Exposure assessment and lung function in pig and poultry farmers

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Abstract

***Objectives*—To describe the relation between spirometric findings and farming characteristics and variables of exposure to organic dust measured during work in animal buildings. Farmers have traditionally been described as having one of the most dangerous occupations, so a large scale study on European farmers was carried out. This is the report of the second part of that study.**

***Methods*—40 pig farmers in Denmark and 36 poultry farmers in Switzerland were chosen randomly and were assessed over 1 working day.**

***Results*—Mean (SD) baseline spirometric results in pig farmers were higher than in poultry farmers (forced expiratory volume in 1 second (FEV_1) (% of reference value) 108.3 (16.7) *v* 100.2 (14.2); p=0.04). Baseline lung function results were significantly associated with ventilation of the animal houses. Furthermore, temperature was related to spirometric findings in pig farmers.**

***Conclusions*—Ventilation of the animal house and temperature might influence respiratory morbidity in farmers.**

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Keywords: ventilation; micro-organism; European multicentre study

As early as 1555 Olaus Magnus recognised the health hazards of farmers connected with grain dusts.[1] More recently epidemiological studies have indicated a greater risk of respiratory disorders in farmers than in non-farming occupations.[2 3] It is known that animal farmers are exposed to organic dust, endotoxins, and hazardous gaseous exposures. These substances may affect one or more parts of the respiratory system of farmers and may induce diseases such as allergic and non-allergic rhinitis,[4] organic dust toxic syndrome (ODTS),[5] bronchitis,[6] asthma,[1] and asthma-like syndrome.[1]

Hence, a European multicentre study on prevalence and risk factors of airway obstruction in farmers[7] was carried out in seven centres in five countries (Denmark, Great Britain, Germany, Switzerland, Spain). In the first part of the study a questionnaire survey on general and work related respiratory symptoms relative to type of farming was carried out on 7752 randomly selected farmers. Pig, cattle, poultry, and sheep farmers, who worked in animal houses were shown to be at highest risk of developing respiratory symptoms. Although poultry farmers showed a significantly higher prevalence of wheezing, in farmers working with housed pigs the prevalence of asthma-like syndrome was significantly higher than in farmers not working with those animals.[8] Because this first stage of the study showed that pig and poultry farmers were at highest risk of developing respiratory symptoms it was decided to study them in more detail.

Therefore, it was the aim of this second part of the survey to investigate the relation between lung function and measures of exposure and farming characteristics. A subsample of pig farmers was chosen in Denmark, and in Switzerland a population of poultry farmers was investigated. To be able to compare the measurements identical methodological approaches were used in both countries.

Table 1 Descriptive data and lung function values of pig and poultry farmers

	Pig farmers	Poultry farmers	p Value
	n (%)	*n (%)*	*Fisher*
Number	40	36	
Male sex	36 (90)*	24 (67)	0.02
Current smokers	9 (23)	11 (31)	0.45
Ex-smokers	11 (28)	5 (14)	0.17
Asthma symptoms†	2 (5)	3 (9)	0.66
Symptoms of chronic bronchitis‡	1 (3)	4 (14)	0.15
Work related respiratory symptoms	20 (50)	21 (58)	0.50
	Mean (SD)	*Mean (SD)*	*t Test*
Age (y)	39 (10)	41 (13)	0.69
Duration of work as a farmer (y)	20 (10)	20 (14)	0.78
FVC before exposure (% ref value)	107.0 (14.1)	101.4 (14.9)	0.13
FVC after exposure (% ref value)	110.2 (15.7)	102.6 (14.0)	0.04
FEV_1 before exposure (% ref value)	108.3 (16.7)	100.2 (14.2)	0.04
FEV_1 after exposure (% ref value)	114.3 (17.0)	101.0 (13.6)	<0.001
$MMEF_{25/75}$ before exposure (% ref value)	101.7 (25.0)	88.8 (20.4)	0.02
$MMEF_{25/75}$ after exposure (% ref value)	108.4 (28.3)	89.1 (22.2)	0.003

*Number in parenthesis=% of total population.
†Woken by an attack of shortness of breath during the past year, asthma attack during the past year, or currently taking medication for asthma.
‡Cough and phlegm on most days for at least 3 months during the preceding year.

Material and methods

STUDY POPULATION

Out of the seven centres participating in the first part of this European study, we decided in the second part to study a subsample of randomly chosen animal farmers in the Danish and Swiss centres in more detail. During the first part of the study, 2002 farmers in Denmark (Arhus region; response rate 80.6%) and 1542 farmers in Switzerland (Zurich region; response rate 81.6%) answered a detailed questionnaire on respiratory symptoms and farming characteristics. Farmers were selected at random from the most recently available census (census of professional farmers organisations in Denmark, state census in Switzerland).[8] Because in Denmark the group of farmers at highest risk of developing respiratory symptoms were pig farmers,[8] 40 pig farmers were chosen randomly from the target population. In Switzerland, the prevalence of work related respiratory symptoms was highest in poultry farmers[8 9]; therefore, 36 poultry

Table 2 Univariate associations between farm characteristics, environmental measurements, and lung function results for pig farmers (mean (SD))

		n	FVC % Ref value	FEV_1 % Ref value	$MMEF_{25/75}$ % Ref value
Automatic feeding	No	8	107.6 (14.3)	103.4 (18.4)	82.9 (21.2)**
	Yes	22	106.8 (14.4)	110.1 (16.1)	108.2 (23.1)
Storage time liquid manure >1 months	No	25	106.3 (14.8)	107.5 (17.8)	100.5 (26.3)
	Yes	5	110.5 (10.8)	112.4 (9.4)	107.8 (17.6)
Air inlet: porous inlet	No	17	106.5 (15.3)	107.1 (17.5)	99.7 (23.6)
	Yes	13	107.6 (12.9)	109.9 (16.1)	104.3 (27.6)
Control: humidity sensor	No	12	101.0 (15.7)*	100.7 (18.9)*	90.8 (19.6)*
	Yes	18	111.0 (11.7)	113.4 (13.2)	108.5 (26.0)
Heating	No	2	Number of farmers without heating in the pig house was too low		
	Yes	28			
Total dust ⩾median (4.0 mg/m³)	No	15	111.2 (14.9)	110.4 (15.6)	100.5 (26.0)
	Yes	16	103.3 (12.7)	106.6 (17.9)	102.7 (24.8)
Endotoxin content in total dust ⩾median (58.0 ng/m³)	No	15	104.9 (12.8)	105.1 (18.2)	99.4 (30.1)
	Yes	16	109.1 (15.5)	111.6 (15.0)	104.0 (18.9)
Total fungi ⩾median (8.7*10⁶/m³)	No	14	106.6 (14.3)	105.7 (19.2)	93.0 (29.2)
	Yes	17	107.3 (14.4)	110.6 (14.4)	108.8 (18.8)
Total bacteria ⩾median (4.2*10⁸/m³)	No	14	105.9 (14.0)	105.1 (19.0)	95.2 (29.9)
	Yes	17	107.9 (14.6)	111.2 (14.4)	107.0 (19.5)
Ammonia ⩾median (6 ppm)	No	14	108.2 (16.6)	108.2 (16.8)	101.2 (25.2)
	Yes	17	106.1 (12.3)	108.4 (17.1)	102.0 (25.6)
CO_2 ⩾median (1200 ppm)	No	14	109.7 (16.1)	111.8 (15.9)	102.6 (17.5)
	Yes	17	104.6 (12.1)	105.3 (17.2)	100.8 (30.3)
Temperature ⩾median (19.9°C)	No	15	113.4 (12.3)*	118.0 (11.7)**	115.0 (19.8)**
	Yes	16	101.4 (13.5)	99.9 (16.0)	89.1 (23.1)
Air humidity ⩾median (75%)	No	17	102.5 (11.9)	105.3 (11.3)	103.1 (19.0)
	Yes	14	112.1 (15.1)	111.8 (21.2)	100.0 (31.5)
Air velocity ⩾median (0.23 m/s)	No	15	107.8 (15.0)	108.4 (16.5)	98.2 (22.2)
	Yes	16	106.2 (13.7)	108.3 (17.5)	104.9 (27.6)

*p<0.05; **p<0.01, *U* test.

farmers were randomly selected from the list of the regional professional farmers' organisation. Combinations of the main type of production with other types of animal or plant farming were documented but were not a selection criteria.

QUESTIONNAIRE

An inventory of farm characteristics was taken by visiting the farm and interviewing the participants about number and kind of animals, heating and ventilation system, type of floor, frequency of cleaning, and location of air exhaust. A special type of ventilation is porous ventilation—porous walls or ceilings. This is characterised by big porous surfaces with plenty of small holes—for example, mineral wool or perforated plates. In animal houses with automatic ventilation, the ventilation flow is mostly controlled by a temperature sensor. A particular type of automatic ventilation control is regulation through humidity sensors, used in houses where supplementary heat is needed. In these buildings a humidity sensor is used in addition to the temperature sensor. This means that the indoor temperature is controlled by the temperature sensor, which influences the air exchange in the animal house; if the indoor relative air humidity increases above the set level, additional heat is supplied. Subsequently the temperature rises and the ventilation flow increases.

Structured interviews were additionally performed with questions on respiratory symptoms within the preceding year, smoking habits, and standardised questions on chronic bronchitis (British Medical Research Council criteria). Asthma was defined as having been woken by an attack of shortness of breath during the past year, reporting at least one asthma attack during the past year, or currently taking asthma medication. Subjects reporting cough and phlegm on most days for at least 3 months during the preceding year were defined as having chronic bronchitis. Special emphasis was given to respiratory symptoms during work that suggested airway narrowing or irritation (shortness of breath, wheezing, and dry cough). In both study centres identical questionnaires were used with some adaptation to the specific kind of animal. The questionnaires were tested for comprehensibility and translated, with back translation into English.

LUNG FUNCTION TESTS

Lung function tests were performed immediately before and after feeding the animals in the morning by two thoroughly trained technicians in both centres. A portable spirometer (Denmark: Flowscreen II, Jaeger, Wuerzburg, Germany; Switzerland: MultiSPIRO-PC, Biotrine, Woburn, MA, USA) was used after daily calibration. Forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), and midexpiratory flow rate ($MMEF_{25/75}$) were measured. All results were analyzed blindly by the same person (GP) according to the American Thoracic Society standardisation criteria—that is, of three acceptable flow-volume curves the largest and the second largest values of FVC and FEV_1 values were not allowed to vary by more than 200 ml or 10%. The $MMEF_{25/75}$ values were recorded from the manoeuvre with the largest sum of FEV_1 and FVC.[11] Lung function results were compared with reference values after adjustment for age and height as proposed by the European Community for Steel and Coal[12] and given as a percentage of the reference value. The decline in lung function variables over the feeding period was calculated as a percentage of the baseline value. As measurements were taken before and after exposure in all subjects, each person served as his or her own control.

ENVIRONMENTAL MEASUREMENTS

Personal monitors were used to collect samples for each farmer during the daily work inside the animal buildings resulting in a median sampling time of 118 minutes. Farmers carried out their usual tasks during measurements wearing the personal pumps while moving from one building to another. The samples collected were analyzed for total dust, endotoxin concentration in total dust, and microbial contamination (total bacteria and fungi). Dust was collected on preweighed (Technischer Überwachungsverein (TÜV) Hanover, Germany), 37 mm diameter glass fibre filters (SKC, Müllheim, Germany) fixed in threaded holders (GSP, Personal air sampler, GSA Meβgerätebau Neuss, Germany) with a constant airflow 3.5 l/min (224 PCXR 7 KB, SKC, Müllheim, Germany). Dust concentration was measured gravimetrically (lower detection limit 0.09 mg/filter) and related to air volume. Endotoxin content of dust samples was measured by a kinetic-turbidimetric limulus assay as described by Hollander *et al*[13] in the laboratory of the Institute of Animal Hygiene and Animal Welfare (School of Veterinary Medicine, Hanover, Germany). Results were related to air volume and expressed as ng/m^3 (EC 6 standard, 8 EU=1 ng, lower detection limit 0.005 EU). Airborne micro-organisms were collected on polycarbonate filters with a pore size of 0.4 μm and a diameter of 25 mm placed on cellulose support pads and sealed in presterilised carbon filled polypropylene air monitoring cassettes (Pegasus Labor, Duesseldorf, Germany) with an airflow of 1 l/min (224 PCXR 7KB, SKC, Muellheim, Germany). The total concentration of airborne micro-organisms was measured by the CAMNEA method[14] with an epifluorescence microscope.

Also, a point measurement of ammonia (Ammonia 5/a, CH 20501, 5 - 70 ppm, Draeger Sicherheitstechnik, Luebeck, Germany), carbon dioxide (Carbon Dioxide 100/a, 81 01811, 100 - 3000 ppm; Draeger Sicherheitstechnik, Luebeck, Germany), temperature, air humidity, and

Table 3 Univariate associations between farm characteristics and lung function results for poultry farmers (mean (SD))

		n	*FVC % Ref value*	*FEV_1 % Ref value*	*$MMEF_{25/75}$ % Ref value*
Automatic feeding	No	1	Number of farmers without automatic feeding in the		
	Yes	35	poultry house was too low		
Storage time liquid manure >1 months	No	16	96.9 (13.4)	96.9 (13.7)	88.9 (20.7)
	Yes	20	105.0 (15.4)	102.8 (14.3)	88.7 (20.7)
Air inlet: porous inlet	No	15	108.5 (15.8)*	105.3 (13.1)	87.5 (15.2)
	Yes	21	96.4 (12.2)	96.6 (14.1)	89.7 (23.9)
Control: humidity sensor	No	34	Number of farmers with humidity sensor in the		
	Yes	2	poultry house was too low		
Heating	No	22	100.3 (11.7)	99.3 (12.9)	87.8 (18.5)
	Yes	13	103.9 (19.8)	102.6 (16.6)	91.1 (24.3)
Total dust ⩾median (7.0 mg/m^3)	No	16	99.6 (14.3)	98.2 (12.9)	87.8 (20.0)
	Yes	16	105.8 (15.9)	103.2 (15.9)	86.6 (17.5)
Endotoxin content in total dust ⩾median (257.6 ng/m^3)	No	16	101.9 (15.5)	100.4 (13.9)	87.5 (16.3)
	Yes	17	102.7 (15.3)	100.6 (15.0)	86.9 (20.2)
Total fungi ⩾median (2.0*10^7/m^3)	No	18	101.6 (13.0)	100.7 (13.8)	88.1 (22.3)
	Yes	18	101.3 (17.0)	99.7 (15.0)	89.5 (18.8)
Total bacteria ⩾median (4.7*10^9/m^3)	No	18	101.5 (14.6)	100.8 (15.2)	90.3 (20.9)
	Yes	18	101.3 (15.6)	99.6 (13.5)	87.2 (20.3)
Ammonia ⩾ median (12 ppm)	No	17	103.8 (12.8)	101.4 (12.8)	89.6 (22.5)
	Yes	19	99.3 (16.6)	99.1 (15.6)	88.0 (18.8)
CO_2 ⩾median (2100 ppm)	No	16	104.3 (11.0)	101.3 (10.7)	85.1 (17.4)
	Yes	19	99.5 (17.8)	99.9 (16.9)	92.2 (22.8)
Temperature ⩾median (16.2°C)	No	18	98.7 (11.5)	97.9 (12.6)	89.1 (19.3)
	Yes	18	104.2 (17.6)	102.5 (15.6)	88.4 (21.9)
Air humidity ⩾median (71%)	No	18	103.7 (11.5)	100.8 (11.2)	87.0 (19.4)
	Yes	18	99.1 (17.6)	99.6 (17.0)	90.6 (21.8)
Air velocity ⩾median (0.01 m/s)	No	1	Number of farmers with air velocity <median in the		
	Yes	34	poultry house was too low		

*p<0.05, *U* test .

Table 4 Environmental measurements

	Pig farmers n=40 Median (range)	Poultry farmers n=36 Median (range)	p Value (Mann-Whitney U test)
Total dust (mg/m^3)	4.0 (1.1–13.8)	7.0 (0.4–21.8)	<0.001
Endotoxin content in total dust (ng/m^3)	58.0 (1.3–1101.7)	257.6 (19.0–1634.8)	<0.001
Total fungi (n/m^3)	8.7×10^6 (<DL–1.4×10^8)	2.0×10^7 (<DL–1.1×10^9)	0.02
Total bacteria (n/m^3)	4.2×10^8 (<DL–1.6×10^9)	4.7×10^9 ($2.7*10^7$–4.2×10^{10})	<0.001
Ammonia (ppm)	6 (<DL–14)	12 (<DL–40)	0.02
CO_2 (ppm)	1200 (800–2500)	2100 (600–4100)	<0.001
Temperature (°C)	19.9 (15.9–22.3)	16.2 (4.2–25.4)	<0.001
Air humidity (%)	75 (60–86)	71 (54–96)	0.10
Air velocity (m/s)	0.23 (0.06–0.52)	0.01 (0.00–0.29)	<0.001

DL=detection limit.

air velocity (Testo 400, Testo, Lenzkirch, Germany) was performed in each of the animal houses under study. Details of the air sampling and laboratory analyses are described elsewhere.[10] In each centre only two people performed the measurements after thorough training by one of the authors (KR). All air quality measurements were evaluated by the same laboratories.

ANALYSIS

Data were analyzed with a statistical package for personal computers (Statistica, Tulsa, USA).

Descriptive data of the two study centres were compared by *t* tests for continuous variables and Fisher's exact test for nominal data. The *t* test for dependent variables was used to compare lung function before and after feeding. Data on lung function of farmers with workplace exposure less than the median (0) or greater than or equal to the median (1) of all samples from each centre were compared by Mann-Whitney *U* test. Only variables with at least five results/group were compared. Also, significant results in the univariate analyses were analysed with multiple linear regression analysis adjusting for smoking (pack-years).

Differences in farming methods and levels of exposure between symptomatic (wheezing, breathlessness, or cough without phlegm at work) and asymptomatic farmers were tested with Fisher's exact test and *t* test for independent variables.

Results

SUBJECTS

The two study groups were comparable for age, duration of work on a farm, prevalence of respiratory symptoms, and smoking (table 1) although the number of male farmers was significantly higher among pig farmers than poultry farmers. Comparing the lung function results before and after work inside the animal houses, pig farmers had significantly higher results than poultry farmers ($p<0.05$, *t* test) in all spirometric variables, except for FVC percentage of the reference value in the morning ($p=0.13$, *t* test). Lung function results after work inside the animal buildings did not differ significantly from the values before exposure ($p>0.05$, paired sample *t* test) for either pig or poultry farmers.

ASSOCIATIONS BETWEEN FARM CHARACTERISTICS AND BASELINE LUNG FUNCTION RESULTS

Tables 2 and 3 show that farming characteristics were significantly associated with lung function results before the feeding period for pig (table 2) and poultry farmers (table 3). A negative influence of ventilation control without a humidity sensor in the pig houses was found for all lung function variables. Pig farmers who used automatic feeding showed significantly higher $MMEF_{25/75}$ percentage of reference value than farmers without. In poultry houses the presence of a porous air inlet was significantly negatively associated with results of FVC. All results were confirmed after adjusting for pack-years of smoking (data not shown).

ASSOCIATIONS BETWEEN ENVIRONMENTAL MEASUREMENTS AND SPIROMETRIC RESULTS

Environmental measurements of exposure were significantly higher in poultry than in pig houses (table 4).

Comparing lung function results of farmers with workplace exposure less than the median with farmers with workplace exposure greater than or equal to the median, pig farmers with higher temperatures inside the pig house had significantly lower lung function results (table 2). This was also confirmed after adjustment for pack-years of smoking (data not shown). No relation between environmental measurements and baseline lung function could be established for poultry farmers (table 3).

SYMPTOMATIC AND ASYMPTOMATIC FARMERS

Farmers not complaining of work related respiratory symptoms (wheezing, breathlessness, or cough without phlegm at work) had significantly higher results for FEV_1 percentage of reference value (108.2 (15.1) *v* 100.1 (15.6); $p<0.05$, *t* test) and $MMEF_{25/75}$ percentage of reference value (100.9 (23.8) *v* 89.5 (22.0); $p<0.05$, *t* test) than farmers with symptoms. The trend towards an increase in lung function over the feeding period was greater in asymptomatic than in symptomatic farmers (table 5). No significant differences in age, duration of farm work, or measures of exposure were found

Table 5 Decline in mean (SD) lung function over the feeding period in the morning (% of baseline value) for all farmers, farmers with, and farmers without work related respiratory symptoms

Respiratory variable	Total (n=67)	With work related symptoms* (n=36)	Without work related symptoms* (n=31)
ΔFVC	−1.52 (6.12)	−1.25 (6.61)	−1.83 (5.58)
ΔFEV_1	−1.73 (6.17)	−0.88 (6.73)	−2.72 (5.38)
$\Delta MMEF_{25/75}$	−1.63 (12.52)	−0.84 (12.11)	−2.50 (13.12)

*Work related symptoms: wheezing, breathlessness, or cough without phlegm at work.

between farmers with work related respiratory symptoms and farmers without such symptoms. Also, farming characteristics did not differ significantly between symptomatic and asymptomatic farmers.

Discussion

The three main findings of this study were (*a*) lower lung function in poultry farmers than pig farmers, (*b*) factors related to work in the housed areas of pigs and poultry (variables of ventilation and feeding management) were significantly associated with decrements in lung function, and (*c*) higher temperatures inside the pig houses were significantly negatively associated with lung function in pig farmers.

To our knowledge, no study has been published on the link between specific characteristics of poultry farming and impairment of lung function. Two studies are known, which focused on pig buildings,[15 16] but only one study, by Vogelzang *et al*, used environmental measurements as well as questionnaire data.[17]

The limitation of our study was the low number of pig and poultry farmers in each centre. To detect farming characteristics resulting in small changes in lung function higher numbers of farmers would be needed to get sufficient statistical power. Nevertheless, we have shown that variables of ventilation and feeding might be related to changes in lung function. The finding of our study that ventilation could be an important factor in the development of occupational airway disease in farmers is compatible with data from previous studies of Bongers *et al*,[16] Vogelzang *et al*,[15 17] and Donham,[18] as well as our earlier study on cattle farmers.[19] In our study of cattle farmers we also detected a negative influence of heating on respiratory symptoms, which is compatible with our finding that higher temperatures might have a negative influence on lung function in pig farmers. The associations between ventilation and heating may indicate that higher temperatures throughout the year and lower rates of exchange of air may result in higher concentrations of endotoxins, glucans, and mites in animal houses and thus in higher respiratory morbidity among farmers. Preller *et al*[20] have shown that besides other variables, type of heating, ventilation, and feeding as a task are associated with high exposure of dust and endotoxin in pig buildings. Comparing exposure variables of ventilation through porous inlets to poultry houses with different ventilation systems we found that ventilation through porous inlets had higher concentrations of fungi, bacteria, ammonia, and CO_2 (data not shown). Also, in pig buildings ventilation control through a humidity sensor and lower temperatures were associated with reduced overall exposure. Therefore, ventilation and temperature might be proxies of total exposure inside the buildings.

As in our study on exposure characteristics in pig and poultry buildings,[10] some previous investigations have shown higher exposure in poultry houses than in pig buildings.[21–23] Other than this, no studies have yet been published comparing lung function of pig and poultry farmers. As shown in our study, poultry farmers did not only have a higher exposure to environmental factors such as dust, endotoxin, and micro-organisms, but also showed lower mean lung function results. To confirm our findings lung function measurements should be performed in pig and poultry farmers from one country with one spirometer to diminish the geographical differences between the farmers and to minimise technical confounders.

No significant change in lung function values was found over the feeding period. This lack of change is probably due to the circadian rhythm of lung function values with lowest values in the early morning and highest in the afternoon.[24] Other studies have shown a significant decline over the feeding period in pig farmers[25] and poultry workers[26] but it has to be borne in mind that the median exposure time in our study was only 118 minutes. Farmers in the study of Donham *et al*[25] had to stay out of the building for at least 48 hours before the testing. In poultry farmers, Thelin *et al*[27] found a mean decrease in FEV_1 of 0.11 l in an exposure period of 1 working day. In our study it was impossible to obtain longer exposure periods because the farmers normally work only for a short time in the morning and in the evening inside the animal houses. Nevertheless, there was a tendency towards a lower increase in FEV_1 over the feeding period in the symptomatic farmers, as was found in other surveys.[25 28]

In this study, a low standard of ventilation control inside the animal houses was related to long term impairment of lung function. Prospective cohort studies including a larger number of poultry farmers are warranted to estimate the effects of farming characteristics on respiratory health in more detail.

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ANSWERS (See page 424 for questions)

(**1**) (*a*) False (*b*) True (*c*) False (*d*) True (*e*) True (*f*) False (*g*) False

(**2**) (*a*) False (*b*) False (*c*) True (*d*) True (*e*) False

(**3**) (*a*) True (*b*) True (*c*) True (*d*) False (*e*) True (*f*) True

(**4**) (*a*) False (*b*) True (*c*) False (*d*) False (*e*) False