eighteen isolates of a nonchromogenic, slowly growing, non-tuberculous species of the genus Mycobacterium were cultured from respiratory specimens obtained over the last eight years from 17 patients in the Netherlands. These isolates were grouped because they revealed a unique 16S rRNA gene sequence and were related to Mycobacterium xenopi. None of the 17 patients met the American Thoracic Society diagnostic criteria for non-tuberculous mycobacterial disease, which distinguishes the novel isolates from the related species, M. xenopi. A polyphasic taxonomic approach, including identification by biochemical and phenotypical analysis, hsp65 gene sequencing and PCR restriction enzyme pattern analysis, and sequence analyses of the rpoB gene and 16S–23S internal transcribed spacer supported the separate species status of the novel isolates. The name Mycobacterium noviomagense sp. nov. is proposed for the novel strains. The type strain is NLA000500338T (DSM 45145T = CIP 109766T). A more distinctive taxonomy of NTM is a prerequisite for the assessment of their clinical relevance. Improved detection and identification techniques have triggered renewed interest in non-tuberculous mycobacteria (NTM) and their role as opportunistic pathogens. PCR techniques and 16S rRNA gene sequence analysis have brought to light a series of novel NTM species, however, the clinical relevance of these species is not always clear (Tortoli, 2003; Tortoli et al., 2001; Griffith et al., 2007).

NTM infections present predominantly as chronic pulmonary disease, although extrapulmonary and disseminated infections have also been described (Griffith et al., 2007). Local immunosuppression due to pre-existing pulmonary disease and systemic immunosuppression, e.g. in haematological malignancy, immunosuppressive medication and HIV/AIDS, have been identified as predisposing factors (Griffith et al., 2007) for NTM infections. Infection has to be differentiated from contamination and pseudo-infection, characterized by the recovery of single NTM isolates from the respiratory or digestive tract without signs of disease (Griffith et al., 2007; Portaels, 1995). Their ubiquitous presence in the environment, survival in flowing water systems and resistance to disinfectants implies that NTM often represent laboratory or medical equipment contamination (Griffith et al., 2007; Portaels, 1995; van Klinkeren & Pullen, 1993). The diagnostic criteria proposed in a Statement by the American Thoracic Society (ATS) are designed to differentiate between true infection and pseudo-infection or contamination, based on clinical, radiological and microbiological features (Griffith et al., 2007).

This study describes the grouping of 18 previously unknown Mycobacterium isolates with identical 16S rRNA gene sequences and with a high degree of gene sequence similarity to strains of Mycobacterium xenopi. As other features of these novel strains were highly distinct...
The 18 novel isolates were acquired from pulmonary samples (13 from sputum, 4 from broncho-alveolar lavage fluid and 1 from a post-mortem lung biopsy) of 17 patients in the Netherlands between January 1999 and January 2007. To determine clinical relevance, we examined the medical records of all 17 patients; their baseline characteristics are displayed in Table 1. The predominance of male patients, mean age and history of chronic pulmonary disease are comparable with previous NTM studies (Griffith et al., 2007; Henry et al., 2004). None of the patients had clinical and radiographic features suggestive of mycobacterial lung disease; one was systemically immuno-compromised due to HIV co-infection. The post-mortem lung biopsy sample showed histological features of bronchopneumonia and invading bacteria, without features of mycobacterial disease such as granuloma formation. All patient samples were negative for acid-fast bacilli on direct microscopy which suggested the presence of a low number of NTM in the original sample or contamination after sample division for culture and microscopy. Although follow-up sputum cultures were performed for 16 patients, only one patient produced another culture that was positive for the novel strains. All others had a single positive culture. Based on these findings, none of the patients from whom the novel strains were isolated met the ATS criteria for pulmonary NTM disease (Griffith et al., 2007). Good clinical response to non-antimycobacterial regimes, the subsequent establishment of alternative diagnoses and the observed spontaneous conversion to negative cultures suggested that the novel strains were not the causative agent of these patients’ symptoms. The novel strains therefore seem to have no clinical relevance, which distinguishes them from phylogenetically related, but more pathogenic species such as *M. xenopi* and *Mycobacterium heckeshornense* (Griffith et al., 2007; Roth et al., 2000; van Ingen et al., 2008).

Two patients received antituberculosis treatment for an average period of 10 weeks, after a presumptive diagnosis of TB. Treatment of patients not meeting the ATS diagnostic criteria is potentially harmful to patients in terms of adverse effects and costs (van Creveld et al., 2001). Geographical clustering of the patients was observed, favouring the south-east of the Netherlands, in adjacent areas of the Limburg (7 cases), Gelderland (5 cases) and Noord-Brabant (2 cases) provinces. This clustering suggested the presence of the novel strains in specific local environments or tap water. Since the clustering was seen geographically, but not over time, contamination from medical machinery or the laboratories involved seemed less likely.

All of the novel isolates were subjected to laboratory diagnosis by the National Mycobacteria Reference Laboratory of the National Institute for Public Health and the Environment (RIVM). The RIVM provides molecular identification, drug susceptibility testing and epidemiological typing of mycobacterial isolates for all healthcare institutions in the Netherlands.

Biochemical identification and HPLC analysis of cell-wall mycolic acid content were performed using previously described approaches (Lévy-Frébault & Portaels, 1992; Centers for Disease Control and Prevention, 1996). Eight isolates (4 *M. xenopi*, 4 of the novel strains) were subjected to biochemical testing. The results are detailed in Table 2. Morphologically, two patterns were clearly discernible. On Middlebrook 7H10 media, the *M. xenopi* isolates were scotochromogenic, showing yellow pigmentation, whereas

### Table 1. Characteristics of the patients in the study group

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>13 (77 %)</td>
</tr>
<tr>
<td>Mean age (yr) (range)</td>
<td>53 (29–86)</td>
</tr>
<tr>
<td>Dutch origin</td>
<td>16 (94 %)</td>
</tr>
<tr>
<td>Pre-existing pulmonary disease</td>
<td>15 (88 %)</td>
</tr>
<tr>
<td>COPD</td>
<td>8 (47 %)</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>4 (24 %)</td>
</tr>
<tr>
<td>Healed tuberculosis</td>
<td>2 (12 %)</td>
</tr>
<tr>
<td>Recurrent pulmonary infection*</td>
<td>3 (18 %)</td>
</tr>
<tr>
<td>Bronchiectasis</td>
<td>2 (12 %)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>5 (29 %)</td>
</tr>
<tr>
<td>Past smoker</td>
<td>3 (18 %)</td>
</tr>
<tr>
<td>Alcohol abuse</td>
<td>3 (18 %)</td>
</tr>
<tr>
<td>HIV infection</td>
<td>1 (6 %)</td>
</tr>
</tbody>
</table>

* >3 In 6 months prior to sampling.

### Table 2. Biochemical identification results for the novel isolates and closely related species

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth at 45 °C</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Morphology</td>
<td>NC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
</tr>
<tr>
<td>Colony size</td>
<td>Small</td>
<td>Large</td>
<td>NP</td>
<td>Small</td>
</tr>
<tr>
<td>Tolerance to (in LJ medium):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isoniazid 10 μg ml⁻¹</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>NP</td>
</tr>
<tr>
<td>Thiophene 2-carboxylic acid</td>
<td>+</td>
<td>+</td>
<td>NP</td>
<td></td>
</tr>
<tr>
<td>Hydroxyurea 250 μg ml⁻¹</td>
<td>V</td>
<td>+</td>
<td>NP</td>
<td></td>
</tr>
<tr>
<td>Para-nitrobenzoate 500 μg ml⁻¹</td>
<td>+</td>
<td>V</td>
<td>NP</td>
<td>NP</td>
</tr>
</tbody>
</table>

Taxa: 1, *M. noviomagense* sp. nov.; 2, *M. xenopi*; 3, *M. heckeshornense* (data from Roth et al., 2000); 4, *M. botniense* (Torkko et al., 2000). None of the taxa were able to tolerate 5 % NaCl in Lowenstein–Jensen (LJ) medium. +, Positive; −, negative; V, variable; NC, nonchromogenic; SC, scotochromogenic; NP, not published.
colonies of the novel species were smaller and nonchromo-
genic. All M. xenopi isolates grew at 45 °C, as previously
reported (Torkko et al., 2000), but the novel strains were
unable to grow at this temperature (Table 2). Biochemically,
the novel isolates were indistinguishable from the cluster
comprising M. xenopi, Mycobacterium botniense and M.
heckeshornense, with negative results for urease, Tween 80
hydrolysis, niacin production, nitrate reductase, acid
phosphatase and semi-quantitative catalase. HPLC of
the novel isolates revealed a pattern characterized by one early
and one late cluster of peaks, a profile similar to that of M.
xenopi, M. heckeshornense and M. botniense (Fig. 1). The
HPLC mycobacterium library (available online at http://
www.MycobacToscana.it) was used for this comparison.

Susceptibility testing was performed for eleven of the novel
isolates from eleven patients using the agar dilution
method (van Klingen et al., 2007). For the novel isolates,
we recorded in vitro resistance to rifampicin (MIC
2 mg l⁻¹), resistance or intermediate susceptibility to
ethambutol (MIC 10–20 mg l⁻¹) and intermediate sus-
exceptibility to isoniazid (MIC 0.5–1 mg l⁻¹). The novel
species proved susceptible in vitro to streptomycin,
cycloserine, prothionamide, amikacin, ciprofloxacin, clo-
fadimine, clarithromycin and rifabutin. The drug suscept-
ibility pattern for the novel isolates differed slightly from
clinical isolates of M. xenopi tested at RIVM which were
mostly susceptible, in vitro, to rifampicin (MIC 0.5–
1 mg l⁻¹). These results for M. xenopi are in accordance
with previous reports (Dauendorff et al., 2002).

For molecular identification, sequencing of the full 16S rRNA
gene and 16S–23S internal transcribed spacer (ITS), partial
rpoB and hsp65 genes, and PCR restriction enzyme pattern
analysis (PRA) of the hsp65 gene were performed using
previously described methods (Kim et al., 1999; Roth et al.,
1998; Springer et al., 1996; Telenti et al., 1993). The sequences
obtained were compared with the GenBank/EMBL (NCBI,

The full 16S rRNA gene sequence for the novel species showed
96 % sequence similarity with that of M. xenopi and was 97 %
similar to those of M. heckeshornense and Mycobacterium
shimoidei. A sequence difference of 1 % has been proposed in
the literature as the threshold for the designation of a novel
species (Hall et al., 2003; Tortoli, 2003).

The full 16S rRNA gene sequence of the novel strains was
aligned with those of reference strains of the closest related
mycobacteria using CLUSTAL-X software (Thompson et al.,
1997). The resulting topology and tree, inferred by
neighbour-joining and visualized using the LOFT software
package (van der Heijden et al., 2007) were evaluated by
bootstrap analyses based on 1000 resamplings (Fig. 2).

Analysing only the hypervariable region A of the 16S rRNA
gene (151 bp), we found a 100 % match in the GenBank/
EMBL database to a strain designated 'most closely
resembling M. xenopi', as reported by Hall et al. (2003).
Analysis of the phenotypic and genetic characteristics of the
novel species (Table 2, Figs 1, 2 and 3) demonstrates that
very subtle 16S rRNA gene sequence differences can be
associated with extensive divergence from the closest
related species. This brings into question the use of
monophasic identification methods.

Analysis of the 16S–23S ITS region revealed mixed
sequence patterns for all 18 novel isolates, even from
single colony cultures, and necessitated cloning. For
cloning of the ITS, amplicons were generated using primers
provided with the INNO LiPA Mycobacteria v2 kit
(Innogenetics), and cloned in the PGEM-T Easy vector
(Prome ga) according to the manufacturer's instructions.
Thirty colonies of transformed Escherichia coli strain DH5F
were picked for each sample, cultured and used to prepare
plasmid DNA using the QIAprep 96 Turbo BioRobot kit
(Qiagen). For sequencing of the ITS region cloned into the
PGEM-T vector, the universal vector primers M13(−21)
and M13rev were used on the plasmid preparation as
target. Cloning resulted in the recognition of two distinct
copies of the ITS, both with <68 % sequence similarity to
M. xenopi. A 93 % sequence similarity was noted between
the two ITS copies. The presence of multiple copies of the
16S–23S ITS region, thus possibly multiple rRNA operons,
is unexpected. This phenomenon has not been described for *M. xenopi* or for closely related slow-growing NTM species and thus supports the separate species status of the novel isolates.

The *rpoB* gene sequence of the novel isolates was 95% similar to that of the recently described species *Mycobacterium seoulense* and only 92% similar to that of *M. xenopi*. For the *hsp65* gene sequence, the most closely related sequences (95%) were found among members of the *Mycobacterium avium* complex and *Mycobacterium brandieri*, with <93% similarity to *M. xenopi*. The considerable divergence in these two targets from the otherwise related cluster comprising *M. xenopi*, *M. botniense* and *M. heckeshornense* supports the separate species status of the novel isolates. The *hsp65* and *rpoB* gene sequences were aligned with those of related mycobacterial species, as for the 16S rRNA gene sequence. The resulting topologies and trees are available as Supplementary Figs S1 and S2 (in IJSEM Online).

The *hsp65* gene PRA results for the novel isolates, *M. xenopi*, *Mycobacterium tuberculosis* H37Rv T and *M. botniense* ATCC 700701 T are shown in Fig. 3. For the novel isolates, digestion with *Bst*EII resulted in fragments of 240/120/100 bp, digestion with *Hae*III gave fragments of 130/10/70/45 bp. A PRAsite (http://app.chuv.ch/prasite/index.html) comparison showed this to be a unique fragment length combination. Isolates of *M. xenopi* and *M. tuberculosis* tested simultaneously were correctly identified using the PRAsite database; no entry was found for *M. botniense*.

**Description of Mycobacterium noviomagense sp. nov.**

*Mycobacterium noviomagense* (no.vi.o.ma.gen’s e. N.L. neut. adj. pertaining to Noviomagus, the Roman name of

![Fig. 3. PRA typing results for the *hsp65* gene. Different fragment length patterns are observed for *M. botniense* (lane 1), *M. xenopi* (lanes 2–5), *M. tuberculosis* H37Rv T (lane 6) and strain NLA000500338 T (*M. noviomagense* sp. nov.; lanes 7–10).](image)
the major city in the endemic region in the Netherlands and the location of the reference hospital; current name: Nijmegen).

Acid-fast and Gram-positive rods. Colonies are nonchromogenic and appear after 4 weeks of culture at 37 °C, no growth occurs at 45 °C. Negative in tests for urease, Tween 80 hydrolysis, niacin production, nitrate reductase, acid phosphatase and semi-quantitative catalase. Can be readily identified by its unique rRNA gene sequences.

The type strain, NLA000500338^T (=DSM 45145^T=CIP 109766^T), was recovered from sputum.

Acknowledgements

We respectfully thank Dr Pirjo Torkko of the Laboratory of Environmental Microbiology, National Public Health Institute, Kuopio, Finland, for providing us with *M. bovis* ATCC 700701^T for comparative analysis. We thank Rebecca Millecamp at Innogenetics, Gent, Belgium, for assistance with the ITS sequencing and Anita Schuerch for assistance with the phylogenetic analyses.

References


