, suboptimal, adequate
	Staining quality	Inadequate, suboptimal, adequate
Biopsy touch imprint	#spicules	Inadequate, suboptimal, adequate
	Hemodilution	Moderate/severe, minimal/mild, none
	Cell preservation	Inadequate, suboptimal, adequate
	Staining quality	Inadequate, suboptimal, adequate
Bone marrow biopsy	Artifacts	Moderate/severe, minimal/mild, none
	Fragmentation	Moderate/severe, minimal/mild, none
	Decalcification	Inadequate, suboptimal, adequate
	Staining quality	Inadequate, suboptimal, adequate
	Mean length	Numeric value entry
	Interpretable length	Numeric value entry
Clot section	#spicules	Inadequate, suboptimal, adequate
	Staining quality	Inadequate, suboptimal, adequate

used to actually measure the criteria) are counted and reported in a Microsoft Excel compatible form. For example, in the sample output below, for bone marrow aspirates, #Spicules contained 3 suboptimal, 4 inadequate, and 21 adequate observations [Table 4].

Postprocessing was performed on the extracted reports to count the occurrences of specific criteria within the reports, and summarize the counts in tabular format. The data from the tabular report were imported into an Excel Spreadsheet for further processing and the creation of reports for review at quarterly meetings of the bone marrow quality improvement committee. An example of a summary bone marrow quality report generated for August, 2017, to December, 2019, is shown in Figure 1.

Finally, the fidelity of content and formatting through correct data transmission was determined in compliance with CAP requirements for both report review and report elements. In all preproduction test runs, the data were received and presented in acceptable formats for the end user, and it was verified that the final data display recapitulated the content and intent of the pathologist's original quality assessment.

Results

The synoptic reporting system to monitor bone marrow quality was developed over a period of 4 years in conjunction with the LIS staff, and went through several iterations before completion in mid-2017. Since August, 2017, the synoptic reporting system has been used to routinely record bone marrow specimen quality from adult patients having procedures in the bone marrow clinic, inpatient wards, and interventional radiology suite of the hospital. From August 1, 2017 to December 30, 2019, data from 3189 adult bone marrow aspirates, 3302 adult core biopsies, and 3183 adult biopsy touch imprints was entered into the synoptic reporting system [Figure 1]. The system was easy to use and did not affect bone marrow real-time reporting or report turnaround times.

Across all locations and groups performing bone marrow procedures, hemodilution constituted the most significant finding affecting the quality of bone marrow aspirates and biopsy touch imprints. However, cell preservation was adequate for all specimen types and staining was also of uniformly good quality for all specimen types. The length of the bone marrow cores obtained varied from 12 to 25 mm. Comparing the length of the biopsies for each of the groups performing the procedure, the mean length of the biopsies was approximately 2 cm for specimens obtained by the nurse practitioners and fellows, while those obtained by the interventional radiology service had a mean length of approximately 1.7 cm. Significant (i.e., moderate or severe) aspiration artifact, and traumatic artifact leading to fragmentation and hemorrhage, were the main quality issues identified in approximately 11% of the core biopsies. Of particular note were samples originating from the interventional radiology suite where aspirate samples with a paucity of spicules and significant hemodilution, and biopsies with aspiration artifact and fragmentation were most often encountered. Data obtained from the synoptic system were reviewed at quarterly meetings of the bone marrow quality improvement committee, discussed with the operators, and procedural changes were recommended to decrease aspirate hemodilution and minimize biopsy aspiration artifact and fragmentation. Further modification of the system to obtain operator-specific data is in progress, together with the addition of quality metrics on pediatric bone marrow specimens. The operator-specific data will include the performance of each operator during a selected period for each quality parameter, including the proportion of bone marrow aspirates with hemodilution, and the proportion of biopsy cores with aspiration artifact and fragmentation.

Discussion

Bone marrow specimens of adequate quality are essential for the accurate and timely diagnosis and treatment of

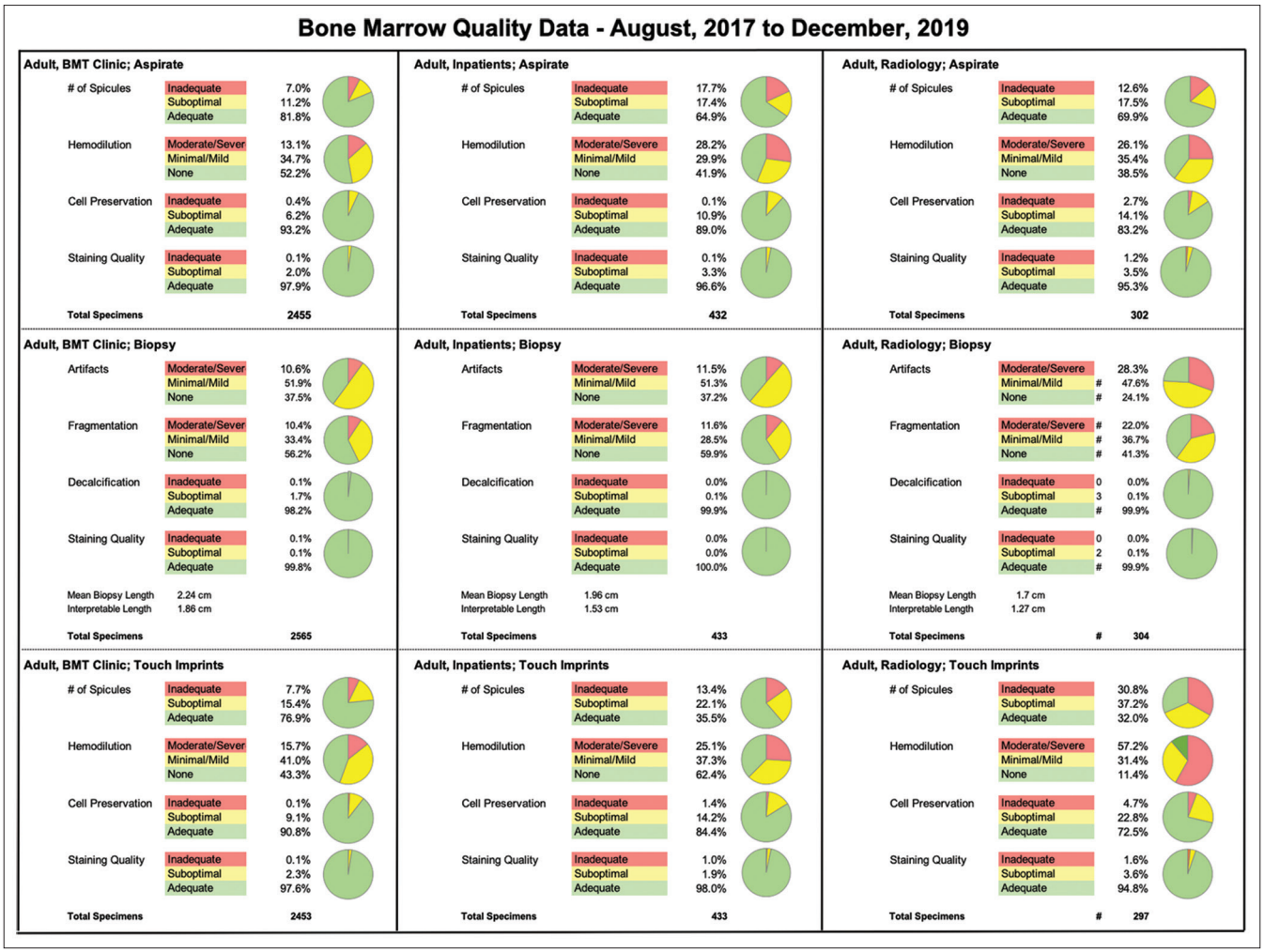

Figure 1: Summary bone marrow quality report

Table 4: Sample output for bone marrow aspirates, showing terms, selection criteria, and scales

Bone marrow aspirates			
#Spicules	**Hemodilution**	**Cell preservation**	**Staining quality**
Inadequate: 4	Moderate/severe: 5	Inadequate: 0	Inadequate: 0
Sub-optimal: 3	Minimal/mild: 6	Sub-optimal: 5	Sub-optimal: 0
Adequate: 21	None: 17	Adequate: 23	Adequate: 28

patients with a wide variety of diseases. Specimen quality is of increasing importance with the more widespread use of expensive molecular techniques and companion diagnostic procedures. At our institution, improving bone marrow specimen quality was identified as an opportunity to improve the quality of care for patients with hematologic diseases, and the development of a consolidated report-based synoptic data entry and report system permitted continuous monitoring of bone marrow specimen quality. Hemodilution of bone marrow aspirates, aspiration artifacts and fragmentation of the biopsies were the major concerns elucidated through this project as opportunities for quality improvement. The standardized and uniform format of the synoptic report was well received by our clinical colleagues and holds significant potential to initiate further efforts to improve the performance of the bone marrow operators. A modification to the system to provide operator-specific data will permit objective feedback to the proceduralists to improve their performance using six-sigma bench-marking and other types of improvement methodologies.

Conclusion

Synoptic reporting has been implemented in multiple pathology subspecialties to improve overall quality, efficiency, and accuracy. The bone marrow quality synoptic reporting system is easy to use, adaptable, and offers distinct advantages in comparison to traditional free-text reporting. Modeled on the criteria recommended by the ISLH and CAP, it offers attributes suitable to the needs of hematopathologists in general with flexibility in the basic design for data entry, customization of protocol-based reports, and data extraction. This study adds to the limited published information regarding the use of a

consolidated report-based data entry system for assessing bone marrow specimen quality, an important component of the overall quality assurance process.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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