

Ergonomics in health care : working conditions in the operating theatre

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Ergonomics in health care: working conditions in the operating theatre

J. A. M. Graafmans

Summary

Hospital management is often confronted with discussions concerning (re)building of the operating theatre. Criteria regarding working conditions and well-being of the staff cannot easily be set. In order to get more insight, relevant aspects were studied interdependently. These were climate, illumination, acoustics, ventilation of anaesthetic gases and concentration of bacteria and dust particles in the operating-room air. The influence of working postures and movements of the operating-room personnel on air quality is briefly characterized. Most measurements were performed during open-heart surgeries, although for some a simulation needed to be set up. Some remarkable results were found. Ventilation systems do not operate as was intended because of the heat production of the surgical team. Microcirculations originating thereof may cause high local concentrations of anaesthetic gases and heavily contaminated spots in the incision area. The hierarchical air pressure distribution in the ward is disturbed by the intense 'traffic'. The static and dynamic load on the surgical team can give rise to complaints. Unless precautions are taken, the indoor climate cannot be comfortable and safe for everybody at the same time. Monitoring systems have to be developed to check the quality of ventilation systems, to visualize microcirculations with respect to bacteria and anaesthetic gases, and to synchronize all different registrations. Optimization of the working conditions concerned implies an indispensable co-operation between a variety of medical and technical disciplines that does not develop automatically.

12.1 Introduction

The main objectives of this study were two-fold: (1) the generation of proposals for the optimization of the working conditions in operating theatres, and (2) the derivation of research proposals directed towards partial solutions for the most unfavourable circumstances.

Attention to human factors in hospitals has been initiated by the Dutch law on working conditions. This law supersedes a number of smaller laws that were operative until the late 1970s. One might expect that the new law will be introduced gradually for a number of reasons. Some of the requirements will hardly be realizable due to technical and/or economical constraints; the conception of well-being at work, such as work satisfaction and comfort, are subjective and therefore not easy to quantify. In medicine and health care a number of protocols, procedures and responsibilities are dictated, inherent to the medical profession.

In general, one can say that there will be exceptive clauses in this law, especially when it concerns the working conditions in health care.

During two workshops, anaesthetists and technologists explored and discussed problem areas concerning working in and functioning of operating wards. A number of aims for research were formulated. The most relevant factors identified were:

- comparative studies concerning reliability of apparatus;
- in order to achieve a better trend-monitoring and data-acquisition, data processing and data presentation, more participation of manufacturers is needed in an attempt to integrate measurements such as ECG, EEG, blood pressures and muscle relaxation;
- human factors, focusing on near accidents and critical incidents caused by improperly designed human-machine interfaces;
- environmental factors, indoor climate, infection hazards are probably correlated, nevertheless an 'integrated' study has not been carried out.

A relation is supposed between a number of variables that determine, in mutual dependence, the environmental conditions under which tasks in the operating theatre, intensive-care unit and recovery room take place. As far as we know, a lot of fundamental but fragmentary research has been carried out, covering all subjects independently (Royal College of Surgeons England, 1964). The aim of this study is the integration of most of the aforementioned aspects. The study concerned three aspects: physical, chemical and bacteriological:

- a. *Physical aspects of the indoor climate.* Expertise exists in the field of thermophysiological load on people during various activities in relation to their metabolism and feelings of comfort (Lammers, 1978). Thermophysiological models incorporate the insulation value of working clothes. Application of these models is specially meaningful when various activities take place under different conditions within the same accommodation, as is the case in the operating theatre (Lammers, 1978).
- b. *Ventilation of anaesthetic gases.* Anaesthetic gases in the operating theatre affect the working conditions and pose a long-term effect on the health of the theatre personnel. For registering the concentration of anaesthetic gases in the operating room air, measuring methods have been developed that are still in use (Ljungqvist, 1979).
- c. *Bacteriological concentrations.* Bacteriological sampling is integrated with the previous point. Although not so relevant to working conditions as a whole (except for the disciplinary rules originating from preventive protocols), bacteria present an infection hazard for the patient.

An integration of these aspects will, together with the measurement of the physical parameters, provide extra information regarding interactive effects. A relation between indoor climate and anaesthetic gases on the one side and indoor climate and bacteriological flora on the other has to be demonstrated.

12.2 Approach

To obtain an overall idea of the working conditions in operating theatres we measured the following:

Air movements and pressure distribution in the operating ward. This implies measurements inside the theatre for comfort and for the estimation of the evacuation and/or dispersion of gases, bacteria or other undesirable pollutions (dust particles). Inside the whole ward in which septic and sterile spaces are separated by architectural provisions, disturbances in the installed hierarchical air pressure distribution were recorded.

Thermal load on the various categories of personnel in relation to their specific activities (sterile/non-sterile). This includes the mapping of the climatic zones in the operating theatre, and assessing the insulation values of various types of clothing. Figure 12.1 shows the warm and cold areas in a typical operating theatre layout during open-heart surgery. Wyon *et al.* (1968) state that thermal conditioning of the patient is of great importance.

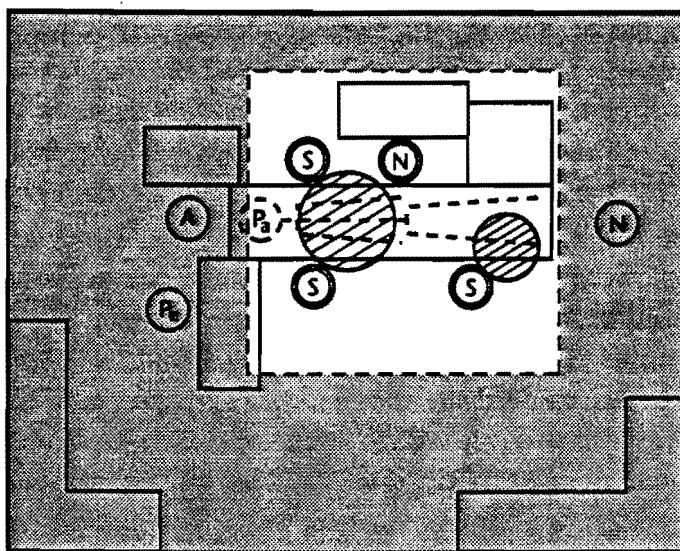


Figure 12.1 Theatre layout during open-heart surgery. The small circles represent the proportional insulation value of the clothing of the persons present. S, surgeon; A, anaesthetist; N, nurse; P_p, perfusionist; P_o, patient.

Illumination, including general lighting (luminances), the operating lamp and its thermal effects, light intensity, possible disturbance of air movements, colour, and so on. Acoustical parameters to be taken into account are speech intelligibility, signal to noise ratios and reverberation time.

Controls and displays require an anthropometrical analysis of the theatre personnel workstations in relation to the positioning of equipment. Attention should be given to the layout of the anaesthesia apparatus including the connections to the patient before, during and after surgery, and to the arrangement of resources and spare materials. A more in-depth analysis on this aspect was made in a separate study (Bijnen and Jetten, 1987). The arrangements of VDUs and other displays dictate working postures, and the observability and interpretation of information depend largely on the selection and redundancy of presented signals. Finally, the manipulation of the patient during transport, transfer and surgery has to be registered.

As it is impossible to record all these aspects without disturbing the normal course of surgery, a number of measurements was performed in an 'empty' theatre, where volunteer staff members simulated an open-heart surgery session. The simulation entailed the recording of acoustical variables (reverberation time,

background noise level), illumination (intensity, luminance) and climatological conditions (skin temperatures, air movements, frequency of air exchanges). The other variables were measured during and in between 12 open-heart surgery sessions over a period of two weeks. All measurements took place in the same theatre and were referred to an adjacent theatre. Surgical interventions were similar (coronary anastomosis) and were performed by the same surgical team.

12.2.1 Indoor climate

Figure 12.2 shows an overview of the measuring points. The skin-temperature sensors that were occasionally fixed to the theatre personnel in an attempt to objectify 'comfort feelings' are not shown. At the end of each surgical session, the staff was interviewed regarding the experience of temperature, relative humidity and so on.

12.2.2 Anaesthetic gases, bacteria, dust particles

The theatre personnel are exposed to anaesthetic gases that circulate in the air. Literature that deals with the ventilation of anaesthetic gases gives much attention to the epidemiological effects. Liver damage appears significant among anaesthesia personnel (Spence *et al.*, 1977; Jynge *et al.*, 1979).

Former research has ignored the movement and position of theatre personnel and the existence of micro-circulations in the operating-room air, causing high local concentrations of anaesthetic gases or other pollutants (Burm *et al.*, 1976;

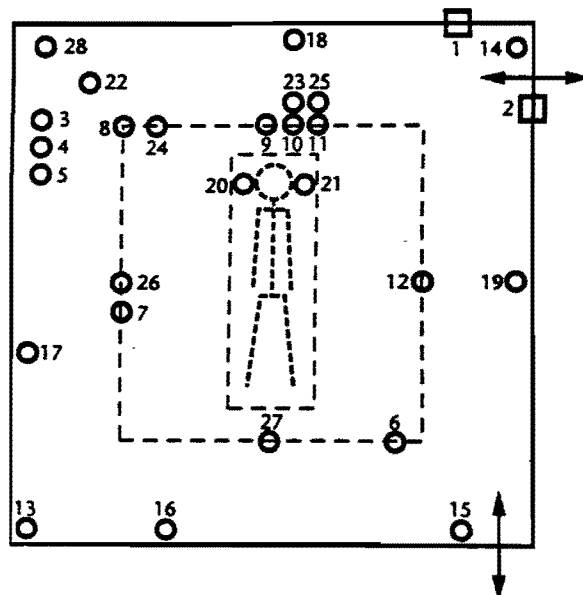


Figure 12.2 Recording the indoor climate. 1. Δp theatre-corridor; 2. Δp theatre-lobby; 3-5. T_A (0.5, 1.5, 3.0 m); 6-12. T_A inlet; 13-14. T_A outlet; 15-19. T wall (2.0 m); 20. T floor; 21, 22. T ceiling; 23, 24. omnidirectional V_A (2.2 m); 25-27. directional V_A (2.9 m); 28. T dew point (rel. humidity). Δp , pressure difference; T_A , air temperature; T , surface temperature; V_A air velocity.

Piziali *et al.*, 1976), thus making the measurement of average concentrations in the outcoming air nonsensical. Also, the hypothesis that equal distribution of dust particles and bacteria is determined by the main airstream is invalid, at least for the combination of laminar and turbulent airflow that exists in many operating theatres. The gathering and analysis of air samples was carried out continuously (miran-analyser) and intermittently (gas chromatograph). The sampling places are shown in Figure 12.3.

The presence of bacteria is highly determined by human activities such as walking, sitting and standing. Therefore, the recording of these activities was carried out simultaneously with the sampling of bacteria. The sampling place was located near the incision area, being the most relevant spot regarding the risks for the patient; especially post-operative infections. The sampling frequency was four per hour. Extra samples were taken at critical moments during the course of the surgical intervention. For evaluation purposes a continuous measurement of dust particles was performed, due to a hypothesized relation between the number of dust particles and bacteria. The sensor was placed in the surgical lamp, close to the sampling place for bacteria.

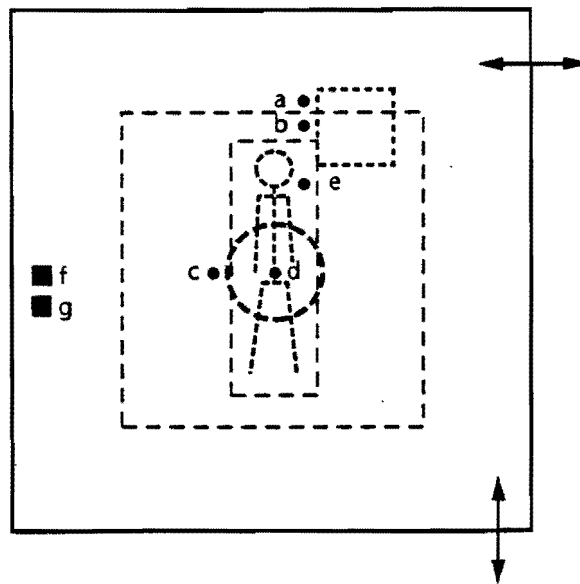


Figure 12.3 Registration of laughing gas. $a = 0.6$ m, $b = 1.8$ m, $c =$ at operating lamp, dust particles (d); bacteria (e at 1.4 m) and activity patterns (f , observer; g , video-observer). Distances express height of measuring point.

12.2.3 Activity patterns

Postures and movements were recorded manually every 30 s. The activity of each person present was scored according to the values in Table 12.1. The arbitrary scores corresponding to the activities are deduced from the scarce literature on this subject (Vigouroux *et al.*, 1975; Hoborn, 1981). The standardization of activities is based on the amount of particles dispersed by man in motion in order to find the effect of activities in the theatre on the total amount of dust particles and bacteria. Outstanding events (for example, perspiration,

Table 12.1 Activity score values (taken every 30 s)

Scores per activity	Activity
1	Motionless person sitting or standing
5	Calm motion of head or hands
10	Motion of trunk or upper extremities
25	Stand up or sit down
50	Walk more than three steps, entrance or exit

vivid communication, noticeable stress), as well as the course of the surgical intervention were recorded with keywords (for example, intubation, perfusion on, and so on). To validate the manual observations, video-recordings were made of two complete sessions. Comparison of the data from video recordings and the manual recordings confirmed the accuracy of the latter.

12.3 Results

12.3.1 Physical aspects

The environmental variables (air temperature T_A , surface temperatures, mean radiant temperature T_{MRT} , relative air velocity v , relative humidity, r.h.) and individual variables (metabolism/activity level M , intrinsic clothing resistance CLO) are combined and interpreted in the thermophysiological model as constructed by Lammers (1978) (see Figure 12.4). This model provides comfort

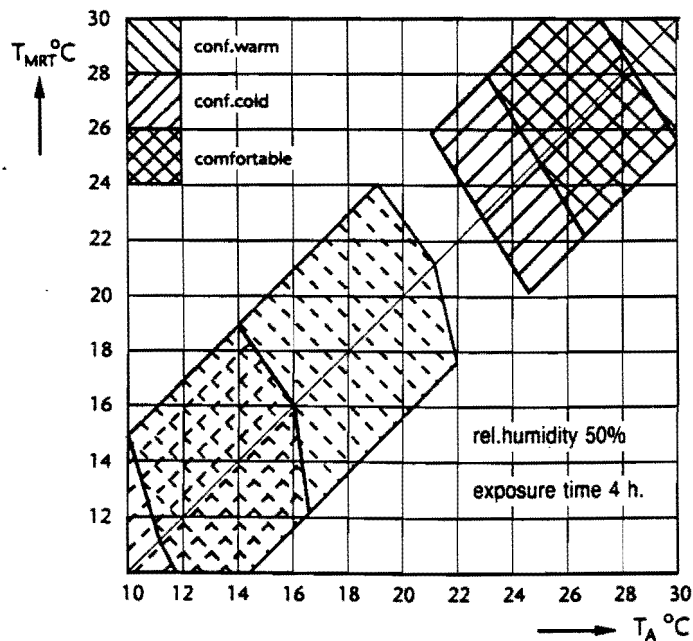


Figure 12.4 Comfort domains for surgeon (---) and anaesthesiologist (—) with, respectively, a metabolism of 110 and 70 W m^{-2} , dressed up to 1.1 and 0.5 intrinsic clothing resistance and exposed to air velocities of 0.3 and 0.4 m s^{-1} .

areas for the different physical activities under various personal and climatological conditions. The air temperature varied between 18.5°C and 22°C. Because of the internal heat production (2.5 kW) by appliances and persons this requires an air-inlet temperature of 15°C. On the premise of an efficient mixture of the fresh air in the theatre this will cause no problems. However, the penetration depth is too great so an uncomfortable draught for the non-sterile team will result. Surface temperatures were constant (walls 21 ± 1°C), or allowable (lamp 53°C). Air velocities > 0.2 m s⁻¹ and ΔT > 2°C gave rise to complaints from the anaesthesia personnel, such as an uncomfortable chilling of the neck and back.

Convective heat originating from the surgical team and the operating lamp (c. 700 W) causes ascending airstreams in the surgical area, the so-called 'chimney effect', in spite of the installed ventilation and air-conditioning system (see Figure 12.5).

Relative humidity varied between 45 and 60% and in accordance with accepted guidelines. To make a distinction between personal variables, a division into three categories is made: patients, surgical team, non-sterile staff (see Table 12.2). With regard to the thermal comfort of the patient, it is stated that the climatological situation is harmless if some precautions are taken (preheated infusion liquids, preheated underlay, warmed and moistened anaesthetic gases). Patient variables are left out of Table 12.2 since they can only be manipulated by the aforementioned precautions.

Table 12.2 Personal and environmental variables for surgeon and anaesthetist averaged over all sessions

Variable	Anaesthetist	Surgeon
Metabolism, M (W m ⁻²)	70	110
Clothing resistance, CLO	0.5	1.1
Relative air velocity, <i>v</i> (ms ⁻¹)	0.4	0.3
Relative humidity, r.h.	0.5	0.5
Exposition time, <i>t</i> (h)	4	4

Figure 12.4 indicates that there is no overlap in the comfort areas of surgeon and anaesthetist. Therefore some precautions have to be taken, for example, extra clothing for the non-sterile team or spot-heating should be provided.

The reverberation time (0.5–0.8 s) in the theatre is in accordance with directives. The background noise level ($L_A = 50$ dB(A)) and NR (45) are high due to the high noise production of the air inlet and the shorting of quelling material in the air channels.

The illumination intensity of the operating lamp is variable between 16 000–105 000 lx. The colour temperature is 3700°K and no shades exist in the incision area. The reflection factors as well as the luminances are according to the standards. The profit of extreme light intensity levels (> 100 000 lx) must be doubted, because above that level there is nothing more to be gained than glare. The general lighting (300–1500 lx) was adequate.

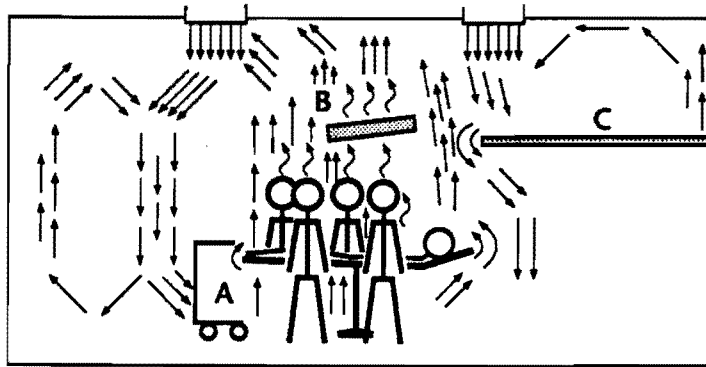


Figure 12.5 Chimney effect. Each curved bold arrow presents c. 100 W. A, Instrument table; B, surgical lamp; C, connections for anaesthetic equipment.

12.3.2 Chemical aspects

Figure 12.6 shows average concentrations of laughing gas in the breathing zone of the anaesthetist. During all sessions this concentration exceeded the US standard (25 p.p.m.)! This high level originates from leakages in connections as well as from operator errors, such as not connecting the rebreathing to the suction system. Under the given conditions the maximum concentration of laughing gas can be 200 p.p.m.

When the suction system is connected the average concentration is 91 p.p.m. and when disconnected it is 191 p.p.m. during the period of administering. A general conclusion may be that under all circumstances this is four to eight times higher than the US standard. The concentration may even be underestimated due to the presence of microcirculations.

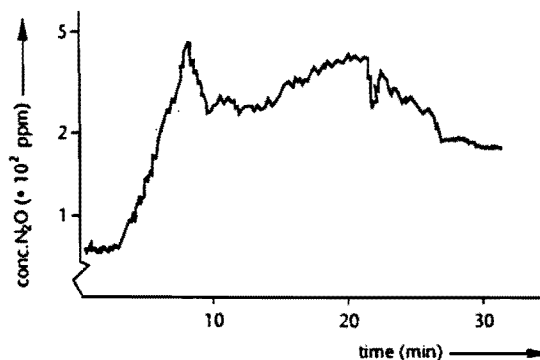


Figure 12.6 N₂O-concentration in the breathing zone of the anaesthetist at the beginning of a surgery.

12.3.3 Bacteriological aspects

The average concentration of bacteria varied between 290–610 colony forming units m⁻³ (CFU m⁻³). The overall average during 12 sessions was 360 ± 140 CFU m⁻³. Figure 12.7 shows the typical patterns as recorded during a session. The average concentration is too high according to Galson and Goddard

(1968) who recommend 124–174 and 113–217 CFU m⁻³ for the air-contamination level during open-heart surgery. However, the sampling place was located in the ascending air ('chimney effect'). Therefore the situation in the incision area might be more favourable.

In Table 12.3 (Spearman non-parametrical rank correlation test), the correlation between the activity patterns (Figure 12.8) of the surgical team and the concentration of dust particles (Figure 12.9) is given. The elaboration of measuring data was hampered by the disturbance of diathermy (emission of soot) and synchronization of all measurements. The results are in agreement with findings of earlier research (Hemker, 1983). The similarity between the contours in the Figures 12.7, 12.8 and 12.9 is remarkable.

Table 12.3 Correlation between activity levels and dust particles

	Act 2 ^b	Dust 1 ^c	Dust ^d
Act 1	0.6266 (160; 0.001)	0.1478 (145; 0.038)	0.1350 (138; 0.057)
Act 2		0.1476 (145; 0.038)	0.1517 (138; 0.038)
Dust 1			0.6683 (145; 0.001)

^aAct 1, activity level surgical team; ^bAct 2, overall activity level; ^cDust 1, particles > 3 × 10⁻⁶ m; ^dDust 2, particles 0.5 × 10⁻⁶–3 × 10⁻⁶ m.

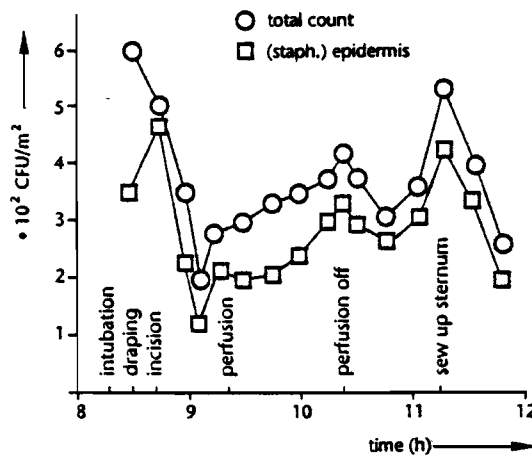


Figure 12.7 Bacterial contamination.

12.4 Conclusions and recommendations

It is possible to create an indoor climate in the operating theatre in which all the staff feels comfortable. To effect this situation, variables like clothing resistance and heat transfer by radiation must be manipulated. In particular the insulation value of the clothing of the non-sterile staff must be increased and

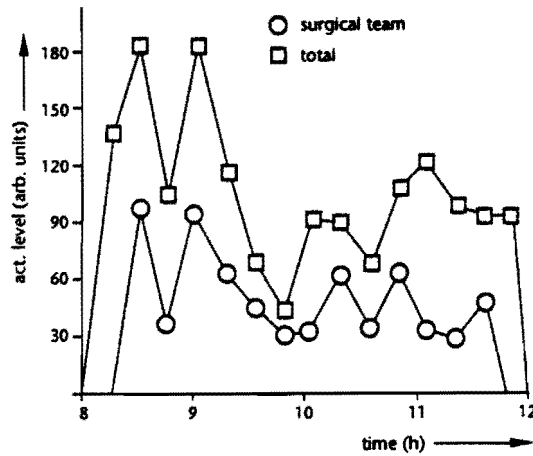


Figure 12.8 Activity level during open-heart surgery.

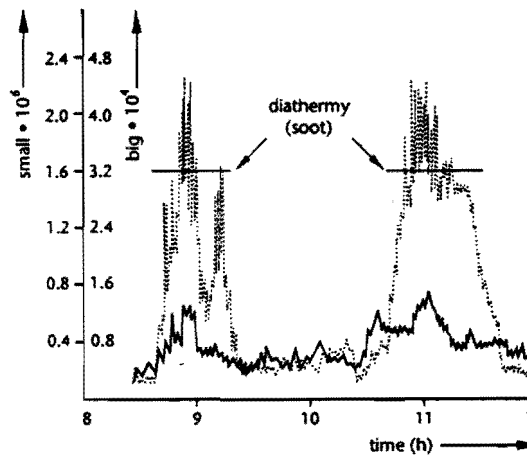


Figure 12.9 Dust particles: smaller than 3 μm (.....), larger than 3 μm (—) equivalent diameter.

radiant spot-heating can compensate the effects of draught in the areas with higher air velocities.

The consequences of warm air rising in the sterile area because of the heat production of the surgical team and the operating lamp, the 'chimney effect', need further analysis. Rising warm air might contaminate the surgical area, because it may be transporting shedded skin. Also the influence of the chimney effect on the originally installed and intended airstream pattern should be examined. All theatre personnel, male and female, should wear sealed off trousers, skirts and rubber overshoes. Cleaning instructions should be revised.

The toxicological risks of exposure to sub-anaesthetic concentrations of laughing gas and halothane during prolonged exposure times need further investigation. A maximum allowable concentration (MAC)-value must be set up. For this purpose, measuring and registration methods must be developed that provide information about local concentrations of anaesthetic gases, exposure times and the influence of airstream patterns. Anaesthetic apparatus have to be designed optimally to reduce the leakage of gases and to compensate for staff operation errors.

Transporting patients to the theatre in their own beds has unknown consequences for the occurrence of post-operative infection. However, the manual transfer of patients to and from the operating table causes inadmissible strain and possible back injuries to the staff. Thus, the organization and design of patient transport systems require more attention (Graafmans, 1984).

Although technical provisions can improve the working conditions in the operating theatre, it must be stated that first 'disciplinary behaviour' is a prerequisite for the optimal completion of tasks to be performed, and secondly, only a multi-disciplinary approach in research will result in better working conditions in the operating theatre.

12.5 Evaluation

The results of the study show that in order to achieve optimal working conditions in the operating theatre, some procedures and installations should be changed. With regard to the indoor climate it is clear that:

'jet ventilation' from the ceiling does not create the desired separation of sterile and non-sterile areas, mainly because of the inevitable 'chimney effect', there exists an uncomfortable cold airstream near the air inlets, the wash-out of anaesthetic gases under these circumstances is not sufficient.

Therefore, new concepts for theatre ventilation should be designed. Warm clothing for the non-sterile staff and spot heating can only provide solutions in existing theatres.

With regard to bacteriological contamination two suggestions are given here:

A complete separation between the operating ward and the hospital staff and equipment. In a follow-up study a transport system for surgical patients is designed to achieve this.

Since the chimney effect is unavoidable as it is caused by the heat production of people and equipment in the theatre, special emphasis should be given to cleaning procedures for the area under and in the direct vicinity of the operating table.

The measurements of anaesthetic gases in the operating room air were not detailed enough to allow direct conclusions with respect to health risks for the staff. A more in-depth study, however, is necessary given the high local concentrations that were found.

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