

## Improving Asthma Control Through Telemedicine: A Study of Short-Message Service

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### ABSTRACT

Home peak expiratory flow (PEF) measurement is recommended by asthma guidelines. In a 16-week randomized controlled study on 16 subjects with asthma ( $24.6 \pm 6.5$  years old, asthma duration  $\geq 6$  months), we examined Global System for Mobile Communications (GSM) mobile telephone short-message service (SMS) as a novel means of telemedicine in PEF monitoring. All subjects received asthma education, self-management plan, and standard treatment. All measured PEF three times daily and kept a symptom diary. In the study group, therapy was adjusted weekly by an asthma specialist according to PEF values received daily from the patients. There was no significant difference between the groups in absolute PEF, but PEF variability was significantly smaller in the study group ( $16.12 \pm 6.93\%$  vs.  $27.24 \pm 10.01\%$ ,  $p = 0.049$ ). forced expiratory flow in 1 second ( $FEV_1$ ; % predicted) in the study group was slightly but significantly increased ( $81.25 \pm 17.31$  vs.  $77.63 \pm 14.80$ ,  $p = 0.014$ ) and in the control group, unchanged ( $78.25 \pm 21.09$  vs.  $78.88 \pm 22.02$ ,  $p = 0.497$ ). Mean  $FEV_1$  was similar in the two groups both before and after the study. Controls had significantly higher scores for cough ( $1.85 \pm 0.43$  vs.  $1.42 \pm 0.28$ ,  $p < 0.05$ ) and night symptoms ( $1.22 \pm 0.23$  vs.  $0.85 \pm 0.32$ ,  $p < 0.05$ ). There was no significant difference between the groups in daily consumption of inhaled medicine, forced vital capacity, or compliance. Per patient, per week, the additional cost of follow-up by SMS was €1.67 (equivalent to approximately \$1.30 per 1 Euro), and SMS transmission required 11.5 minutes. Although a study group of 40 patients is needed for the follow-up study to achieve the power of 80% within the 95% confidence interval, we conclude that SMS is a convenient, reliable, affordable, and secure means of telemedicine that may improve asthma control when added to a written action plan and standard follow-up.

### INTRODUCTION

THE PREVALENCE OF ASTHMA, a chronic illness with considerable morbidity and mortality, has been increasing.<sup>1,2</sup> A combination of inhaled corticosteroid (ICS) and long-acting  $\beta_2$ -agonist (LABA) is often effective in sympto-

matic control. Dosing of these drugs is influenced by patient's symptoms, forced expiratory volume in the first second ( $FEV_1$ ), and peak expiratory flow (PEF). Disease exacerbation occurs even in optimally treated compliant subjects with asthma, but poor compliance among them is frequent.<sup>3</sup> Consistent follow-up

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is therefore advisable and recommended by the current guidelines.<sup>4,5</sup> Control of asthma may be assessed by the symptom score noted by the patient in a diary and by office pulmonary function tests (PFT). Although not a substitute for full PFT, PEF obtained by the patient at home with a peak expiratory flow meter (PEFM) may provide additional insight into day-to-day asthma activity and may facilitate disease control. Problems with compliance and reliability limit the use of symptom diaries and PEF measurements.<sup>3,6-8</sup> Another means of careful asthma follow-up is regular consultation with an asthma specialist.

The optimal strategy of asthma assessment and monitoring has not been established, because evidence to date has been inconsistent,<sup>9-12</sup> but combining measurement of PEF with physician follow-up might considerably improve asthma control, especially if the physician had immediate access to daily PEF measurements. This can be conveniently achieved with the use of a messaging service incorporated into conventional Global System for Mobile Communications (GSM) mobile telephones, the short-message service (SMS).

Our aim was to assess the feasibility and reliability of GSM SMS as a tool of asthma monitoring and to ascertain its impact on control of asthma.

## PATIENTS AND METHODS

Sixteen patients with asthma from our clinic (9 males, mean age  $24.6 \pm 6.5$  years) experienced in SMS were enrolled in this prospective randomized clinical trial. All had moderate persistent asthma for at least 6 months and were being treated with ICS and LABA. None

had a history of smoking, chronic bronchitis, or emphysema. Patients without consistent access to a cell telephone or unable to use SMS were excluded. No patient withdrew from the study after enrollment.

Each patient had a 1-hour asthma education session with a specialist at the clinic, in which were discussed symptoms of asthma and the asthma symptom score (Table 1), indicators of asthma control and exacerbation, use of medication, and the correct technique for using metered dose inhalers (MDI) and PEFM. A mini-Wright PEFM of the same model was issued for each patient. The patients were to note PEF measurements, medication use, and symptoms in a paper diary. PEF was to be determined three times per day: immediately upon waking in the morning, at 4:00 PM, and at bedtime. Each PEF measurement was to be performed three times and the highest value recorded.

Patients were randomized by computer into either the SMS study group or the control group. Patients in the SMS group were instructed to send their PEF results daily via SMS to our Ericsson® SH 888 GSM mobile telephone (Ericsson Mobile Communications, Research Triangle Park, NC), connected via a serial port to a Pentium processor-based computer running the Asthma Center 0.90 Software (Polimedika d.o.o., Zagreb, Croatia). The software automatically computed maximal, minimal, and mean PEF, PEF variability, and compliance. PEF values were displayed graphically in relation to the green, yellow, and red zones of asthma control (>80%, between 50% and 80%, and <50% of predicted PEF, respectively).

Office spirometry was performed before and after the study. Both groups were treated according to GINA guidelines,<sup>5</sup> but the patients in the SMS group received weekly instructions

TABLE 1. SYMPTOM SCORE

|   | <i>Wheezing</i> | <i>Cough</i> | <i>Sleep quality</i>                           | <i>Maximal tolerated activity</i> |
|---|-----------------|--------------|------------------------------------------------|-----------------------------------|
| 0 | None            | None         | Sleeping all night                             | Regular                           |
| 1 | Mild            | In the night | Waking up: no medication required <sup>a</sup> | Moderate                          |
| 2 | Moderate        | Frequent     | Waking up: medication required <sup>a</sup>    | Reduced                           |
| 3 | Severe          | All day      | Awake all night                                | Rest                              |

<sup>a</sup>Medication required for immediate control of symptoms.

by SMS from an asthma specialist on adjustments of therapy and recommended follow-up, based on PEF values received from them by SMS. When data received from a patient in the SMS group indicated significant asthma exacerbation (progressive decrease in PEF or PEF < 50% predicted despite change-of-treatment advice), a request for an office visit was sent to the patient by SMS. The controls were seen in the office at the end of the study period, when their diary data were reviewed. Study design is illustrated schematically in Figure 1.

The data collected over 16 weeks of study comprised office PFT measurements; clinical records from the study period; patient's daily records of PEF and symptoms; demographic data; and details of asthma medication. PEF variability (PEFV) defined as the difference between the maximal and the minimal PEF measurements of a day divided by the maximal PEF for that day. Differences within and between groups were analysed by Wilcoxon signed rank test. Contingency  $\chi^2$  test was used on discontinuous variables. Results were recorded as mean  $\pm$  standard deviation. Statistical significance was defined by a  $p$  value < 0.05. SMS was compared to standard follow-up, represented by controls, regarding PFT results, compliance, and cost in terms of time and money for physician and patient. Reliability of SMS was determined by comparing the SMS database with the patients' diaries.

## RESULTS

Table 2 is a summary of study data. Figures 2–4 show the findings of FEV<sub>1</sub>, PEF, and symp-

toms, respectively. There were 21 office visits, 2 hospital admissions, and 35 changes of medication in the study group, and 15, 7, and 29, respectively, in the control group. Six of the 21 visits in the study group were requested by monitoring physicians. PEF was highest at bed time and lowest in the morning. PEF variability was significantly smaller in the study group ( $16.12 \pm 6.93\%$  vs.  $27.24 \pm 10.01\%$ ,  $p = 0.049$ ). There was no difference in compliance with PEF measurement (66% vs. 61%,  $p = 0.878$ ) or absolute PEF ( $p = 0.721$  for morning;  $p = 0.505$  for afternoon;  $p = 0.520$  for evening) between the groups.

At 16 weeks, FEV<sub>1</sub> (% predicted) in the study group was slightly but significantly increased ( $81.25 \pm 17.31$  vs.  $77.63 \pm 14.80$ ,  $p = 0.014$ ) and in the control group remained unchanged ( $78.25 \pm 21.09$  vs.  $78.88 \pm 22.02$ ,  $p = 0.497$ ). According to Altman's nomogram, FEV<sub>1</sub> power calculation yielded a value of 40%. No difference was found in mean FEV<sub>1</sub> between the two groups either at the beginning ( $p = 0.798$ ) or at the end ( $p = 0.573$ ) of the study. Controls had considerably higher symptom scores for cough ( $1.85 \pm 0.43$  vs.  $1.42 \pm 0.28$ ,  $p < 0.05$ ) and night symptoms ( $1.22 \pm 0.23$  vs.  $0.85 \pm 0.32$ ,  $p < 0.05$ ) but not for wheezing or limitation of activity. There was no difference between the groups with respect to daily consumption of inhaled medicine (steroids:  $625 \pm 332$  vs.  $530 \pm 200$   $\mu$ g,  $p = 0.574$ ;  $\beta_2$ -agonists:  $118 \pm 63$  vs.  $84 \pm 28$   $\mu$ g,  $p = 0.383$ ) (Fig. 5) or forced vital capacity ( $p = 0.959$ ). Compliance with SMS transmission of PEF was 99%. In all, 1769 SMS messages were received from the patients in the SMS group (221 per patient), and 139 messages were sent to them, including 6 requests for urgent visit and 5 unscheduled medication changes.

Per patient, SMS cost 0.67 (Euros) per week more than standard follow-up, and added 11.5 minutes per week to the time spent on home PEF monitoring. Physician time was 2 minutes per week per patient at a cost of €1 (Euro) per week per patient.

Eighteen more SMS messages were received than there were corresponding entries in the patients' diaries. Of these, 12 were duplicate messages and 6 represented data sent by SMS but not recorded in the diary. No SMS message

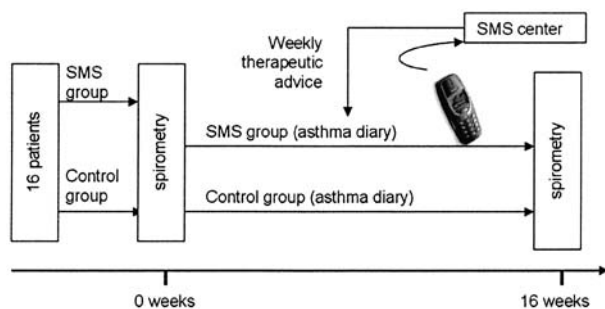


FIG. 1. Study design.

TABLE 2. PATIENT CHARACTERISTICS AND STUDY FINDINGS

| <i>Variable</i>                              | <i>Study group</i> | <i>Control group</i> | <i>p value</i> |
|----------------------------------------------|--------------------|----------------------|----------------|
| Number of patients                           | 8                  | 8                    |                |
| Male (%)                                     | 63                 | 50                   |                |
| Age (years)                                  | 24.8 ± 6.3         | 24.5 ± 7.1           |                |
| Medical history (%)                          |                    |                      |                |
| Smoking                                      | 0                  | 0                    |                |
| Chronic bronchitis                           | 0                  | 0                    |                |
| Emphysema                                    | 0                  | 0                    |                |
| Events during study period                   |                    |                      |                |
| Acute respiratory illness                    | 8                  | 6                    |                |
| Office visits                                | 21                 | 15                   |                |
| Hospital admissions                          | 2                  | 7                    |                |
| SMS messages                                 | 1769               | 0                    |                |
| Compliance with PEF measurement (%)          | 66.2 ± 16.9%       | 61.3 ± 22.9%         | 0.878          |
| PEF values transmitted (% measured PEF)      | 99                 | 0                    |                |
| Changes of medication                        | 35                 | 29                   |                |
| Average symptom score                        |                    |                      |                |
| Wheezing                                     | 0.80 ± 0.77        | 0.89 ± 0.88          |                |
| Cough                                        | 1.42 ± 0.28        | 1.85 ± 0.43          | 0.028          |
| Sleep quality                                | 0.85 ± 0.32        | 1.22 ± 0.23          | 0.021          |
| Maximal tolerated activity                   | 0.54 ± 0.50        | 0.84 ± 0.75          |                |
| Spirometry                                   |                    |                      |                |
| FEV <sub>1</sub> (% predicted)               |                    |                      |                |
| Beginning of study                           | 77.63 ± 14.80      | 78.88 ± 22.02        | 0.798          |
| End of study                                 | 81.25 ± 17.31      | 78.25 ± 21.09        | 0.573          |
|                                              | <i>p</i> = 0.014   | <i>p</i> = 0.497     |                |
| PEF by time of day (L/min)                   |                    |                      |                |
| Morning                                      | 380.00 ± 44.08     | 365.15 ± 30.42       | 0.721          |
| Afternoon                                    | 405.35 ± 45.67     | 385.48 ± 31.17       | 0.505          |
| Evening                                      | 415.27 ± 45.67     | 395.60 ± 30.75       | 0.520          |
| PEF variability (%)                          | 16.12 ± 6.93       | 27.24 ± 10.01        | 0.049          |
| Forced vital capacity (% predicted)          |                    |                      |                |
| Beginning of study                           | 88.63 ± 14.50      | 86.63 ± 12.14        | 0.721          |
| End of study                                 | 87.63 ± 15.12      | 89.00 ± 15.40        | 0.959          |
|                                              | <i>p</i> = 0.496   | <i>p</i> = 0.292     |                |
| Daily consumption of inhaled medication (μg) |                    |                      |                |
| Steroid                                      | 625 ± 332          | 530 ± 200            | 0.574          |
| Long-acting β <sub>2</sub> -agonist          | 118 ± 63           | 84 ± 28              | 0.382          |
| Cost of monitoring (per week, per patient)   |                    |                      |                |
| Money (€)                                    |                    |                      |                |
| Patient                                      | 0.67               |                      |                |
| Physician                                    | 1.00               |                      |                |
| Time (min)                                   |                    |                      |                |
| Patient                                      | 26.2               | 14.7                 |                |
| Physician                                    | 2.0                | 0                    |                |

SMS, short-message service; PEF, peak expiratory flow; FEV<sub>1</sub>, forced expiratory volume in 1 second.

appeared to have been lost, and no data corruption by transmission was detected.

## DISCUSSION

We conclude that asthma overall was better controlled in the SMS group, based on our finding of reduced PEF variability and slightly but

significantly improved FEV<sub>1</sub> as well as better symptomatic control in the intervention group but not in the controls. Because both groups followed the same self-management at acceptable levels, confirmed by written diary, we attribute this difference to the approximately 20% higher dose of ICS and LABA in the intervention group and to the benefit of advice on other aspects of asthma control regularly conveyed to

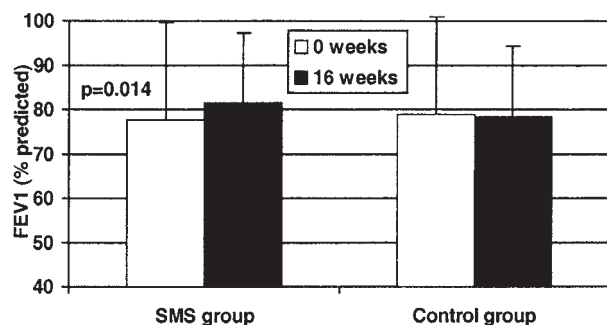


FIG. 2. Forced expiratory volume in 1 second (FEV<sub>1</sub>) ( $n = 616$ ).

these patients. The effect of medication dose has been observed previously.<sup>13,14</sup> The lowest absolute PEF was in the morning for all patients. This is well known<sup>15</sup> and is thought to relate both to the relatively low levels of medication at that time and to intrinsic airway properties.<sup>16,17</sup> As a whole, patients in both groups had good asthma control, as indicated by average symptom scores, FEV<sub>1</sub> (approximately 80% predicted), and absolute PEF (lower limit of normal: 400 L/min to 500 L/min<sup>18</sup>). Symptom profile, considered as one of the most important markers of asthma control, was better in the intervention group. This was significant only for cough and for night symptoms. We postulate this is because wheezing, unless significant, is harder to classify or to perceive at all for the patient as compared to other symptoms, and a clinically significant difference may not be detected. The same reasoning applies to limitation of activity. Cough showed the highest average absolute value. This is likely because cough is easily noticed and because other conditions common to patients with asthma, such as environmental allergies, postnasal drip, and upper respiratory tract infection, commonly cause cough. The additional cost of monitoring was minimal in terms of both time and money. Patients thought SMS was convenient, and it did not intrude into their daily activities. This is consistent with findings of previous studies of telemedicine in asthma,<sup>19</sup> and is confirmed by the nearly perfect compliance with PEF transmission by SMS. Annual cost of asthma per patient may be as high as €3,000 (Euros).<sup>20</sup> Hospital expenses account for half of this amount.<sup>21</sup> A self-man-

agement program has been found to improve asthma control<sup>22</sup> and to reduce the annual cost of the disease by some €500.<sup>23</sup> Because in our study no consistent hospital admission criteria were in place and no particulars of hospital admissions were disclosed to us, and because the study population was small, we cannot make firm conclusions about the impact of our method of telemedicine on asthma-related hospitalization. Notwithstanding, our finding of improved asthma control with SMS telemedicine as compared with a self-management plan suggests that the method, at a minimal cost, may produce greater savings than those reported previously.

To date, telemedicine in asthma has included the use of telephone to transmit breath sounds<sup>24</sup> and spirometry data<sup>25</sup> for assessment of disease severity, Internet-based monitoring systems,<sup>26</sup> and videoconferencing.<sup>27</sup> We used familiar, universally available mobile equipment that offers flexibility and security of communication. Facsimile has similar characteristics but lacks the same level of security and is more difficult to integrate into automatic data analysis systems, which is true also of telephone voice communication. Several of the previous studies of telemedicine in asthma by means of electronic download of spirometry data demonstrated no significant difference between the study and control groups,<sup>19,25,28</sup> but this is likely because of their much shorter study duration (3–4 weeks) and may also be related to study design. A theoretical limitation of SMS is the possibility of erroneous electronic data entry

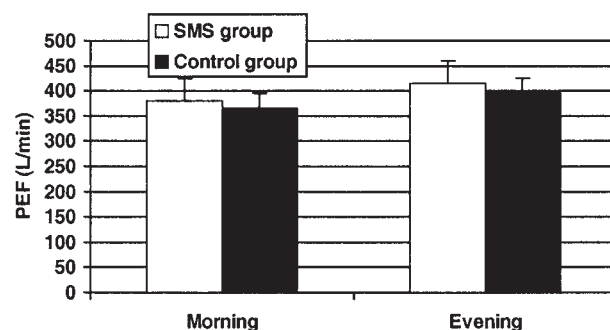


FIG. 3. Peak expiratory flow (PEF) by time of day ( $n = 16$ ).

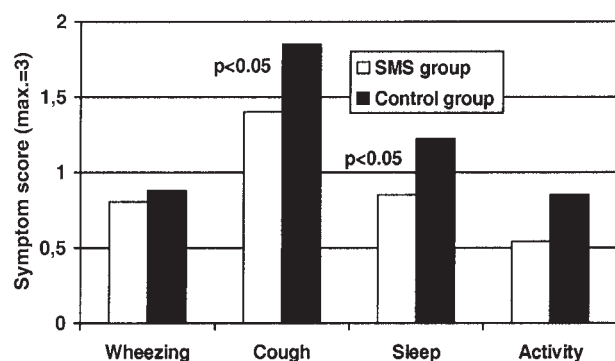


FIG. 4. Symptom score ( $n = 16$ ).

by the patient. This cannot be completely avoided, but the alternative, telephone voice communication of spirometric data, is prone to as much or more error, because it requires data entry into the computer by the receiving health care team, which must deal with many measurements of several patients at once. Our setup allows automated data entry into the software once the message is transmitted. In addition, SMS circumvents the difficulties in-

herent in telephone voice communication, including engaged lines and the requirement of continuous staffing of the call center. Human error can be excluded entirely only by automatic transmission of the data, without any participation by the patient, by the spirometer or peak flow monitor. These devices rarely possess this capability at this time. In this study, we have found SMS to be 100% reliable with respect to both message transmission and data integrity. Similar results should be obtained in practice, as long as patients are adequately instructed and the system receiving SMS is correctly set up.

Current guidelines recommend that asthmatics should be educated in and advised about monitoring their disease and that they should adhere to a written self-management plan.<sup>4,5</sup> Also recommended is regular follow-up with an asthma specialist guided by patients' continuous objective assessment of disease activity by means of a symptom diary and home peak flow monitoring, in addition to office spirometry. A combination of all these

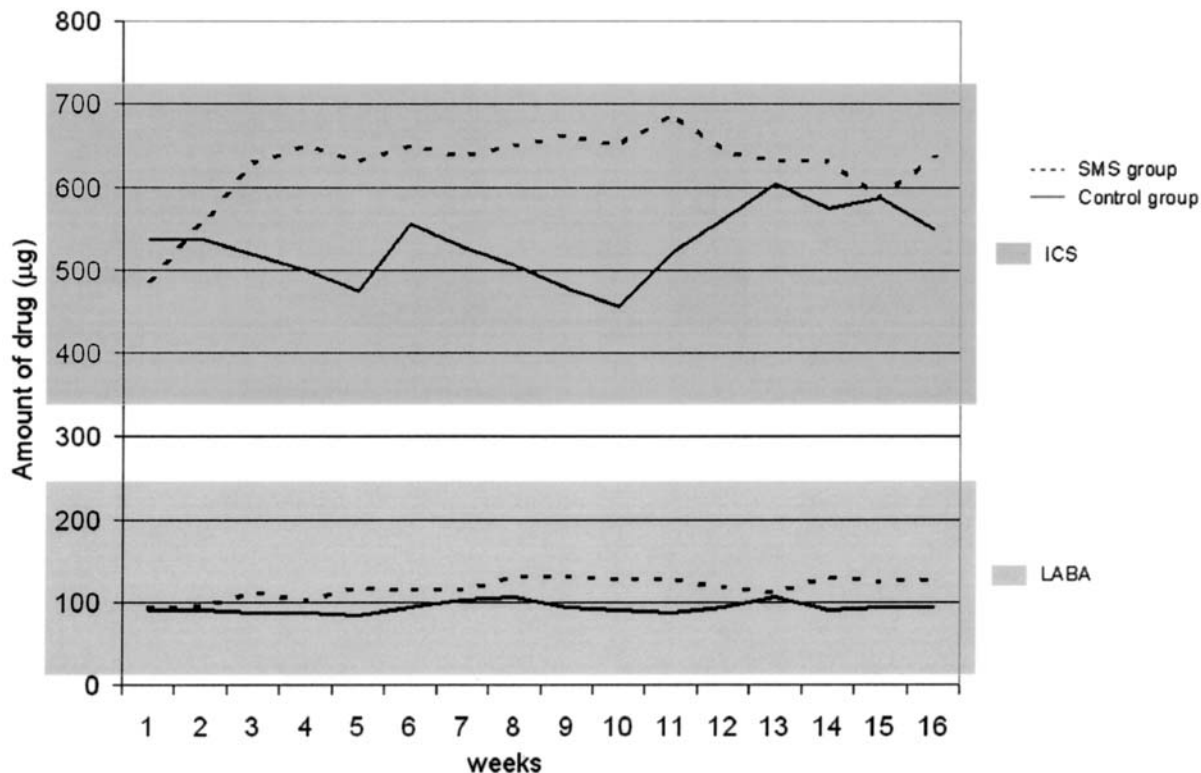


FIG. 5. Average daily dose of inhaled corticosteroids (ICS) and long-acting  $\beta_2$ -agonists (LABA) in short-message service (SMS) over time (weeks of study).

means should overcome individual limitations. In particular, symptom monitoring, a true measure of disease activity in theory, has serious limitations related to the variable and subjective nature of perception of symptoms,<sup>6,29</sup> including consistent underestimation of nocturnal symptoms.<sup>30</sup> PEF monitoring complements symptom diary by introducing an objective measure of airway obstruction. Measurement of PEF by a PEFM was found to be very consistent repeatedly and also accurate compared to a full-function office spirometer.<sup>31,32</sup> PEF measurement may be especially valuable in patients with asthma who poorly perceive their symptoms. Several studies showed PEF monitoring to be beneficial, with reduced number of exacerbations and hospital admissions,<sup>10,11</sup> although this may not be true in mild asthma.<sup>22</sup> One-time or occasional spirometry, however, greatly limits one's ability adequately to assess and follow asthma.<sup>33</sup> Continual assessment is advised. Yet, this too may be difficult to achieve. Although short-term compliance with PEF monitoring was approximately 60% in previous studies, it progressively diminished with time. By 6 months of follow-up it was only approximately 40%.<sup>3</sup> PEF values recorded in patients' diaries, moreover, may often be inaccurate, and are easily misreported.<sup>34</sup> In a previous study, patients questioned about home PEF monitoring found the procedure simple and quick, but would measure PEF no more than twice per day.<sup>19</sup> In view of the foregoing, a symptom diary together with PEF measurement once-per-day in the morning before bronchodilator administration may represent the optimal approach to continuous monitoring of stable asthma, and our method of telemedicine may be the optimal means for this. Alternatively, telemonitoring may be reserved for patients with at least moderate disease who inadequately perceive their symptoms or for short-term monitoring of newly discovered asthma, of persistently worsening disease, and of the patients who may be poorly compliant with treatment.

This study is limited by the small number of patients and by the particulars of the population studied (young persons without history of smoking, chronic bronchitis, or emphysema). A study powered at 80% within the 95% confi-

dence interval would require a study group of 40 patients. The follow-up period may not have been sufficiently long to reveal all significant differences between the groups. No conclusion could be drawn from the difference in hospital admission rate, as explained earlier. The study was not blinded, but this, we believe, has not influenced the outcome. First, compliance was not significantly different in the two groups. Second, the patients in both groups were managed by the same current guidelines. Despite the limitations and the need for larger confirmatory studies, we believe this study has established feasibility and utility of SMS as a means of telemedicine of asthma. Its use in asthma may contribute to better disease control, symptomatic improvement, and a more favorable spirometric profile. The same method of telemedicine may be useful in other situations in which repeated prompt communication of data from patient to physician is of clinical benefit.

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