Nasal Mucociliary Clearance in Smokers: A Systematic Review

Awal Prasetyo1,2 Udadi Sadhana2 Jethro Budiman1,2,3

1 Department of Biomedical Science, Faculty of Medicine, Diponegoro University, Semarang, Indonesia
2 Department of Anatomic Pathology, Faculty of Medicine, Diponegoro University - Dr. Kariadi Hospital, Semarang, Indonesia
3 Department of Emergency Unit, Panti Wilasa Citarum Hospital, Semarang, Indonesia

Address for correspondence Jethro Budiman, MD, Faculty of Medicine, Diponegoro University, Jl. Prof. Sudharto, SH Tembalang, Semarang 50275, Indonesia (e-mail: jethrobudiman93@gmail.com).

Abstract

Introduction Smoking is one of the most important causes of mortality and morbidity in the world, as it is related to the risk factor and etiology of respiratory-tract diseases. Long-term smoking causes both structural and functional damage in the respiratory airways, leading to changes in nasal mucociliary clearance (NMC).

Objectives The aim of the present study was to look systematically into the current literature and carefully collect and analyze results to explore NMC in smokers.

Data Synthesis Two independent reviewers conducted a literature search on some Electronic database: Pubmed, Medline, Ebsco, Springer Link, Science Direct, Scopus, and Proquest searching for articles fulfilling the inclusion and exclusion criteria. The lead author independently assessed the risk of bias of each of the included studies and discussed their assessments with the other two authors to achieve consensus. Of the 1,654 articles identified in the database search, 16 met the criteria for this review. Most of the articles (15 out of 16) showed the impairment of NMC in smokers.

Conclusion The present systematic review suggests that there is an impairment of NMC in smokers. The impairment is not only observed in cigarette smoking, but also in passive smoking, bidi smoking, electronic smoking, and hookah smoking. The impairment of NMC in chronic exposure to smoking is caused by the ciliotoxic effect, hypersecretion and viscoelastic change of mucous, airway surface liquid depletion, increased oxidative stress, and deteriorations in the inflammatory and immune systems.

Keywords ► nasal mucociliary clearance ► smokers ► smoking

Introduction Smoking is one of the most important causes of mortality and morbidity in the world, especially in developing countries.1–4 According to the World Health Organization (WHO), there are around 1.1 billion smokers in the world, and half of them die every year (2015).1 There are many types of smoking, such as cigarette smoking, bidi smoking, hookah smoking, electronic cigarette (EC) smoking, passive smoking, and many more.2–7 All of these types of smoking are related to the risk factor and etiology of many health problems, especially in the respiratory tract. In the respiratory tract,
smoking is related to upper respiratory tract infection, asthma, chronic obstructive pulmonary disease, nasopharyngeal cancer, and lung cancer. Smoking is a significant risk factor for respiratory diseases, considering its ability to lead to an alteration of nasal mucociliary clearance (NMC).

Nasal mucociliary clearance is the primary innate defense mechanism of the nose and paranasal sinuses, and it consists of mucous layer, airway surface liquid layer, and ciliary epithelia. Mucus produced by the goblet cells of the mucosa is required for binding of the airborne pathogens (such as inhaled microbes and irritants). Ciliated epithelial cells are expectorated or swallowed. Normal functioning of the NMC requires high frequency, coordinated, and directional ciliary beating (metachronal waves) as well as proper mucus secretion and airway surface liquid. Ciliary beat frequency (CBF) was shown to be the major determinant of NMC efficiency. Nasal mucociliary clearance is influenced by physiological factors, such as mucus production and CBF; anatomic factors, such as nasal airflow and patency of the sinus ostia in the prechambers; and biochemical factors, such as mucus composition.

Various factors, like aging, body temperature, drugs (like adrenaline, acetylcholine, corticosteroid, and intranasal drug), tobacco use and smoking, and environment factors (like pollutant, smoke, and dust) affect this system, besides pathological conditions such as rhinits allergy, acute or chronic rhinosinusitis, and deviated nasal septum. Any dysfunction in this defense system increases the inflammatory process and stasis of airborne pathogens, and the respiratory system becomes prone to obstructive airway diseases and infections. Long-term smoking causes both structural and functional damage in the respiratory airways, leading to changes in NMC.

The adverse effects of smoking on NMC have been reported and explained in various studies, but we could not find any systematic review about NMC in smokers. The aim of the present study was to look systematically into the current literature and carefully collect and analyze results to explore NMC in smokers.

**Review of the Literature**

**Scope of the Review: Inclusion and Exclusion Criteria**

**Inclusion criteria:**

1. Publication type: full-text articles discussing NMC in smokers
2. Objective and outcome measures are not relevant (are not about NMC in smokers)
3. Confounding variables are related to outcome of NMC in smokers

**Exclusion criteria:**

1. Population: in-vitro samples
2. Objective and outcome measures are not relevant (are not about NMC in smokers)
3. Confounding variables are related to outcome of NMC in smokers

**Literature Search**

The current systematic review was conducted in accordance with Cochrane handbook for systematic reviews and is reported by using the guidelines of the preferred reporting items for systematic review and meta-analysis (PRISMA). A systematic search strategy was conducted in the following electronic databases: Pubmed, Medline, Ebsco, Springer Link, Science Direct, Scopus, and Proquest. The search was conducted using the following keywords for title and abstract: nasal mucociliary clearance OR nasal mucociliary transport AND smoke OR smoker OR smoking OR cigarette. In the Pubmed database, the keywords were searched through the [tiab] and [MeSH] tags. No limitation was applied during the search. The reference lists of the retrieved papers were also examined to avoid missing any published data.

**Data Collection and Analysis**

Studies were selected for retrieval after two independent reviewers (A. P. and U. S.) had collected titles and abstracts identified in the electronic search. The results of the two reviewers were compared by a third independent reviewer (J. B.), and any differences of opinion were resolved by discussion. Full papers from potential studies were independently assessed by the investigators (A. P. and U. S.).

All studies selected for this systematic review were screened by two reviewers indepently to validate the results (A. P. and U. S.). The data from all retrieved studies are

**Table 1** Newcastle-Ottawa scale (prospective study)

| No. | First author, year | Selection | Comparability | Outcome | Total |
|-----|--------------------|-----------|---------------|---------|-------|
| 1   | Dülger et al, 2018  | *         | *             | *       | 5     |
| 2   | Utiyama et al, 2016 | *         | *             | *       | 7     |
| 3   | Yadav et al, 2014  | *         | *             | *       | 7     |
| 4   | Ramos et al, 2011  | *         | *             | *       | 7     |

*Maximum points for comparability were 2.
presented in the summary table (Table 1) featuring key points of each study. The following data were collected: first author and year, study design, sample, sample characteristic (age and gender), smoking characteristic (type, years of smoking, cigarettes-/day or packs/year), NMC measurement test, and result.

Quality Assessment
The lead author independently assessed the risk of bias of each of the included studies and discussed their assessments with other two authors to achieve consensus. The Newcastle-Ottawa scale adapted for cross-sectional studies, Newcastle-Ottawa scale cohort version, and the Cochrane risk of bias were used to assess the methodological quality of the studies.21,23–25 The Newcastle-Ottawa scale adapted for cross-sectional studies was used to assess cross sectional studies; interpretation of the total score was: 9 to 10 points were considered very good studies, 7 to 8 points were considered good studies, 5 to 6 points were considered satisfactory studies, and 0 to 4 were considered unsatisfactory studies.23 The Newcastle-Ottawa scale cohort version was used to assess prospective studies; interpretation of the total score was: ≥ 7 points were considered good studies, 5 to 6 points were considered fair studies, and < 5 points were considered poor studies.24–27 The Cochrane risk of bias was used to assess randomized control trial studies, whose results were either high risk or some concerns or low risk.21

Results

Selection of Articles for Review
Fig. 1 summarized the identified, screened, and included articles for review. Initially, 1,622 peer-reviewed articles were identified from electronic databases, and an additional 32 articles were identified through other sources (search engine). After removing duplicates, 384 articles remained for title and abstract screening. Articles that did not meet the inclusion and exclusion criteria were not further screened. Twenty-six articles were screened for eligibility, 16 of which met all the inclusion criteria.

Assessment of Study Validity (Risk of Bias)
All eligible studies were associated with NMC in smokers. Table 2 provides quality scores for cross-sectional studies; all studies that got 6 to 8 points were included in the satisfactory and good studies category. Table 1 provides quality scores for prospective studies; all studies that got 5 to 7 points were included in the fair and good studies category. Table 3 provides quality scores for randomized control trial studies; all studies presented results of some concerns or low risk.

Study Characteristic
Study characteristics for the included studies could be seen in Table 4. The majority of the studies followed the cross-sectional design (11 out of 16). Most of the samples were in productive age and reported cigarette smoking. Nasal mucociliary clearance measurement tests mostly used saccharin transfer/transit time test.

Most of the studies showed the impairment of NMC in smokers. Nasal mucociliary clearance in cigarette smokers was explained in 13 studies (11 studies reported significant impairment in smokers, 1 study reported insignificant impairment in smokers, 1 studies reported that the NMC value in smokers was significantly lower than in non-smokers). Nasal mucociliary clearance in passive smokers was explained in three studies, and all of the studies reported that the NMC value in passive smokers was significantly lower than in non-smokers.
Nasal Mucociliary Clearance in Smokers

Most of the studies (15 out of 16 studies) showed the impairment of NMC in smokers. One study (Nicola et al, 2014) reported that the NMC value in smokers was lower than non-smokers. Nicola et al (2014) speculated that young smokers may have a protective response to cigarette smoking (increase of the CBF and transport system). The impairment was not only observed in active cigarette smoking, but also in bidi, EC, hookah, and passive smoking. This happens because all of them contain harmful constituents that affect NMC. The saccharin transfer time test was used in many studies to evaluate NMC because it is easy, safe, and inexpensive. Various chemicals present in cigarette smoke, including acrolein, formaldehyde, carbon monoxide, nicotine, cotinine, acetaldehyde, phenol, and potassium cyanide, have been identified as having high toxicity to NMC. The gaseous phase of cigarette smoke contains high concentrations of free radicals (>10^15 molecules per puff), resulting in increased oxidative stress that, in turn, causes changes in the structure and function of the NMC. The impairment of NMC in chronic exposure to cigarette smoke is caused by the ciliotoxic effect, hypersecretion and viscoelastic change of mucous (particularly of more viscous properties), airway surface liquid depletion, increased oxidative stress, and deteriorations in the inflammatory and immune systems (increased of macrophages, neutrophils, and proinflammatory cytokines), which cause elongation of the NMC time and stagnation of toxic substances. The ciliotoxic effect of cigarette smoking reduces cilia genesis, paralyzes ciliary beating activity (reduces CBF), is related to abnormality in the cilia ultrastructure, and decreases the number of cilia. Cigarette smoking also causes metaplastic changes of the respiratory mucosa, with increase in the number and size of the goblet cells that leads to increased production of respiratory airway secretions. The acrolein in cigarette smoke reduces the cystic fibrosis transmembrane conductance regulator (CFTR) gene expression, resulting in airway surface liquid depletion and mucus stasis in the airway epithelium. Other studies also showed that chronic exposure to cigarette smoke stimulates the parasympathetic nervous system (glandular hypersecretion and vasodilatation), inhibits secretion of Cl^- and K+ conductance in normal respiratory epithelium cells, alters epithelial salts and water transport, alters morphology of the epithelium in the entire of respiratory tract (metaplasia with keratinisation), reduces cells viability, and induces cell apoptosis (opposite mitogenic effect or proapoptotic depending on the concentration of smoke and impairment of cell regeneration in respiratory epithelium), induces matrix metalloproteinases (zinc.

### Table 2: Newcastle-Ottawa scale adapted for cross-sectional studies

| No. | First author, year | Selection 1 | Selection 2 | Selection 3 | Selection 4 | Comparability 1 | Comparability 2 | Outcome 1 | Outcome 2 | Total |
|-----|--------------------|-------------|-------------|-------------|-------------|----------------|----------------|-----------|-----------|-------|
| 1   | Arıcıgil M and Arbağ, 2018^2 | *           | *           | *           | *           | *              | *              | *         | *         | 6     |
| 2   | Paul et al, 2018^3 | *           | *           | *           | *           | *              | *              | *         | *         | 7     |
| 3   | Solak et al, 2018^2 | *           | *           | *           | *           | *              | *              | *         | *         | 6     |
| 4   | Uzeloto et al, 2018^48 | *           | *           | *           | *           | *              | *              | *         | *         | 6     |
| 5   | Habesoglu et al, 2015^29 | *           | *           | *           | *           | *              | *              | *         | *         | 6     |
| 6   | Pagliuca et al, 2015^12 | *           | *           | *           | *           | *              | *              | *         | *         | 6     |
| 7   | Baby et al, 2014^17 | *           | *           | *           | *           | *              | *              | *         | *         | 6     |
| 8   | Nicola et al, 2014^28 | *           | *           | *           | *           | *              | *              | *         | *         | 6     |
| 9   | Xavier et al, 2013^20 | *           | *           | *           | *           | *              | *              | *         | *         | 7     |
| 10  | Habesoglu et al, 2012^38 | *           | *           | *           | *           | *              | *              | *         | *         | 8     |
| 11  | Proença et al, 2011^33 | *           | *           | *           | *           | *              | *              | *         | *         | 8     |

Maximum points for selection number 4, comparability, and outcome number 1 were 2.

### Table 3: Cochrane risk of bias: Kumral TL, 2016^6

| No. | Domain | Description of domain | Results |
|-----|--------|-----------------------|---------|
| 1.  | Domain 1 | risk of bias arising from the randomization process | some concerns |
| 2.  | Domain 2 | risk of bias due to deviations from the intended interventions (effect of adhering to intervention) | some concerns |
| 3.  | Domain 3 | missing outcome data | low risk |
| 4.  | Domain 4 | risk of bias in measurement of the outcome | low risk |
| 5.  | Domain 5 | risk of bias in selection of the reported result | low risk |
### Table 4 Study characteristics

| No. | First author, year | Study design | Sample (N) | Sample characteristic: age (year), gender (male, female) | Smoking characteristic: type, years of smoking, cigarettes/day and/or packs/year | NMC measurement test | Result |
|-----|-------------------|--------------|------------|-------------------------------------------------|---------------------------------------------------------------------------------|---------------------|--------|
| 1.  | Arıcil and Arbağ, 2018 | Cross-sectional | Non-smokers: 40, Smokers I (once every week): 20, Smokers II (more than once a week/2–5 session-week): 18 | Age: 18–41 years, Non-smokers: 27.5 ± 6.4, Smokers I: 27.6 ± 6.8, Smokers II: 27.7 ± 6.3, Gender: Male, Non-smokers: 22.18, Smokers I: 21.9, Smokers II: 10.8 | Hookah smoking | Saccharin transfer/transit time test | NMC value (STT) in smokers was significantly higher than in non-smokers (p < 0.001). NMC value (STT) in the smokers-II group was significantly higher than in the smokers-I group and non-smokers (19.2 ± 2.5; 11.9 ± 2.8; 11.1 ± 3; p < 0.001). |
| 2.  | Dulger et al, 2018 | Prospective study (2 years period) | Non-smokers: 35, Smokers: 50 | Age: 18–65 years, Non-smokers: 27.5 ± 6.4, Smokers: 26.9 ± 6.8, Gender: Male, Non-smokers: 22.18, Smokers: 21.9 | Cigarette smoking | Saccharin transfer/transit time test | NMC value (STT) in smokers was significantly higher than in non-smokers (12 minutes, 9 minutes; p < 0.001). No statistically significant difference in nasal MCC value and packs/year (p = 0.943). |
| 3.  | Paul et al, 2018 | Cross-sectional | Non-smokers: 20, Cigarette smokers: 20, Bidi smokers: 20 | Age: 20–40 years, Non-smokers: 29.3 ± 6.25, Cigarette smokers: 31.2 ± 5.42, Bidi smokers: 30.2 ± 6.77, Gender: Male | Cigarette and Bidi smoking | Methylen blue dye test | NMC value was significantly decreased in bidi smokers as compared with cigarette smokers and non-smokers (59.25 ± 12.38 mm; 67 ± 5.48 mm; 67.89 ± 4.10 mm; p < 0.05). Multivariate analysis revealed a significant association between NMC and bidi smoking, number of cigarettes or bidis smoked per day, and packs/year (p < 0.05). |
| 4.  | Solak et al, 2018 | Cross-sectional | Non-smokers: 74, Smokers: 123 | Age: 18–55 years, Non-smokers: 38.79 ± 9.66, Cigarette smokers: 40.33 ± 8.94, Gender: Male, Non-smokers: 58.16, Smokers: 23.100 | Cigarette smoking | Saccharin transfer/transit time test | NMC value (STT) in smokers was significantly higher than in non-smokers (536.19 ± 254.81 seconds 320.43 ± 184.98 seconds p < 0.001). Positive correlation between STT and number of cigarettes/day (p = 0.012, r = 0.225), STT and packs/year (p = 0.001, r = 0.296). STT and years of smoking (p = 0.027, r = 0.200). |
| 5.  | Uzeloto et al, 2018 | Cross-sectional | Non-smokers: 69, Smokers: 70 | Age: 30–50 years, Non-smokers: 39.5, Cigarette smokers: 40.00, Gender: Male, Non-smokers: 32.37, Smokers: 33.37 | Cigarette smoking | Saccharin transfer/transit time test | NMC value (STT) in smokers was significantly higher than in non-smokers (9.7 minutes; 9.145 minutes; p > 0.05). |
| 6.  | Kumral et al, 2016 | Prospective randomized | Non-smokers: 40, Smokers: 58 | Age | EC smoking duration: 3 months | Saccharin transfer/transit time test | NMC value (STT) in electronic cigarette was significantly higher than in... |
| No. | First author, year | Study design | Sample (N) | Sample characteristic: age (year), gender (male, female) | Smoking characteristic: type, years of smoking, cigarettes/day and/or packs/year | NMC measurement test | Result |
|-----|--------------------|--------------|------------|--------------------------------------------------------|--------------------------------------------------------------------------------|---------------------|--------|
| 7.  | Utiyama et al, 2016 | Prospective study (12 months duration) | Quitters: 20, Smokers: 13 | Age: Quitters: 51 ± 9, Smokers: 52 ± 10; Gender: Quitters: 9,11, Smokers: 6,7 | Cigarette smoking Packs/year: Quitters: 40 ± 27, Smokers: 45 ± 28 | Saccharin transfer/transit time test | • NMC value (STT) in smokers showed increases of impairment after 12 months observation (±14 minutes; ±15 minutes). • NMC value (STT) in quitter showed decreases of impairment after 12 months observation (±15 minutes, ±10 minutes). |
| 8.  | Habesoglu et al, 2015 | Cross-sectional | Group I (control): 18 Group II (living with at least one adult smoker outside the house): 15 Group III (living with at least one adult smoker inside the house): 17 | Age: 6–14 years Group I: 10.22 ± 2.39, Group II: 11.2 ± 1.97, Group III: 10.65 ± 2.09; Gender: Group I: 9.9, Group II: 7.8, Group III: 9.8 | Passive smoking | Saccharin transfer/transit time test | • NMC value (STT) in group II was insignificantly higher than in group I (p = 0.067). • NMC value (STT) in group III was significantly higher than in group I (p < 0.001). • NMC value (STT) in group III was insignificantly higher than in group II (p = 0.173). • NMC value (STT) in groups I, II, and III: 7.33 ± 2.91 minutes, 10.00 ± 4.78 minutes, 12.41 ± 3.44 minutes. |
| 9.  | Pagliuca et al, 2015 | Cross-sectional | Non-smokers: 30 Ex-smokers: 30, Smokers:30 | Age: Non-smokers: 53.17 ± 5.53, Ex-smokers: 50.73 ± 6.51, Smokers: 51.97 ± 6.02; Gender: Non-smokers: 19,11, Ex-smokers: 23,7, Smokers: 24,6 | Cigarette smoking Cigars/day: ex-smokers:25 ± 7.76 smokers: 24.67 ± 6.3 | Saccharin transfer/transit time test | NMC value (STT) in smokers was significantly higher than in others (smokers: 15.6 minutes, ex-smokers: 11.77 minutes, non-smokers: 11.71 minutes, p < 0.0001). |
| 10. | Baby et al, 2014 | Cross-sectional | Non-smokers: 30, Smokers: 30 | Age: 21–40 years Non-smokers: 26.8 ± 1.2, Smokers: 24.96 ± 1; Gender: male | Cigarette smoking | Saccharin transfer/transit time test | NMC value (STT) in smokers was significantly higher than in the non-smokers group (481.2 ± 29.83 seconds 300.32 ± 17.42 seconds; p < 0.01). A statistically significant increase in the NMC value was observed with an increase in duration of smoking habit (NMC in smoking <1 year: 492.25 ± 79.93 seconds; 1–5 years: 516.7 ± 34.01 seconds > 5 years: 637.5 ± 28.49 seconds p = 0.0000). |

(Continued)
### Table 4 (Continued)

| No. | First author, year | Study design | Sample (N) | Sample characteristic: age (year), gender (male, female) | Smoking characteristic: type, years of smoking, cigarettes/day and/or packs/year | NMC measurement test | Result |
|-----|-------------------|--------------|------------|----------------------------------------------------------|-------------------------------------------------------------------------------|---------------------|--------|
| 11. | Nicola et al, 2014<sup>28</sup> | Cross-sectional | Non-smokers: 32  
Light smokers: 14  
Moderate smokers: 34  
Heavy smokers: 27  
Smokers < 2.5 packs/year: 20  
Smokers > 2.5 packs/year: 20  
Age: 18–35 years  
Non-smokers: 21  
Smokers < 2.5 packs/year: 19  
Smokers > 2.5 packs/year: 24  
Gender  
Non-smokers: 29, 3  
Smokers < 2.5 packs/year: 20.0  
Smokers > 2.5 packs/year: 17.3 | Cigarette smoking  
Years of smoking: 33  
Smokers < 2.5 packs/year: 3  
Smokers > 2.5 packs/year: 7  
Packs/year: 2.5 packs/year: 0.7  
Gender  
Non-smokers: 29, 3  
Smokers < 2.5 packs/year: 20.0  
Smokers > 2.5 packs/year: 17.3 | Saccharin transfer/transit time test |  
NMC value (STT) in smokers was significantly lower than in non-smokers (5.9 ± 3.1 minutes; 7.7 ± 4.1 minutes; p = 0.033). |
| 12. | Yadav et al, 2014<sup>7</sup> | Prospective study (five years duration) | Non-smokers: 50  
Active smokers: 50  
Passive smokers: 50  
Age: 20–50 years  
Non-smokers: 38.7  
Active smokers: 39.1  
Passive smokers: 35.1  
Gender:  
Non-smokers: 44.6  
Active smokers: 42.8  
Passive smokers: 24.26 | Cigarette smoking (active and passive) | Saccharin transfer/transit time test |  
NMC value (STT) in smokers (active and passive) was significantly higher than in non-smokers (23.08 ± 4.60; 20.31 ± 2.51; 8.57 ± 2.12; p < 0.0003).  
NMC value (STT) in active smokers was insignificantly higher than in passive smokers (p = 0.03). |
| 13. | Xavier et al, 2013<sup>20</sup> | Cross-sectional | Non-smokers: 24  
Light smokers: 14  
Moderate smokers: 34  
Heavy smokers: 27  
Age: Non-smokers: 50 ± 11  
Light smokers: 51 ± 15  
Moderate smokers: 49 ± 7  
Heavy smokers: 46 ± 8  
Gender:  
Non-smokers: 7.17  
Light smokers: 5.9  
Moderate smokers: 14, 20  
Heavy smokers: 13, 14 | Cigarette smoking  
Years of smoking: 33 ± 17  
Moderate smokers: 29 ± 9  
Heavy smokers: 32 ± 8  
Packs/day: 24 ± 8  
Gender:  
Non-smokers: 7.17  
Light smokers: 5.9  
Moderate smokers: 14, 20  
Heavy smokers: 13, 14 | Saccharin transfer/transit time test |  
NMC value (STT) in moderate and heavy smokers was significantly higher (p = 0.0001) than in light smokers and non-smokers.  
A positive correlation was observed between STT and cigarettes/day (r = 0.3; p = 0.02). |
| 14. | Habesoglu et al, 2012<sup>28</sup> | Cross-sectional | Non-smokers: 15  
Passive smokers: 15  
Active smokers: 17  
Age: 17–47 years  
Active smokers: 28.12 ± 10.79  
Passive smokers: 29.17 ± 12.18  
Non-smokers: 27.92 ± 11.29  
Gender:  
Active smokers: 11, 6  
Passive smokers: 8, 7  
Non-smokers: 6, 9 | Cigarette smoking (active and passive) | Saccharin transfer/transit time test |  
NMC value (STT) in active smokers was significantly higher than in passive smokers and non-smokers (23.59 ± 12.41 minutes; 12.18 ± 1.55 minutes; p < 0.01).  
NMC value (STT) in the passive group was significantly higher than in the non-smokers group (p < 0.01). |
| 15. | Proença et al, 2011<sup>25</sup> | Cross-sectional | Non-smokers: 19  
Smokers: 19  
Age: Non-smokers: 47 ± 11  
Smokers: 51 ± 16  
Gender:  
Non-smokers: 47 ± 11  
Smokers: 51 ± 16  
Gender:  | Cigarette smoking  
Years of smoking: 33 ± 11  
Packs/year index: 27 ± 11  
Gender:  
Non-smokers: 47 ± 11  
Smokers: 51 ± 16  
Gender:  | Saccharin transfer/transit time test |  
NMC value (STT) in smokers was significantly higher than in non-smokers 8 hours after smoking (16 ± 6 minutes; 10 ± 4 minutes; p = 0.005) and insignificantly higher immediately after smoking (9 ± 5 minutes; p = 0.06). |
Table 4 (Continued)

| No. | First author, year | Study design | Sample (N) | Sample characteristic: age (year), gender (male, female) | Smoking characteristic: type, years of smoking, cigarettes/day and/or packs/year | NMC measurement test | Result |
|-----|--------------------|--------------|------------|----------------------------------------------------------|--------------------------------------------------------------------------------|----------------------|--------|
| 16. | Ramos et al, 2011   | Prospective study (1 year-period) | Non-smokers: 33, Smokers: 33 | Age Non-smokers: 52 ± 14 Smokers: 49 ± 12 Gender: Non-smokers: 18, 18 Smokers: 12, 21 | Cigarette smoking Years of smoking: 21 ± 8 Cigarettes/day: 20 ± 10 Packs/year index: 44 ± 25 | Saccharin transfer/transit time test | • NMC value (STT) in smokers was significantly higher than in non-smokers (±14 minutes, ±8 minutes, p = 0.002). |
|     |                    |              |            |                                                          |                                                                              |                      |   |

Abbreviations: min, minutes; mm, millimeters; NMC, nasal mucociliary clearance; s, seconds; STT, saccharin transfer time.

The hookah, also known as a shisha or water pipe, is a traditional method of smoking tobacco. Both hookah and bidi contain nicotine, harmful gases such as carbon monoxide, and volatile aldehydes, acetate particles, and carcinogenic polycyclic aromatic hydrocarbons (PAHs). The hookah is not a barrier for the noxious smoke from reaching the nasal cavity. The bidi contains nicotine, harmful gases such as carbon monoxide, producing slightly higher serum cotinine, which is a metabolite of nicotine, and slightly higher serum cotinine, which is a metabolite of nicotine, and slightly higher serum cotinine, which is a metabolite of nicotine.
After comparing a 45-minute hookah session to smoking a single cigarette, it was found that hookah smokers had higher concentrations of nicotine, carbon monoxide, and PAHs than cigarette smokers.\textsuperscript{3,4,44} Hookah smoking resulted in increased airway resistance, inflammation, immune cells (neutrophils and lymphocytes), oxidative stress, nitric oxide, and catalase activity in the lungs and NMC of animals.\textsuperscript{5,45,46} In the study by Ayciğil, the group that used hookahs more than once a week was shown to have impaired NMC. This predisposes them to upper respiratory tract inflammation and injury.\textsuperscript{5}

The electronic cigarette (EC) is a device that carries aerosolized nicotine to the respiratory tract.\textsuperscript{6} The EC is marketed as a safer alternative to conventional cigarettes due to its defined composition and noncombustible nature.\textsuperscript{6,36,47} A short-term study investigating the possible side-effects of EC use revealed that EC was safer than cigarettes but had more side-effects than nicotine replacement therapy.\textsuperscript{6} Propylene glycol is the primary ingredient in the majority of EC cartridges on the marketplace today.\textsuperscript{6} Nasal mucociliary clearance in EC smokers was impaired by oxidative stress induced by nicotine exposure via transient receptor potential ankyrin 1 (TRPA 1) receptors.\textsuperscript{6,47} These receptors induce airway surface liquid volume loss and decrease mucus density.\textsuperscript{6,47} Other studies also reported that formaldehyde in EC-generated aerosols related to DNA strand breaks and cell death and propylene glycol thicken the respiratory epithelium by increasing the number of goblet cells and increasing the content of mucin within the goblet cell.\textsuperscript{6,36}

**Strength and Limitation of the Study**

The present systematic review included studies that reported NMC in many types of smoking (cigarette, passive, bidi, hookah, and electronic smoking). In addition, a comprehensive literature search was followed as well as bias protection methods, such as using three independent reviewers.

The limitation of the study was related to the minimal sample of each study and the fact that most of the studies were cross sectional. There were only one randomized controlled trial (RCT) and three prospective studies.

**Future Implication**

The current systematic review is expected to be a scientific consideration to clinician-related NMC in smokers and general information related the dangers of smoking for the public society. Further research is needed on each component of the NMC for development upon this systematic review.

**Final Comments**

Our findings suggest that there is an impairment of NMC in smokers. The impairment is not only seen in cigarette smokers but also in passive, bidi, electronic, and hookah smokers. The impairment of NMC in chronic exposure to smoking is caused by the ciliotoxic effect, hypersecretion and viscoelastic change of mucous, airway surface liquid depletion, increased oxidative stress, and deteriorations in the inflammatory and immune systems.

**Conflict of Interests**

The authors have no conflict of interests to declare.

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