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Typing of *Campylobacter jejuni* Isolated from Turkey by Genotypic Methods, Antimicrobial Susceptibility, and Virulence Gene Patterns: A Retrospective Study.

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Typing of *Campylobacter jejuni* Isolated from Turkey by Genotypic Methods, Antimicrobial Susceptibility, and Virulence Gene Patterns: A Retrospective Study / Manfreda, G.; Parisi, A.; De Cesare, A.; Mion, D.; Piva, S.; Zanoni, R.G.. - In: *FOODBORNE PATHOGENS AND DISEASE*. - ISSN 1535-3141. - STAMPA. - 13:2(2016), pp. 93-100. [[10.1089/fpd.2015.2048](https://doi.org/10.1089/fpd.2015.2048)]

Availability:

This version is available at: <https://hdl.handle.net/11585/535202> since: 2020-02-26

Published:

DOI: <http://doi.org/10.1089/fpd.2015.2048>

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Manfreda G., Parisi A., De Cesare A., Mion D., **Piva S.**, Zanoni R.G.. (2016). Typing of *Campylobacter jejuni* Isolated from Turkey by Genotypic Methods, Antimicrobial Susceptibility, and Virulence Gene Patterns: A Retrospective Study. *FOODBORNE PATHOGENS AND DISEASE*, vol.13, p. 93-100.

Final publication is available from Mary Ann Liebert, Inc., publishers <https://doi.org/10.1089/fpd.2015.2048>

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Typing of *Campylobacter jejuni* isolated from turkey by genotypic methods, antimicrobial susceptibility and virulence gene patterns: a retrospective study

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24 Keywords: typing, *C. jejuni*, turkey isolates

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ABSTRACT

In this retrospective study, typing ability, discriminatory power and concordance between typing results obtained on 123 *Campylobacter jejuni* turkey isolates, collected in 1998, within 14 different farms, applying Multi-Locus Sequence Typing (MLST), Pulsed Field Gel Electrophoresis (PFGE), determination of antibiotic resistance profile and virulence gene pattern, were assessed and compared. Overall, 33 Sequence Types (ST), 28 pulsotypes, 10 resistotypes and 5 pathotypes were identified. MLST and PFGE showed the better discriminatory ability (i.e., Simpson's diversity index (DI) > 0.90) as well as unidirectional (i.e., Wallace and adjusted Wallace coefficients > 0.86) and bidirectional (i.e., adjusted Rand coefficient > 0.60) concordance. Moreover, both methods showed a good unidirectional and bidirectional concordance with the resistotype. On the contrary, the congruence of both genotyping methods and resistotype with the pathotype seemed due to chance alone. A clonal relationship was identified among 66.7% of the isolates. 59.7 % of the investigated isolates were resistant to two or more antimicrobials and 91.93% to tetracycline. All the isolates harbored *cadF* and *pldA* genes, whereas a *flaA* gene product and a *cdtB* gene product were amplified from 85.4% and 79.7% of the isolates using the primers designed by Bang et al. (2003). 85.4 and 79.7% showed the presence of *flaA* and *cdtB* genes, respectively. The results of this study clarify the level of genetic diversity among the *C. jejuni* originating from turkeys. MLST level of correlation with PFGE, resistotype and pathotype is assessed. This result supports the selection of type and number of typing methods to use in epidemiological studies. Finally, the identification of Clonal Complexes (CC) (i.e., groups of profiles differing by no more than one gene from at least one other profile of the group using the entire *Campylobacter* MLST database) shared between turkey and human isolates suggests that turkeys could be a possible source of *Campylobacter* infection.

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INTRODUCTION

In 2013, the prevalence of *Campylobacter* within the European Union was 18.43% in the turkey slaughterhouses, 12.81% in the cutting plants and 10.4 % in turkey meat at retail (EFSA, 2015).

Two features of *Campylobacter* infection have hindered investigations into the epidemiology of human campylobacteriosis: (i) human disease is most commonly sporadic and (ii) the bacterium is widespread and can be readily isolated from the intestine of different animals as well as environmental sources, water and soil (Brown *et al.*, 2004). Accurate isolate typing is consequently essential to trace back the source of infection. Among the genotyping methods available for *Campylobacter* typing, Multi-Locus Sequence Typing (MLST) exploits the relative conservation in sequence of certain genes in which variations are more likely to be selectively neutral because of their housekeeping functions. This approach is recognized as the gold standard typing method for this bacterial genus (Sheppard *et al.*, 2009). In the past Pulsed Field Gel Electrophoresis (PFGE) was considered the reference method for *Campylobacter* for its high discriminatory power (Maslow *et al.*, 1993). The drawbacks of PFGE are the time and labor necessary to perform the protocol properly, and the fact that restriction-based methods are less reproducible and difficult to interpret than sequence-based methods.

67 Beside molecular methods, different isolates can be characterized according to their antibiotic resistance profile and pattern in
68 virulence genes. The pathogenesis of *Campylobacter* infection is not fully elucidated, although flagella mediated-motility, adhesion to
69 intestinal mucosa, invasion and production of cytotoxin have been identified as virulence determinants (Konkel *et al.*, 1997; Wassenaar,
70 1997, Datta *et al.*, 2003). Therefore, four genes, each one responsible for one virulence factor, were investigated in this study; *flaA*,
71 responsible for motility; *cadF*, for adhesion; *pldA*, for invasion; *cdtB*, for toxin production.

72 When different typing methods are applied to a set of isolates, they should be compared to verify possible correlations in terms of
73 results obtained in order to avoid duplications and to highlight the inability of some of them to provide epidemiological information.
74 Carrico *et al.* (Carrico *et al.*, 2006) proposed the use of the adjusted Rand coefficient (AR) as measure for the quantitative assessment of
75 bidirectional correspondence between typing methods taking into account that agreement may arise by chance alone. Severiano *et al.*
76 (Severiano *et al.*, 2011) proposed the adjusted Wallace (AW) and corresponding confidence intervals (CI) as quantitative measures of
77 unidirectional congruence between typing methods.

78 In this research typing ability, discriminatory power and concordance between typing results collected on *C. jejuni* turkey isolates
79 applying MLST, PFGE, determination of antibiotic resistance profile and virulence gene patterns were assessed and compared because
80 (1) the majority of the available knowledge on typing results concerns broiler isolates; (2) more than one isolate was typed from each
81 farm and animal; (3) few publications are available on quantitative assessment of the concordance between typing results applied to the
82 same set of isolates.

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MATERIALS AND METHODS

85

86 **Sampling scheme.** In March 1998 a total of 196 turkey caeca were collected in two slaughterhouses that gathered turkeys coming
87 from 14 different farms located in Emilia-Romagna and Veneto regions (northern Italy). At the slaughterhouse, from each farm, 14
88 animals, belonging to the same group, were randomly selected from the line. Within 5 h after sampling, approximately 5 g of individual
89 caecal contents were diluted 1:1 into saline solution (0.154 M NaCl), homogenized by vortex mixer and diluted further 1:10 and 1:100 in
90 the same solution. Ten microliters of these last two dilutions were then streaked onto two plates of *Campylobacter* Blood-Free Selective
91 Agar (CCDA, Oxoid). The plates were incubated at 37±1°C under microaerobic atmosphere with hydrogen (Bolton *et al.*, 1992) and after
92 48 h of incubation were checked daily up to 5 days for colonies. From each plate, 4 colonies of Gram negative spiral shaped bacteria that
93 looked like *Campylobacter* spp. were sub-cultivated, cloned, submitted to a *Campylobacter* genus specific PCR (Linton *et al.*, 1996) and
94 stored at -80 ± 3°C for further typing. In 2014, with the beginning of this retrospective study, the isolates were thawed and submitted to a
95 *C.jejuni-C. coli* specific multiplex PCR (Denis *et al.*, 1999). Among the *C. jejuni* isolates, at least one isolate for each animal was selected
96 or more than one based on the colony morphological appearance. Overall, 123 *C. jejuni* isolates were submitted for further investigations.

97

98 **Multilocus Sequence Typing (MLST).** The DNA of the *C. jejuni* isolates was purified using the Chelex® 100 procedure (Biorad,
99 Milan, Italy) and characterized by MLST as previously described (Dingle *et al.*, 2001). Allele numbers, Sequence Types (STs), and
100 Clonal Complexes (CCs) were assigned using the PubMLST database (<http://pubmlst.org/campylobacter/>) (Jolley and Maiden, 2010).
101 The Clonal Complexes (CC) have been defined as groups of profiles differing by no more than one gene from at least one other profile of

102 the group (Feil, 2004) using the entire *Campylobacter* MLST database. Novel alleles and STs were coded through submission to the
103 MLST database.

104

105 **Pulsed Field Gel Electrophoresis (PFGE).** The *C. jejuni* isolates were typed using PFGE with the use of *Sma*I (Zhou *et al.*, 2011).
106 Band patterns were analyzed with BioNumerics 7.5 software (BioNumerics, Applied Maths, Keistraat, Belgium). DNA patterns were
107 compared using the Dice coefficient and the unweighted pair group method with arithmetic averages (UPGMA), with a 1.0% tolerance
108 limit and 1.0 % optimization. Isolates showing a PFGE patterns similarity level of 90% were grouped in the same “PFGE cluster”. The
109 PFGE patterns were classified as pulsotypes.

110

111 **Antimicrobial susceptibility testing.** The resistotype (R-type was obtained using the Etest method (AB bioMerieux, Solna, Sweden).
112 Mueller-Hinton Agar II (Becton Dickinson, Franklin Lakes, NJ) containing 5% defibrinated sheep blood was used as medium. The
113 antimicrobial agents tested were ciprofloxacin (CIP), enrofloxacin (EN), gentamicin (G), tetracycline (T), chloramphenicol (C), nalidixic
114 acid (NA), ampicillin (AM) and erythromycin (ER). The plates were incubated at $37 \pm 1^\circ\text{C}$ under microaerobic atmosphere for 48 h.
115 *Campylobacter jejuni* ATCC 33560, *Staphylococcus aureus* ATCC 29213 and *Escherichia coli* ATCC 25922 were used as control
116 strains. NARMS (2012) cutoff values were used for all the antibiotics tested, except for enrofloxacin and ampicillin, for which the CLSI
117 2008 cutoff values for *Enterobacteriaceae* and *Campylobacter* were used, respectively. The following resistance breakpoint ($\mu\text{g/ml}$) were
118 considered: ciprofloxacin ≥ 1 , enrofloxacin ≥ 4 , gentamicin ≥ 4 , tetracycline ≥ 2 , chloramphenicol ≥ 32 , nalidixic acid ≥ 32 , ampicillin \geq
119 32 and erythromycin ≥ 8 . The identified R-types were labelled using different numbers.

120

121 **Detection of virulence genes.** The DNA of the *C. jejuni* isolates was amplified by PCR to detect the presence of toxin and virulence
122 genes (*cdtB*, *cadF*, *flaA* and *pldA*), using primers VAT2–WMI-R (5'-GTTAAAATCCCCTGCTATCAACCA-3';
123 5'GTTGGCACTTGGAATTTGCAAGGC3'), F2B-R1B (5'-TGGAGGGTAATTTAGATATG-3'; 5'-CTAATACCTAAAGTTGAAAC-
124 3'), *flaA-F-flaA-R* (5'-GGATTTTCGTATTAACACAAATGGTGC3'; 5'-CTGTAGTAATCTTAAAACATTTTG-3') (Bang *et al.*, 2003),
125 *pldA-84-Pld-981* (5'-AAGCTTATGCGTTTTT-3'; 5' TATAAGGCTTTCTCCA3') (Datta *et al.*, 2003) respectively. *C. jejuni* ATCC
126 33560 was used as positive control and sterile water as negative control. Each pathotype was labelled as P-type.

127

128 **Calculation of discriminatory power and congruence among typing methods.** The discriminatory indexes (DI) of MLST, PFGE,
129 R-type and pathotype were calculated using the Simpson's diversity index described by Hunter and Gaston (Hunter and Gaston, 1988).
130 The Wallace's coefficient (W), the adjusted Wallace's coefficient (AW) and the adjusted Rand (AR) coefficient, along with the respective
131 confidence intervals (CIs), were all calculated using the Comparing Partitions website
132 (<http://darwin.phylviz.net/ComparingPartitions/index.php?link=Toll>). As explained above, W and AW indexes assess the unidirectional
133 concordance between typing methods and AR the bidirectional concordance.

134

135

RESULTS

136

137 **MLST.** All the 123 isolates were successfully typed by MLST. Five new alleles were discovered in this study. Overall, the isolates
138 were classified in 33 STs: 11 were unique STs, identified in single isolates, whereas 22 were shared between 2 to 15 isolates. The
139 majority of the common STs (i.e., 59.1%) were shared between isolates collected from turkeys reared in the same farm. The remaining
140 STs were shared between isolates collected from animals housed in different farms, located in the same (i.e., 31.8%) or different regions
141 (i.e., 9.1%). In 71.4% of the tested farms the isolates were characterized by two to four different STs. The most spread ST was ST879,
142 identified among isolates collected in three different farms, followed by STs 50, 227, 3334, 1880, 3476 and 7496 associated to isolates
143 from two different farms. All the remaining STs were identified among isolates coming from a single farm.

144

145 **PFGE.** All the 123 isolates were typed by PFGE. Overall, 28 pulsotypes were associated to the isolates genotyped; 13 were unique
146 pulsotypes, identified in single isolates, whereas 15 were shared between 2 to 26 isolates. The majority of the common pulsotypes (i.e.,
147 53.3%) were shared between isolates collected from turkeys reared in the same farm. The remaining pulsotypes were shared between
148 isolates collected from animals housed in different farms, located in the same (i.e., 20%) or different regions (i.e., 26.7%). In 57.1% of the
149 tested farms the isolates were characterized by two to four different pulsotypes. The most spread pulsotypes were those labelled as 1 and
150 30, identified among isolates collected in five different farms, followed by pulsotype 11, associated to isolates from three farms, and
151 pulsotypes 3, 14, 15 and 28, associated to isolates from two different farms. All the remaining pulsotypes were identified among isolates
152 coming from a single farm.

153

154 **Resistotype (R-type).** The distribution of the Minimum Inhibitory Concentration (MIC) values of the 123 isolates tested is shown in
155 Table 1. All the 123 isolates of *C.jejuni* were sensitive to gentamicin and chloramphenicol whereas four to all antimicrobials tested.
156 Furthermore, 92% of the tested isolates were resistant to tetracycline, 55% to nalidixic acid, 52% to enrofloxacin and ciprofloxacin, 13%
157 to ampicillin. Finally, one isolate was resistant to erythromycin. Overall, according to the resistance to antimicrobials, 10 different R-
158 types were identified and labelled with numbers (Figure 1). The R-type 1 (T) was found in 35% of the isolates; R-type 2 (CIP-EN-T-NA)
159 in 43%; R-type 3 (CIP-EN-NA) in 2%; R-type 4 (AM) in 2%; R-type 5 (T-NA) in 3%; R-type 6 (T-AM) in 4%; R-type 8 (CIP-EN-T-
160 NA-AM) in 6%; R-types 7 (CIP-EN-T-NA-ER) and 9 (CIP-EN-NA-AM) in 1% of the isolates each; R-type 11 (S), referred to *C.jejuni*
161 susceptible to all antibiotic tested, in 3% of the isolates.

162

163 **Pathotype (P-type).** All the 123 *C. jejuni* isolates harbored the *cadF* gene responsible for adherence. The presence of *pldA* gene,
164 responsible for invasion, was highlighted in all isolates, while the *flaA* gene, involved in isolate motility, was determined in 105 isolates
165 (85.4%). As regards *cdtB* gene, associated with toxin production, it was present in 98 (79.7%) *C. jejuni* isolates. Totally, 5 different P-
166 types, labelled as numbers, were identified according to the pathotype (Figure 2). The P-type 10 (*cadF*-*flaA*-*pldA* - *cdtB*) was identified
167 in 68% of the isolates, followed by P-types 4 (*cadF* - *flaA*- *pldA*) (16%) and 5 (*cdtB* - *cadF* - *pldA*) (11%). The two remaining P-types, 7
168 (*cadF*-*pldA*) and 3 (*cadF* - *flaA*) were identified in 4 and 2 isolates, respectively.

169

170 **Isolate discrimination.** The discriminatory indexes (DI) of the applied typing methods ranged between 0.946 for MLST and 0.499 for
171 P-type (Table 2). Both MLST and PFGE showed a DI higher than 0.90. Therefore, they both show a probability to discriminate *C. jejuni*

172 isolates different from a genetic point of view higher than 90%. The DIs calculated for each different typing method were significantly
173 different ($p < 0.001$).

174

175 **Concordance among typing methods.** The Wallace's coefficient (W) and the adjusted Wallace coefficient (AW) concerning
176 unidirectional concordance between MLST, PFGE, R-type and P-type (Table 3) showed a strong concordance (i.e., W and AW > 0.86)
177 between MLST and PFGE, as well as a good concordance (i.e., W and AW > 0.73) between MLST and R-type. As explained in the
178 introduction, this result means that the classification, in terms of different or identical type strains obtained using MLST can predict that
179 found using PFGE and R-type. A sufficient level of concordance (i.e., W and AW > 0.43) was observed also between PFGE and both
180 MLST and R-type (Table 3). Finally, a very low degree of concordance (i.e., W and AW > 0.097) was found between R-type and both
181 MLST and PFGE. The P-type did not show concordance with the other typing methods, meaning that agreements between the results
182 provided by P-type and one of the other methods is due to chance only (Table 3). In fact in Table 3 the W_i values calculated for the
183 unidirectional concordance between P-type and MLST, PFGE and R-type are always included in the CI of the W coefficient for each
184 combination of typing methods. Therefore, all the AW values are very low (Table 2). The results on the bi-directional concordance
185 showed an AR > 0.60 between MLST and PFGE only (Table 4). This AR value was significantly higher ($p < 0.001$) than the AR values for
186 PFGE and R-type (AR 0.164) and MLST and R-type (AR 0.171). Finally all the AR values between P-type and all the other typing
187 methods were significantly lower ($p < 0.001$) of the AR values between the other combinations of typing methods.

188

189 **Type strains identified.** The isolates tested were assigned to different type strains according to their ST, R-type, pulso-type and P-type
190 (Table 5). Clonal relationships, referred to isolates belonging to the same type strain, were identified for 66.7% of the tested farms (Table
191 5). They referred mainly to isolates from the same farm. However, isolates belonging to the same type strain isolated in different farms of
192 the same region were also detected (Table 5). Overall, the number of type strains identified within the same farm ranged between 2 and 8.

193

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DISCUSSION

195

196 In this study MLST and PFGE showed the better discriminatory ability, followed by R-type and P-type. Moreover, MLST and PFGE
197 showed a good unidirectional and bidirectional concordance. A good unidirectional concordance was also observed between MLST and
198 R-type, PFGE and both MLST and R-type, as well as R-type and the two investigated genotyping methods. These results seems to
199 suggest that MLST only can be applied to trace clonal relationships between isolates. However, the isolates classified in the ST 3476,
200 obtained in farms 5 and 15 displayed different pulso-types and R-types; therefore they would be improperly classified as clonal by MLST
201 only. The same consideration can be extended to isolates with ST 50, collected in the farms 7 and 19, as well as to the isolates with ST
202 7496, from farms 6 and 52. This picture is important in order to approach the analysis of different typing data when available. However,
203 the most promising technique in the analysis of outbreak-associated isolates, leading to faster and more precise source identification and
204 to discriminate between alternative epidemiological hypotheses is currently represented by whole-genome sequencing (WGS) (Revez *et*
205 *al.*, 2014; Harrison *et al.*, 2013).

206 The CC21 identified in 23.38% of the turkey isolates included in this study has been previously described for chicken *C. jejuni* isolates
207 (Ragimbeau *et al.*, 2009; Sheppard *et al.*, 2009; Colles and Maiden, 2012; Kittl *et al.*, 2013). Moreover, additional CCs, like CC443 and
208 CC446, associated to 7.25 and 1.61% of the turkey isolates were already identified among chicken strains (Ragimbeau *et al.*, 2008; Kittl
209 *et al.*, 2013). Interestingly, both CC21 and CC443, along with CC206 and CC257, associated to 4.84 and 12.09% of the turkey isolates,
210 respectively, were already identified among human *C. jejuni* isolates and have been frequently associated with human diseases
211 (Ragimbeau *et al.*, 2008; Sheppard *et al.*, 2009; de Haan *et al.*, 2010; Colles and Maiden, 2012). The identification of CC shared between
212 turkey and human isolates suggests that turkeys could be a possible source of *Campylobacter* infection.

213

214 The 59.7 % of the investigated isolates were resistant to two or more antimicrobials. Although the turkey isolates investigated in this
215 study were collected before the adoption of EU Regulation 1831/2003 banning the use of antibiotics as growth promoters in animal feeds,
216 high occurrences of multidrug-resistant in *C. jejuni* isolated from turkeys have been reported more recently. A high prevalence of
217 tetracycline resistance in *C. jejuni* isolates from chickens and turkeys has been described (Luangtongkum *et al.*, 2009; Andersen *et al.*,
218 2006; Gu *et al.*, 2009; Zhao *et al.*, 2011). In this study high resistance rates to (fluoro)quinolones were also observed. High level of
219 tetracycline and (fluoro)quinolones resistances were also reported in *C. jejuni* human, animals and food isolates in 2013 (EFSA, 2015).

220 In regard to the detection of virulence genes, the pathotype results do not correlate to other methods employed in this study; however,
221 this study contributes to the limited data available on virulence genes of *Campylobacter jejuni* isolates from turkeys (Bang *et al.*, 2004;
222 Thorsness *et al.*, 2008). The occurrence of the virulence genes observed in this study is in agreement with previous surveys performed on
223 *C. jejuni* isolated from turkeys where *cadF*, *pldA* and *flaA* genes resulted the most conserved genes. The majority of our isolates were

224 positive for all four virulence genes in agreement with that observed by Thorsness *et al.* (2008), suggesting a potential ability of these
225 *Campylobacter* to colonize turkeys and a potential capability to induce human *Campylobacter* infection (Konkel *et al.*, 2000). However
226 infection is a multifactorial process and studies on the regulation and expression of these genes *in vitro* and *in vivo* will be needed to
227 better understand the role of these genes in the pathogenesis of campylobacteriosis.

228

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CONCLUSIONS

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231 The results of this study show that the population of *C. jejuni* isolates colonizing turkeys includes different type strains within the same
232 farm, which must be discriminated in order to make source attribution in case of human campylobacteriosis link to turkey or turkey
233 products. Therefore, a representative number of animals and isolates must be collected during epidemiological investigations. Even if we
234 already entered the WGS era, whenever an alternative typing method must be selected for typing *C. jejuni*, MLST is confirmed as the best
235 choice. In fact, in this study MLST shows the best discriminatory ability and good correlation with PFGE and R-type. Even if this result
236 seems to indicate to avoid to run all methods on the same isolates, isolates sharing the same MLST profile with different PFGE and R-
237 type were identified.

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REFERENCES

240 Andersen SR, Saadbye P, Shukri NM, Rosenquist H, Nielsen NL, Boel J. Antimicrobial resistance among *Campylobacter jejuni* isolated
241 from raw poultry meat at retail level in Denmark. *Int J Food Microbiol* 2006;107:250–255.

242 Bang DD, Moller NE, Scheutz F, Pedersen K, Handberg K, Madsen M.. PCR detection of seven virulence and toxin genes of
243 *Campylobacter jejuni* and *Campylobacter coli* isolates from Danish pigs and cattle and cytolethal distending toxin production of the
244 isolates. J.Appl. Microbiol. 2003;94:1003-1014.

245 Bang DD, Bork B, Nielsen EM, Scheutz F, Pedersen K, Madsen M. Detection of seven virulence and toxin genes of *Campylobacter*
246 *jejuni* isolates from Danish turkeys by PCR and cytolethal distending toxin production of the isolates. J. Food. Protect.
247 2004;67:2171-2177.

248 Bolton FJ, Wareing DRA, Skirrow MB, Hutchinson DN. Identification and biotyping of campylobacters. In: Board, R.G., Jones, D.,
249 Skinner, F.A. (Eds.), Identification Methods in Appl. Environmental Microbiology. Blackwell Scientific Publications, Oxford,
250 1992, pp.151-161.

251 Brown PE, Christensen OF, Clough HE, Diggle PJ, Hart CA, Hazel S, Kemp R, Leatherbarrow AJ, Moore A, Sutherst J, Turner J,
252 Williams NJ, Wright EJ, French NP. Frequency and spatial distribution of environmental *Campylobacter* spp. Appl. Environ.
253 Microbiol. 2004;70:6501–6511.

254 Carrico J A, Silva-Costa C, Melo-Cristina C, Pinto FR, de Lencastre H, Almeida JS, Ramirez M. Illustration of a common framework for
255 relating multiple typing methods by application to macrolide-resistant *Streptococcus pyogenes*. J. Clin. Microbiol. 2006;44:2524–
256 2532.

257 CLSI 2008. Performance standards for antimicrobial disk dilution susceptibility tests for bacterial isolated from animals. Approved
258 Standard-Third Edition. CLSI document M31-A3.

259 Colles FM, Maiden MCJ. *Campylobacter* sequence typing databases: applications and future prospects. *Microbiol.* 2012;158:2695–2709.

260 Datta S, Niwa H, Itoh K. Prevalence of strains isolated from humans, poultry meat and broiler and bovine faeces. *J. Med. Microbiol.*

261 2003;52:345-348.

262 de Haan CP, Kivisto R, Hakkinen M, Rautelin H, Hanninen ML. Decreasing trend of overlapping multilocus sequence types between

263 human and chicken *Campylobacter jejuni* isolates over a decade in Finland. *Appl Environ Microbiol* 2010;76:5228–5236.

264 Denis M, Soumet C, Rivoal K, Ermel G, Blivet D, Salvat G, Colin P. Development of a m-PCR assay for simultaneous identification of

265 *Campylobacter jejuni* and *C. coli*. *Lett. Appl. Microbiol.* 1999;29:406-410.

266 Dingle KE, Colles FM, Wareing DR, Ure R, Fox AJ, Bolton FE, Bootsma HJ, Willems RJ, Urwin R, Maiden MC. Multilocus sequence

267 typing system for *Campylobacter jejuni*. *J. Clin. Microbiol.* 2001;39:14–23.

268 European Food Safety Authority and European Centre for Disease Prevention and Control. 2015. The European Union Summary Report

269 on Trends and Sources of Zoonoses, Zoonotic Agents and Food-borne Outbreaks in 2013. *EFSA Journal* 13(1).

270 Feil EJ. Small change: keeping pace with microevolution. *Nat. Rev. Microbiol.* 2004; 2: 483-495.

271 Gu W, Siletzky RM, Wright S, Islam M, Kathariou S. Antimicrobial susceptibility profiles and strain type diversity of *Campylobacter*

272 *jejuni* isolates from turkeys in Eastern North Carolina. *Appl. Environ. Microbiol.* 2009;75:474–482.

273 Harrison EM, Paterson GK, Holden MT, Larsen J, Stegger M, Larsen AR, Petersen A, Skov RL, Christensen JM, Bak Zeuthen A,

274 Heltberg O, Harris SR, Zadoks RN, Parkhill J, Peacock SJ, Holmes MA. Whole genome sequencing identifies zoonotic

275 transmission of MRSA isolates with the novel *mecA* homologue *mecC*. *EMBO Mol. Med.* 2013;5:509–515.

276 Hunter PR, Gaston MA. Numerical index of the discriminatory ability of typing systems: an application of Simpson's index of diversity.
277 J. Clin. Microbiol. 1988;26:2465–2466

278 Jolley KA, Maiden MCJ. BIGSdb: scalable analysis of bacterial genome variation at the population level. BMC Bioinformatics
279 2010;11:595.

280 Kittl S, Heckel G, Korczak BM, Kuhnert P. Source attribution of human *Campylobacter* isolates by MLST and *fla*-typing and association
281 of genotypes with quinolone resistance. PLoS One 8 2013; e81796.

282 Konkol ME, Garvis SG, Tipton SL, Anderson DE, Cieplak W. Identification and molecular cloning of a gene encoding a fibronectin-
283 binding protein (CadF) from *Campylobacter jejuni*. Mol. Microbiol. 1997;24:953-963.

284 Konkol ME, Joens LA, Mixter PF. Molecular characterization of *Campylobacter jejuni* virulence determinants. In Nachamkin I., Blaser
285 M.J., *Campylobacter*, 2nd ed. American Society for Microbiology, Washington, D.C., 2000, pp. 217-240.

286 Linton D, Owen RJ, Stanley J.. Rapid identification by PCR of the genus *Campylobacter* and of five *Campylobacter* species
287 enteropathogenic for man and animals. Res. Microbiol. 1996;147:707-718.

288 Luangtongkum T, Jeon B, Han J, Plummer P, Logue CM, Zhang Q. Antibiotic resistance in *Campylobacter*: emergence, transmission and
289 persistence. Future Microbiol. 2009;4:189–200.

290 Maslow JN, Mulligan ME, Arbeit RD. Molecular epidemiology: application of contemporary techniques to the typing of microorganisms.
291 Clin. Infect. Dis. 1993;17:153–162.

292 NARMS-National Antimicrobial resistance Monitoring System: enteric bacteria. 2012. Annual Human Isolates Report
293 <http://www.cdc.gov/narms/reports/annual-human-isolates-report-2012.html>.

294 Ragimbeau C, Schneider F, Losch S, Even J., Mossong J. Multilocus sequence typing, pulsed-field gel electrophoresis, and fla short
295 variable region typing of clonal complexes of *Campylobacter jejuni* strains of human, bovine, and poultry origins in Luxembourg.
296 *Appl Environ Microbiol* 2008;74: 7715–7722.

297 Revez J, Llarena AK, Schott T, Kuusi M, Hakkinen M, Kivistö R, Hänninen ML, Rossi M. Genome analysis of *Campylobacter jejuni*
298 strains isolated from a waterborne outbreak. *BMC Genomics* 2014;15:768.

299 Severiano A, Pinto FR, Ramirez M, Carriço JA. Adjusted Wallace coefficient as a measure of congruence between typing methods. *J.*
300 *Clin. Microbiol.* 2011;49:3997–4000.

301 Sheppard SK, Dallas JF, Strachan NJ, MacRae M, McCarthy ND, Wilson DJ, Gormley FJ, Falush D, Ogden ID, Maiden MC, Forbes KJ.
302 *Campylobacter* genotyping to determine the source of human infection. *Clin. Infect. Dis.* 2009;48:1072–1078.

303 Thorsness JL, Sherwood JS, Danzeisen GT, Doetkott C, Logue CM. Baseline *Campylobacter* prevalence at a new turkey production
304 facility in north Dakota. *J. Food. Protect.* 2008;71:2295-2300.

305 Wassenaar TM. Toxin production of *Campylobacter* spp.. *Clin. Microbiol. Rev.* 1997;10:466-476.

306 Zhao S, Young SR, Tong E, Abbott JW, Womack N, Friedman SL, McDermott PF. Antimicrobial resistance of *Campylobacter* isolates
307 from retail meat in the United States between 2002 and 2007. *Appl. Environ. Microbiol.* 2010;76:7949–7956.

308 Zhou P, Hussain SK, Liles MR, Arias CR, Backert S, Kieninger JR, Oyarzabal OA.. A simplified and cost-effective enrichment protocol
309 for the isolation of *Campylobacter* spp. from retail broiler meat without microaerobic incubation. *BMC Microbiol.* 2011;11:175.