Between 1987 and 2007, different groups developed digital image analysis systems for the diagnosis of benign and malignant skin tumors. As the result of significant differences in the technical devices, the number, the nature and benign/malignant ratio of included skin tumors, different variables and statistical methods any comparison of these different systems and their results is difficult. For the use and comparison of the diagnostic performance of different digital image analysis systems in the future, some principle basic conditions are required: All used systems should have a standardized recording system and calibration. First, melanocytic and nonmelanocytic lesions should be included for the development of the diagnostic algorithms. Critical analyses of the results should answer the question if in future only melanocytic lesions should be analyzed or all pigmented and nonpigmented lesions. This will also lead to the answer if only dermatologists or all specialties of medical doctors will use such a system. All artifacts (eg, hairs, air bubbles) should be removed. The number of variables should be chosen according to the number of included melanomas. A high number of benign skin lesions should be included. Of all lesions only 10% or better less should be invasive melanomas. Each system should be developed by a training-set and controlled by an independent test-set. Each system should be controlled by the user with the final decision and responsibility and tested by independent users without any conflict of financial interest.

**KEYWORDS** digital image analysis, skin tumors, melanoma, melanocytic nevi
Table 1 Summary of the study groups that have developed digital dermoscopy analysis for digitized pictures

<table>
<thead>
<tr>
<th>First author</th>
<th>Year</th>
<th>Variables (n)</th>
<th>Source</th>
<th>Statistical method</th>
<th>Lesions</th>
<th>Trainings-set</th>
<th>Melanoma</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cascinelli7</td>
<td>1987</td>
<td>no spe. slides</td>
<td>no spe.</td>
<td>mel. + non-mel.</td>
<td>20</td>
<td>no spe.</td>
<td>no spe.</td>
<td>no spe.</td>
<td>no spe.</td>
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<td>Cascinelli8</td>
<td>1992</td>
<td>8 patients</td>
<td>no spe.</td>
<td>mel. + non-mel.</td>
<td>169</td>
<td>43</td>
<td>96</td>
<td>60</td>
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<tr>
<td>Schindewolf9</td>
<td>1993</td>
<td>23 slides</td>
<td>CART</td>
<td>mel.</td>
<td>353</td>
<td>215</td>
<td>94</td>
<td>88</td>
<td></td>
</tr>
<tr>
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<td>CART</td>
<td>mel.</td>
<td>309</td>
<td>80</td>
<td>89</td>
<td>88</td>
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<td>Green11</td>
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<td>22 patients</td>
<td>discr.-anal.</td>
<td>mel. + non-mel.</td>
<td>164</td>
<td>18</td>
<td>89</td>
<td>89</td>
<td></td>
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<tr>
<td>Ecral12</td>
<td>1994</td>
<td>14 slides</td>
<td>neur.-netw.</td>
<td>mel. + non-mel.</td>
<td>326</td>
<td>136</td>
<td>80</td>
<td>86.3</td>
<td></td>
</tr>
<tr>
<td>Menzies13</td>
<td>1997</td>
<td>no spe. slides</td>
<td>log. regr.</td>
<td>mel. + non-mel.</td>
<td>170</td>
<td>75</td>
<td>93</td>
<td>67</td>
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<tr>
<td>Husemann14</td>
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<td>neur.-netw.</td>
<td>no spe.</td>
<td>215</td>
<td>no spe.</td>
<td>&gt;95</td>
<td>&gt;95</td>
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<td>Seidenari16</td>
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<td>22 patients</td>
<td>discr.-anal.</td>
<td>mel.</td>
<td>917</td>
<td>65</td>
<td>93</td>
<td>95</td>
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<td>Binder17</td>
<td>1998</td>
<td>16 slides</td>
<td>neur.-netw.</td>
<td>mel.</td>
<td>120</td>
<td>39</td>
<td>90</td>
<td>74</td>
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<td>Seidenari18</td>
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<td>26 patients</td>
<td>discr.-anal.</td>
<td>mel.</td>
<td>383</td>
<td>18</td>
<td>100</td>
<td>92</td>
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<td>Handels19</td>
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<td>26 patients</td>
<td>neur.-netw.</td>
<td>mel.</td>
<td>44</td>
<td>19</td>
<td>97.7</td>
<td>100</td>
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<tr>
<td>Andreassi20</td>
<td>1999</td>
<td>13 patients</td>
<td>discr.-anal.</td>
<td>mel.</td>
<td>147</td>
<td>57</td>
<td>88</td>
<td>81</td>
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<tr>
<td>Blum21</td>
<td>1999</td>
<td>3 a patients</td>
<td>factor an. + log. regr.</td>
<td>mel. + non-mel.</td>
<td>116 a</td>
<td>10 a</td>
<td>90 a</td>
<td>81.1 a</td>
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<tr>
<td></td>
<td></td>
<td>6 b</td>
<td></td>
<td></td>
<td>51 b</td>
<td>27 b</td>
<td>70.4 b</td>
<td>70.4 b</td>
<td></td>
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<tr>
<td>Stolz22</td>
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<td>no spe. patients</td>
<td>log. regr.</td>
<td>mel.</td>
<td>466</td>
<td>125</td>
<td>86.4</td>
<td>92.7</td>
<td></td>
</tr>
<tr>
<td>Bauer23</td>
<td>2000</td>
<td>38 patients</td>
<td>neur.-netw.</td>
<td>mel. + non-mel.</td>
<td>315</td>
<td>42</td>
<td>92.9</td>
<td>97.8</td>
<td></td>
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<tr>
<td>Elbaum24</td>
<td>2001</td>
<td>13 patients</td>
<td>lin. class. + ROC</td>
<td>mel.</td>
<td>246</td>
<td>63</td>
<td>100</td>
<td>85</td>
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<tr>
<td>Rubegni26</td>
<td>2002</td>
<td>10 patients</td>
<td>neur.-netw.</td>
<td>mel.</td>
<td>147</td>
<td>57</td>
<td>93</td>
<td>92.8</td>
<td></td>
</tr>
<tr>
<td>Hoffmann29</td>
<td>2003</td>
<td>no spe. patients</td>
<td>neur.-netw.</td>
<td>mel. + non-mel.</td>
<td>2.218</td>
<td>187</td>
<td>no spe.</td>
<td>no spe.</td>
<td></td>
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<tr>
<td>Burroni30</td>
<td>2004</td>
<td>10 patients</td>
<td>lin. class. + ROC</td>
<td>mel.</td>
<td>840</td>
<td>391</td>
<td>98</td>
<td>79</td>
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<tr>
<td>Blum31</td>
<td>2004</td>
<td>3 a patients</td>
<td>factor an. + log. regr.</td>
<td>mel.a,b</td>
<td>605 a</td>
<td>25 a</td>
<td>80 a</td>
<td>82.4 a</td>
<td></td>
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<td></td>
<td>6 b</td>
<td></td>
<td></td>
<td>232 b</td>
<td>59 b</td>
<td>82.7 b</td>
<td>84.1 b</td>
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<tr>
<td>Menzies33</td>
<td>2005</td>
<td>103 patients</td>
<td>d + ROC</td>
<td>mel. + non-mel.</td>
<td>2.430</td>
<td>382</td>
<td>91</td>
<td>68</td>
<td></td>
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<tr>
<td>Manousaki35</td>
<td>2006</td>
<td>3 patients</td>
<td>log. regr. + mult. mod. + ROC</td>
<td>mel.</td>
<td>132</td>
<td>23</td>
<td>60.9</td>
<td>95.4</td>
<td></td>
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<tr>
<td>Fikrle37</td>
<td>2007</td>
<td>2 patients</td>
<td>log. regr.</td>
<td>mel.</td>
<td>46</td>
<td>46</td>
<td>91.3</td>
<td>90.7</td>
<td></td>
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<tr>
<td>Wollina38</td>
<td>2007</td>
<td>35 patients</td>
<td>no spe.</td>
<td>mel. + non-mel.</td>
<td>3544</td>
<td>52</td>
<td>90-95</td>
<td>79.6-93.3</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: no spe., no specification; CART, Classification And Regression Trees; discr.-anal., discrimination analysis; neur.-netw., neuronal network; factor an., factor analysis; log. regr., logistic regression; lin. class., linear classification; ROC, Receiver Operating Characteristics; mel., melanocytic skin lesions; non-mel., non-melanocytic skin lesions; mult. mod., multivariate model.

a = small, completely imaged lesions
b = large, partially imaged lesions
c = images were calibrated
d = discriminant variables with associated weighting factors and relationship features.
sitivity and specificity obtained by a trained expert of dermoscopy (Fig. 1). An advantage of a digital dermoscopy diagnostic system would be that the instrument and analyzing works independent of time. The digital system will not be influenced by different levels of attention as in human beings. Additionally, it might be a useful tool, particularly for centers without expertise in dermoscopy. On the other hand, it is not likely that the digital system will completely substitute the expert in dermoscopy. Well-trained users will recognize certain, significant details in melanocytic lesions which lead to the diagnosis of a disease with malignant potential. These details, just visible in one small area of the entire lesion, couldn’t have the impact to change the lesion from benign to malignant for the computer algorithm yet (Fig. 2).

Computer diagnostic algorithms could also be used in the follow-up of patients with atypical moles (Fig. 3). The comparison of images recorded at different times is helpful in these patients. In addition, the results of computer diagnostic algorithms of the lesion could be useful for decisions in clinical management of patients with atypical mole syndrome.

For using and comparison the results of digital image analysis in future, some principle conditions are proposed:

- All used systems should have a standardized recording system of the lesions of the patients. This includes the use and correct interpretation of immersion contact or polarized light dermoscopy with or without contact.
- All used systems should have a standardized calibration of the camera that should be applied regularly.
- First, melanocytic and nonmelanocytic lesions should be included for the development of the diagnostic algorithms. Critical analyses of the results should answer the question if in future only melanocytic lesions should be analyzed or all pigmented and nonpigmented lesions. This will also lead to the answer if only dermatologists or all specialties of medical doctors will use such a system.
- All artifacts (eg, hairs, air bubbles) should be removed.
- The number of variables should be chosen according to the included melanomas (ratio between 1:10 and 1:100).
- A high number of benign melanocytic and nonmelanocytic lesions should be included.
- To represent the routine setting of a mole clinic, only 10% or better less of all lesions should be invasive melanomas.
- Each system should be developed by a training-set and controlled by an independent test-set with the same ratios of benign and malignant tumors.
- Each system should be controlled by the user with the final decision and responsibility and tested by independent users without any conflict of financial interest.

The final and unsolved question until now is: Who will use this technology?

If automated diagnostic systems will be used by general practitioners or in pharmacies and shopping centers, these systems should be work with very high sensitivity and reasonably good specificity. Therefore, malignant tumors would...
be detected in early stage and unnecessary excision of benign lesions would be avoided. If the target is the “nonexpert” user, studies should be designed to test the accuracy of automated systems on a broad range of benign and malignant, melanocytic and nonmelanocytic pigmented and nonpigmented skin lesions. Atypical lesions such as Spitz nevi, atypical nevi, or seborrheic keratoses could still be missed by the analyzing system but would be more easily diagnosed by a good dermatologist using his/her clinical experience and additional criteria (eg, ugly duckling sign, clinical history) that can not be evaluated by an automated system.

If the target is the “expert” user, studies should be designed with the aim to help clinicians in distinguishing atypical benign lesions from malignant tumors of the skin. An increase in specificity might be the goal for an automated system directed to expert users together with a sensitivity at least equal to that achieved by the expert.

References


Figure 3 Computer-assisted analyzing of nevus in the follow-up over a period of 6 months: upper lesion is smaller (area 15.9 mm²) and lower lesion is bigger (area 24.5 mm²) with a symmetric growth. A distinct change from the yellow to the yellow-red area is seen in the classification of both lesions.21,31 (Color version of figure is available online.)
Digital image analysis


