Modelling the Future: System Dynamics in the Cutaneous Malignant Melanoma Care Pathway

Acta Derm Venereol 2016; 96: 181–185

INVESTIGATIVE REPORT

Modelling the Future: System Dynamics in the Cutaneous Malignant Melanoma Care Pathway

Magdalena CLAESON[1], Stefan HALLBERG[2], Paul HOLMSTRÖM[2], Ann-Marie WENNBERG[1], Helena GONZALEZ[1] and John PAOLI[1]
[1]Department of Dermatology and Venereology, Sahlgrenska Academy, and [2]Centre for Health Care Improvement, Chalmers University of Technology, Gothenburg, Sweden

Incidence rates for cutaneous malignant melanoma are increasing worldwide. Estimates of the future number of melanoma cases are important for strategic planning of the care pathway. The aim of this study was to use system dynamics modelling to evaluate the long-term effects of changes in incidence, population growth and preventive interventions. Historical data on invasive melanoma cases in Western Sweden from 1990 to 2006 were obtained. Using computer simulation software, a model estimating the accumulated number of melanoma cases for 2014 to 2023 was developed. Five future scenarios were designed: stable incidence, business-as-usual, 25% reduced patient's delay, 50% reduced doctor's delay, and a combination of the last two, called improved overall secondary prevention. After 10 years, improved overall secondary prevention would have resulted in a 42% decrease in melanomas >4 mm and a 10% increase in melanomas ≤1 mm, compared with business-as-usual. System dynamics is a valuable tool, which can help policymakers choose the preventive interventions with the greatest impact. ***Key words: cutaneous malignant melanoma; system dynamics; simulation; care pathway; doctor's delay; patient's delay.***

Accepted Aug 19, 2015; Epub ahead of print Aug 25, 2015

Acta Derm Venereol 2016; 96: 181–185.

Magdalena Claeson, Department of Dermatology and Venereology, Sahlgrenska Academy, SE-413 45 Gothenburg, Sweden. E-mail: magdalena.claeson@vgregion.se

The incidence of cutaneous malignant melanoma (CMM) is increasing steadily worldwide (1). The fair-skinned Swedish population has one of the highest incidences of CMM (2), with rates of 36.9 for men and 32.6 for women per 100,000 population (age standardized to the Swedish population in 2000). This corresponds to world standard rates of 19.8 for men and 21.0 for women per 100,000 population (3). In the last decade, the national incidence rates have increased by more than 5% yearly (4). Every year, approximately 500 Swedes die of CMM, which corresponds to a national mortality rate of 5.2 per 100,000 population. Since the 1970s, the incidence of CMM has been higher in Western Sweden than the national average (5).

CMMs are categorized according to their histogenetic subtype: nodular melanoma (NM), acrolentiginous melanoma (ALM), superficial spreading melanoma (SSM) and lentigo maligna melanoma (LMM). The most vital prognostic feature is tumour thickness, measured in mm according to Breslow (6). The Breslow thickness divides the CMM into T-classes: Tis (*in situ*), T1 (≤1.0 mm), T2 (1.01–2.0 mm), T3 (2.01–4.0 mm) and T4 (>4.0 mm). The Breslow thickness at diagnosis depends on the rate of growth and the time of development of the tumour.

The time interval from the appearance of symptoms until the patient seeks medical care is commonly referred to as patient's delay. Accordingly, the time interval from the patient seeking medical care until diagnosis and treatment is known as doctor's delay. Shorter delays in the CMM care pathway lead to early detection of thin CMMs; the importance of early detection for long-term survival cannot be overstated. Five-year survival rates for patients with thin CMMs (T1) exceed 90% in Sweden (4).

The economic impact of CMM detection, treatment and follow-up on healthcare is substantial (7). Thus, the possibility of forecasting costs and resource allocations is important for policy planning in healthcare. When carrying out such planning, different simulation methods can be valuable tools for decision-makers. System dynamics (SD) modelling is a well-known technique to model changes in complex systems, such as healthcare organizations. It is characterized by its ability to generate quantitative results by taking into account feedback and non-linear causal relationships within defined boundaries (8). SD modelling has been used in healthcare internationally with reliable results (9, 10). SD can also be used in the work of refining guidelines and designing preventive strategies (11). Collaborative development methods are available to facilitate effective teamwork involving both medical expertise and SD modellers (12). To the best of our knowledge, SD has not been applied to CMM healthcare. However, we believe that lessons learned from modelling the CMM care pathway could help plan strategies to decrease future morbidity and mortality rates.

The aim of this study was to use an SD simulation model to predict effects on the number of CMM cases in Western Sweden, in case of a continued increase

 doi: 10.2340/00015555-2222
 ISSN 0001-5555

in incidence. A further objective was to model future plausible scenarios in the CMM care pathway, through changes in patient's delay and doctor's delay.

METHODS

Setting

The study focused on the geographical area of Western Sweden, with 1.6 million inhabitants, corresponding to 17% of the national population.

Ethical considerations and basic data

The regional ethics board approved the data extraction from the Swedish Melanoma Registry. Since the reporting to this registry is compulsory, it has an excellent coverage. The registry provided 6,229 cases of invasive CMM from 1990 until 2006, which was the year when this study began. Melanoma *in situ* was not included. Characteristics of the CMM basic data are shown in Table I. The data were used as a foundation to construct the SD model.

System dynamics modelling

The SD population model was designed exclusively for this study, with the purpose of producing estimates of accumulated CMM cases for the next 10-year period of 2014–2023. The ithink® computer simulation software (isee Systems Inc., New Hampshire, USA; iseesystems.com) was used. The model simulates disease progression in a population. In the CMM care pathway, T-classes specify disease progression. The concept of an ageing chain is used, meaning that the condition of the individual depends on the time elapsed since onset of the tumour. Individuals are grouped at discrete stages of progression. This enables calculation of the number of patients at a specific stage of the disease over time.

The modelling initiative consisted of 4 consecutive steps: (a) model construction, including technical validation; (b) calibration and validation with local data and up-to-date research; (c) defining 5 plausible future scenarios for the CMM care pathway; (d) producing the SD simulations.

During step (a) the computer model was constructed. In step (b) local data were extracted from the Swedish Melanoma Registry. The current CMM incidence in Western Sweden of 44 per 100,000 population (for men and women combined, age-standardized to the Swedish population in 2000) was used as a base level in the simulation model (13). During the period 2001–2011, the incidence increased by 5.25% yearly (4). This increase was used in the simulation model, along with demographic data and a prognosis of an 8% population growth in the coming decade, obtained from governmental Statistics Sweden (14, 15).

Furthermore, the rates of growth for the different CMM subtypes were extracted from retrospective calculations made by Tejera-Vaquerizo et al. (16). To keep the SD model simple and user-friendly, only 2 different rates of growth were used in the calculations. NM, ALM and other more unusual histogenetic subtypes of melanoma were considered fast-growing. SSM and LMM were classified as slow-growing. The baseline time for doctor's delay was set to one month, based on historical data from the largest hospital in Western Sweden (17). The model also needed input data for patient's delay. The baseline time for patient's delay was calculated using basic data on Breslow thickness at diagnosis and combining this with calculations on the rate of growth made by Tejera-Vaquerizo et al. (16). A diagram with an S-shaped curve was created, showing the number of patients seeking medical care distributed over time. Separate graphs were created for fast-growing and slow-growing CMM. The graphic distributions indicated that 80% of patients with fast-growing CMM sought medical care within 15 months. The corresponding patient's delay for slow-growing CMM was 31 months.

Finally, the simulation model was calibrated by comparing the simulation results with findings from Blum et al. (18). Looking at the delay times in the CMM care pathway in the study by Blum et al. led to a calibration of the mathematical equations for the growth phase of CMM. The assumed growth rates were altered from constant linear growth to 2-phase growth functions, where the rate of growth increased after the tumour had reached a Breslow thickness of 1 mm. This made the assumed growth rates more comparable to the Gompertz model, used in tumour biology research to describe tumour growth (19). The growth rates used in the model for fast-growing CMMs were 0.25 mm/month initially, followed by 0.40 mm/month. For the slow-growing CMMs, the growth rates were 0.02 mm/month initially, followed by 0.05 mm/month.

During step (c) 5 plausible future model scenarios for the CMM care pathway were defined: stable incidence, business-as-usual, reduced patient's delay, reduced doctor's delay, and improved overall secondary prevention. All the scenarios took the growing population into account, but were different regarding incidence increase and preventive interventions (see Fig. 1 for details). Finally, in step (d), the SD simulations were produced.

Table I. *Characteristics of all cases of cutaneous malignant melanoma (CMM) in Western Sweden during 1990–2006*

Characteristics	*n* (%)	Mean
Male:female	2,987:3,108 (49:51)	
Total	6,095 (100)	
CMM (cases)		
Male:female	3,052:3,177 (49:51)	
Total	6,229 (100)	
Mean age, years, male:female		62:59
CMM histiogenetic subtype		
Nodular melanoma	1,441 (23.1)	
Acrolentiginous melanoma	107 (1.7)	
Superficial spreading melanoma	3,656 (58.7)	
Lentigo maligna melanoma	510 (8.2)	
Other	515 (8.3)	
T-class (Breslow thickness)		
T1 (≤1.0 mm)	3,482 (55.9)	
T2 (1.01–2.0 mm)	1,206 (19.4)	
T3 (2.01–4.0 mm)	884 (14.2)	
T4 (>4.0 mm)	657 (10.5)	
Mean Breslow thickness, mm		1.84

RESULTS

A flow chart of the simulation outcome of the 5 model scenarios is shown in Fig. 1. The outcome is presented both as the accumulated cases of CMM after 10 years, as well as the number of cases in the first year (2014) and 10th year (2023). The number of cases per year may perhaps be of more use for comparison with other geographical regions.

Comparing the improved overall secondary prevention and the business-as-usual scenarios, there was a difference in Breslow thickness of the future CMM cases. Improving both patient's and doctor's delay would have resulted in a shift towards thinner tumours, with 10% more cases of stage T1 CMMs and 42% less cases of stage T4 CMMs (Fig. 2A). When analysing

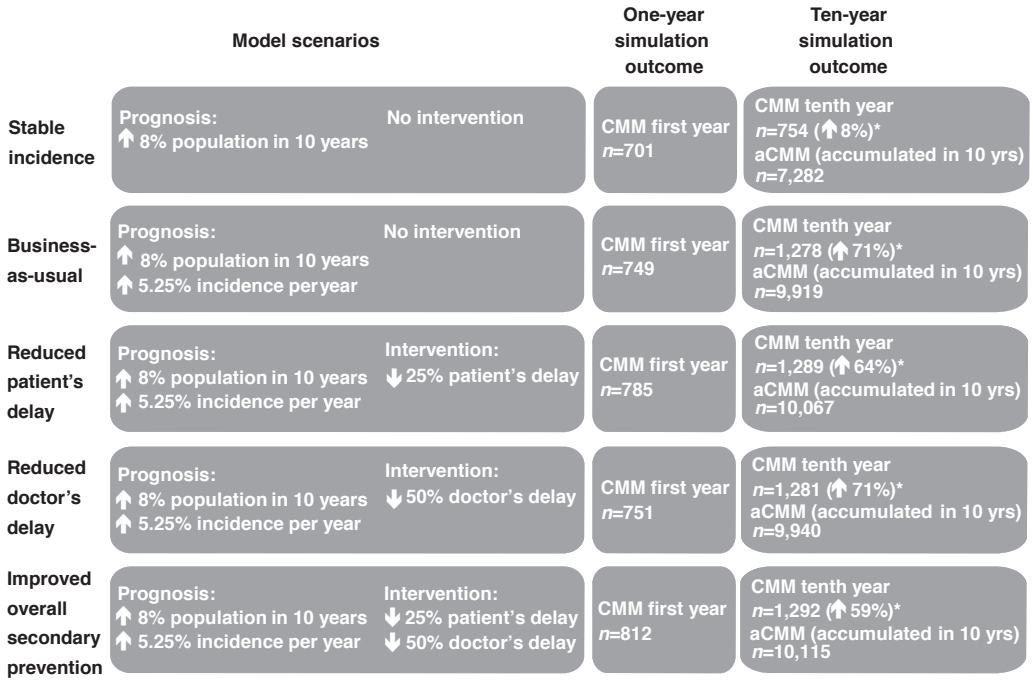

Fig. 1. Outcome of the 5 future model scenarios for the cutaneous malignant melanoma (CMM) care pathway. aCMM= accumulated number of CMM in 10 years. *Compared with the number of CMMs in the first year.

the simulation outcome of patient's and doctor's delay separately, it was evident that reduced patient's delay would have had the greatest impact on decreasing the number of stage T4 CMMs. The reduced patient's delay would have resulted in 26% less cases of stage T4 CMMs compared with reduced doctor's delay (Fig. 2B).

We also analysed the scenarios for fast-growing and slow-growing CMMs separately. One important finding was that the improved overall secondary prevention would have had a more substantial impact on reducing the thickness of fast-growing CMMs than it would on the slow-growing CMMs. Thus, improving the secondary prevention of fast-growing CMMs would have reduced the number of stage T4 CMMs by 47%, compared with business-as-usual. Consequently, improving the secondary prevention of slow-growing CMMs would only have reduced the number of stage T4 CMMs by 3%, compared with the business-as-usual scenario (Fig. 3).

DISCUSSION

We have shown that the SD model can be used for studying incidence changes of CMM and for predicting effects of different preventive interventions. The numbers presented in this paper should be regarded as reliable approximations. The model was validated by comparing simulation data from the population of Gothenburg, a subset of the 1990–2006 data for Western Sweden, with corresponding historical metadata. The validation showed that the error in simulating the total number of accumulated CMM was +3%. The corresponding results for slow- and fast-growing CMM

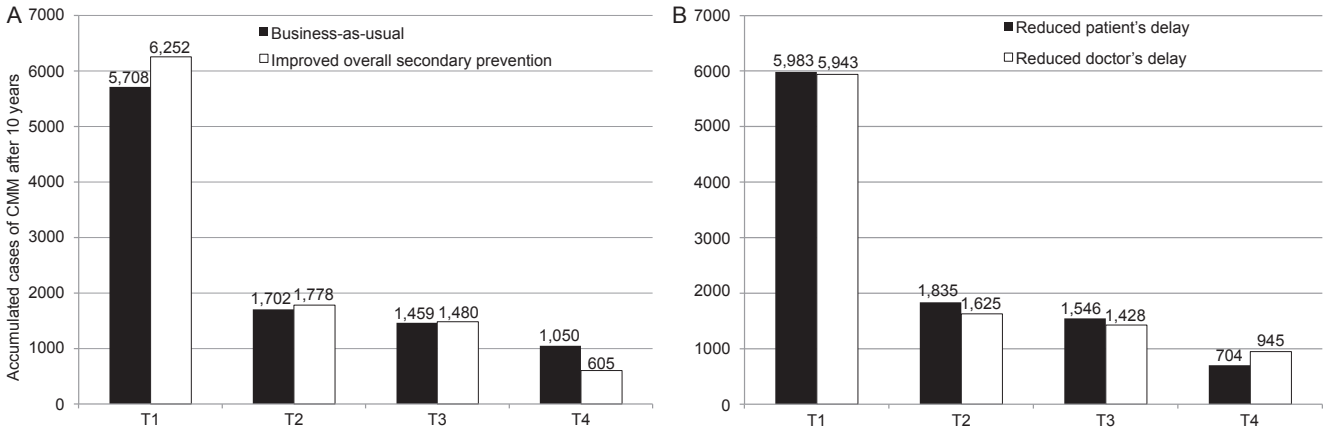

Fig. 2. Accumulated number of cases of cutaneous malignant melanoma after 10 years, divided into T-classes. A comparison between (A) the business-as-usual and improved overall secondary prevention scenarios and (B) the reduced patient's delay and reduced doctor's delay scenarios.

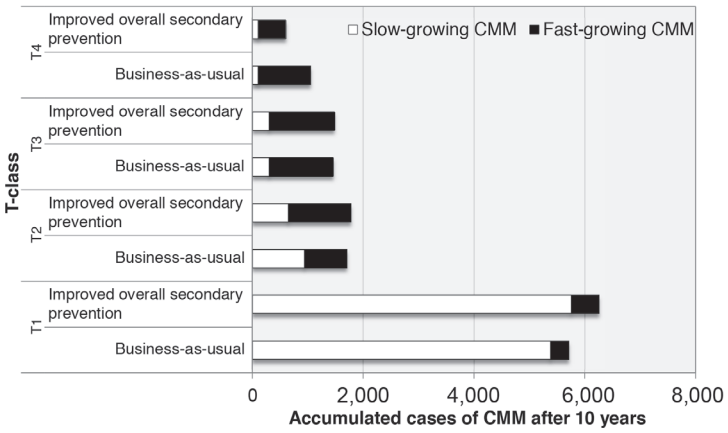

Fig. 3. Accumulated number of cases of cutaneous malignant melanoma (CMM) after 10 years, divided into T-classes. A comparison between the business-as-usual and improved overall secondary prevention scenarios. Scenarios are shown for slow- and fast-growing CMM.

were +2% and +7%, respectively. Thus, the simulation was considered to show acceptable accuracy compared with true historical data, not least because all model assumptions were deliberately chosen not to give output that was too optimistic from a patient perspective.

The results of the business-as-usual scenario demonstrated a future with an increasing incidence, but with an unchanged CMM care pathway regarding preventive interventions. This would have resulted in 36% additional CMM cases over 10 years, compared with the stable incidence scenario. Although a stable incidence scenario seems unlikely for Sweden in the near future, there are indications that effective primary prevention can stabilize or decrease CMM trends in the youngest age groups. This seems to be the case for more recently born cohorts in, for example, Australia (20). Another finding was that the improved overall secondary prevention scenario would have resulted in 196 (2%) more cases of CMM during the next 10-year period compared with the business-as-usual scenario. This can be explained through understanding that a reduction in patient's delay and doctor's delay equals a reduction in time to diagnosis of previously unknown tumours. Hence, an increased number of CMM cases would have been detected during the same time-period. This can be compared with mammography research, where screening results in an increased number of early-stage breast cancer being diagnosed (21). However, once the increase in screening use levels off, the rate of the disease would also be expected to level off.

As shown in the results section, the improved overall secondary prevention scenario would have resulted in the greatest impact on decreasing the number of thick CMMs. This decrease would be likely to substantially reduce future mortality rates. Hence, treatment costs for metastasized CMM, including the new personalized immune therapies, would be markedly lower. Death due to CMM is a high cost to society, since CMM affects a younger population, compared with many other types of cancer. As a result, the loss of life years could be reduced. Comparing the effects of patient's and doctor's delay, we found that even though we simulated a 25% reduction in time for patient's delay and a 50% reduction in doctor's delay, it would be more important to adjust the patient's delay than the doctor's delay. The reason for this is that patient's delay consists of a much longer time-period, with a corresponding longer growth phase for the CMM. Of course, reducing patient's delay is not an easy task. To reduce patient's delay, public awareness would have to increase. Moreover, there are studies showing that introducing skin self-examination practices improves early detection. Skin self-examination could preferably be taught to high-risk populations (22). On the other hand, although reduced doctor's delay does not give as good effect on the results of our simulations, it is more within the hands of the healthcare organizations to change. The time from the patient's call until diagnosis and treatment could, for instance, be reduced through easier access to a dermatologist with dermoscopy skills (23). Furthermore, technological advances such as teledermoscopy, as well as the use of total body photography and digital dermoscopy, for follow-up of high-risk populations, could also substantially improve doctor's delay (17, 24, 25). The results of our simulations showed that it would be considerably more important to target an improved overall secondary prevention on the population of fast-growing CMMs, compared with slow-growing CMMs. Thus, it would be of great value to reduce patient's and doctor's delay for nodular CMM, which is the largest entity among the fast-growing CMM in a population such as Western Sweden.

A limitation of our SD model was that demographic changes due to an ageing population were not taken into account. This could be expected to further increase the number of CMM cases. Another limitation was that we did not take into account the increased migration into Sweden of people at low risk of CMM, for instance from the Middle East and Africa. These migrants may contribute to a reduction in the CMM incidence rates in Sweden in the future. Although we could achieve estimations with good certainty regarding demographic and incidence parameters, another known limitation of our study was the use of retrospective calculations for the rate of growth (16). However, to our knowledge this is the best research data available at present. A study on growth rates by Liu et al. (26) showed the same differences when comparing the different CMM subtypes, although not with the exact same values. We based our simulations on the study with the slowest growth rates in order not to overestimate the effects of preventive interventions. Some authors consider ALM to be a slow-

growing tumour, but the rate of growth in the studies mentioned above made us categorize it as a fast-growing CMM. Nevertheless, ALM comprises only 1.7% of all CMMs in our study population.

The great advantage of SD modelling is the possibility to modify input data and create new scenarios on request, as soon as new statistics and research data become available. Furthermore, this specific SD population model produced quantitative data, but can also be regarded as a module with specified boundaries and dynamic characteristics, which can subsequently be fitted into larger SD models. These can include feedback loops that enable scenarios for critical resources, which depend on, but also influence, simulated decisions from the current model. Also, SD modelling can be used for other cancer care pathways.

Sweden must prepare for the expected rise in CMM cases over the next 10-year period due to an increasing incidence and growing population. With this knowledge, our SD model will be valuable for strategic planning of the CMM care pathway, helping policymakers to choose the preventive intervention with the greatest impact. It is time for national and regional government to make long-standing investments that will ease pressure on our strained health system. As shown here, improved prevention is vital in this respect.

ACKNOWLEDGEMENTS

The authors thank Leyla Núñez, statistician at the Regional Cancer Centre Western Sweden, for the extraction of data from the regional part of the Swedish Melanoma Registry. We also thank Martin Gillstedt, statistician at the Department of Dermatology, for designing the graphs in this paper.

The federal government supported this study financially under the ALF agreement. The Gothenburg Medical Society and the Edvard Welander Foundation also supported the study financially.

REFERENCES

1. Godar DE. Worldwide increasing incidences of cutaneous malignant melanoma. J Skin Cancer 2011; 2011: 858425.
2. Swedish National Board of Health and Welfare. Cancer incidence in Sweden 2011, 2012. [Accessed 2013 Dec 26] Available from http://www.socialstyrelsen.se/publikationer2012/2012-12-19.
3. International Agency for Research on Cancer, World Health Organization. Cancer Incidence, Mortality and Prevalence-Worldwide in 2008, 2008. [Accessed 2013 Mar 8] Available from http://globocan.iarc.fr/Default.aspx.
4. Swedish Melanoma Study Group. Malignant melanoma. National guidelines. Linköping, 2013. [Accessed 2013 Dec 31] Available from http://www.cancercentrum.se/sv/Vardprogram/Malignt-melanom/.
5. Regional cancer centre Western Sweden. Malignant melanoma of the skin – regional registry report 1990–2011. Göteborg, 2013. [Accessed 2013 Dec 31] Available from http://www.cancercentrum.se/sv/vast/Patientprocesser/melanom/.
6. Breslow A. Thickness, cross-sectional areas and depth of invasion in the prognosis of cutaneous melanoma. Ann Surg 1970; 172: 902–908.
7. Guy GP, Jr., Ekwueme DU, Tangka FK, Richardson LC. Melanoma treatment costs: a systematic review of the literature, 1990–2011. Am J Prev Med 2012; 43: 537–545.
8. Sterman J. Business dynamics. McGraw-Hill: 2000.
9. Hirsch G, Homer J, Evans E, Zielinski A. A system dynamics model for planning cardiovascular disease interventions. Am J Public Health 2010; 100: 616–622.
10. Homer JB, Hirsch GB. System dynamics modeling for public health: background and opportunities. Am J Public Health 2006; 96: 452–458.
11. Tobias MI, Cavana RY, Bloomfield A. Application of a system dynamics model to inform investment in smoking cessation services in New Zealand. Am J Public Health 2010; 100: 1274–1281.
12. Vennix JAM. Group model building: facilitating team learning using system dynamics: Wiley, 1996.
13. Swedish National Board of Health and Welfare. The Swedish Cancer Registry, 2013. [Accessed 2015 Jan 1] Available from http://www.socialstyrelsen.se/statistik/statistikdatabas/cancer.
14. Statistics Sweden. The future population of Sweden 2012–2060. BE51 Demographic reports 2012, [Accessed 2015 Jan 1] cited; available from: http://www.scb.se.
15. Statistics Sweden. Population statistics, 2013. [Accessed 2013 Mar 12] Available from http://www.scb.se.
16. Tejera-Vaquerizo A, Barrera-Vigo MV, Lopez-Navarro N, Herrera-Ceballos E. Growth rate as a prognostic factor in localized invasive cutaneous melanoma. J Eur Acad Dermatol Venereol 2010; 24: 147–154.
17. Borve A, Dahlen Gyllencreutz J, Terstappen K, Johansson Backman E, Aldenbratt A, Danielsson M, et al. Smartphone teledermoscopy referrals: a novel process for improved triage of skin cancer patients. Acta Derm Venereol 2015; 95: 186–190.
18. Blum A, Ingvar C, Avramidis M, von Kannen A, Menzies SW, Olsson H, et al. Time to diagnosis of melanoma: same trend in different continents. J Cutan Med Surg 2007; 11: 137–144.
19. Laird AK. Dynamics of tumor growth. Br J Cancer 1964; 13: 490–502.
20. Erdmann F, Lortet-Tieulent J, Schuz J, Zeeb H, Greinert R, Breitbart EW, et al. International trends in the incidence of malignant melanoma 1953–2008 – are recent generations at higher or lower risk? Int J Cancer 2013; 132: 385–400.
21. Bleyer A, Welch HG. Effect of three decades of screening mammography on breast-cancer incidence. N Engl J Med 2012; 367: 1998–2005.
22. Curiel-Lewandrowski C, Chen SC, Swetter SM. Screening and prevention measures for melanoma: is there a survival advantage? Curr Oncol Rep 2012; 14: 458–467.
23. Durbec F, Vitry F, Granel-Brocard F, Lipsker D, Aubin F, Hedelin G, et al. The role of circumstances of diagnosis and access to dermatological care in early diagnosis of cutaneous melanoma: a population-based study in France. Arch Dermatol 2010; 146: 240–246.
24. Borve A, Terstappen K, Sandberg C, Paoli J. Mobile teledermoscopy – there's an app for that! Dermatol Pract Concept 2013; 3: 41–48.
25. Salerni G, Carrera C, Lovatto L, Puig-Butille JA, Badenas C, Plana E, et al. Benefits of total body photography and digital dermatoscopy ("two-step method of digital follow-up") in the early diagnosis of melanoma in patients at high risk for melanoma. J Am Acad Dermatol 2012; 67: e17–e27.
26. Liu W, Dowling JP, Murray WK, McArthur GA, Thompson JF, Wolfe R, et al. Rate of growth in melanomas: characteristics and associations of rapidly growing melanomas. Arch Dermatol 2006; 142: 1551–1558.