Acta Orthop. Belg., 2004, **70**, 38-45

Outcome assessment in osteoarthritic patients undergoing total knee arthroplasty

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The purpose of this study was to better understand the relationship between knee pain, locomotor functional status, and health-related quality of life (*HRQoL*) outcomes in osteoarthritic (*OA*) patients undergoing primary total knee arthroplasty (*TKA*). Nine *OA* patients were recruited. Pain, locomotor function, and *HRQoL* were evaluated one day before and 6 months after *TKA* by means of a visual analogue scale (*VAS*) for knee pain, the function score of the Knee Society (*KS*), the metabolic cost of gait (*C*), the total mechanical work during gait (W_{tot}), and the Medical Outcomes Study Short Form-36 Health Survey (MOS SF-36). Our results showed a decrease in knee pain and metabolic cost of gait and an improvement in quality of life. Moreover we showed a relationship between : (1) the *VAS* score for knee pain, the function score of the *KS*, and MOS SF-36 Physical Functioning, Role-Physical, and Bodily Pain subscales ; and (2) the *C*, the W_{tot}, and the MOS SF-36 Vitality subscale.

INTRODUCTION

There is now general agreement that the treatment of choice for patients aged over 55 years with severe pain and disability from knee osteoarthritis (*OA*) is arthroplasty (*19*). The assessment of outcome after total knee arthroplasty (*TKA*) has evolved since the 1970s when early studies (*6, 12*) concentrated only on the surgeon's view of outcome, i.e., knee pain, joint deformity, and knee motion. More recent studies (*13, 17*) have evaluated the patient's view using generic health-related quality of life (*HRQoL*) questionnaires to assess outcome. The *HRQoL* subjective concept is now recognized as an important outcome measure in clinical studies among patients undergoing *TKA* (*20*), perhaps as important as conventional clinical assessment.

The major aims of *TKA* are first to relieve pain and reduce joint deformity, second to enhance physical function, and more specifically locomotor function, and third to improve *HRQoL* (*5, 13, 16, 17*). In clinical practice, the relief of knee pain after *TKA* is conventionally assessed using visual analogue scales (*16, 21*) or subscales included in various knee-rating systems (*1, 11, 12*). The locomotor functional status after *TKA* is usually investigated using instrumented gait analysis (*5*) and metabolic cost of gait (*9, 23*). As regards *HRQoL*, the orthopaedic

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Table I. — Anthropomorphic characteristics of patients

Number	Sex (F/M)	Height (m)	Weight (kg)	BMI (kg m^{-2})	Age (years)
1	F	1.57	82	33.27	72
2	F	1.60	60	23.44	69
3	F	1.68	95	33.66	65
4	F	1.68	100	35.43	67
5	M	1.83	105	31.35	66
6	M	1.77	90	28.72	65
7	F	1.68	86	30.47	75
8	F	1.56	66	27.12	76
9	M	1.55	82	34.13	64
Mean ± SD		1.66 ± 0.1	85.1 ± 15	30.8 ± 4	68.8 ± 4

F : female, M : male, BMI : Body Mass Index = weight/height^2

community acknowledges that self-reported questionnaires, such as the Medical Outcomes Study Short Form-36 (MOS SF-36), are appropriate for outcome measurement in the *TKA* population (*13, 15, 17*).

Despite recent increasing focus on *HRQoL* in patients undergoing *TKA*, little is known about the relationship between knee pain, locomotor functional status, and *HRQoL*. However, interdependency between these variables seems to exist. Kroll *et al* (*16*), and Olsson and Barck (*21*) explored the relationship between changes in gait and changes in pain that occurred after *TKA*. More recently, Fuchs *et al* (*8*) tried to correlate quantitative gait measurements with MOS SF-36 in *TKA* patients.

Thus, the purpose of our study was to better understand the relationship between knee pain, locomotor functional status, and *HRQoL* among *OA* patients undergoing primary *TKA*.

METHODS

Nine adult patients (3 males and 6 females) with unilateral degenerative knee *OA* (6 right and 3 left) were consecutively recruited from our orthopaedic department and participated in this study. They had a mean age of 68.8 years (SD : ± 4), a mean weight of 85.1 kg (± 15), and a mean height of 1.66 m (± 0.1). The inclusion criteria were the following : severe unilateral knee *OA* (grade 4) according to Kellgren and Lawrence (*14*), ability to walk on a treadmill without aids, no systemic, cardiologic, respiratory, neurological or other orthopaedic disease, no gross obesity (Body Mass Index < 40) (*10*), and no mental deficit. Table I shows the anthropomorphic characteristics of the patients. All patients gave informed consent to participate in this study and were recruited on a volunteer basis. The local ethics committee approved the study.

The same highly trained orthopaedic surgeon performed all the arthroplasties. All patients received a posterior-stabilised implant (Legacy PS ; Zimmer Inc., Warsaw, IN, USA). In all cases, fixation of the tibial and femoral components was done with cement. The articulating surface of the patella was also replaced. Postoperative management consisted of physical therapy exercises beginning on the first day after surgery and continued for eight weeks. Walking rehabilitation began about the third day after surgery with a walker for three or four days, two crutches for the subsequent two to four weeks and, finally, one crutch for the last two to four weeks. During this period, no postoperative complications of the *TKA* were observed in any patient.

Pain, locomotor functional status, and *HRQoL* were assessed, one day before and 6 months after *TKA*.

A 10-cm visual analogue scale (*VAS*) was used to assess the knee pain, just after the quantitative gait tests (see below).

The locomotor functional status was clinically assessed by the function score of the *KS* (*11*) (the knee score was also performed), and by instrumented gait analysis for the following variables : gait speed, total mechanical work during gait, and metabolic cost of gait. The patients were requested to walk as naturally as possible at their self-selected gait speed along a 10-m long walkway. A large (1.8 m long, 0.6 m wide) strain-gauge force platform (Pharos System Inc. ; Lynnfield, MA, USA) was embedded in the center of the walkway, and two photocells were placed at either end of the platform The gait speed was computed from the photocells, by dividing the distance between the photocells by the time taken to cross them. The total mechanical work (W_{tot}) during gait was the sum of the external mechanical work (W_{ext}) and the internal mechanical work (W_{int}) during one stride. The W_{ext}, the work performed to lift and accelerate the body center of mass (CM_b) relative to the surroundings during gait, was computed from the measurement of the three-dimensional ground reaction forces (*GRFs*) at a sampling rate of 50 Hz, following the method described in detail by Cavagna (*4*). From the raw *GRFs*, the instantaneous vertical, lateral and forward accelerations of the CM_b were computed. Mathematical integration of the accelerations allowed the instantaneous velocities of the CM_b to be obtained. A second integration of the vertical velocity determined the vertical displacement of the CM_b, and was used to compute the instantaneous gravitational potential energy. From the instantaneous velocities, the instantaneous kinetic energy of the CM_b in the vertical, lateral, and forward directions was calculated. The gravitational potential and kinetic energies were summed to obtain the total mechanical energy of the CM_b. The W_{ext} during gait was determined by summing the positive increments of the total mechanical energy of the CM_b curve during a stride. The W_{int}, the work performed to move the limbs relative to the CM_b during gait, was computed simultaneously to W_{ext} from kinematics and anthropometrical data, following the method described by Cavagna and Kaneko (*3*). The displacement of passive retroreflective markers placed on the acromion (*AC*), the greater trochanter (*GT*), the lateral condyle of the knee (*LC*), the head of the fibula (*HF*), the lateral malleolus (*LM*), and the base of the fifth metatarsal (*VM*), was filmed using an optoelectronic system (Elite ; BTS, Milan, Italy) with 4 cameras at a sampling rate of 50 Hz. The body was divided into 7 rigid segments : head-arm-trunk (*HAT*) (*AC-GT*), thighs (*GT-LC*), shanks (*HF-LM*) and feet (*LM-VM*). Anthropometrical tables of Winter (*25*) were used to determine the position of the center of mass of each body segment and the CM_b. The internal mechanical energy of the body segments corresponded to the sum of the rotational and translation energies of these segments due to their movements relative to the CM_b. For each lower limb, the internal mechanical energy curves of the thigh, shank and foot were summed. Then, the W_{int} of each lower limb and the *HAT* segment were separately calculated as the sum of the positive increments of the respective internal mechanical energy curves during one stride. The W_{int} corresponded to the sum of the W_{int} done to move the lower limbs and the *HAT* segment.

The assessment of the metabolic cost of gait (*C*) was performed on a motor driven treadmill (Mercury LT med ; H/P/Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany). Breath by breath O_2 consumption and CO_2 production were measured with an ergospirometer (Quark b² ; Cosmed S.r.l, Rome, Italy), and heart rate with a Polar© belt (Polar ; Electro Finland Oy, Kempele, Finland). Measurement of the O_2 rate consisted of a rest period, the patient standing on the treadmill, followed by a gait period at a gait speed equivalent to that spontaneously adopted during the assessment on level ground (W_{int} and W_{ext}). Each period was maintained until a steady state was reached and for a period of at least 2 minutes. The respiratory quotient (*RQ*), determined by the ratio between CO_2 rate and O_2 rate, was always less than one. The O_2 rate of the subject was converted in energy expended as function of the *RQ* value (18). The net O_2 rate was the energy expended during gait minus the energy expended at rest. The *C* was determined by the ratio between net O_2 rate and gait speed of the subject.

Following the quantitative gait tests, the patients were asked to complete a self-administered validated French (Belgian) version of the MOS SF-36 (IQOLA, 1993). Only the five subscales related to the physical component (*22*) were selected, i.e. Physical Functioning, Role-Physical, Bodily Pain, Vitality, and General Health Perception. Scores for each subscale were transformed to a scale of 0-100 (100 = best possible score).

Statistical analysis

A Wilcoxon signed rank test (SigmaStat for Windows V2.0 ; SPSS Science Software GmbH, Erkrath, Germany) was performed on the results of the ordinal scales (*VAS* score for knee pain, knee and function scores of the *KS*, and MOS SF-36 subscales) and paired t-test (SigmaStat for Windows V2.0 ; SPSS Science Software GmbH, Erkrath, Germany) on the gait variables (W_{int}, W_{ext}, W_{tot}, and *C*) in order to evaluate a significant difference before and after *TKA*. The effect of gait speed on results was excluded by a preliminary two-way ANOVA (SigmaStat for Windows V2.0 ; SPSS Science Software GmbH, Erkrath, Germany). Significance was assumed at $p < 0.05$.

In addition, a multivariate statistical method, a Principal Component Analysis (*PCA*) (StatView for Windows V5.0 ; SAS Institute Inc., Cary, NC, USA),

Table II. — Statistical results for pre and postoperative clinical and instrumented gait variables

	χ^2 / t	P	Preoperative Mean (± SD)	Postoperative Mean (± SD)
Clinical variables				
Knee score of the KS	45	0.004	44.00 (40.3-46.8)$^{\$}$	92.00 (88.8-94.3)$^{\$}$
Function score of the KS	45	0.004	50.00 (32.5-60.0)$^{\$}$	100.00 (90.0-100.0)$^{\$}$
VAS score for knee pain (cm)	-45	0.004	4.60 (3.7-4.8)$^{\$}$	0.50 (0.0-0.8)$^{\$}$
MOS SF-36 subscales				
Physical Functioning	45	0.004	35.00 (23.8-37.5)$^{\$}$	70.00 (58.8-80.0)$^{\$}$
Role-Physical	36	0.008	0.00 (0.0-25.0)$^{\$}$	75.00 (25.0-100.0)$^{\$}$
Bodily Pain	45	0.004	32.50 (25.0-45.0)$^{\$}$	57.50 (45.0-75.0)$^{\$}$
Vitality	22	0.078	45.00 (38.8-56.3)$^{\$}$	55.00 (45.0-60.0)$^{\$}$
General Health Perception	16	0.219	60.00 (55.0-70.0)$^{\$}$	70.00 (58.8-80.0)$^{\$}$
Mechanical variables				
W_{ext} (J kg $^{-1}$ m $^{-1}$)	1.008	0.343	0.48 (± 0.2)	0.39 (±0.1)
W_{int} (J kg $^{-1}$ m $^{-1}$)	0.340	0.743	0.39 (± 0.1)	0.37 (± 0.1)
W_{tot} (J kg $^{-1}$ m $^{-1}$)	2.246	0.055	0.93 (± 0.3)	0.76 (± 0.1)
Metabolic variable				
C (J kg $^{-1}$ m $^{-1}$)	2.558	0.034	5.19 (± 1.2)	4.27 (± 1.4)

Wilcoxon signed rank test (clinical variables and MOS SF-36 subscales) and paired t-test (instrumented gait variables).

$^{\$}$ Median values (25-75 percentiles).

Significance was assumed at $p < 0.05$ (highlighted values).

was applied to identify the main structure of the data by describing the variation in the data. This technique was performed on 10 variables : the treatment (*TKA* surgery), the five subscales of the MOS SF-36 that are related to the physical component (Physical Functioning, Role-Physical, Bodily Pain, Vitality, General Health Perception), the function score of the *KS*, the *VAS* for knee pain, the quantitative mechanical and metabolic variables (W_{tot}, and C). Only the first three principal components (*PCs*) were retained as important factors, explaining over 80% of total variance after orthogonal rotation (Varimax). Finally, we gave a meaning to each of the three first *PCs*, and each *PC* was labeled. To determine what each *PC* measures, only variables having the highest correlation with each *PC* (factor loadings with a threshold value of 0.6 or higher) were considered.

RESULTS

Table II shows the results of clinical and instrumented gait variables assessed pre and postoperatively. The median knee score of the *KS* improved postoperatively (from 44 to 92, p=0.004). The median function score of the *KS* also improved (from 50 to 100, p = 0.004), and the median *VAS* score for knee pain decreased (from 4.6 to 0.5, p = 0.004). In the MOS SF-36, the Physical Functioning subscale score (from 35 to 70, p = 0.004), Role-Physical subscale score (from 0 to 75, p = 0.008), and Bodily Pain subscale score (from 32.5 to 57.5, p = 0.004) improved postoperatively. The Vitality (p = 0.078) and General Health Perception (p = 0.219) subscales scores did not change significantly.

No significant differences were found in the mechanical variables (W_{ext}, W_{int}, and W_{tot}). The metabolic variable, C, decreased (from 5.19 to 4.27 J kg^{-1} m^{-1}, p = 0.034). Fig 1 shows the mean values of W_{tot}, and C of patients expressed as a function of gait speed. W_{tot} showed a tendency to decrease but this was not significant (p = 0.055, Table II), and C decreased significantly.

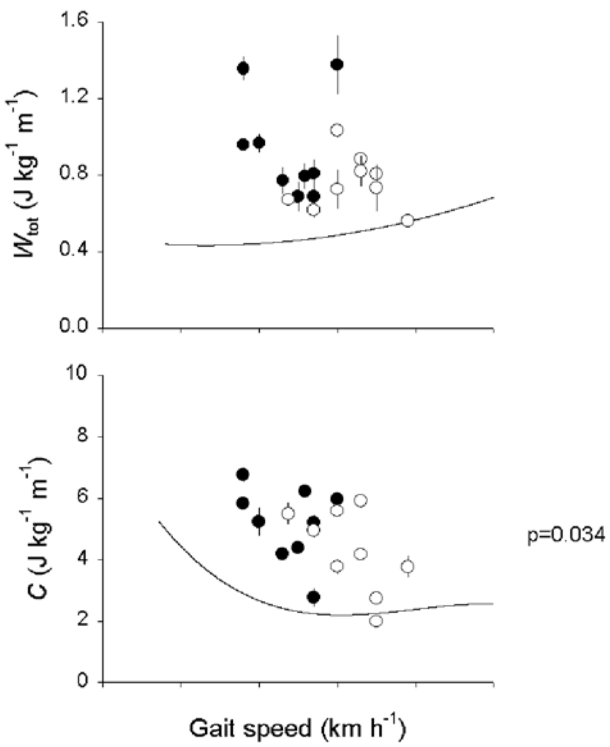

Fig. 1. — Mean results and standard deviations (± SD) of mechanical and metabolic variables. W_{tot} and C of patients are expressed as a function of gait speed. Black symbols represent preoperative values and white symbols, postoperative. The lines refer to normal gait and are redrawn from Willems *et al* (24) and DeJaeger *et al* (7).

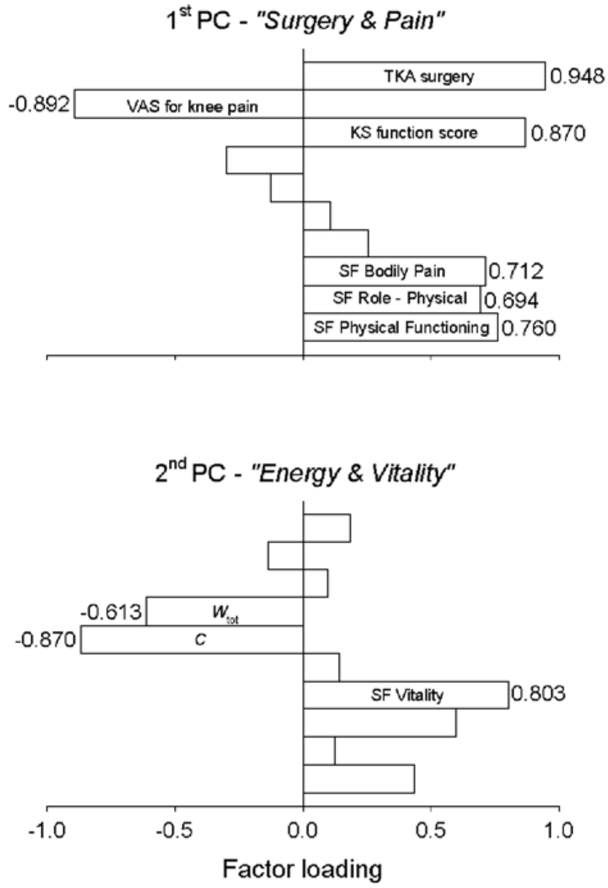

Fig. 2. — *PCA* results. The first two *PCs* are presented : *"Surgery & Pain"*, *"Energy & Vitality"*. The factor loading of each variable on each *PC* is shown.

Relationship between pain, locomotor functional status, and health-related quality of life

The orthogonal solution of the *PCA* allowed the determination of three *PCs*. The first *PC* was labeled as *"Surgery & Pain"*, the second as *"Energy & Vitality"*, and the third as *"Health Perception"*. Fig 2 presents the factor loadings of each variable on the two first *PCs*. The *TKA* surgery (factor loading : 0.948), the *VAS* score for knee pain (-0.892), the function score of the *KS* (0.870), the MOS SF-36 Bodily Pain subscale (0.712), the MOS SF-36 Role-Physical subscale (0.694), and the MOS SF-36 Physical Functioning subscale (0.760) loaded on the *"Surgery & Pain"* component. The C (factor loading : -0.870), the W_{tot} (-0.613), and the MOS SF-36 Vitality subscale (0.803) loaded on the *"Energy & Vitality"* component. The MOS SF-36 General Perception subscale loaded on the third *PC* (not shown), the *"Health Perception"* component (factor loading : 0.921). The variance proportion was distributed as : 56.7% for the first *PC*, 13.7% for the second, and 10.2% for the third, with a total of 80.6% of total variance.

DISCUSSION

The major goals of *TKA* are to relieve knee pain, correct knee joint deformity, improve locomotor functional status, and enhance *HRQoL* (*5, 13, 16, 17*). In our study, all these variables were assessed simultaneously, before, and 6 months after, *TKA* surgery.

Previous clinical studies (*2, 8, 16, 21*) have assessed the binomial relationships between pain and locomotor functional status, or locomotor functional status and *HRQoL*. In our study, we examined interrelationships among multiple variables and observed a relationship between knee pain, locomotor functional status, and *HRQoL*. These latter variables interact together and our results suggest that in future studies it would be judicious to assess the outcomes of *TKA* surgery by means of multivariate statistical analysis or multiple linear regression models.

Our results showed a significant decrease in knee pain after *TKA*. The low median *VAS* score (4.6 cm) for preoperative pain could be explained by the fact that patients were taking anti inflammatory (*AI*) or pain medication preoperatively. Nevertheless, our preoperative results were obtained from *OA* patients who were unable to conduct their daily living activities without taking NSAIDs or pain medication. Indeed, a quantitative locomotor function assessment of this kind was not bearable on the day prior to surgery among this *OA* population without any medication. In addition, no patient was still taking any form of NSAID or pain medication at the time of the postoperative assessment.

The *C* is a measure of the gait economy in metabolic energy terms. Like Fusi *et al* (*9*), we observed a decrease in *C* 6 months after *TKA* surgery. How could this decrease in *C* be explained ? Postoperatively, we observed an increase in gait speed associated with a decrease in W_{tot}. The decrease in W_{tot} could explain the decrease in *C*, since W_{tot} provides a single mechanical measure that reflects the overall locomotor function. Indeed, W_{tot} is also a measure of gait economy, but in terms of mechanical, rather than metabolic, energy.

The MOS SF-36 Physical Functioning, Bodily Pain, and Role-Physical subscales scores were significantly improved after *TKA*. Before surgery, the patients had poor MOS SF-36 Physical Functioning, Bodily Pain, and Role-Physical subscales scores. According to March *et al* (*17*), these results are a clear reflection of the impact of chronic knee *OA* on *HRQoL*.

Relationship between pain, locomotor functional status, and health-related quality of life

A multivariate statistical analysis, a *PCA*, was performed on pain, locomotor function, and *HRQoL* variables collected by OA patients undergoing primary TKA in order to explore the relationship between these variables in this population. The PCA results allowed the determination of three *PCs* : *"Surgery & Pain"*, *"Energy & Vitality"*, and *"Health Perception"*.

The surgery and VAS for knee pain were loaded on the first PC with the function score of the KS, and the MOS SF-36 Physical Functioning, Role-Physical, and Bodily pain subscales. This *PC* was labeled *"Surgery & Pain"* since the pain relief, which is directly related to the surgery, could explain changes in the locomotor functional status and the *HRQoL*. Several previous studies (*2, 16*) have shown the impact of knee pain relief after *TKA* on the locomotor function status in *OA* patients. Our *PCA* results are in agreement with these studies.

Fuchs *et al* (*8*) failed to prove correlations between locomotor function status, assessed by spatio-temporal and segmental knee joint kinematic variables, and *HRQoL*. Our PCA results are not in agreement with their results since we observed relationships between locomotor functional status and *HRQoL*. We believe that the assessment of the locomotor functional status using global quantitative variables such as *C* and W_{tot}, is probably more relevant than its assessment by spatio-temporal and segmental knee joint kinematic variables.

In addition, the PCA results indicate that *C* and W_{tot} simultaneously loaded with the MOS SF-36 Vitality subscale on the second *PC*. This *PC* was labeled *"Energy & Vitality"* since the metabolic and mechanical energy expenditure of gait and the subjective perception of vitality (energy level and fatigue) were loaded on the same *PC*. Despite a significant decrease in *C* after surgery, this variable was not loaded with the *"Surgery & Pain"* component. We hypothesise that the surgery would have only an indirect impact on *C*, by simultaneously increasing gait speed and reducing W_{tot}.

In conclusion, relationships exist between knee pain perception, locomotor functional status, and *HRQoL*. Semi-quantitative scales such as *VAS* for knee pain, function score of the *KS*, and MOS SF-36 Physical Functioning, Role-Physical, and Bodily Pain subscales, are clinical tools sufficiently sensitive for assessing the interrelationships between knee pain, locomotor function, and *HRQoL*. Nevertheless, after *TKA*, quantitative energetic assessments such as *C* and W_{tot} are useful to explore gait economy, which is strongly correlated to the MOS SF-36 Vitality subscale, measuring the subjective perception of vitality in terms of energy level and fatigue.

Clinical relevance

A previous clinical study (*2*) has underlined the fact that instrumented gait analysis is time-consuming, expensive, and not applicable in daily clinical practice. In our study, we show that semi-quantitative clinical scales such as the *VAS* for knee pain, the function score of the *KS*, and the MOS SF-36 Physical Functioning, Role-Physical, and Bodily Pain subscales, are tools sufficiently sensitive to define the interrelationships between pain, locomotor function, and *HRQoL*. Consequently, we demonstrate that the use of instrumented gait analysis is not essential to explore the locomotor function status in the *TKA* population. In addition, the MOS SF-36 Vitality subscale could be used to subjectively assess gait economy without any quantitative measure. Nevertheless, in clinical research, instrumented gait analysis is a useful tool to objectively explore gait economy and to validate new therapeutic approaches.

Acknowledgment. This study was supported by grants from the Fonds National de la Recherche Scientifique Médicale (FRSM) of Belgium, the Fonds Spécial de Recherche (FSR) of the Université catholique de Louvain, and the Région wallonne (Programme Wallonie-Développement-Université, Easyform).

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