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**Validation of an easy handling sample preparation and triplex real time PCR for rapid detection of *T. equigenitalis* and other organisms associated with endometritis in mares.**

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## **Abstract**

Isolation and identification of *Taylorella equigenitalis*, the causative agent of contagious equine metritis (CEM), by bacteriology is laborious and does not permit differentiation from the other member of the genus, *Taylorella asinigenitalis*. Moreover, other organisms such as *Klebsiella pneumoniae* and *Pseudomonas aeruginosa* can also cause endometritis in mares and warrant diagnostic detection. Our objectives were to develop a rapid preparation method for field swab samples and to validate this protocol using new multiplex real time PCR (rtPCR) detection tools for identification of these four pathogens. The complete analytical process from sample preparation to PCR analysis was then evaluated against bacteriology, the World Organisation for Health's (OIE) gold standard method for *T. equigenitalis* and commonly used for the other three pathogens. The diagnostic sensitivity and specificity of this method, which used direct lysis and a multiplex rtPCR, were 100% and greater than 92% respectively. This study provided a simple-to-use method for pre-breeding screening of mares and stallions.

**Keywords:** Equine; Contagious Equine Metritis; direct lysis; rtPCR; diagnostics

## 1. Introduction

Bacterial endometritis is an important cause of subfertility in the mare. Endometrial infections are reported in 25-60% mares which failed to conceive following breeding, which contributes towards major economic losses for the equine industry [1]. Infection with *Taylorella equigenitalis* (*T. equigenitalis*) during natural or artificial breeding with contaminated semen from a carrier stallion [2,3] causes the disease contagious equine metritis (CEM), which results in a transient endometritis causing early embryonal death. *Taylorella equigenitalis* shares 98% sequence similarity with the other member of the *Taylorella* genus, *Taylorella asinigenitalis* (*T. asinigenitalis*), which was first isolated from donkey jacks in the United States (US) in 1987 [4,5]. *Taylorella asinigenitalis* is considered non-pathogenic in horses [4-7] and the main importance of this organism is the difficulty in differentiating it from *T. equigenitalis* using traditional bacterial culture [5,8]. Other opportunistic bacteria, especially *Klebsiella pneumoniae* (*K. pneumoniae*) and *Pseudomonas aeruginosa* (*P. aeruginosa*), are also venereally-transmitted pathogens in horses causing endometritis and infertility in mares [9,10].

Isolation and identification of *T. equigenitalis* by culture is recognized as the OIE gold standard for detection of the organism and is used for purposes of international trade. However, bacterial culture has several limitations including an extended period to obtain visible colonies (3-10 days), fastidious growth requirements (eg. microaerophilic conditions, selective media), overgrowth by other commensal flora from the urogenital tract, the possibility of false negatives due to low bacterial numbers in the sample [11,12], and the inability to distinguish colonies from *T. asinigenitalis* [13]. Various PCR methods have been developed to detect *T. equigenitalis* [11, 13-17] where sensitivity and/or specificity varied from 83.3 % to 100 % and offer good alternatives to culture. The objectives of this study were to develop an easy sample preparation method and to evaluate the performance of two rapid

and robust triplex rtPCRs, which allowed the detection and discrimination of *T. equigenitalis* from *T. asinigenitalis* and *K. pneumoniae* from *P. aeruginosa*, respectively.

## 2. Material and methods

### 2.1. Samples

Bacterial strains were used to evaluate the specificity and sensitivity of two rtPCRs and were obtained from the Institut Pasteur (Institut Pasteur, Paris, France), the American Type Collection (ATCC, Virginia, USA) or from the ANSES collection (ANSES Dozulé, EU reference laboratory, France) as described in table S1. Nucleic acid extracts from other bacteria and viruses used in this study were provided by ADIAGENE (ADIAGENE, Ploufragan, France) or isolated as described below in culture session, and were identified with VITEK<sup>®</sup> 2 (BioMérieux, Marcy L'étoile, France) or Maldi-Tof technologies (Bruker Daltonics, Wissembourg, France) at LABÉO (Supplementary data: table S1).

Genital swab samples (n=467; 288 from mares and 179 from stallions) were used to evaluate diagnostic specificity (Dsp) and sensitivity (Dse) and were obtained from 290 horses (1 to 5 swabs/animal) and 33 semen samples submitted to the LABÉO's (Caen, France) diagnostic CEM laboratory. Genital swabs samples (n=467) included clitoral sinuses/fossa (n=215), urethral fossa (n=75), cervix (n=73), urethra (n=51), penile sheath (n=30), urethral sinus (n=8), prepuce (n=9) and fossa glandis (n=6).

To obtain spiked samples, genital swabs collected from horses and confirmed negative for all four pathogens on both PCR and culture were vortexed in PBS and pooled. This negative solution was divided in 4 and spiked with 3 different level concentrations of each *T. equigenitalis* (CIP 7944) and *T. asinigenitalis* (CIP 107673) cultures. The titration of this solution was done on chocolate blood agar. One solution was kept as a control. Forty dry swabs (Copan, Brescia, Italy) were then dipped in the spiked solution and 6 dry swabs were

dipped in the control solution. All 46 swabs were kept at room temperature in a culture transport system (Copan) and subsequently sent for PCR analysis at ADIAGENE and LABÉO laboratories.

## 2.2. Culture conditions

Test swabs (467 clinical and 46 spiked samples) were analyzed within 24 hours (or 48 hours if transported under cold conditions) of preparation according to the OIE manual [18] and the French AFNOR Norm recommendations [19] for *T. equigenitalis*. Each swab was inoculated on 5% heated blood “chocolate” agar and *Taylorella* selective medium containing trimethoprim (1 µg/ml), clindamycin (5 µg/ml) and amphotericin b (15 µg/ml). Plates were incubated at 35-37°C, in 5-10% CO<sub>2</sub> microaerophilic condition at for least 7 days. The swabs were also streaked on Columbia blood agar supplemented with 5% sheep EDTA blood and eosin methylene blue agar (37°C +/- 2°C for 24-48 h) for the detection of *Pseudomonas* and *Klebsiella* bacterial species. Identification of the four pathogens was confirmed using Gram’s test followed by VITEK<sup>®</sup> 2 (BioMérieux) or MALDI-TOF (Bruker Daltonics).

## 2.3. DNA extraction

Genomic bacterial DNA was extracted from 1ml of bacterial liquid culture (adjusted to 3 Mac Farland (McF)) using the QIAamp<sup>®</sup> DNA Mini Kit (Qiagen, Courtaboeuf, France) according to the manufacturer’s instruction and stored at -20°C (short term storage) or -80°C (long term storage). The DNA concentration of each extract was measured with a NanoDrop 2000c Spectrophotometer (Thermoscientific, Illkirch, France).

Swabs were vortexed in 500 µl of PBS, 100 µl was used for the direct lysis method (incubated 10 min at 95°C and cooled at room temperature or at +5°C +/- 3°C) and 200 µl was

used to perform a commercial column purification using QIAamp® DNA mini kit (Qiagen). DNA from 200 µl of semen was extracted with QIAamp® DNA mini kit (Qiagen).

#### 2.4. PCR

Primers and probes were designed using the Primer Express Software V.3.0 (Life Technologies, Saint Aubin, France) to target *TEQUI\_1010* (O-antigen export system permease protein RfbD, 1052325-1052410), *TASI\_0169* (Zinc ABC transporter, ATP-binding protein ZnuC, 171816-172112), *ecfx* (extracytoplasmic function gene, GenBank accession no. DQ996551) and *mdh* (malate dehydrogenase housekeeping gene, GenBank accession no. AM051124) genes of *T. equigenitalis* [20], *T. asinigenitalis* [20], *P. aeruginosa* [21] and *K. pneumonia* [22], respectively. Two commercial PCR assays, ADIAVET CEMO *Taylorella* REAL TIME and ADIAVET KLEB/Pseudo REAL TIME (ADIAGENE) have been developed based on these genes.

For each experiment, 20 µl of amplification solution (ADIAGENE) was mixed with 5 µl of DNA extract. rtPCR was performed on a QuantStudio™ cyclers (Life Technologies) using a program with initial steps at 50°C for 2 min and 95°C for 10 min followed by 45 cycles at 95°C for 15 s and 60°C for 1 min. Data were analyzed using the QuantStudio™ software (Life Technologies). Each assay included a negative control for the extraction step and negative (Rnase free water) and positive (calibrated DNA extracts) controls for the amplification steps.

Characterization of both ADIAVET REAL TIME PCR (ADIAGENE) (i.e. efficiency, repeatability, reproducibility, specificity and limit of detection (LOD)) and the complete analytical method (from DNA extraction to rtPCR analysis) were done according to the French AFNOR Norm [23]. To evaluate specificity, 24 different strains of *T. equigenitalis*, 14 of *T. asinigenitalis*, 33 of *K. pneumoniae* and 16 of *P. aeruginosa* were used. The LOD<sub>Method</sub>

was determined using 3 five-fold serial dilutions of calibrated bacterial suspension added to a negative emulsion of swabs or semen. Four replicates of each sample were extracted and amplified during 2 independent runs. The LOD<sub>Method</sub> at 95% was the last concentration where 8 out of the 8 replicates were positive. The Dse and Dsp were determined by analyzing 500 clinical samples using rtPCR and comparing these results with the gold standard culture. The 95% score confidence interval for sensitivity and specificity was calculated using the Wilson method (EP12-A2 guide, 2008).

### 2.5. rtPCR inter-laboratory comparison assay

*T. equigenitalis* spiked swabs (3 levels of infection: high (480 LOD<sub>Method</sub>), intermediate (48 LOD<sub>Method</sub>), and low (4.8 LOD<sub>Method</sub>)) and *T. asinigenitalis* spiked swabs (3 levels of infection: 100, 10 and 1 LOD<sub>Method</sub>) were used for the inter-laboratory comparison assay. A total of 46 swabs were sent to each laboratory (ADIAGENE and LABÉO), including 2 high, 8 intermediate and 10 low spike swabs for each pathogen and 6 negative controls. All analyses were conducted under blinded condition.

### 2.6. Analysis of data

For the determination of Dse and Dsp, statistical analyses were performed using Microsoft Excel 2010. The multifactorial ANOVA was performed with Sta51tGraphics® Centurion XVI Version 16.1.12 for windows (StatPoint Technologies Inc).

## 3. Results

All results regarding the characterization of the rtPCR and method are detailed in Table 1. A R<sup>2</sup> equal to 0.99 demonstrates a high degree of precision with a coefficient of variation (CV) <10%. No cross hybridization was observed with any of the bacteria or viruses tested



(Table S1). The Dse (calculated from the clinical samples) for *K. pneumoniae* and *P. aeruginosa* was 100% after both direct lysis and column purification methods, but could not be determined for *T. equigenitalis* and *T. asinigenitalis* as all tested clinical samples were found to be negative on both culture and rtPCR. The Dsp varied between 92.7% and 100% after direct lysis or column purification for all four pathogens (Table 1).

The results of the inter-laboratory comparison assay for the *Taylorella* species are illustrated in Figure 1A. For high (480 and 100 LOD<sub>Method</sub> for *T. equigenitalis* and *T. asinigenitalis*, respectively) and intermediate (48 and 10 LOD<sub>Method</sub> for *T. equigenitalis* and *T. asinigenitalis*, respectively) levels of spiking, all results obtained by direct lysis and column purification methods were classed as positive by both ADIAGENE and LABÉO. For low (4.8 and 1 LOD<sub>Method</sub> for *T. equigenitalis* and *T. asinigenitalis*, respectively) spiking levels: 1) after direct lysis, 80% of *T. equigenitalis* and 90% of *T. asinigenitalis* spiked swab were found positive by both laboratories; 2) after column purification, only 50% of *T. equigenitalis* and 30% of *T. asinigenitalis* spiked swabs were found positive. All negative samples were found negative by both laboratories. The multifactorial ANOVA of cycle threshold (Ct) values obtained after analysis of *T. equigenitalis* samples (Figure 1B) reported significant differences between the levels of spiking (p-value <0.0001), the methods of purification (i.e. direct lysis or column purification, p-value < 0.0001) and the significant but limited difference between laboratories (p-value = 0.017). The multifactorial analysis of *T. asinigenitalis* samples reveals significant differences between the spiking levels (p-value <0.0001) and the purification methods (p-value = 0.0001), but no differences between the two laboratories (p-value = 0.29).

#### **4. Discussion**

The combination of direct lysis and rtPCR analysis offers a new, rapid screening tool for identification of *T. equigenitalis* and other organisms such as *T. asinigenitalis*,

*K. pneumoniae* and *P. aeruginosa* in both genital swabs and semen. Previously described PCR assays targeted the 16S rRNA gene [11], which may result in cross-reactivity with other bacteria such as *Oligella urethralis*. In order to increase the specificity of the amplification process, our approach targeted specific genes for each pathogen of interest. Using several different strains for each targeted pathogen the impact of genetic variability was evaluated and found to be negligible. Our results also demonstrated the absence of cross reactivity (i.e. exclusivity) of the assays with 91 unrelated pathogens, including *Oligella urethralis*. Evaluation of efficiency, repeatability and reproducibility verified the robustness of our rtPCRs. The LOD<sub>PCR</sub> of our assays seemed higher than those calculated with the only commercially available kit [11]. The duration of the preparation process (i.e. direct lysis) for detection of *K. pneumoniae* and *P. aeruginosa* using the new method was greatly reduced when compared with column purification and with substantially better Dse and Dsp. Direct lysis has previously been proposed [11, 14] as an alternative to DNA purification, however the new protocol described here is significantly quicker (10 min vs 1 h) than previously reported [7, 10-15]. Regarding the characterization of the method, the Dse and Dsp obtained in our study (including the 4 pathogens) are comparable for both direct lysis and column purification to those obtained previously [11]. Due to the absence of positive field samples available in France, the Dse for *T. equigenitalis* and *T. asinigenitalis* was not calculated. As an alternative, a PCR blinded inter-laboratory comparison assay (n=46) for direct lysis and column purification was performed. As the limit of detection of the method was reached, increasingly discordant results were observed due to problems of reproducibility. These two rtPCR assays have been successfully used to test samples received in the context of official inter-laboratory comparison culture and rtPCR assays organized by the Horserace Betting Levy Board and the EU reference laboratory for equine diseases (ANSES Dozulé, data not

shown). Consequently, these methods are now approved by ANSES laboratory for diagnosis of *T. equigenitalis*.

Rapid detection of *K. pneumoniae* and *P. aeruginosa* within 1-2 hours by rtPCR (compared to 48h by culture) would improve pre-breeding screening for these pathogens and prevent unjustified use of antibiotics.

Unlike culture, the rtPCR method reported here provided a robust method to differentiate the two *Taylorella* species, with important implications for international trade. When compared to other assays, the increased sensitivity of this rtPCR might result in a higher number of positive results. Due to the grave implications to both the equine industry and international trade [2], all positive *T. equigenitalis* samples warrant further clinical investigation, molecular characterization and treatment [24].

## **5. Conclusion**

An easy handling sample preparation (direct lysis) associated with two triplex rtPCR are proposed for rapid detection of *T. equigenitalis* and other organisms associated with infertility in mares. The duration of the assay is significantly reduced and the diagnostic specificity and sensibility are substantially increased when compared with the conventional column extraction method. This combination offers a good alternative to culture for pre-breeding screening to improve biosecurity practices on stud farms and for the international movement of horses. Multiplex assays for infectious diseases may become the principal screening methods in veterinary diagnostic laboratories.

## **Conflict of interest**

The authors declare that they have no conflict of interest.

## **Ethical Statement**

None

## **Funding sources**

This research received no external funding.

## **Author's contributions**

AL, PG and BB participated to the conceptualization, methodology, supervision and project administration. LD, SC and YV performed formal analysis, data curation and validation. AL and BB coordinated the contributions from all co-authors. AL, PG and BB analyzed the data, discussed the results and wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

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### **Supplementary material**

Table S1: Results of analytical specificity of ADIAVET CEMO *Taylorella* REAL TIME and ADIAVET KLEB/PSEUDO REAL TIME PCR.

1 **Table 1.** Characteristics of PCR and the methods according to the pathogen

|                                       |              | <i>T. equigenitalis</i> |       | <i>T. asinigenitalis</i> |       | <i>K. pneumoniae</i> |       | <i>P. aeruginosa</i> |       |
|---------------------------------------|--------------|-------------------------|-------|--------------------------|-------|----------------------|-------|----------------------|-------|
|                                       |              | Swab                    | Semen | Swab                     | Semen | Swab                 | Semen | Swab                 | Semen |
| <b>A. Characterization of PCR</b>     |              |                         |       |                          |       |                      |       |                      |       |
| Efficiency (%)                        |              | 97                      |       | 91                       |       | 79                   |       | 82.5                 |       |
| R <sup>2</sup>                        |              | 0.99                    |       | 0.99                     |       | 0.99                 |       | 0.99                 |       |
| Repeatability (range of CV %)         |              | 0.9-1.7                 |       | 0.9-3.2                  |       | 1.3-2.9              |       | 1.2-3.4              |       |
| Reproducibility (range of CV %)       |              | 2-3.1                   |       | 3.3-4.5                  |       | 0.9-1.4              |       | 2.8-3.6              |       |
| Analytical specificity                |              | OK                      |       | OK                       |       | OK                   |       | OK                   |       |
| LOD <sub>PCR</sub> (GE/reaction)      |              | 5                       |       | 20                       |       | 20                   |       | 20                   |       |
| <b>B. Characterization of methods</b> |              |                         |       |                          |       |                      |       |                      |       |
| LOD <sub>Method</sub> (CFU/ml)        | Direct lysis | 750                     | /     | 2750                     | /     | 100                  | /     | 7500                 | /     |

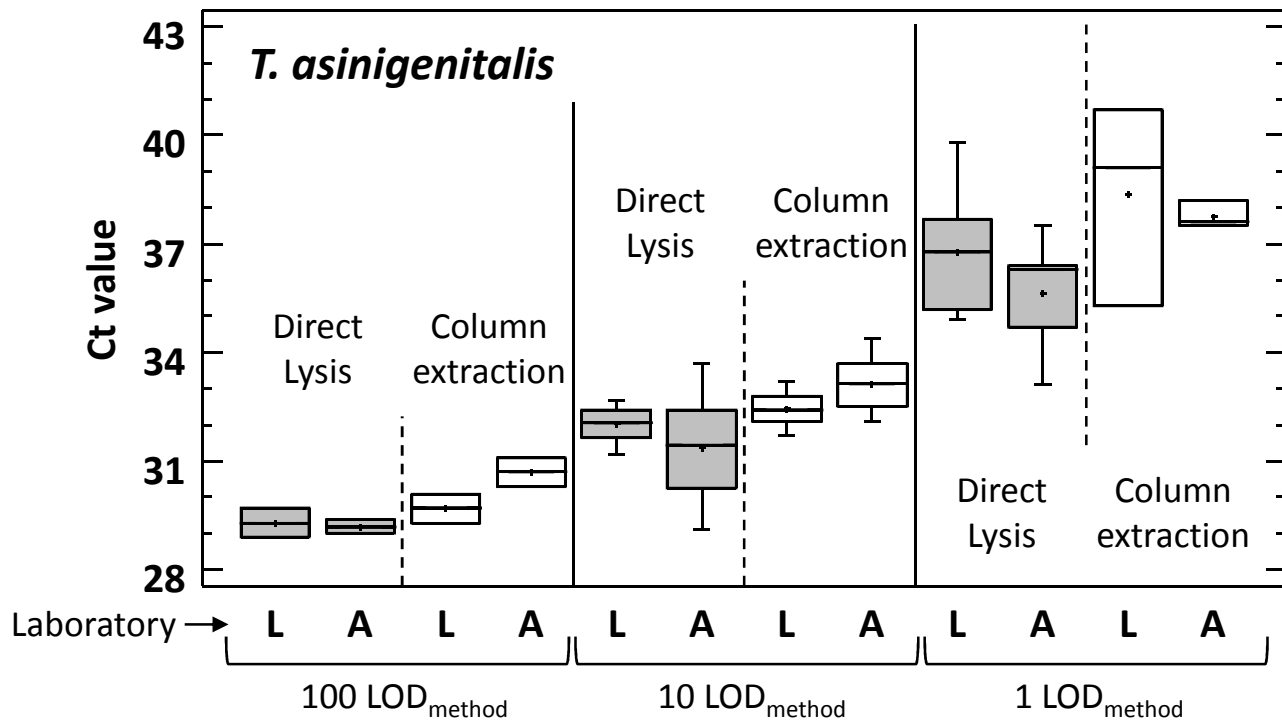
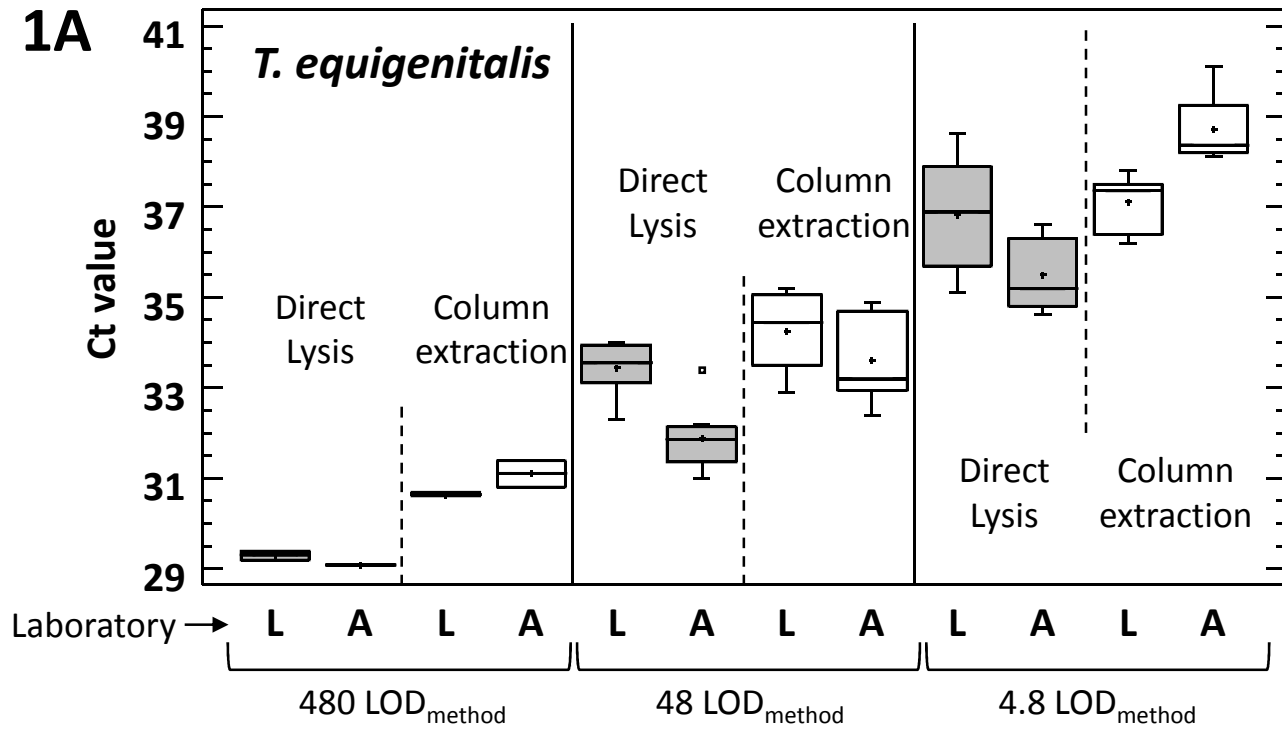


|    |         |                     |                |                |                  |                  |  |
|----|---------|---------------------|----------------|----------------|------------------|------------------|--|
| 2  |         |                     |                |                |                  |                  |  |
| 3  |         | Column purification | 750 3000       | 2750 550       | 500 5000         | 7500 15000       |  |
| 4  | DSe (%) | Direct lysis        | ND             | ND             | 100 [84.5;100]   | 100 [72.2;100]   |  |
| 5  |         | Column purification | ND             | ND             | 100 [84.5;100]   | 100 [72.3;100]   |  |
| 6  | DSp (%) | Direct lysis        | 100 [99.2;100] | 100 [99.2;100] | 92.7 [90;94.7]   | 99 [97.6;99.6]   |  |
| 7  |         | Column purification | 100 [99.2;100] | 100 [99.2;100] | 93.1 [90.5;95.1] | 99.4 [98.2;99.8] |  |
| 8  |         |                     |                |                |                  |                  |  |
| 9  |         |                     |                |                |                  |                  |  |
| 10 |         |                     |                |                |                  |                  |  |
| 11 |         |                     |                |                |                  |                  |  |
| 12 |         |                     |                |                |                  |                  |  |

13 LOD<sub>PCR</sub>: Limit of detection PCR; GE: genome equivalent; LOD<sub>Method</sub>: Limit of detection method; Dse: Diagnostic sensitivity; Dsp: Diagnostic  
14 specificity; ND: Not Determined; /: Not realized; CV: Coefficient of variation; CFU: Colonies Forming Units; []: confidence interval

15 **Figure legend**

16 **Figure 1.** Results of the inter-laboratory comparison assay (1A). Box and whiskers plot  
17 presentation of Ct values obtained for *T. equigenitalis* (top graphic) and *T. asinigenitalis*  
18 (bottom graphic) using direct lysis (grey plots) or column extraction (white plots). The rectangle  
19 represents 50% of observed responses for each group, horizontal line indicates median of the  
20 group, and the cross indicates the average of the group. Square indicates outlier results. L =  
21 LABÉO, A = ADIAGENE. Multifactorial ANOVA of Ct values obtained for *T. equigenitalis*  
22 and *T. asinigenitalis* (1B), with spiking levels, Laboratories and purification methods (direct  
23 lysis or column purifications) used as factors. Statistically significant differences are indicated  
24 in bold text. The contribution of each factor was measured having removed the effects of all  
25 other factors



**1B**

| Factors              | Details      | <i>T. equigenitalis</i> |                   | <i>T. asinigenitalis</i> |                   |
|----------------------|--------------|-------------------------|-------------------|--------------------------|-------------------|
|                      |              | Ct (average)            | p-value           | Ct (average)             | p-value           |
| Spiking levels       | early        | 30.0±0.35               |                   | 29.7±0.43                |                   |
|                      | intermediate | 33.3±0.18               | <b>&lt;0.0001</b> | 32.2±0.22                | <b>&lt;0.0001</b> |
|                      | late         | 36.9±0.2                |                   | 37.0±0.26                |                   |
| Laboratories         | LABEO        | 33.7±0.19               | <b>0.0173</b>     | 33.2±0.24                | 0.2921            |
|                      | Adiagène     | 33.1±0.2                |                   | 32.8±0.24                |                   |
| Purification methods | Direct lysis | 32.7±0.19               | <b>&lt;0.0001</b> | 32.3±0.22                | <b>0.0001</b>     |
|                      | Column       | 34.1±0.2                |                   | 33.6±0.26                |                   |