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Flock Health Indicators and *Campylobacter* spp. in Commercial Housed Broilers Reared in Great Britain▽

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This study investigated the relationship between flock health and *Campylobacter* infection of housed commercial broilers in Great Britain. Thirty ceca were collected at slaughter from batches of broilers from 789 flocks, at either full or partial depopulation, between December 2003 and March 2006 and examined individually for *Campylobacter* by direct plating onto selective media. Management and health data were collected from each flock and included information on mortality or culling during rearing, the number of birds rejected for infectious or noninfectious causes at slaughter, the proportion of birds with digital dermatitis (also termed hock burn), and other general characteristics of the flock. *Campylobacter* spp. were isolated from 280 (35%) flocks. The relationship between bird health and welfare and *Campylobacter* status of flocks was assessed using random-effects logistic regression models, adjusting for region, month, year, and rearing regime. *Campylobacter*-positive batches of ceca were associated with higher levels of rejection due to infection (odds ratio [OR], 1.5; 95% confidence interval [$CI_{95\%}$], 0.98 to 2.30) and digital dermatitis (OR, 2.08; $CI_{95\%}$, 1.20 to 3.61). Furthermore, higher levels of these conditions were also associated with the highest-level category of within-flock *Campylobacter* prevalence (70 to 100%). These results could indicate that improving health and welfare may also reduce *Campylobacter* in broilers.

Campylobacter spp. are one of the most common bacterial causes of human enteritis in industrialized countries, according to the World Health Organization (http://www.who.int/mediacentre/factsheets/fs255/en/index.html). Chicken meat is frequently contaminated with *Campylobacter* (12, 26) and is a major source of human infection (1, 13). Reducing the number of contaminated carcasses would result in a reduction of food poisoning incidents. One way of achieving this would be to reduce the number of flocks carrying this pathogen, preslaughter (2).

Campylobacter is generally regarded as a commensal in broiler chickens (21), but it may be possible to exclude it from housed flocks by the use of effective biosecurity, as studies in northern Europe and the United Kingdom have shown (2). However, this can be difficult to sustain in the long term (2), although monitoring may create incentives and promote consistent application of biosecurity. Other interventions may be necessary to support biosecurity (14), and one approach could be to improve our understanding of factors affecting the resistance of the birds to *Campylobacter* colonization. There is usually a commensal relationship between *Campylobacter* and chickens, but the bacteria have been associated with vibrionic hepatitis in these animals (28, 31). Preliminary work by the Bristol Group compared two farms in one company over six flock cycles. The farm with a high prevalence of *Campylobacter*-positive birds (97%) had higher levels of digital dermatitis and rejections at slaughter than the one where only 1.4% of birds were *Campylobacter* positive over the same time period (2). Recent work in Norway reported an association between *Campylobacter* and *Clostridium perfringens*, which causes necrotic enteritis in broilers (24). Such studies could suggest that a reasonable hypothesis to explore would be that *Campylobacter* may be found more frequently in birds compromised by poor health. To examine this, we investigated the association between the *Campylobacter* status of batches of commercial broilers, which had not previously been depopulated, and their health and welfare status, as classified during the life of the flock and at slaughter.

MATERIALS AND METHODS

Study design and study population. The study population originated from flocks reared on farms supplying three integrated poultry companies in Great Britain (GB) between December 2003 and March 2006. Information on the total number of commercial poultry premises rearing broiler chickens indoors was obtained from the GB Poultry Register (10), and the participating farms comprised ~13% of those producing housed broilers in GB. All birds were reared indoors, and samples were collected only from batches removed at first full or partial depopulation from a flock to avoid the possible influence of thinning, a major risk factor for flock infection with *Campylobacter* (15). Only one batch of birds from each flock was examined. Fifteen percent of flocks were fed a maize-based rather than a standard wheat-based diet.

Determination of *Campylobacter* status of the batch. From each slaughter batch (minimum size, 828; mean size, 6,966; maximum size, 59,388), 30 intact pairs of ceca were collected from birds immediately after evisceration except for very few flocks from which only 28 to 29 were examined. Ceca were bagged

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TABLE 1. Description of bird health-related conditions recorded for flocks

Condition[a]	Definition	Cause(s)[b]
Skin lesions	Inflammation or lesions on skin	I, O
Septicemia	Extensive discoloration (dark red/brown) of bird	I
Pericarditis	Inflammation, discoloration, and/or adhesions of heart tissue	I
Subcutaneous pus	Bulged skin area with pus on inspection	I, O
Perosis and green leg	Green/blue discoloration of leg areas	I, O
Chronic respiratory disease	Inflammation on lung tissue sometimes accompanied by discoloration/adhesions	I
Enlarged liver	Abnormal liver size	I
Peritonitis	Inflammation, discoloration, and/or adhesions of gut cavity/peritoneum tissue	I
Perihepatitis	Inflammation, discoloration, and/or adhesions of liver tissue	I
Ascites	Increased fluid in abdomen	O
Runts	Severe lack of muscle tissue and/or underweight bird	O
Digital dermatitis (hock burn)	Black/brown discoloration accompanied by ulceration of lower-leg (tarsometatarsus) area	O

[a] Possible causes are described in reference 23.
[b] I, infection; O, other.

aseptically and sent by courier to the laboratory. The dates for collection and examination of the ceca were recorded; intact ceca were held at 4°C after collection and examined within 4 days. Cecal contents from each pair were sampled by immersing a sterile swab (Medical Wire and Equipment, Corsham, Wiltshire, United Kingdom) into the cecum, which was opened by an incision at the blind end. The swab was streaked onto modified charcoal cefoperazone deoxycholate agar (mCCDA) plates (Oxoid CM739 with SR155 supplement), which were incubated at 37°C for 48 h in a microaerobic atmosphere (4). The atmosphere was achieved by evacuating the air from gas jars (Don Whitley Scientific Ltd., West Yorkshire, United Kingdom; Launch Diagnostics Ltd., Kent, United Kingdom) and replacing it with a gas mixture that resulted in an atmosphere comprising 5 to 6% O_2, 3 to 7% CO_2, and 7% H_2 in a balance of nitrogen. After incubation, mCCDA plates were examined for the presence of typical *Campylobacter* colonies (grayish, flat, and moist colonies with a tendency to spread). One to three typical colonies per sample were subcultured onto duplicate plates of Columbia blood agar with 5% (vol/vol) defibrinated horse blood (Oxoid Ltd.) and confirmed as *Campylobacter* spp. by using standard tests (6). Quality control assessment of this method has shown that it is capable of detecting >100 *Campylobacter* g^{-1} feces.

Two outcome measures of *Campylobacter* status were used in the analyses: (i) a binary variable assigning status to each batch as positive (defined as one or more positive ceca) or negative, and (ii) an ordinal categorical variable describing the within-flock prevalence as 0, 0.1 to 20.9, 21 to 69.9, and/or 70 to 100% *Campylobacter*-positive ceca of those tested.

In one experiment, we determined the numbers of campylobacters after 24, 48, and 96 h at 4°C to assess the possible effect of storage of intact ceca prior to examination for campylobacters. Thirty-six ceca (12 from each of three flocks) were collected at the abattoir and transported to the laboratory in a cool box. Ceca were surface sterilized, and 1 g of cecal material was removed from each. Decimal dilutions were prepared in maximum recovery diluent (Oxoid CM733), and 500-μl volumes were spread onto duplicate mCCDA plates. After microaerobic incubation, typical campylobacter colonies were counted to determine the number of campylobacters per gram of cecal material, and three colonies per sample were confirmed as *Campylobacter*, as described above. The remainder of each cecum was stored aerobically at 4°C in a sterile petri dish sealed with parafilm (Whatman Ltd., Banbury, United Kingdom). The number of *Campylobacter* in the cecal contents was determined after 24, 48, and 96 h storage. Differences in the numbers of campylobacters in cecal contents, before and after storage, were evaluated using a paired Student *t* test on the $\log_{10}$ of the counts.

Recording of flock health indicators. Postmortem inspectors reject carcasses from the poultry processing line when deemed unfit for the food chain based on a variety of bird disease/welfare indicators by using defined criteria (Table 1). Carcasses were taken off the line either pre- or postevisceration, and if they were removed for one condition, they were not assessed for others. Carcasses were also inspected for digital dermatitis but were left on the processing line regardless of the outcome. The reasons for rejection were classified as infectious or noninfectious according to likely cause, assessed in collaboration with a panel of industry representatives, which included veterinarians.

If a bird was rejected due to pathology that could be caused by both an infectious agent and/or a noninfectious cause, it was coded as "yes" for both variables. The within-batch *Campylobacter* prevalence of rejected birds did not follow a normal distribution, and a series of binary variables were created by the expert panel to assign the prevalence to either a "lower" or a "higher" category. The cutoff points between the lower and higher prevalence categories were 1% for total number of rejections, 0.5% for rejections due to infectious disease, 0.5% for rejections due to noninfectious pathology, 2% for digital dermatitis, and 3% for mortality or culling during rearing. Data checking and consistency checks were carried out prior to statistical analyses. Any outliers were checked for transposition errors, and if correct, queried with the original record made by postmortem inspectors to ensure that the submitted data were correct.

Recording of other data. Other variables relating to the flocks were obtained. Rearing regimes were defined as standard if the birds were of the Ross or Cobb breed and reared according to standard procedures and as nonstandard if they were Hubbard, Ross, or Cobb birds and fed a maize-based diet. The number of birds in the broiler house of origin, age of the flock at slaughter, and the month and year of sampling were recorded. Postcode district information was provided to locate the farms in the study. Each district covers an area of ~30 km^2 (http://www.graticule.com/data/postcode/index.php). The grid references for the postcode of the district centroids were obtained and sent to the Climate Production Department of the United Kingdom Met Office, which assigned them to the standard weather districts, namely, East Anglia, eastern and northeastern England, northwestern England and northern Wales, southeastern and central England, southwestern England and southern Wales, Midlands, and western Scotland. For the analysis, the regions were collated into three main regions: South (southern and central England, southwestern England and southern Wales S), Central (eastern England, East Anglia, Midlands), and North (eastern and northeastern England, northwestern England and northern Wales, Scotland).

Statistical analysis. The flock health and welfare indicators and the *Campylobacter* status of the flocks were described for each season to adjust for potential seasonal trends between the variables, as data from other countries have associated season with *Campylobacter* prevalence in broiler flocks (5, 29).

Associations between *Campylobacter*-positive batches and flock health indicators. The method of collecting indicator variables was likely to cause dependencies between them, and to avoid violating the models' assumption of independence between variables, a stepwise approach using multiple models was applied. Initially, individual risk factors and potential confounders that were likely to bias and influence the associations between *Campylobacter* and flock health indicators were identified and comprised a "base model." A random-effects logistic regression model was used to account for the clustering of batches for each farm. The health indicators "rejections due to infections" and "rejections due to noninfectious causes" were initially included in a model together with the following potential confounding variables: "rearing regime," "month," "year," "region," "age at slaughter," and "number of chickens in house during rearing." The remaining health indicator "total rejections" was not included, because the other previously mentioned health indicators were nested within this variable and inclusion of all variables would have violated the independence assumption of the model. The last health indicator, "digital dermatitis," was not included in the construction of the base model, because the large proportion (20%) of missing values would have affected the accuracy of the finished model. Stepwise removal of nonsignificant ($P > 0.05$) variables resulted in a model with only significant variables. The remaining health indicators were then removed, and the model, which now consisted only of confounders, was considered our "base model." These variables were not explored further due to the restricted number of

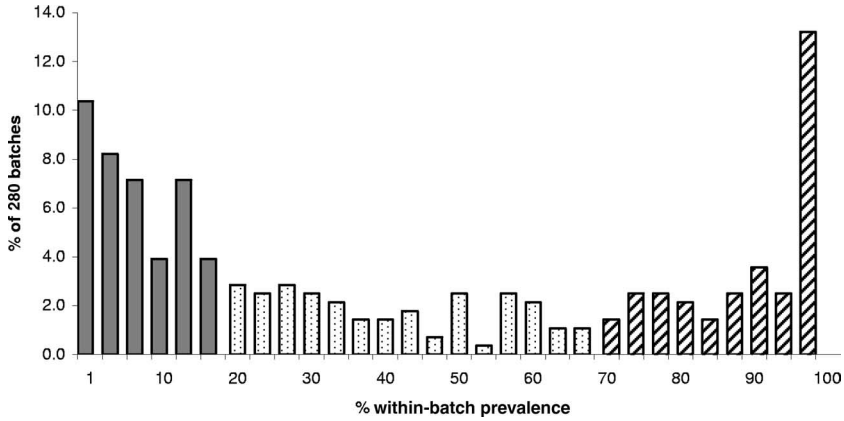

FIG. 1. The within-batch prevalence of *Campylobacter* in 280 broiler batches in GB. Thirty ceca from each batch were examined. Batches with 1 to 20% positive birds were assigned to category I (gray bars), those with 20.1 to 70% were in category II (dotted bars), and those with >70% positive ceca were in category III (striped bars).

observations but were included only to adjust associations and *P* values between *Campylobacter* and the health indicators.

Each component of the flock health/welfare indicators was added to a separate "base model," yielding five multivariable models. The strength of the identified associations was measured using odds ratios (OR), where an OR of >1 indicates an increased risk and an OR of <1 indicates a reduced risk. If the 95% confidence interval of the OR included 1, the *P* value was >0.05. Inclusion of the base model ensured that each OR and *P* value was adjusted for the confounding effect of these variables, and thus, the estimates of association obtained from the multivariable models were more precise than those observed by the univariable analyses.

Associations between flock health indicators and the prevalence of *Campylobacter* within the flock. Associations between each indicator and the categories of *Campylobacter* prevalence within the flock were assessed using the base model of confounders described above. Random-effects logistic regression models including farm as the random effect and *Campylobacter* levels as factor effects were fitted with each of the flock health indicators of interest as a binary outcome variable in Intercooled STATA 9.1 (StataCorp, College Station, TX). This provided an adjusted OR for the association between each category of within-flock prevalence and health indicators.

RESULTS

Campylobacter spp. were isolated from 280 (35%) of 789 batches of broilers originating from 214 farms located throughout England, Scotland, and Wales. Thus, 65% of the flocks were determined to be *Campylobacter*-negative, using our surveillance techniques, with these nonthinned birds. A total of 40.7% of the positive flocks had a within-flock *Campylobacter* prevalence between 1 and 20% (category I), 27.9% had a prevalence between 20.1 and 70% (category II), and 30.8% had a prevalence of >70% positive ceca (category III) (Fig. 1). All 30 ceca were *Campylobacter* positive in 37 (13.2%) of the positive flocks. Storage of ceca at 4°C for 24, 48, or 96 h had no significant impact ($t = -0.886$; $P = 0.382$) on the numbers of *Campylobacter* in the ceca according to a general linear modeling analysis, which accounted for flock variation.

The raw data were presented by seasons; an increased number of rejections due to infections were observed in winter and spring compared to in summer and autumn (Table 2). The percentages of mortality/culling during rearing and of digital dermatitis were, however, highest in summer and autumn. Furthermore, the data were described by the distribution of within-batch prevalence for the different health and welfare indicators (Table 3). To adjust the raw data for other variables that could influence the relationship between *Campylobacter* and bird health, the "base model" was created. The base model consisted of placement year and month, regime, and geograph-

TABLE 2. The average percentage of birds assigned to each health indicator in *Campylobacter*-positive and -negative flocks, stratified by season

Seasons	Health indicator[a]	No. of flocks[b]	Mean % of birds in indicated batch		
			All	*Campylobacter* positive	*Campylobacter* negative
Summer and autumn	Total Rej.	326	1.34	1.27	1.40
	Rej. due to infections	318	0.58	0.57	0.60
	Rej. due to noninfectious causes	323	0.63	0.58	0.67
	Mortality/culling during rearing	274	3.31	2.92	3.63
	Digital dermatitis	278	14.20	12.96	15.09
Winter and spring	Total Rej.	418	1.41	1.43	1.36
	Rej. due to infections	397	0.71	0.72	0.70
	Rej. due to noninfectious causes	410	0.65	0.60	0.68
	Mortality/culling during rearing	286	3.00	2.55	3.11
	Digital dermatitis	354	12.70	10.02	13.90

[a] Rej., rejections.
[b] Missing values were omitted.

TABLE 3. Distribution of within-flock *Campylobacter* prevalence at different levels of health in 789 broiler batches

Health indicator	% of batch	No. of flocks[a]	% of positive batches with *Campylobacter* prevalence of (%):			
			0	1–20	21–69	70–100
Rejections due to infections	<0.5	365	64.4	16.2	10.7	8.8
	≥0.5	350	64.6	12.9	7.4	15.1
Rejections due to noninfectious causes	<0.5	402	63.2	16.9	10.5	9.5
	≥0.5	331	66.2	11.2	8.1	14.5
Total rejections	<1	305	62.0	17.4	11.5	9.2
	≥1	439	65.8	12.5	8.2	13.4
Mortality/culling during rearing	<3	294	58.2	17.7	14.3	9.9
	≥3	266	71.1	11.3	6.8	10.9
Digital dermatitis	<2	152	63.8	8.6	13.2	14.5
	≥2	480	64.4	15.8	8.5	11.3

[a] Missing values were omitted.

ical region and was used to adjust all associations between health parameters and the *Campylobacter* status of a batch.

A high level of digital dermatitis in a flock was associated with a *Campylobacter*-positive status (OR, 2.1; $P = 0.01$) (Table 4). Thus, a flock was twice as likely to be *Campylobacter* positive when the incidence of dermatitis was ≥2% as when this condition was less frequently observed. Furthermore, an association was found between broiler batches with a high prevalence of *Campylobacter* positivity (category III) and increased levels of dermatitis (OR, 2.7; $P = 0.05$) (Table 5). Together these findings indicate that if digital dermatitis was present in ≥2% of the batch of birds examined, not only were such flocks more likely to carry *Campylobacter*, they were also more likely to have a high proportion of positive birds.

A weaker association was found between flocks having higher percentages of rejections due to infections and their *Campylobacter* status (OR, 1.5; $P = 0.06$) (Table 4). However, this was considered relevant, because such flocks were also more likely to have a high within-flock prevalence of *Campylobacter* (OR, 3.2; $P = 0.01$) than those with fewer infections (Table 5). We found no evidence that the percentage of total rejections, the percentage of rejections due to noninfectious causes, or the mortality/culling of birds during rearing was associated with either the *Campylobacter* status of the batch or the within-flock prevalence (Table 4 and 5).

DISCUSSION

This study demonstrates that it is possible with GB-reared housed broilers to keep the majority (65%) of flocks *Campylobacter* free until first depopulation. However, the principal purpose of the work was to test the hypothesis that the presence of *Campylobacter* in housed broilers is associated with indicators of poor flock health, such as increased rates of infectious disease and digital dermatitis. We identified an association between a high within-batch prevalence of *Campylobacter* and high levels of rejections due infections. There was also an association between increased levels of digital dermatitis in flocks and high *Campylobacter* prevalence. To our knowledge, it is the first time that a relationship between the level of *Campylobacter* colonization and the levels of digital dermatitis/rejections due to infectious disease in broilers reared under commercial conditions has been demonstrated.

There are a number of possible reasons for the above-mentioned associations. They could be related to poor biosecurity and/or common environmental effects. Higher within-flock prevalence of *Campylobacter* could be due to early infection and/or increased transmission of the bacteria within a flock. More frequent breaches of biosecurity could introduce an infection earlier, and inadequate biosecurity has also been associated with other aspects of husbandry, possibly exacerbating infectious diseases in general, of which *Campylobacter* could be one (27). Digital dermatitis can also be exacerbated by husbandry factors, including poor ventilation (21), and this could result in litter conditions more likely to allow campylobacters to survive (20).

There may be a causal link in that *Campylobacter* infection could become more easily established and/or spread more rapidly in birds suffering from infectious diseases, like avian pathogenic *Escherichia coli*, and/or painful dermatitis. Such a link might occur because stressed animals, and infected ones, can have raised neurotransmitter levels (3, 8, 18). In vitro, it has been shown that *Campylobacter* spp. achieve higher growth

TABLE 4. Associations between *Campylobacter* status and health indicators in 789 broiler batches[a]

Health indicator[b]	Prevalence level (% of batch)	No. of flocks[c]	OR	95% CI	*P* value
Rejections due to infections	Lower (<0.5)	365			
	Higher (≥0.5)	350	1.5	1.0–2.3	0.063
Rejections with noninfectious causes	Lower (<0.5)	402			
	Higher (≥0.5)	331	0.9	0.5–1.4	0.531
Total rejections	Lower (<1)	305			
	Higher (≥1)	439	0.9	0.6–1.4	0.672
Mortality/culling during rearing	Lower (<3)	294			
	Higher (≥3)	266	1.3	0.7–2.4	0.399
Digital dermatitis	Lower (<2)	152			
	Higher (≥2)	480	2.1	1.2–3.6	0.009

[a] The base model included placement year and month, regime, and geographical region and was used to adjust all associations between health parameters and the *Campylobacter* status of a batch. CI, confidence interval.
[b] Added to base model individually.
[c] Missing values were omitted.

TABLE 5. Associations between higher levels of health indicators and the within-batch prevalence of *Campylobacter* spp. in 789 broiler batches[a]

Health indicator[b]	Values for indicated *Campylobacter* prevalence categories (%)[c]					
	1–20		20.1–70		70.1–100	
	OR ($CI_{95\%}$)	*P* value	OR ($CI_{95\%}$)	*P* value	OR ($CI_{95\%}$)	*P* value
Rejections due to infections	1.1 (0.6–2.2)	0.755	1.4 (0.6–3.3)	0.432	3.2 (1.3–8.0)	0.012
Rejections due to noninfectious causes	0.6 (0.3–1.3)	0.229	1.1 (0.4–3.1)	0.807	2.0 (0.9–4.7)	0.102
Total rejections	1.1 (0.7–2.1)	0.795	1.3 (0.6–2.8)	0.533	1.8 (0.8–3.9)	0.156
Mortality/culling during rearing	0.7 (0.3–1.6)	0.436	1.1 (0.4–2.8)	0.833	2.1 (0.8–5.9)	0.147
Digital dermatitis	1.4 (0.6–3.5)	0.465	0.6 (0.2–1.7)	0.340	2.7 (1.0–7.2)	0.052

[a] The base model included region, year, month, and rearing regime. Missing values were omitted from the analysis and table.
[b] Added to the base model individually.
[c] The baseline for OR ($CI_{95\%}$) values was the numbers of *Campylobacter*-negative flocks. $CI_{95\%}$, 95% confidence interval.

rates and upregulate motility when grown in the presence of the neurotransmitter noradrenaline (9). Thus, stress- and/or infection-associated release of noradrenaline could cause increased shedding of campylobacters by birds, resulting in more-rapid spread of the bacteria and, thus, a higher prevalence at testing.

Other situations may also be important in facilitating *Campylobacter* infection. It is not uncommon for broiler chickens to experience periods of both acute and chronic stress under commercial production systems. Examples of the former include catching and transport and feed deprivation before this (2). The latter can include dermatitis and also poor air quality (21). Transport stress has been shown to result in increased contamination of carcasses at slaughter (25), while it is less clear whether transport stress also results in increased levels of *Campylobacter* in ceca/feces from poultry subjected to transport stress (7, 25, 30).

It is also possible that stresses encountered by the birds result in changes in gut flora composition and/or host immune responses which may increase their susceptibility to *Campylobacter* and other infections in chickens (11, 16, 17, 19, 22). *Escherichia coli* infection in broilers affects their gut health, possibly through changing the balance of potentially protective commensal floras, and this may also affect *Campylobacter* infection. It is likely that *E. coli* was the cause of the majority of the infections prompting rejection in our study according to our expert panel. The possible association between *E. coli* infections and *Campylobacter* could relate to the latter being established more easily in birds infected with the former. This is being investigated.

The design of the study did not allow us to determine whether *E. coli* infection and/or increased dermatitis preceded or followed the entry of *Campylobacter* into the flock. Published data (2, 21) would suggest that flocks show evidence of all three around the same time, at 3 to 4 weeks of age. *Campylobacter* is generally regarded as being a commensal in broiler chickens (21), even though it may cause diseases like vibrionic hepatitis (28, 31). The link between bird health (rejections due infections) and welfare (dermatitis) and *Campylobacter* status presented here represents an interesting new development in our understanding of the relationship of *Campylobacter* and this avian host. This study has indicated that improving health and welfare could also reduce *Campylobacter* levels in broilers, but further studies are required to ascertain the mechanism underlying this association.

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