Evaluation of Research Addressing Chronic Health in Coal-Dependent Communities in Central Appalachia

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ABSTRACT

In recent years peer-reviewed articles reporting on the health effects of coal mining in central Appalachian populations have appeared with increasing frequency. Studies reported on various health conditions, ranging from cancer, cardiovascular disease and diabetes, to health related measures of quality of life, to birth defects and tooth decay. The objective of this study was to evaluate original research articles on the basis of relevance and assess the strength of evidence elements. Peer-reviewed research publications on chronic diseases in coal dependent communities in central Appalachia began to appear around the year 2000. We scored identified publications using a rubric developed to objectively and consistently rate study relevance. An integrated method of evaluating study protocols was adapted from commonly used methods of rating health related publications. From more than 60 articles initially identified, 16 were written relating coal mining to human health and ten addressed the concerns of diabetic patients, but without concern for the environmental exposure to coal mining activities. The mean relevance scores for the articles focused on the prevalence of chronic diseases, the management of diabetes, and the third grouping of all other studies were 95%, 77% and 53%, respectively. Almost all studies utilized research protocols that were ecological, descriptive, retrospective, cross-sectional and most often dependent on secondary public data sources. The publications selected were limited by protocol design, thus limiting the strength of the evidence. Future studies are needed that can (1) directly assess environmental exposures in humans, (2) relate exposure directly to chronic disease etiology, and (3) overcome other geographic, temporal and human behavior factors. Epidemiological and, more specifically, ecological studies have the advantage of focusing attention on 'the big picture' and highlighting areas for future research. Experimental protocols are needed to provide science-based evidence to support regulations and policies impacting the balance between our national and global needs for energy and human health.

INTRODUCTION

In a recent publication we reported on original research articles appearing since about 2000 relating coal industry activities in Appalachian communities to increased prevalence rates of chronic diseases (Meacham et al. 2012). The increase in articles on this topic parallels the heightened policy debates surrounding Environmental Protection Agency (2012) permitting for coal mining activities, particularly, mountaintop removal coal mining. Legitimate concerns exist related to human health and environmental

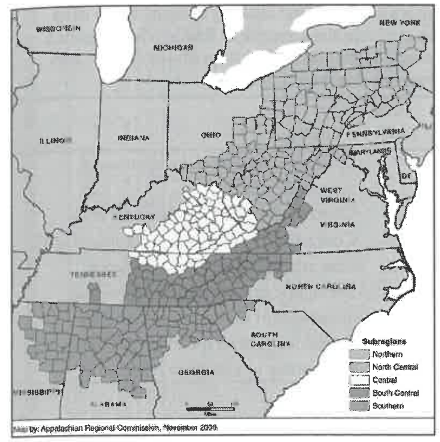

Figure 1. Central Appalachia is defined by the Appalachian Regional Commission (ARC) as the area that includes counties in Kentucky, Tennessee, Virginia, and West Virginia (ARC 2012)

issues with all large scale industries, including the coal industry. It is imperative that science based evidence guide decision making regarding coal production, human health, and environmental impacts. In this communication we report the process used to identify relevant publications and evaluate research methodologies in publications reporting on the effects of coal mining on human health in central Appalachia.

Central Appalachia is defined by the Appalachian Regional Commission (ARC) as the area that includes counties in Kentucky, Tennessee, Virginia, and West Virginia. Much of the central Appalachian area is considered economically distressed and 'at risk' with high poverty rates, high unemployment rates and low high school and college completion rates (Figure 1) (ARC 2012). The primary economic driver in this region has been the coal industry. Central Appalachia has the highest volume of mountain top removal coal mining in the United States. Mountaintop removal mining, more than other types of surface mining and underground mining, has spurred public debates regarding environmental and health concerns (Sayler 2012).

For years various government agencies and non-profit organizations have released information about human health in the area through annual reports, intervention program outcomes, etc. Relatively few original research studies have been published and most rely on protocol designs that can suggest, but not confer, cause-effect relationships about environmental exposures and the development of chronic disease. Research protocol designs have great bearing on the strength of results and, in turn, the strength of the evidence used to support policy development.

Systematic evaluations of original research are customary and serve to inform health policies, i.e., the U.S. recommended dietary allowances (Dietary Reference Intakes 1997; Meacham 2003; Meacham et al. 2008). Nursing professionals also developed a ranking rubric to systematically evaluate protocol designs for various treatment regimens (Melnyk, B.M. and Fineout-Overholt, E. 2005). Systematic literature reviews are generally performed by panels of experts who distill the science based evidence for various applications, including policy development.

Systematic reviews are also specific to the question, often adaptations of previous models. When a review focused on disease etiology in cancer an expert panel noted that hierarchal systems were inadequate. Consequently, an inclusive system was created to utilize data produced by all types of original research data, including descriptive and experimental, retrospective and prospective, and epidemiological, clinical and laboratory based (World Cancer Research Foundation/American Institute for Cancer Research 2007).

For our objective and consistent analysis of data on coal and human health, we adopted an inclusive strategy to review epidemiological literature. The objectives of our study were to identify relevant studies and assess the strength of the evidence based on protocol designs to answer the question, "Do coal mining activities contribute to chronic health disparities in central Appalachian communities?"

METHODOLOGY

An initial literature search of computerized databases, PubMed, EBSCO and CiNAHL was performed using the root search terms 'Appalachian,' 'coal' and 'health'. In a previous publication we reported that over 60 articles were identified with 38 articles written in English addressing health in Appalachian communities. The most stringent inclusion criteria limited the search to peer-reviewed, original research articles and found most articles to have been published since about 2000. A relevance rating was assigned to each study based on geographic region, chronic disease and community health and the inclusion of coal as an environmental exposure. Due to the limited number of publications meeting all the inclusion criteria special notations were made of publications written as commentaries, editorials or introductions to special editions. Likewise, noted were articles that were not peer reviewed, were outside our geographic scope or reported on mental health, occupational health or sociocultural concepts (Meacham et al. 2012).

Publications identified were scored for relevance based on the following factors: original research, geographic location, human study, chronic disease, and coal as an environmental exposure. Each factor was rated on a scale of 1 to 5 points, with 5 points being the highest possible rating. An overall relevance score was assigned as a percentage of the total possible, 25 points.

In addition to relevance, publications were reviewed on the basis of study design: study type, study level, data source, and data level. Study types were generally epidemiological and were further described as ecological studies if the analyses were performed with units of measure at levels other than individual levels, i.e., county levels. Retrospective and prospective were also used to identify study types. Using an integrated rating system studies were aligned according to study level using a 1–7 hierarchal scale (Table 1). Controlled randomized trials had higher rankings than cohort studies or cross-sectional studies. Data from public data bases were described as public and self-reported survey responses were considered sources of individual data. Data collected from individuals for the purpose of the study were referred to as primary data. Data obtained from public databases or originally collected through another protocol were referred to as secondary data.

Table 1. Hierarchal ranking of study types used to evaluate the strength of findings from studies at each level (Modified from Melnyk, B.M., and Fineout-Overholt, E. 2005)

Study Level	Study Type
7	Systematic reviews of randomized, controlled trials
6	Controlled studies, randomized trails
5	Controlled studies, non-randomized trials
4	Case controlled and cohort studies
3	Systematic reviews of descriptive and qualitative or cross-sectional studies
2	Single descriptive, qualitative studies
1	Committee or authority reports

RESULTS

As reported previously more than 60 articles were grouped into three categories, those primarily addressing the prevalence of chronic diseases, a second group of articles addressing the management of diabetes mellitus, hereafter referred to as diabetes, and a third group of other publications related but with a less specific focus (Meacham et al. 2012). Michael Hendryx, Ph.D. at West Virginia University (WVU) appeared as an author on 24 of 61 articles; all 16 articles on chronic diseases (Table 2), one of ten articles on diabetes (Table 3) and seven of 35 other articles (Table 4). Sharon Denham, Ph.D., R.N., at Ohio University, appeared as an author on 14 articles, including nine articles on diabetes (Table 3) and five other articles (Table 4).

The mean relevance score for the first group of articles was 95% and addressed specifically chronic disease in coal dependent communities in central Appalachia (Table 2).

Table 3 lists the publications identified in the systematic literature review that addressed diabetes, most found through the CiNAHL database search. The mean relevance score for the publications on diabetes was 77%. Nine publications

Table 2. Relevance scores for studies published by Dr. Michael Hendryx and others reporting on health in Appalachian communities that included coal as an environmental exposure variable

Reference	Original Research	Geographic Area: National	Geographic Area: Appalachian	Geographic Area: Central Appalachia	Human Study	Community Chronic Disease	Coal	Sum	%
	5 points	3 points	4 points	5 points	5 points	5 points	5 points	25 points	
1. Ahern, M., Hendryx,M., Conley, J., Fedorko, E., Ducatman, A., and Zullig, K.J. 2011. The association between mountaintop mining and birth defects among live births in central Appalachia, 1996–2003. Environ. Res. 111(6):838–846.	5			5	5	3	5	23	92%
2. Epstein P.R., Buonocore, J.J., Eckerl, K. Hendryx, Stout, B.M., Heinberg, R., Clapp, R.W., May, B., Reinhart, N.L., Ahern, M.M., Doshi, S.K. and Glustrom, L. 2011. Full cost accounting for the life cycle of coal. Ann. N.Y. Acad. Sci. 1219:73–98.	5	3			5	3	5	21	84%
3. Esch, L. and Hendryx, M.S. 2011. Chronic cardiovascular disease mortality in mountaintop mining areas of central Appalachian states. J. Rural Health. 27(4):350–357.	5			5	5	5	5	25	100%
4. Hendryx, M.S. 2009. Mortality from heart, respiratory, and kidney disease in coal mining areas of Appalachia. Int. Arch. Occup. Environ. Health. 82(2):243–249.	5		4		5	5	5	24	96%
5. Hendryx, M.S. 2011. Poverty and mortality disparities in central Appalachia: mountaintop mining and environmental justice. J. Health Disparities Research and Practice. 4(3):44–53.	5			5	5	5	5	25	100%
6. Hendryx, M.S. and Ahern, M.M. 2008. Relations between health indicators and residential proximity to coal mining in West Virginia. Am. J. Public Health. 98(4):669–671.	5			5	5	5	5	25	100%
7. Hendryx, M.S. and Ahern, M.M. 2009. Mortality in Appalachian coal mining regions: the value of statistical life lost. Public Health Rep. 124(4):541–550.	5		4		5	4	5	23	92%
8. Hendryx, M.S., Ahern, M.M. and Nurkiewicz, T.R. 2007. Hospitalization patterns associated with Appalachian coal mining. J. Toxicol. Environ. Health, Part A. 70(24):2064–2070.	5			5	5	5	5	25	100%
9. Hendryx, M.S., Fedorko, E. and Anesetti-Rothermel, A. 2010. A geographical information system-based analysis of cancer mortality and population exposure to coal mining activities in West Virginia, United States of America. Geospat. Health. 4(2):243–256.	5			5	5	5	5	25	100%
10. Hendryx, M.S., Fedorko, E. and Halverson, J. 2010. Pollution sources and mortality rates across rural-urban areas in the United States. J. Rural Health. 26(4):383–391.	5	3			5	5	5	23	92%
11. Hendryx, M.S, O'Donnell, K. and Horn, K. 2008. Lung cancer mortality is elevated in coal-mining areas of Appalachia. Lung C ancer . 62(1):1–7.	5		4		5	5	5	24	96%
12. Hendryx, M., Wolfe, L., Luo, J. and Webb, B. 2011. Self- reported cancer rates in two rural areas of West Virginia with and without mountaintop coal mining. J. Community Health. DOI 10.1007/s10900–011–9448–5.	5			5	5	5	5	25	100%
13. Hendryx, M.S. and Zullig, K.J. 2009. Higher coronary heart disease and heart attack morbidity in Appalachian coal mining regions. Prev. Med. 49(5):355–359.	5		4		5	5	5	24	96%
14. Hitt, N.P. and Hendryx, M.S. 2010. Ecological integrity of streams related to human cancer mortality rates. Ecohealth . 7(1):91–104.	5			5	5	5	5	25	100%
15. Zullig, K.J. and Hendryx, M.S. 2010. A comparative analysis of health-related quality of life for residents of U.S. counties with and without coal mining. Public Health Rep. 125(4):548–555.	5	3			5	3	5	21	84%
16. Zullig, K.J. and Hendryx, M.S. 2011. Health-related quality of life among central Appalachian residents in mountaintop mining counties. Am. J. Public Health. 101(5):848–853.	5			5	5	3	5	23	92%

Table 3. Relevance scores for studies on diabetes in Appalachian communities

Reference	Original Research	Geographic Area			Human Study	Community Chronic Disease	Coal	Sum	
		National	Appalachian	Central Appalachia					
	5 points	3 points	4 points	5 points	5 points	5 points	5 points	25 points	%
1. Barker, L.C., Gerzoff, R., Denham, S., Shrewsberry, M. and Cornelius-Averhart, D. 2010. Residence in a distressed county in Appalachia as a risk factor for diabetes, Behavioral Risk Factor Surveillance System, 2006–2007. *Preventing Chronic Disease: Public Health Research, Practice, and Policy.* 7(5):1–9.	5		4		5	5	0	19	76%
2. Denham, S.A., Manoogian, M. and Schuster, L. 2007. Managing family support and dietary routines: Type 2 diabetes in rural Appalachian families. *Families, Systems & Health.* 25(1):36–52.	5			5	5	5	0	20	80%
3. Denham, S.A., Remsburg, K. and Wood, L. 2010. Diabetes education in the Appalachian region: providers' views. *Rural Remote Health.* 10(2):1321.	5		4		5	5	0	19	76%
4. Denham, S.A., Ware, L.J., Raffle, H. and Leach, K. 2011. Family inclusion in diabetes education: a nationwide survey of diabetes educators. *Diabetes Educ.* 37(4):528–535.	5	3			5	5	0	18	72%
5. Denham, S.A., Wood, L.E. and Remsberg, K. 2010. Diabetes care: provider disparities in the US Appalachian region. *Rural Remote Health.* 10(2):1320.	5		4		5	5	0	19	76%
6. Manoogian, M.M., Harter, L.M. and Denham, S.A. 2010. The storied nature of health legacies in the familial experience of type 2 diabetes. *J. Family Communication.* 10:40–56.	5		4		5	5	0	19	76%
7. O'Brien, T. and Denham, S.A. 2008. Diabetes care and education in rural regions. *Diabetes Educ.* 34(2):334–347.	5	3			5	5	0	18	72%
8. Pollard, C., Bailey, K.A., Petitte, T., Baus, A., Swim, M. and Hendryx, M. 2009. Electronic patient registries improve diabetes care and clinical outcomes in rural community health centers. *J. Rural Health.* 25(1):77–84.	5			5	5	5	0	20	80%
9. Schwartz, F.L., Denham, S.A., Heh, V., Wapner, A. and Shubrook, J. 2010. Experiences of children and adolescents with Type I diabetes in school: Survey of children, patents, and schools. *Diabetes Spectrum.* 23(1):47–55.	5			5	5	5	0	20	80%
10. Schwartz, F.L., Ruhil, A.V., Denham, S.A., Shubrook, J., Simpson, C. and Boyd, S.L. 2009. High self-reported prevalence of diabetes mellitus, heart disease, and stroke in 11 counties of rural Appalachian Ohio. *J. Rural Health.* 25(2):226–230.	5			5	5	5	0	20	80%

appearing since 2007 addressed the management of diabetes in Appalachian communities and were coauthored by Sharon Denham. Another publication, by Pollard et al. (2009), included Hendryx as a coauthor and reported on the effectiveness of using electronic patient records as an important part of self-management in diabetes care.

In Table 4 there were 35 additional studies identified in the original search that discussed chronic diseases in coal dependent communities in central Appalachia. The mean relevance score was 53%. Borak et al. (2012) had a relevance score of 96% for the publication reassessing data previously reported in three publications with Hendryx as a coauthor; Hendryx (2009), Hendryx and Ahern (2009), and Hendryx et al. (2008). Three studies by Blackley et al. (2011), McGarvey et al. (2011), and Schoenberg et al. (2011) had relevance scores of 76%, 80% and 76%, respectively. These authors addressed chronic health conditions in Appalachian communities but did not consider coal as an environmental variable, nor did they specifically address diabetes management. Likewise, articles by Hendryx and Fedorko (2011), Luo and Hendryx (2011), and Luo et al. (2011) had relevance scores of 72%, 76% and 76%, respectively. The authors reported on the incidence of cancer associated with toxic chemicals released in the environment but did not consider toxins released specifically from coal related activities.

In the list of additional studies (Table 4) there were seven publications where Hendryx appeared as an author. These articles were not included with the "original 16" in Table 2 which listed work conforming to the most stringent inclusion criteria, chronic disease in coal dependent communities in Appalachia. Hendryx's publications listed in Table 4, as mentioned above, addressed toxic release inventory discharges, as well as other aspects of health, i.e., mental health (Hendryx 2008) or access to health care (Hendryx et al. 2002). One article was an introduction to a special section of a scientific meeting (Hendryx 2011) and another, a commentary, published in the policy section of *Science* (Palmer et al. 2010).

Articles by Denham also appeared on the list of additional studies (Table 4), but these works did not address coal or diabetes management. In these publications other sociocultural concepts were the main points of interest, i.e., family health (Denham 2003); health education (Denham et al. 2004); spirituality (Diddle and Denham 2010); and alcohol and tobacco use (Meyer et al. 2008). The additional studies identified (Table 4) reported on related concerns, i.e., food environments (Ahern et al. 2011), occupational health and international mining activities (Bilban 2005; Donoghue 2004; Feng and Qiu 2008; Gold et al. 2008; Huang and Finkelman 2008; Joy 2004; Kang and Kim 2010).

The 'original 16' in Table 2 were evaluated based on features of the protocol design. Study types, study levels, data types and data levels appear in Table 5. Studies were rated using a 1 to 7 hierarchal scale with a score of 7 reflecting the most rigorous research protocol design (Table 1). The original 16 Hendryx group studies were categorized as study level 2; all were single studies rather than systematic reviews, all were descriptive rather than experimental, and all were cross-sectional rather than cohort.

Table 5 also indicates reports that all but one study was considered retrospective. Only one study had a prospective method of collecting data with a door-to-door survey in a community-based participatory study (Hendryx et al. 2011). An earlier survey study utilized individual survey data from a state telephone study conducted years earlier; thus the data was referred to as secondary, having been collected with intentions other than those for which the data were used in the current study (Hendryx and Ahern, 2008). Study types were also generally described as ecological studies if the analyses were performed with units of measure at county levels or another geographic area rather than individual levels, i.e., Hendryx et al. (2007); Hendryx and Ahern (2008); Hendryx (2009); and Esch and Hendryx (2011). Exceptions were seen with studies referred to as exploratory, i.e, the analysis of birth defect data (Ahern et al. 2011) and with studies we described as modeling with unique presentations that monetized the

Table 4. Relevance scores for other studies identified and less directly associated with chronic diseases in Appalachian mining communitiest

Reference	Original Research	Geographic Area: International	Geographic Area: Appalachian	Geographic Area: Central Appalachia	Human Study	Community Chronic Disease	Coal	Sum	
	5 points	2 points	3 points	4 points	5 points	5 points	5 points	5 points	%
1. Ahern, M., Brown, C., and Dukas, S. 2011. A national study of the association between food environments and county-level health outcomes. *J. Rural Health.* 27(4):367–379.	5		3			5			52%
2. Bernhardt, E.S. and Palmer, M.A. 2011. The environmental costs of mountaintop mining valley fill operations for aquatic ecosystems of the Central Appalachians. *Ann. NY Acad. Sci.*1223:39–57.					5			5	40%
3. Bilban, M. 2005. Occupational medicine in the Slovene area. *J. Occup. Health.* 47(3):193–200.		2				5	0	5	48%
4. Blackley, D., Behringer, B. and Zheng, S. 2011. Cancer mortality rates in Appalachia: descriptive epidemiology and an approach to explaining differences in outcomes. *J. Community Health.* DOI:10.1007/s10900–011–9514-z.	5			4		5	5		76%
5. Borak, J., Salipante-Zaidel, C., Slade, M.D. and Fields, C.A. 2012. Mortality disparities in Appalachia: reassessment of major risk factors. *J. Occup. Environ. Med.* 54(2):146–156.	5			4		5	5	5	96%
6. Cohen, R.A., Patel, A. and Green, F.H. 2008. Lung disease caused by exposure to coal mine and silica dust. *Semin. Respir. Crit. Care Med.* 29(6):651–661.			3			5	0	5	52%
7. Denham, S.A. 2003. Relationships between family rituals, family routines and health. *J. Family Nurs.* 9(3):305–330.			3			5			32%
8. Denham, S.A. 1999. Part 3: Family health in an economically disadvantaged population. *J. Family Nurs.* 5(2):184–213.	5			4		5	2		64%
9. Denham, S.A., Meyer, M.G., Toborg, M.A. and Mande, M. J. 2004. Providing health education to Appalachia populations. *Holist. Nurs. Pract.* 18(6):293–301.	5			4		5	2		64%
10. Diddle, G. and Denham, S.A. 2010. Spirituality and its relationships with the health and illness of Appalachian people. *J. Transcult. Nurs.* 2010;21(2):175–182.				4		5			36%
11. Donoghue, A.M. 2004. Occupational health hazards in mining: an overview. *Occup. Med.* 54(5):283–289.		2				5	0	5	48%
12. Feng, X. and Qiu, G. 2008. Mercury pollution in Guizhou, southwestern China–an overview. *Sci. Total Environ.* 400(1–3):227–237.		2						5	28%
13. Gold, L.S., De Roos, A.J., Waters, M., and Stewart, P. 2008. Systematic literature review of uses and levels of occupational exposure to tetrachloroethylene. *J. Occup. Environ. Hyg.* 5(12):807–839.			3				0		12%
14. Gulumian, M., Borm, P.J., Vallyathan, V. Castranova, V., Donaldson, K., Nelson, G. and Murray, J. 2006. Mechanistically identified suitable biomarkers of exposure, effect, and susceptibility for silicosis and coal-worker's pneumoconiosis: a comprehensive review. *J. Toxicol. Environ. Health B. Crit. Rev.*9(5):357–395.		2				5	0	5	48%
15. Hendryx, M.S. 2008. Mental health professional shortage areas in rural Appalachia. *J. Rural Health.* 24(2): p.179–182.	5			4		5	3		68%
16. Hendryx, M.S. 2011. Introduction to special section: Environmental health for rural populations. *J. Rural Health. 27(4): 339–341.*									
17. Hendryx, M.S., Ahern, M.M., Lovrich, N.P. and McCurdy, A.H. 2002. Access to health care and community social capital. *Health Serv. Res.* 2002. 37(1):87–103.	5		3			5	3		64%
18. Hendryx, M.S. and Fedorko, E. 2011. The relationship between toxics release inventory discharges and mortality rates in rural and urban areas of the United States. *J. Rural Health* . 27(4):358–366.	5		3			5	5		72%

(table continues)

Table 4. Relevance scores for other studies identified and less directly associated with chronic diseases in Appalachian mining communities (continued)

Reference	Original Research	Geographic Area: International	Geographic Area: Appalachian	Geographic Area: Central Appalachia	Human Study	Community Chronic Disease	Coal	Sum	
	5 points	2 points	3 points	4 points	5 points	5 points	5 points	5 points	%
19. Huang, X. and Finkelman, R.B. 2008. Understanding the chemical properties of macerals and minerals in coal and its potential application for occupational lung disease prevention. *J. Toxicol. Environ. Health B Crit. Rev.* 11(1):45–67.	5		3			5	0	5	72%
20. Joy, J. 2004. Occupational safety risk management in Australian mining. *Occup Med (Lond).* 54(5):311–315.		2				5	0		28%
21. Kang, S.K. and Kim, E.A. 2010. Occupational diseases in Korea. *J. Korean Med. Sci.* 25(Suppl):S4–12.		2				5	5	5	68%
22. Kavanagh, A.M., Bentley, R., Turrell, G., Broom, D.H.and Subramanian, S.V. 2006. Does gender modify associations between self rated health and the social and economic characteristics of local environments? *J. Epidemiol. Community Health* . 60(6):490–495.	5	2				5			48%
23. Lee, S.Y., Chen, W.L. and Weiner, B.J. 2004. Communities and hospitals: social capital, community accountability, and service provision in U.S. community hospitals. *Health Serv. Res.* 39(5):1487–1508.	5		3			5			52%
24. Li P., Feng, X.B., Qiu, G.L., Shang, L.H. and Li, Z.G. 2009. Mercury pollution in Asia: a review of the contaminated sites. *J. Hazard. Mater* . 168(2–3):591–601.		2				5			28%
25. Luo, J., and Hendryx, M.S. 2011. Environmental carcinogen releases and lung cancer mortality in rural-urban areas of the United States. *J. Rural Health.* 27(4):342–349.	5		3			5	5	1	76%
26. Luo, J., Hendryx, M.S. and Ducatman, A. 2011. Association between six environmental chemicals and lung cancer incidence in the United States. *J. Environ. Public Health.* 2011: Article ID 463701, 9 pages. doi:10.1155/2011/463701463–701.	5		3			5	5	1	76%
27. Ma Y., Prasad, M.N., Rajkumar, M. and Freitas, H. 2011. Plant growth promoting rhizo bacteria and endophytes accelerate phytoremediation of metalliferous soils. *Biotechnol. Adv.* 29(2):248–258.			3			5			32%
28. McGarvey, E.L., Leon-Verdin, M., Killos, L.F., Guterbock T. and Cohn W.F. 2011. Health disparities between Appalachian and non-Appalachian counties in Virginia USA.*J. Community Health.* 36(3):348–356.	5				5	5	5		80%
29. Meyer, M.G., Toborg, M.A., Denham, S.A. and Mande, M.J. 2008. Cultural perspectives concerning adolescent use of tobacco and alcohol in the Appalachian mountain region. *J.Rural Health.* 24(1):67–74.	5			4		5	2		64%
30. Palmer, M.A., Bernhardt, E.S., Schlesinger, W.H., Eshleman, K.N., Foufoula-Georgiou, E., Hendryx, M.S., Lemly, A.D., Likens, G.E., Loucks, O.L., Power, M.E., White, P.S. and Wilcock, P.R. 2010. Science and regulation. Mountaintop mining consequences. *Science* . 327:148–149.					5	5			40%
31. Ross, M.H. and Murray, J. 2004. Occupational respiratory disease in mining. *Occup. Med. (Lond).* 54(5):304–310.		2				5	0	5	48%
32. Schoenberg, N.E., Bardach, S.H., Manchikanti, K.N. and Goodenow, A.C. 2011. Appalachian residents' experiences with and management of multiple morbidity. *Qual. Health Res.* 21(5):601–611.	5			4		5	5		76%
33. Sharma, S. and Rees, S. 2007. Consideration of the determinants of women's mental health in remote Australian mining towns. *Aust. J. Rural Health.* 15(1):1–7.		2				5			28%
34. Vearrier, D. and Greenberg, M.I. 2011. Occupational health of miners at altitude: adverse health effects, toxic exposures, pre-placement screening, acclimatization, and worker surveillance. *C lin. Toxicol. (Phila).*49(7):629–640.			3			5	0	5	52%
35. Zipper, C.E., Burger, J.A., Skousen, J.G., Angel, P.N., Barton, C.D., Davis, V. and Franklin, J.A. 2011. Restoring forests and associated ecosystem services on appalachian coal surface mines. *Environ. Manage,* 47(5):751–765.				4				5	36%

Table 5. Relevance scores, study type, study level, data source and data level for studies published by Dr. Michael Hendryx and colleagues reporting on health in Appalachian communities that included coal as an environmental exposure variable

Study Reference	Relevance Score	Study Type (Study Level)	Health Data Source (Data Level)
Ahern, M., Hendryx, M., Conley, J., Fedorko, E., Ducatman, A., and Zullig, K.J. 2011. The association between mountaintop mining and birth defects among live births in central Appalachia, 1996–2003. *Environ. Res.* 111(6):838–846.	92%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Epstein P.R., Buonocore, J.J., Eckerl, K. Hendryx, Stout, B.M., Heinberg, R., Clapp, R.W., May, B., Reinhart, N.L., Ahern, M.M., Doshi, S.K. and Glustrom, L. 2011. Full cost accounting for the life cycle of coal. *Ann. N.Y. Acad. Sci.* 1219:73–98.	84%	descriptive, modeling, retrospective, (2)	public, secondary
Esch, L. and Hendryx, M.S. 2011. Chronic cardiovascular disease mortality in mountaintop mining areas of central Appalachian states. *J. Rural Health.* 27(4): 350–357.	100%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Hendryx, M.S. 2011. Poverty and mortality disparities in central Appalachia: mountaintop mining and environmental justice. *J. Health Disparities Research and Practice.* 4(3):44–53.	100%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Hendryx, M.S. 2009. Mortality from heart, respiratory, and kidney disease in coal mining areas of Appalachia. *Int. Arch. Occup. Environ. Health.* 82(2):243–249.	96%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Hendryx, M.S. and Ahern, M.M. 2009. Mortality in Appalachian coal mining regions: the value of statistical life lost. *Public Health Rep.* 124(4):541–550.	92%	descriptive, modeling retrospective, cross-section (2)	public, secondary
Hendryx, M.S. and Ahern, M.M. 2008. Relations between health indicators and residential proximity to coal mining in West Virginia. *Am. J. Public Health.* 98(4): 669–671.	100%	ecological, descriptive, retrospective, cross-section (2)	self-report/ secondary
Hendryx, M.S., Ahern, M.M. and Nurkiewicz, T.R. 2007. Hospitalization patterns associated with Appalachian coal mining. *J. Toxicol. Environ. Health, Part A.* 70(24):2064–2070.	100%	individual/ecological descriptive, retrospective, cross-section (2)	public/ individual, prim/second
Hendryx, M.S., Fedorko, E. and Anesetti-Rothermel, A. 2010. A geographical information system-based analysis of cancer mortality and population exposure to coal mining activities in West Virginia, United States of America. *Geospat. Health.* 4(2):243–256.	100%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Hendryx, M.S., Fedorko, E. and Halverson, J. 2010. Pollution sources and mortality rates across rural-urban areas in the United States. *J. Rural Health.* 26(4):383–391.	92%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Hendryx, M.S, O'Donnell, K. and Horn, K. 2008. Lung cancer mortality is elevated in coal-mining areas of Appalachia. *Lung Cancer.* 62(1):1–7.	96%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Hendryx, M., Wolfe, L., Luo, J. and Webb, B. 2011. Self-reported cancer rates in two rural areas of West Virginia with and without mountaintop coal mining. *J. Community Health.* DOI 10.1007/s10900–011–9448–5.	100%	descriptive, prospective, cross-section (2)	self-report, primary
Hendryx, M.S. and Zullig, K.J. 2009. Higher coronary heart disease and heart attack morbidity in Appalachian coal mining regions. *Prev. Med.* 49(5):355–359.	96%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Hitt, N.P. and Hendryx, M.S. 2010. Ecological integrity of streams related to human cancer mortality rates. *Ecohealth.* 7(1):91–104.	100%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Zullig, K.J. and Hendryx, M.S. 2011. Health-related quality of life among central Appalachian residents in mountaintop mining counties. *Am. J. Public Health.* 101(5):848–853.	92%	ecological, descriptive, retrospective, cross-section (2)	public, secondary
Zullig, K.J. and Hendryx, M.S. 2010. A comparative analysis of health-related quality of life for residents of U.S. counties with and without coal mining. *Public Health Rep.* 125(4):548–555.	84%	ecological, descriptive, retrospective, cross-section (2)	public, secondary

public health burdens of environmental hazards (Epstein et al. 2011) or calculated the statistical value of life (Hendryx and Ahern 2009).

DISCUSSION

Legitimate concerns exist related to human health and environmental issues with all large scale industries such as coal. Science based evidence is more important than ever to guide decision making regarding coal production, human health and environmental impacts. Strength of evidence relies on various elements of protocol design; study quality, quantity, consistency impact and generalizability. In a previous article we discussed research publication quantity, quality and consistency regarding chronic diseases in coal dependent communities in central Appalachia. We noted an increase in publishing frequency paralleling the EPA permit controversies and the number of publications with common authors. The use of journal impact factors as an objective, yet indirect, proxy for publication quality was acknowledged and the limitations stated (Meacham et al. 2012). While the researchers have discussed the study limitations within their publications, others, as presented below, expressed additional concerns that hamper the impact of findings produced through study protocols that may not produce the strongest evidence.

Our comprehensive, computerized electronic search identified articles in three commonly used databases, PubMed, EBSCO and CiNAHL. CiNAHL promotes being the largest electronic database collection of nursing and allied health literature available and produced articles on diabetes not detected in reviews of PubMed or EBSCO. Through analysis of research study design, we further examined research quality on the basis of scientific design and validity.

We designed a rubric tool to objectively and consistently evaluate each article on relevance and then we classified the articles based on strength of evidence elements. We began the process of grouping the articles by convenience as described earlier; prevalence of chronic disease, those that addressed the management of diabetes, and other articles related but less specifically focused (Meacham et al. 2012). The publications appearing in Table 2 had the highest mean relevance scores (95%) and all with a common author, Michael Hendryx, Ph.D. As seen in Table 5 our classification of study protocols confirmed a consistency in study levels and study types; almost all of the WVU studies were ecological, descriptive, retrospective, cross-sectional and reliant on secondary data. This consistency does not highlight successive improvements in study designs to elevate the strength of evidence elements or highlight distinctive study characteristics as seen in the study ranking rubric in Table 1.

Conversely, within this study design context, various methodology strategies were demonstrated by the WVU group to quantify the impact of coal on health. The studies conducted by the WVU group portrayed logical and creative stepwise advances in the methods employed with each successive study reported. Zullig and Hendryx (2010, 2011) reported on the impact of coal mining on health-related quality of life indicators in Appalachian communities. A number of publications reported 'monetized' measures of the impacts of coal on the environment and human life. Hendryx and Ahern (2009) examined the mortality rates in Appalachian coal mining areas and estimated a corresponding 'statistical life lost' value. Similarly, Hendryx and coworkers estimated the full cost accounting for the life cycle of coal based on environmental and health factors (Epstein et al. 2011). The theoretical models used to derive this economic measure have been used by government agencies to convey the public health burden of environmental exposures, such as the suggested negative health consequences of coal mining.

Caution should prevail when mathematical models of human disease conditions are presented, as this type of study design can easily lead to faulty conclusions. In a recent presentation, Stahl et al. (2012) warned of the dangers of "proofiness" in the evaluation of the impact of mountaintop removal coal mining. Stahl used the term "proofiness" to refer to the use or misuse of mathematical arguments to arrive at misleading conclusions. They discussed the need for caution when determining the appropriateness of data and methodologies when making controversial environmental assessments.

In general, prospective studies have a number of advantages over retrospective studies. One study in the "suite of studies" from WVU (Table 2) can be considered prospective, having used a community based participatory research project collecting data from 773 adults in a door-to-door survey (Hendryx et al. 2011). The self-reported health data presented by Hendryx and Ahern (2008) had been collected retrospectively with a telephone survey conducted in 2001. In these two survey studies, the data collected were considered primary data while most other data sources were typically secondary. Primary data is generally preferred over secondary data. However, self-reported health data introduce their own inherent limitations. Personal biases, reporting errors, etc., are difficult to overcome.

The first experimental study has recently been published by Hendryx and colleagues, progressing beyond observational and descriptive study designs (Knuckles et al. 2012). They reported on the physiological impact of simulated mountain top mining particulate matter exposure on rats, demonstrating impaired microvascular function. They concluded that a similar physiological effect may contribute to cardiovascular disease in humans exposed to particulate matter as a result of coal mining activities in Appalachia. These findings have not been confirmed by clinical trials in humans and are not yet translatable to realistic exposure levels in natural environments.

Publications in Table 3 had a mean relevance score of 77% and focused on managing diabetes in Appalachian populations. Sharon Denham, Ph.D., R.N., and coworkers produced nine of the ten articles. While diabetes is a chronic disease, the publications on managing diabetes deserved special attention; as such they were grouped separately from the articles addressing other health conditions. Diabetes, in contrast to other chronic conditions, can in many cases be managed and allow patients a high quality of life despite their condition. Thus, the opportunities for successful and effective intervention programs are greater for this condition than for most, i.e., end stage renal failure or chronic obstructive pulmonary disease. The diabetes literature also preferentially reported on self-management education for patients with support from care givers, health care providers and health education programs (Denham et al. 2007; O'Brien and Denham 2008; Manoogian et al. 2010; Denham et al. 2010ab; Denham et al. 2011). These studies were not evaluated further due to variability in study protocol, which made using a rubric less meaningful, and the Denham studies have not been called into question.

All other articles (Table 4) identified in the initial literature search did not reference coal or focus on diabetes directly and typically addressed occupational health in international settings. However, the articles do offer insights into the generalizability and global significance of the problem. While the mean relevance score for articles listed in Table 4 was 53% there were several regionally appropriate studies that had relevance scores similar to those authored by the Hendryx and Denham groups; McGarvey et al. (2011) from Virginia and Blackley et al. (2011) from Tennessee. We previously discussed these studies and acknowledged their discussions of cultural sensitivity as important components of the health care process in Appalachian communities (Meacham et al. 2012).

Our conservative lists of articles grouped into defendable categories provided a logical means of discussing the original research. A more liberal literature search would yield a larger number of articles. Without the explicit reference to coal mining, for example, many articles would be included, such as those authored by Nancy Schoenberg and colleagues from Kentucky, reporting primarily on cultural aspects of health and cancer. A recent publication by this team shared research findings that inform community interventions (Kruger et al. 2012). Other reports confronted managing multiple morbidities (Schoenberg et al. 2011) and 'deconstructing fatalism' in underserved Appalachian residents (Drew and Schoenberg 2011; Paskett et al. 2011). Another recent publication by a research team in Kentucky has also examined geographic

patterns of lung cancer incidence (Christian et al. 2011). Again, the limitations of these ecological studies are fundamental to the study designs and, as stated by the authors, require further research with biological and environmental samples to confirm cause-effect relationships.

Thus, to date the majority of studies on health in coal dependent communities in Appalachia have increased awareness on negative health impacts by reporting on increased rates of a broad spectrum of conditions: diabetes, diseases of the cardiovascular, respiratory and digestive systems, and even birth defects and tooth loss. However, the inherent limitations in study designs cannot be overridden by publishing more studies, collecting more data on robust subject numbers or refining measurement techniques, i.e., geospatial analysis. Likewise, as discussed, the studies performed by others with similarly high relevance scores were also limited to these same protocols, i.e., McGarvey et al. 2011; Blackley et al. 2011; Schoenberg et al. 2011) (Table 4).

The authors have acknowledged their study limitations, those inherent to the research protocols as well as the shortcomings in implementation, i.e., small sample sizes, geographically and temporally appropriate measures for diseases that progress over time in residents that move in and out of communities, etc. The results have also been found to differ between, and even within, author groups.

Concurrently, reassessments and critiques have cast doubt, primarily on the results presented by Hendryx and coworkers (Borak et al. 2012; Exponent 2012; Kirby 2013). Borak et al. (2012) performed a statistical reassessment of the publicly available data used in three of the articles published by Hendryx and others (Hendryx 2009, Hendryx and Ahern 2009 and, Hendryx et al. 2008). Borak et al. reassessed the predictive value of coal mining and other risk factors for explaining reported higher mortality rates in Appalachia. Their results confirmed poverty, income, education, location, obesity, and gender as factors independently related to age-adjusted, all-cause mortality. Coal mining, as well as other factors, i.e., unemployment, insurance, and access to care, were not per se independent risk factors for increased mortality in Appalachia. Borak et al. (2012) reported instances in the studies reassessed where incomplete or inconsistent definitions of covariates introduced analytical complications. In another critique, the statistical assessment of the association between mountaintop mining and birth defects in central Appalachia conveyed that Ahern et al. (2011) failed to fully recognize and account for limitations in U.S. natality files, used an internet blog to provide mining data, lacked valid and reliable data on confounding factors, and thus the quality and type of data was insufficient to support the conclusions made by the authors (Exponent, Health Sciences 2011).

More recently Kirby (2013) cautioned readers using the results of the study on birth defects and mountaintop removal coal mining by Ahern et al. 2011. Kirby's critique conveyed that the appreciation for detail was lacking in terms of both birth defect research and environmental epidemiological methods. The use of better data sources and analytical methods was needed as the current procedural flaws that render the conclusion, "the observation that risk for birth defects may be increased for residents of counties with mountaintop mining," suspect at best.

While there is doubt about the statistical and practical validity of the state-of-the-science at this time, the reports appear to have had an impact. For example, EPA news releases report changes in regulations for permitting mining operations in central Appalachia on the basis of reported health claims (EPA, 2010, 2012). Most of the current news releases relate to water quality data. It is imperative that study limitations and, thus, weak evidence, is accurately and fairly portrayed when reporting chronic health data, particularly data that raise serious doubts as just described in reassessments, critiques and editorial retorts.

The generalizability of disputed findings provides additional concerns. Reports provided to international commissions to inform policy makers on the health effects and environmental consequences of coal mining have incorporated the studies currently disputed. The independent report commissioned by Beyond Zero Emissions in response to concerns in the Hunter Region of New South Wales (Colagiuri et al. 2012) is lengthy and addresses four major questions. For the question, "What specific diseases or other health problems are associated with coal mining in local communities?" the evidence table in the report cited 13 articles as evidence; 11 were research publications by the Hendryx group (Kirby 2013). Kirby cautioned that superficially the efforts of Hendryx and others appeared plausible, but the detail in methodology was lacking to produce conclusions supported by sound evidence.

Science based evidence is more important than ever to guide decision making regarding coal production, human health and environmental impacts. National and international debates surrounding energy and coal production are anticipated, and are expected to be politically controversial, tied to economic and environmental issues and vulnerable to subjective and emotional public reactions, not to mention easily inferred, and preferred, interpretations of data. While the authors clearly acknowledged the limitations of their studies, the repeated protocol strategies, the consistency in conclusions and the successive publications with a consistently contributing researcher are not capable of moving science to cause-effect conclusions. Consistent conclusions are generally regarded as a strong point in research, with the publications representing a wide array of independent researchers and varying research protocols. However, the consistent findings in this instance were reported with a common researcher on all publications. In actuality, this weakens rather than strengthens the argument whether the conclusions are free of serious doubt or not.

The inferences made from cause-effect relationships combined with the assumptions drawn by readers too easily, and possibly conveniently, propel authors' carefully stated concluding statements to erroneously accepted conclusions. Public biases toward optimism taken from inferences are hard to redirect and correct. The 'fine print,' or more appropriately, the 'final print,' the copious limitations proclaimed at the end of a publication are often overlooked, the caveats lost and the context of science dwarfed once a media sensation builds, bending to public biases toward expected rather than science supported conclusions. Epidemiological studies have limitations and come to a point where an inference can be made about cause-effect relationships but they, as well as any other single type of study design, cannot determine or 'prove' whether an exposure caused a specific disease. Strong study designs are needed to produce valid support for cause-effect relationships with statistically significant findings. Direct measures of biomarkers indicating environmental exposures affecting chronic disease rates are needed.

CONCLUSION

Epidemiological studies are concerned with the incidence of disease and direct attention to the etiology of disease progression. The majority of studies reviewed serve as an important 'spring board' for the design and implementation of experimental and intervention studies as 'next steps' in the quest to identify health concerns associated with coal mining. Regardless of the specific etiology of the chronic diseases studied, Appalachia remains a region with documented health disparities. There is a need for further research to bend the trends that report increasing prevalence rates of chronic diseases, accelerate the implementation of effective intervention programs and anticipate the successes to be realized through health education, cultural awareness, increased access to primary care providers and utilization of emerging technologies to reach rural areas in Appalachian communities.

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