Review: Domestic hygiene and diarrhoea – pinpointing the problem

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Summary   Improving domestic hygiene practices is potentially one of the most effective means of reducing the global burden of diarrhoeal diseases in children. However, encouraging behaviour change is a complex and uncertain business. If hygiene promotion is to succeed, it needs to identify and target only those few hygiene practices which are the major source of risk in any setting. Using biological reasoning, we hypothesize that any behaviours which prevent stools from getting into the domestic arena, the child's main habitat, are likely to have a greater impact on health than those practices which prevent pathogens in the environment from being ingested. Hence safe stool disposal, a primary barrier to transmission, may be more important than hand-washing before eating, which constitutes a secondary barrier, for example. We review the epidemiological evidence for the effect of primary and secondary barrier behaviours and suggest that it supports this conclusion. In the absence of local evidence to the contrary, hygiene promotion programmes should give priority to the safe disposal of faecal material and the adequate washing of hands after contact with adult and child stools.

keywords hygiene, diarrhoea, excreta, hand washing, developing countries

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Introduction: clearing away the fog

Hygiene is a complex and confusing subject. Whilst hygienic practices play a fundamental role in the prevention of infectious disease, they also serve other needs. Amongst these are the desire to create order and beauty and to demonstrate respect for social morality (Curtis 1998). Those who seek to promote safe hygiene need to both understand the motivations underlying hygiene behaviour in general and be able to identify specific practices that may be putting health at risk.

Whilst hygiene promotion is increasingly favoured by policymakers because of its potential to deliver reductions in diarrhoeal diseases at low cost, such interventions are often 'foggily formulated' (Burgers *et al*. 1988). 'Good' hygiene, in the moral sense, is confused with 'safe' hygiene in the epidemiological sense. This confusion is apparent in Table 1, which gives examples of messages about hygiene collected from hygiene education programmes in developing countries.

Changing people's behaviour is a difficult and uncertain process. Programmes have to focus their efforts on a small number of messages of proven public health importance if they are to avoid wasting the resources both of programmes and of the communities which they target (Loevinsohn 1990; Huttly *et al*. 1997). Public health planners have thus to make hard choices about which specific hygiene practices to promote. Logically, these should reflect the particular practices that are putting health most at risk. It is usually not feasible or desirable to carry out full-scale risk factor studies before designing an intervention. Hence decisions have to be made in the light of what is known about the interaction between human behaviour and the behaviour of pathogens.

In this paper we review the biological, ecological and epidemiological evidence concerning the role of specific hygiene behaviours in the transmission of diarrhoeal disease. We look for basic principles to guide practitioners in the targeting of hygiene promotion programmes. The picture that emerges is incomplete and we highlight areas where more research is needed. Though this review confines itself to developing countries, the distinction between developed and

Table I Some common messages in hygiene education

Cover water containers	Wash hands before eating
Cover food	Wash hands before preparing food
Use fly screens for food	Wash hands before feeding a child
Wash vegetables	Wash children's hands
Add disinfectant to vegetable washing water	Wash hands after defaecation
Construct soakaways for waste water	Wash hands after contact with child faeces
Boil drinking water	Construct plate drying racks
Wear clean clothes	Keep a special dipper for dipping drinking water
Do not spit in public	Sprinkle lime
Filter drinking water with sand	Burn rubbish
Add disinfectants to drinking water	Bury rubbish
Place basins of water in the sun	Transport rubbish to a depot
Chlorinate well water	Issue health certificates to street food vendors
Keep finger nails cut short	Do not bottle feed
Clean nipples with alcohol before breast feeding	Do not store food
Wash hands with soap	Reheat food
Wash hands with ash or mud	Comb hair
Do not wash hands with mud	Wash latrine slabs
Bury faeces	Disinfect latrine slabs
Spray insecticides	Wash well surrounds
Construct water containers with taps	Construct latrines

developing countries is growing blurred and a further global review of the problem of diarrhoeal disease transmission is urgently needed.

Routes of transmission

Diarrhoeal diseases are responsible for over a quarter of the deaths of children in the world today (WHO 1996). Most of the 3.3 million deaths each year (Bern *et al.* 1992) take place in developing countries and are entirely preventable. Because most transmission occurs in the domestic domain, which is the child's principal habitat, it can be prevented by changes in domestic hygiene behaviour (Cairncross 1990).

Though some diarrhoeas are due to errors of metabolism, chemical irritation or organic disturbance, the vast majority are caused by infectious pathogens (Gracey 1985.) Agents include viruses, bacteria, protozoa and parasitic worms. These can employ a number of routes to reach new hosts. Figure 1 schematizes the alternatives. The simplest option for the pathogen is to emit infective material into the environment in faeces in the hope that it will be ingested by a new human host (route 1a). Slightly more complicated is the option for the pathogen progeny to multiply in the environment, thus increasing the chance of meeting and colonizing a new human host (route 1b). A third possibility is for the infective material to leave a human host via faeces, multiply (or not) in the environment, be ingested by an animal host, colonize the animal host, release infective material back to the environment to multiply (or not), before being ingested by a new human host (route 1c). A fourth option is for

pathogens that normally cycle through animals to cross over to and colonize humans via the environment (route 1d).

Examples of enteric pathogens for which man is the principal reservoir, and whose transmission mostly originates from human faeces (route 1a) are *Entamoeba histolytica* and viruses such as the rotaviruses, adenoviruses and astroviruses. Whilst viruses cannot multiply in the environment and may rapidly lose viability in warm conditions, the vast numbers in which they are excreted maximize the chances that some will reach a new host. Some protozoa are capable of remaining viable for many months in the environment (Feachem *et al.* 1983a). Unlike viruses, some bacteria can multiply in the environment, especially when nutrients and warmth are available, for example in food which has been kept at ambient temperature (Rowland 1985) (route 1b). Pathogen species employing this strategy include pathogenic *Escherichia coli*, *Shigella* spp., and species of *Salmonella*. Some of these can survive for long periods in apparently hostile environments such as on fingertips (Hutchinson 1956; Knittle *et al.* 1975).

Enteric pathogens including *Campylobacter jejuni*, *Giardia* spp., *Salmonella enteriditis* and one genotype of *Cryptosporidium parvum*, have been isolated from both human and animal faeces (Feachem *et al.* 1983b; Crawford & Vermund 1988) suggesting that they have animal reservoirs (routes 1c and 1d).

Though there are a number of gut pathogens which have found other routes of transmission (for example it has been suggested that rotavirus can be passed on in droplets of water breathed in after toilet flushing (Ho *et al.* 1989)), the major infectious agents use one of the four routes described above

(a) Human-to-human via the environment
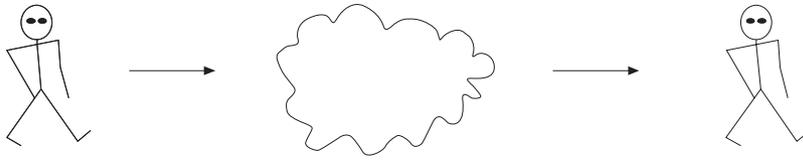
(b) Human-to-human multiplying in the environment
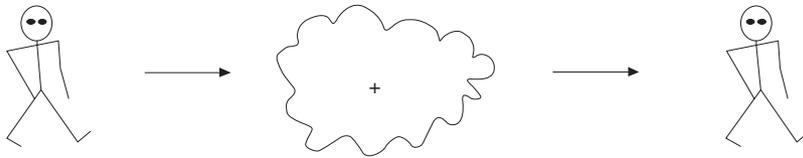
(c) Human-to-animal-to-human via the environment
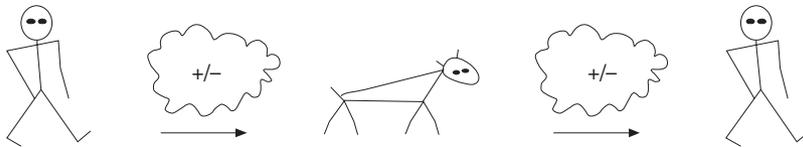
(d) Animal-to-human via the environment
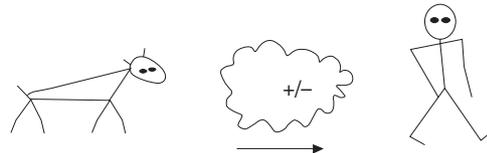
Figure 1 Alternative routes of transmission of diarrhoeal pathogens.

to reach human hosts. In situations where faecal contamination of the domestic environment is high, the majority of cases of endemic disease probably occur either by human-to-human transmission, or from the human-to-human transmission of pathogenic agents which have multiplied in the environment (routes 1a or 1b) (Feachem 1984).

Cholera vibrio differs from other bacteria in its capacity to maintain a reservoir in the environment; it is believed to live in the brackish water of estuaries in association with zooplankton (Drasar & Forrest 1996). It can also multiply in the domestic environment, on warm rice for example (Glass *et al.* 1991). Despite this, cholera relies on human-to-human transmission to maintain outbreaks (Said & Drasar 1996).

In every one of the potential transmission routes sketched in Figure 1, the pathogen has to pass through the environ-

ment. What does 'the environment' mean in this context? The 'F-diagram' of Wagner & Lanoix (1958) reproduced in Figure 2 schematizes the routes that faecal pathogens take through the environment to reach a new host. Once excreted, most of the pathogen progeny usually die. However, some may get onto fingers, into food or fluids and some of these may reach a new host. Flies landing on excreta can carry pathogens to foods or surfaces that are used for food preparation or eating. Human or animal feet that tread in faecal material deposited in the open bring pathogens into the domestic environment, and children playing with, or eating, faecally contaminated earth can ingest pathogens. Excreta can contaminate water sources, and contaminated water can be drunk directly or used in food preparation. For small children, the principal victims of diarrhoeal disease, 'the

Figure 2 The F-diagram.
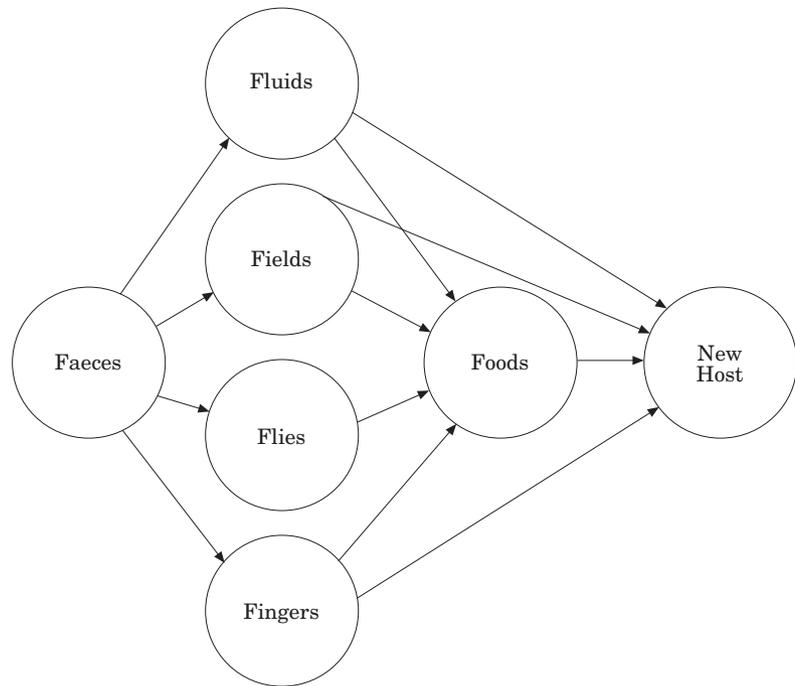
environment' is likely to be the home and its immediate vicinity.

All of the transmission routes shown in the F-diagram (Figure 2) can be blocked by changes in domestic hygiene practice. Improved infrastructure, such as water and excreta disposal facilities, can also contribute to preventing transmission. However, public infrastructure can only be fully effective if employed in conjunction with safe hygiene practices in the home (Cairncross 1990).

Figure 2 allows a distinction to be made between primary and secondary measures to prevent the spread of diarrhoeal pathogens in the environment (Bateman 1994). The four arrows originating from excreta on the left represent the primary routes by which infectious organisms get into the environment. Primary barriers are the practices that stop this happening. These include the disposal of stools in such a way that they are isolated from all future human contact (by the use of latrines, sewers, burying, etc.) and the removal of traces of faecal material from hands after contact with excreta. Secondary barriers are hygiene practices that stop faecal pathogens that have got into the environment in stools or on hands, from multiplying and reaching new hosts. Secondary barriers thus include washing hands before preparing food or eating, and preparing, cooking, storing and

re-heating food in such a way as to avoid pathogen survival and multiplication. They also include protecting water supplies from faecal contaminants and water treatments such as boiling or chlorination. Other secondary barriers include keeping play spaces free of faecal material, preventing children from eating earth, and controlling flies.

Risk practices: the evidence

Though it has been around for over 40 years, lessons can still be learned from the F-diagram. Firstly, it reminds us that diarrhoeal pathogens originate in stools. Secondly, it suggests that if primary barriers to the transmission of faecal pathogens were in place, then secondary barriers would be less important. Interventions to encourage the safe disposal of stools and adequate hand-washing after stool contact should thus pay greater dividends than those that concentrate on the secondary barriers. Is this common-sense conclusion borne out by the epidemiological evidence? In the next sections we evaluate the evidence for the effectiveness of specific practices constituting primary and secondary barriers including safe stool disposal, hand-washing, protecting water, fly control and food hygiene in the light of this hypothesis.

Safe stool disposal

The association between stool disposal and child diarrhoea has been investigated in a number of epidemiological studies. Indiscriminate defaecation near the home or in living areas was found to be associated with an increased incidence of diarrhoea (Stanton & Clemens & 1987; Han & Moe 1990). Baltazar & Solon (1989) found a 64% increase in pathogen-positive diarrhoea in families where children's stools were inadequately disposed. Mertens *et al.* (1992) reported that unsafe stool disposal was associated with a 54% greater diarrhoea risk in Sri Lanka and deduced that if such practices were reduced from 91% to 50% of the population then 12% of diarrhoeal episodes could be prevented. They also concluded that latrine ownership on its own was not enough to prevent disease, but had to be associated with safe stool disposal behaviour. A case-control study of the risk factors for diarrhoea in children under three in Burkina Faso (Traoré *et al.* 1994) reported that the unsafe disposal of child stools (left lying on the ground, thrown on a heap or outside the compound) was associated with a 50% increase in the risk of hospitalization with diarrhoea by comparison with disposal in a latrine (95% confidence interval 1.09–2.06). The risk to be hospitalized with diarrhoea was about a third higher for children who lived in compounds where human stools were observed on the ground. In Nicaragua, families with children using nappies or underclothes were at reduced risk of diarrhoea than those that went without, presumably because less faecal material got into the environment (Gorter *et al.* 1998).

A further source of evidence for the importance of safe stool disposal is the literature on the impact of sanitation programmes in developing countries. If the construction of latrines reduces diarrhoeal disease then the effect is presumably due to the safe disposal of stools. Rahaman *et al.* (1985) found that postneonatal mortality rates were 68% lower in families with latrines than in those without. In Lesotho, Daniels *et al.* (1990) suggested that the presence of a latrine may reduce diarrhoeal infection by a quarter, especially in households with good hygiene practices. An informal consultation held by WHO to review the evidence on water and sanitation-related hygiene recommended that human excreta should be disposed of safely, particularly the faeces of young children, babies and children with diarrhoea (WHO 1993).

Whilst the epidemiological evidence appears to support the suggestion that safe stool disposal is one of the key barriers to the transmission of pathogens, the conclusions of such studies require critical examination. They all shared the difficulty of getting good measures of what people actually do about stool disposal. Finding out about excreta disposal can be very difficult, and interview surveys provide results generally biased towards safer practices (Curtis *et al.* 1993;

Cousens *et al.* 1996; Manun'Ebo *et al.* 1997). Since such studies have not randomised the intervention, they may suffer from confounding. For example, a study claiming to show that unsafe stool disposal is a risk factor for diarrhoeal disease might actually be showing the effect of some other factor, such as wealth, or attitude to hygiene in general, which had ultimately affected both a child's diarrhoea status and the reported hygiene practice of the mother. Studies of the apparent effectiveness of latrines rely on self-selected exposure groups: those who chose to install latrines may have differed in some significant way from those who did not. Though most of the studies discussed here attempt to control for confounding, some factors, such as 'mother's attitude to hygiene' for example, are difficult to control for effectively.

Nevertheless, the consistent nature of the above findings and the force of the biological argument that human stools in the domestic environment are a source of diarrhoeal infection for small children, support the conclusion that the safe disposal of stools should be one of the key measures to prevent diarrhoeal diseases.

Hand washing

Hand washing can interrupt several of the transmission routes in the F-diagram (Figure 2). It is important, however, to distinguish between hand-washing as a primary barrier (to remove faecal matter after contact with stools) and hand-washing as a secondary barrier (before preparing food, handling fluids, feeding, eating). This is because it is not reasonable to expect hand-washing with soap on every conceivable occasion. A research team in Guatemala asked mothers to wash hands after using the latrine, after changing a nappy, before preparing food, before eating, before giving food to the infant, before touching the cooking or drinking water, and before going to bed. They found that this required mothers to wash their hands an average of 32 times, needed an additional 20 l of water and an additional hour per day (Graeff *et al.* 1993). The cost of soap also limits hand-washing by the family in many settings. Hygiene promotion programmes thus have to make a choice as to when hand-washing is most needed for health protection.

Han *et al.* (1986) showed that hands readily became contaminated after defecation, even with the use of toilet paper. Hand washing after stool contact is far from universal, for example in Peru only 11% of people were observed to wash hands after defaecation and the use of soap was still rarer (Huttly *et al.* 1994). The use of bare hands to cleanse the bottom of a child after it has defecated is common practice in much of the world and provides an easy route for faecal pathogens to reach the environment. Observations in Burkina Faso, for example, showed that only 4% of mothers

used soap to wash their hands after using them to clean a child's bottom (Curtis *et al.* 1993).

There are a number of epidemiological studies on hand washing which claim substantial reductions in diarrhoeal morbidity. However, few make any distinction between hand washing as a primary or secondary barrier. Wilson *et al.* (1991) reported a reduction in diarrhoea incidence of 89% through the promotion of hand washing in four different circumstances, including after defaecation, in an Indonesian village. Han and Hlaing (1989) claimed a 30% reduction in diarrhoea morbidity in Burma through encouraging regular hand-washing with soap. An intervention study by Khan (1982) reduced the incidence of shigellosis by 84% and other diarrhoeas by 37% through hand-washing with soap after defecation and before ingesting food. Many studies have been carried out in Bangladesh, where Clemens and Stanton (1987) and Alam *et al.* (1989) suggested that hand-washing was one of the factors which lowered the incidence of diarrhoea in interventions. Hoque *et al.* (1996) found a reduction in diarrhoea prevalence associated with lower numbers of faecal colony-forming bacteria on hands, six years after an intervention to improve water, sanitation and hygiene in Bangladesh. Pinfold *et al.* (1996) found a significant reduction in hand contamination and in diarrhoeal disease from an intervention to promote hand-washing and dishwashing in Thailand. Shahid *et al.* (1996) claim to have reduced diarrhoea incidence by almost two thirds through the provision of soap for hand-washing before eating or handling food and after urination and defaecaction. The presence of soap in households in a refugee camp in Malawi was associated with 27% fewer episodes of diarrhoea (Peterson *et al.* 1998).

Water availability is likely to have an impact on the frequency of hand washing. When water is further than about a kilometre from the home, mothers tend to restrict their use of water for hand-washing. On the other hand, when water is freely available at close range, hand-washing becomes more frequent (Cairncross 1997). This may provide at least a partial explanation for why interventions to improve water supply have been shown to have a health benefit in a number of settings (see below).

Boot and Cairncross (1993) suggest that the agent of hand-washing may be less important than the time spent cleaning hands, as some effort is required to remove adhered particles. Kaltenthaler *et al.* (1991) propose that unless the price or availability of soap is a major obstacle, it is probably easiest to promote hand-washing with soap. The promotion of hand washing with soap is an intervention that appears to be both highly effective, reducing diarrhoea incidence by between 27 and 89%, and feasible. To prevent stool pathogens from gaining access to the domestic environment, efforts should concentrate on hand-washing after stool contact, especially after defaecation or after cleaning up a child.

Preventing transmission through water

The F-diagram shows how diarrhoeal pathogens use water as a route to reach new hosts. Primary barriers to this transmission route include preventing contamination of water by faecal material, both at source and in transit. Secondary barriers remove pathogens once they have got into water supplies, and include methods of purification both at source and in the home. Fluids can also become contaminated by a failure of other barriers, via unwashed fingers, for example. Preventing transmission through water thus requires action in both the public domain and in the sphere of domestic hygiene (Cairncross *et al.* 1996).

Until the late 1980s, the assumption that poor quality drinking water was the primary source of diarrhoeal diseases was widespread. However, expenditure on improving the quantity of water available may have more impact on the common endemic diarrhoeas in developing countries than ensuring that supplies meet high standards of purity (Cairncross 1990). This is because accessible, plentiful supplies of water facilitate and encourage better hygiene in general, and more hand-washing in particular. Esrey *et al.* (1985 and 1991) attempted to distinguish the importance of water quantity from water quality in a review of 67 studies in 28 countries in 1986, and a further 17 studies in 1991, and concluded that improvements in water availability were probably more important than in water quality. Their conclusions are supported by findings from Nicaragua, where children from homes with poor water availability had a 34% higher rate of diarrhoea (Gorter *et al.* 1991). When all other sources of diarrhoeal pathogens are eliminated, via effective sanitation, then water quality becomes relatively more important (Vanderslice & Briscoe 1995), as it is in industrialized countries.

Of course, water that is free of pathogenic agents at the source may become contaminated with faecal material in the private domain as it is carried home, stored and used. In Sri Lanka, for example, only about 5% of ground water samples contained faecal indicator bacteria, but 50% of samples were contaminated during or after being drawn. However, there was no direct association between this bacterial contamination of drinking water and diarrhoeal disease (Mertens *et al.* 1990). Kirchhoff *et al.* (1985) found that heavily contaminated water in the home and chlorination to remove it had no effect on diarrhoea incidence, but Yeager (1991) found that diarrhoea incidence was lower in households where water was stored in a container with a tap in Lima, Peru. It is common in hygiene promotion programmes to promote the boiling or disinfection of water for drinking, but boiling water is expensive (Gilman & Skillicorn 1985), and there is little evidence that such practices are useful.

Though abundant water may have more impact on health

than pure water, the prevention of the faecal contamination of public water at source is a vital primary barrier to pathogen transmission. Mertens *et al*. (1990) and Vanderslice and Briscoe (1991) point out that water contamination at source may represent a greater hazard than contamination in the home. This is because new pathogens coming from outside the home may have more impact on health than pathogens that are already circulating among family members. Maintaining water supplies free of contamination from faeces is also important for the prevention of epidemics of diseases such as typhoid and cholera. Eliminating the transmission of diarrhoeal pathogens in water supplies may also reduce the virulence of microbial strains (Ewald 1991). The breakdown of water purification for large populations during war, in refugee camps, during flooding or other disasters may set off epidemics of severe disease. Even during such outbreaks, transmission is maintained through poor hygiene practice, especially the unsafe disposal of stools and insufficient hand-washing. Safe hygiene promotion is therefore no less a priority in potentially epidemic conditions than in the much commoner context of endemic disease transmission.

Keeping water supplies free of faecal contamination at source and in transit is clearly important for preventing diarrhoeal disease. However, the best way to do this may be to ensure that faecal material is not released into the environment and so does not get into water. This again requires safe stool disposal and effective hand-washing after stool contact.

Flies

Flies are commonly thought of as a source of diarrhoeal disease. Flies have been shown to carry pathogens on their feet, in their faeces and in the digestive juices which they regurgitate onto foods (Oo Khin Nwe *et al*. 1989; Esrey 1991). A number of studies have linked flies to diarrhoea incidence. Cohen *et al*. (1991) demonstrated a significant reduction in diarrhoea incidence amongst soldiers with yeast-baited fly traps in Israel. A fly control programme using insecticide in villages in Pakistan with heavy domestic animal and human faecal contamination reported a 23% reduction in the incidence of diarrhoeal disease; however, baited traps were ineffective (Chavasse *et al*. 1999). Emerson *et al*. (1999) found about 25% less diarrhoea in villages sprayed with delta-methrin than in controls, but pointed out that insecticiding is not likely to be sustainable or cost-effective.

Though fly control might be desirable in settings where flies form a major nuisance and where there is substantial faecal contamination of the environment, it is not yet achievable. The logic of the F-diagram again leads to the conclusion that the primary need is to prevent flies gaining access to stools in the first place. Common house flies (*Musca*

domestica) and the related *Musca sorbens* may breed in scattered human faeces, but only rarely do they breed in latrines (Chavasse 1998). Safe stool disposal in latrines, sewers, or by burying thus has two benefits. It reduces opportunities for flies to breed and it removes the source of fly transported pathogens.

Food-borne transmission of diarrhoeal diseases

The F-diagram shows food as a possible link in the chain of transmission of diarrhoeal pathogens from stools to new host. Potential interventions to break this chain include the secondary barriers of hand-washing before food preparation and handling, safe food storage, avoidance of contaminated foods, adequate cooking and reheating, cleaning kitchens, surfaces and utensils, and hand washing before eating or feeding children. Food is potentially important for disease transmission because pathogens on food have an easy route into the digestive system, and because some gastro-enteric pathogens can multiply on food and thereby increase the dose ingested.

Esrey and Feachem (1989) reviewed 70 studies related to the impact of food hygiene on diarrhoea morbidity and mortality. They found that there was evidence for the contamination of foods with agents including *Salmonella* spp., *E. coli* and *Klebsiella*. They found studies that reported the presence of faecal indicator bacteria in food. A number of studies also showed that indicator and some pathogenic bacteria could multiply during the storage of food, in particular in weaning foods. Though these findings indicated that it was highly plausible, from a biological point of view, that food contamination was linked to diarrhoea incidence, they found that evidence for the impact of safer food hygiene in developing countries was sparse and inconclusive. Several studies suggested that improvements in food hygiene had led to reductions in diarrhoeal disease, but few could conclusively demonstrate that better food hygiene had been the cause of the improvement. Indeed, a number of studies that had specifically looked for links between bacterial contamination and diarrhoea were unable to show any significant association.

More recently Motarjemi *et al*. (1993) reviewed the arguments that weaning foods are a dangerous source of diarrhoeal pathogens for children and concluded that interventions to improve food hygiene should be a priority for diarrhoeal disease control. However, their review was based mostly on the biological plausibility of the argument, did not distinguish between illness caused by food spoilage toxins and that caused by diarrhoeal pathogens, and did not address the concerns of Esrey and Feachem about the paucity and limitations of the epidemiological evidence.

Seasonal patterns of diarrhoeal disease give a hint of

pathogen multiplication in food. Many studies have shown a peak of bacterial diarrhoeal disease in the hottest season (e.g. Projet Diarrhées 1994). One explanation for this could be that pathogenic bacteria can multiply more readily on stored food in warmer temperatures (route 1b) (Cairncross 1979).

If there is little convincing epidemiological evidence for the importance of food hygiene in developing countries, this may be because other sources of pathogens are more important. It may alternatively be due to the methodological difficulty of such studies, requiring, as they do, a combination of expertise in epidemiology, food microbiology and behavioural research.

In the absence of conclusive evidence, further studies are needed to clarify this issue. In the meantime, what can we conclude about the risk practices that we should target in our efforts to prevent diarrhoeal disease? First, in the public domain foods should be protected from contamination before they come into the home, especially from food handlers' stools. Second, since food contamination with diarrhoeal pathogens in the domestic domain can only result if stools are inadequately disposed of, or if hands are inadequately washed after stool contact, hand washing and stool disposal are, yet again, key to diarrhoea prevention.

Bottle-feeding

A further issue associated with child feeding that has been the focus of much work is the bottle-feeding of infants. Many studies in developing countries have shown bottle-feeding to be a major risk factor for diarrhoeal disease (see the review by DeZoysa *et al*. 1991). Breast-feeding not only protects against infection through better nutrition and the supply of maternal antibodies to the infant, but also reduces the contact that the child has with milk and bottles which may have become contaminated with pathogenic agents. These pathogenic agents come from faecal material, so better hand-washing after stool contact and safer stool disposal are of especial importance for parents who bottle-feed, for whatever reason.

Animal faeces as a source of human infection

This review has so far considered only the prevention of the transmission of pathogenic agents originating in human faeces (routes 1a and 1b). Animal faeces have been shown to harbour a number of organisms that may also be infective to humans such as certain *Salmonellae*, *Campylobacter* and *Cryptosporidium*. Animal dung in the environment also encourages fly proliferation. There are a few studies in developing countries that have shown an association between animal faeces and diarrhoea. For example, Bukenya and Nkwolo (1991) found that children in houses which kept pigs

had 69% greater diarrhoea incidence than houses without. However, Huttly *et al*. (1987) found that the presence of animals inside the house was associated with a reduced risk of childhood diarrhoea. Other studies relate to specific pathogens; two studies reported possible links between the presence of chickens in the home environment and an increased isolation of *Campylobacter* in children (Grados *et al*. 1988; Georges-Courbot *et al*. 1990). Mølbak *et al*. (1990) found that young children in households with pigs were 2.5 times more likely to suffer from *Cryptosporidium* diarrhoea in Guinea-Bissau.

Whilst animal faeces in food or water is a matter of current concern in developed countries, they may be of less relative importance in areas where human faeces are disposed of inadequately. Though similar pathogens can be identified in animals and man, there may be less cross-infection than previously thought, as recent genotyping studies suggest (Kariuki *et al*. 1999). Animals may carry some pathogens infective to man, and their faeces may encourage flies; however, pigs and dogs may also protect human health by eating faeces. Further study of this issue is required. In the meantime, human faeces, even of apparently healthy people, are likely to contain more human pathogens than animal faeces and should therefore be targeted as the first priority, unless we have evidence to the contrary.

Multiple routes of infection

Though it is important to evaluate the individual importance of different potential transmission routes, clearly an intervention to improve one type of hygiene behaviour may be useless if children still receive infective doses of pathogens via other routes. There is controversy as to whether the risk of disease is reduced proportionately by eliminating single transmission routes if other routes remain (Briscoe 1984; Cairncross 1987). Human pathogens also have myriad strategies for getting from one host to another, and some transmission routes are more important for some diarrhoeal pathogens than others. *Shigella*, for example, is easily transmitted on hands (Khan 1982) whilst other pathogens cannot tolerate such inhospitable surfaces for long enough to infect new hosts. This may imply that hygiene promotion efforts should be tailored to local pathogen patterns. Though impractical at present, the development of cheap and simple pathogen detection techniques may facilitate such approaches in the future.

A number of studies have concluded that several interventions at a time are more effective than one alone. Alam *et al*. (1989) demonstrated that a combination of clean water, absence of faeces in the yard and hand-washing resulted in 40% less diarrhoea than when one practice alone was observed. Haggerty *et al*. (1994) reported an 11% reduction

in diarrhoea reporting in villages where hand washing and the disposal of human and animal faeces were promoted. By removing human stools from the domestic environment and hand-washing after stool contact, the source of the diarrhoeal pathogens is removed. If this is achieved, other hygiene practices become irrelevant for diarrhoea transmission. Families may still be at risk from contaminated materials that are brought in to the household from outside and need to adopt a variety of hygiene practices. However, in the real world, where 'perfect protection' is unrealistic, practitioners have to make hard choices, and target high-risk practices first.

Conclusions

Much evidence in the understanding of the diarrhoeal diseases and their transmission is still missing. Not enough is known about the relative importance of transmission from animals or through food, particularly in developing countries. The role of host resistance and factors that make diarrhoeal agents pathogenic for some and not others, including issues of infectious dose, need further study. More infectious gastroenteric pathogens remain to be discovered, and new serotypes and species will certainly emerge, since the setting–up of barriers creates selection pressure for the evolution of pathogens that can evade these defences.

Nevertheless, public health specialists have to operate in the real world, which implies making decisions based on the best available evidence. Hygiene promotion programmes are to be clearly formulated and demonstrably effective, hard choices have to be made about which behaviours to target. Employing too many messages confuses and exhausts the attention and goodwill of target populations and so wastes precious public health resources. Practitioners cannot opt out of making a considered diagnosis of the one or two practices most likely to be sources of risk. This needs to be done in the light of the biological and epidemiological evidence and on the basis of a careful diagnosis of behaviour (Almedom *et al*. 1997; Curtis *et al*. 1997).

Can the evidence of this review be distilled into a simple set of principles which can be used by those planning programmes to prevent diarrhoeal diseases? By combining the biological reasoning of the F-diagram and the epidemiological findings from observational and intervention studies, it seems reasonable to conclude that the hygiene practices to prioritize should be those that constitute the primary barriers to pathogen transmission. These are the practices that prevent faecal material from entering the domestic environment of the susceptible child. Human stools should be regarded as public enemy number one.

The implications for action lie in two domains. In the public domain the process of acquisition of the means of excreta disposal must be given higher priority. New solutions are needed for the estimated 2 billion people that still need sanitary facilities, and the process of acquisition of latrines and sewers must be facilitated and supported both legislatively and financially. Public authorities must continue to be responsible for the provision of water that is free of faecal contaminants. In the private domain hygiene promotion should focus on the elimination of human stools from the domestic environment and effective hand-washing after stool contact.

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