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DEVELOPMENT OF METHOD FOR REVERSE ENGINEERING IN CREATION OF 3D CAD MODEL OF KNEE IMPLANT

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Abstract. *The paper gives a description of the Reverse Engineering technology application procedure for the creation of 3D CAD model of femoral component of total knee endoprothesis based on available meltable wax model for investment casting. Once CAD data record is accepted it presents an information management center for its geometry throughout the lifetime of the knee implant component. Thus, in the case a change in the component construction should be made, it can be managed quickly and consistently made available for all CAx-tools which accompany the product development. The procedure is defined within the work conducted in the international IPA cross-border cooperation project Romania-Republic of Serbia where the Reverse Engineering technologies and Additive Manufacturing (AM) are studied.*

Key Words: *Reverse Engineering, Meltable Wax Model, Investment Casting, 3D CAD model, Knee Endoprothesis*

1. INTRODUCTION

The most recent approaches to technological innovations include technological innovations of products and processes as competition factors as well as the new information and flexible manufacturing technologies having new properties. Modern development and design of new products and technologies is based on CAD/CAM/CAE technology application. Computer aided technologies are being increasingly used for the solution of many problems associated with Biomedical Engineering. A significant number of these have proven to be espe-

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cially useful in orthopedics. Medical imaging is often used for obtaining patient-specific data, which usually serves as the basis for CAD modeling of bone-joint system and surrounding tissue. The resulting CAD models find many practical applications [1].

Additive Manufacturing technologies is the most frequently used name for a technology family (Rapid Prototyping - RP, Rapid Tooling - RT, Rapid Manufacturing - RM and Reverse Engineering - RE) which are used for development of physical objects directly from a three-dimensional 3D CAD model [2]. When the AM technology application started in investment casting, the parts produced within the first AM systems were applied as meltable wax models in order to shorten the time and costs of casting. AM processes application in investment castings is one of the widest used applications. Economic benefit which the AM meltable models provide is reduced to individual and small series production due to high AM material costs.

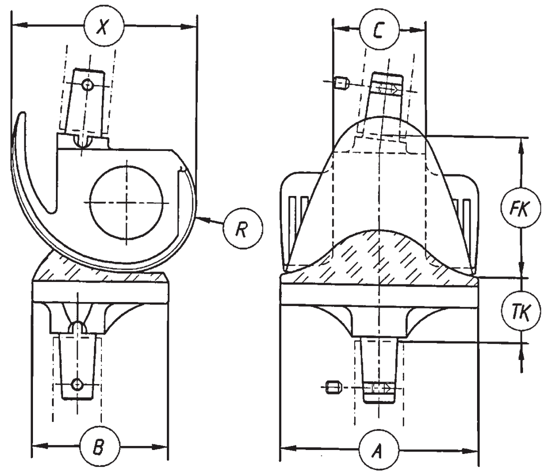
The latest research in the technology of the AM meltable models development is redirected to the development and application of the Rapid Tooling technology thus ensuring fast development of tools/molds for meltable wax models development in investment casting. The name Rapid Investment Casting (RIC) is RP and RT techniques application in investment casting [3]. Additive Manufacturing technology is optimal for the process of custom implants. These are the reasons why RP and RE technologies have such an important role in medicine. After years of development the rapid prototyping technologies are now being applied in medicine for manufacturing dimensionally accurate human anatomy models from high resolution medical image data [4].

2. Investment Casting of Metal Implants

The main feature of technological process used for making cast products by investment casting is to inject under pressure an easily melted model mass in the tools made of metal or other material: after solidifying in the tool the mass assumes the shape of a cast piece. The injecting system is made in another tool. The cast piece model is joined to the injecting system model after it has been removed from the model tool. Since the models are of small dimensions, more models are joined for one injecting system which makes a wax sprue. Several layers of suspension are applied to the prepared wax sprue, which forms a solid shell after drying. The shell is made by melting the model assembly then it is put into special boxes and sprinkled with sand or grains.

The box containing the shell is heated in a furnace to a relatively high temperature and then cast. After cooling down the cast pieces are removed from the shell and then detached from the injecting system and cleaned. If necessary, thermal treatment of cast pieces is performed. Investment casting is used for making cast pieces of ferrous, non-ferrous and light metals [5].

Metal orthopedic implants made of meltable models are partial knee endoprothesis and Fig. 1 shows the main dimensions of joint i.e. knee based on which implant are made. The material of metal implants is CoCrMo alloy.



Size	A mm	B mm	C mm	FK mm	X mm	TK mm	R mm
middle/right	65	45	30	46	62	22	23
middle/left	65	45	30	46	62	22	23

Fig. 1 Main dimensions of joint/knee [6]

Investment casting of metal implants consists of the following operations: development of the cast piece drawing, meltable model tool design, model structure melting, meltable model development by injection, disjoining of tools, model assembling into a model, coating of wax sprue with ceramic suspension, wax melting out and roasting of ceramic shells, metal implants casting (Figs. 2,3,4 and 5) [6].

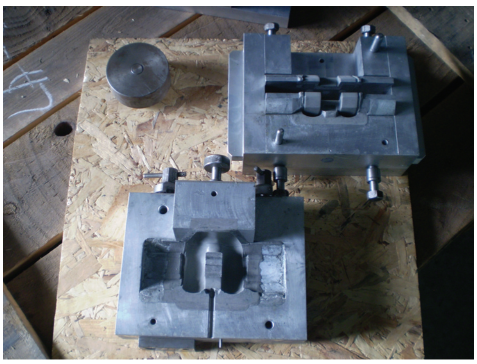


Fig. 2 Tool for meltable implant model

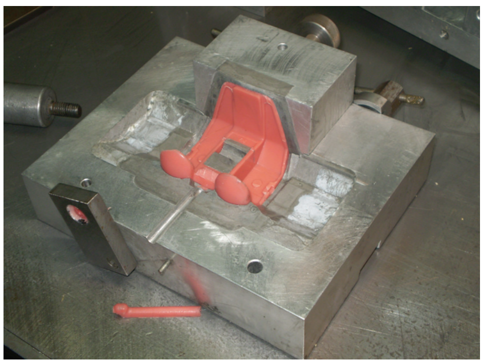


Fig. 3 Dissembled tool with meltable wax model

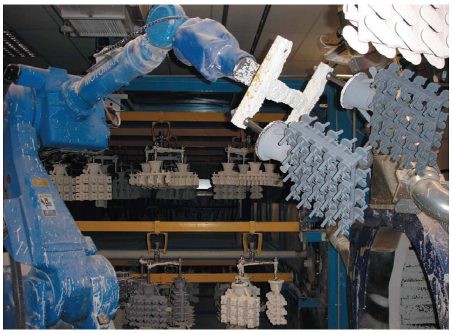


Fig. 4 Coating of model sprue

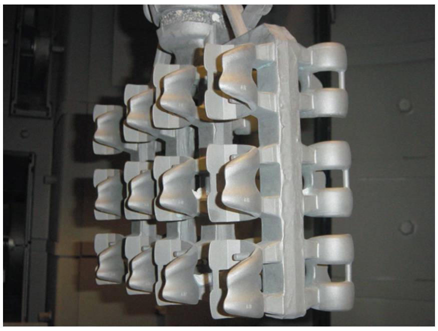


Fig. 5 Finished knee implant metal cast piece

3. Reverse Engineering Application in the Creation of 3D CAD Model for Investment Casting of Knee Implant

In this part of the paper the development of method for reverse engineering of knee implant meltable model is shown; the method will include 3D scanning of the present standard meltable model, treatment of point cloud and formation of 3D mesh model which may later be defined by parameters. The obtained result is the creation of 3D CAD model in software package SolidWorks.

Non-contact 3D scanning OptiNum and software packages Numisoft, Geomagic Wrap and Rapidform XOR are used for development of the method, while 3D CAD solid model of implant meltable model will be developed in SolidWorks.

Phases of obtaining 3D CAD model:

1. Generating the point cloud by 3D scanning Noomeo Optinum and Numisoft software
2. The obtained point cloud processing and conversion into mesh model in Geomagic Wrap software
3. Mesh model processing and transfer into neutral CAD format in Rapidform XOR software
4. Model import and conversion into 3D CAD solid model in SolidWorks software.

Reverse engineering – 3D Scanner Noomeo Optinum

The 3D Scanner Noomeo Optinum (Fig. 6) is a portable scanner connected to the acquisition system via USB 2.0 with autonomy offered by the battery included in the configuration. The scanner uses the "Vision based self positioning" technology, the point cloud acquisition is performed by successive multiple photographic images, through a CCD sensor with resolution 1024 × 768 pixels, which can take up to 500,000 points/image.

The scanner dimensions are 230 mm × 230 mm × 80 mm and the weight is less than 2 kg. The volume of the scanned objects fall in 10 cm3 ÷ 1m3, the minimum purchase size is 1 cm.

Noomeo Optinum scanner technology combines structured light, which allows instant capture of the geometry through the deformation analysis of repetitive light projected onto the object, with 2D image processing, leading to the scanner position to the object concerned and capture its texture. Thus, by 2D image processing, the autoposition is calculated, which eliminates the need for markers and the light flow provides additional information for taking geometry as a cloud of points. The scanner system does not require preparation of items scanned, their installation in a reference system or reference markers.

Fig. 7 shows meltable wax model of knee implant which are produced on semi-automatic presses for wax injection: Var-Flex, Inject-model 35 (Tempcraft, SAD). Material used for production was the wax - W1/1 (Dussek Campbell Limited, London, UK).

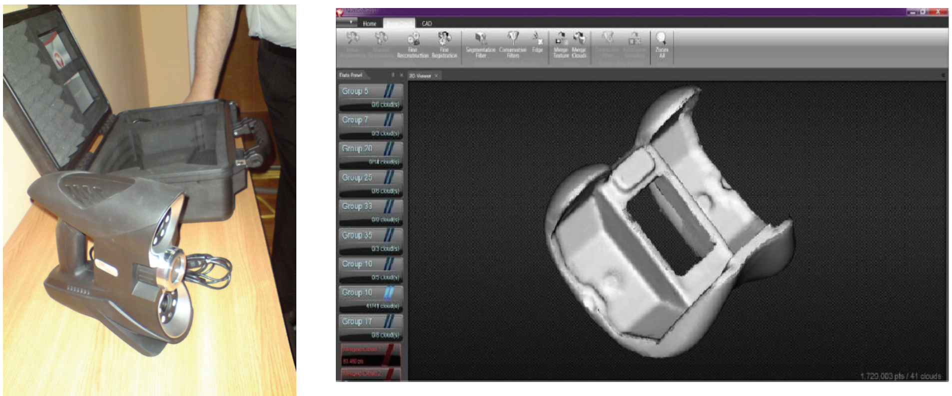


Fig. 6 3D Scanner Noomeo Optinum and generating point cloud in Numisoft software (Center for Numerical Simulation and Digital/Rapid Prototyping, University "Eftimie Murgu" Resita, Romania)

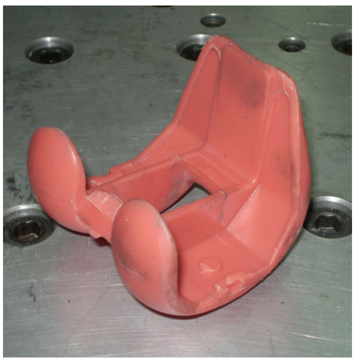
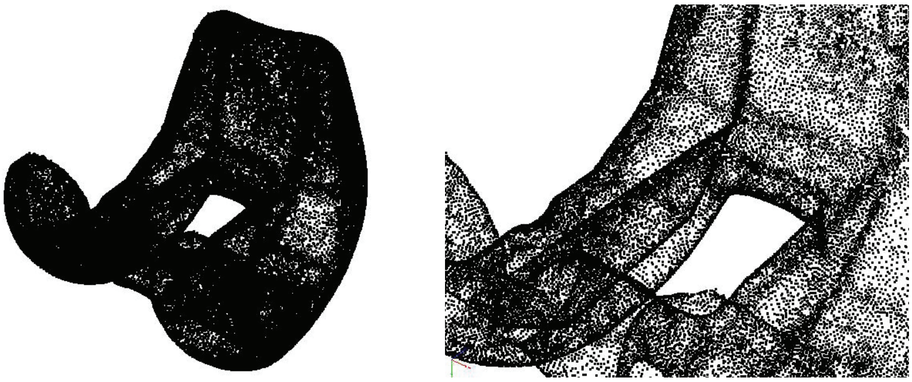


Fig. 7 Meltable wax pattern of knee implant

Processing of point cloud and the mesh model generation

Geomagic Wrap software is a software tool for the cloud point transforming of the scan result into a 3D polygonal network (mesh) (Fig. 8), which can be used in the design, analysis and manufacturing. Geomagic Wrap can process large data sets, collected from different types of scanners; it provides for the opportunities to optimize the scanned data (using remove outliers, reduce noise and other available tools), align and merge multiple scan data sets, create polygon mesh from point cloud data, automatically detect and correct errors in the polygon mesh, detect and create features in the model, repair and sharpen boundary edges, 3D model export in different formats: STL, OBJ, VRML1/2, DXF, PLY and 3DS.



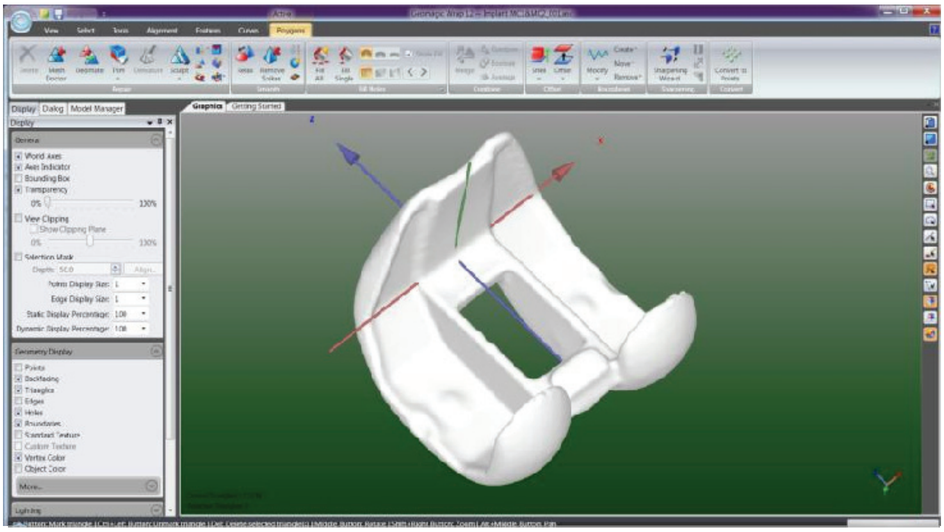


Fig. 8 Mesh created in Geomagic Wrap software

Mesh model processing

Rapidform XOR software is an Reverse Engineering application that combines CAD with 3D scan data processing, to create parametric, editable solid models of virtually anything scan data sets (fig. 9). Because Rapidform XOR is based on Parasolid kernel, it can generate history - based CAD models with feature trees and export the geometry into the SolidWorks, Pro/E, AutoCAD, CATIA and other native formats.

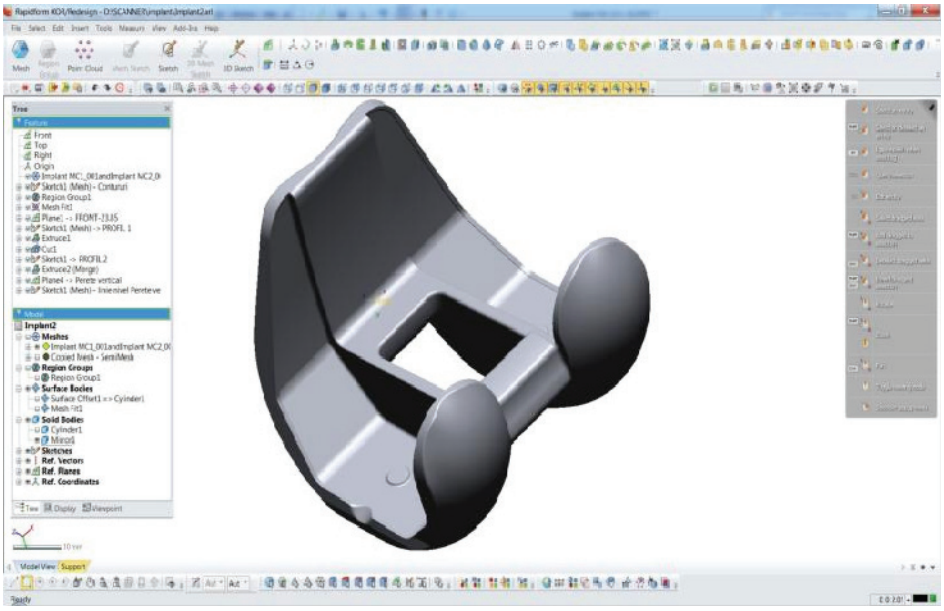


Fig. 9 Knee implant geometry recreated in Rapidform XOR software

In the last phase of model adaption in Rapidform XOR software, the knee model is exported in neutral CAD format (STL or IGS) in order to be readable for all leading CAD applications.

Importing model and converting in 3D CAD solid model

To generate the 3D CAD solid model of the human knee implant, SolidWorks (CAD) application is selected for its wide range of possibility to operate with mesh and surface models.

SolidWorks is a 3D CAD program that runs on Microsoft Windows and is being developed by Dassault Systèmes SolidWorks Corp., a subsidiary of Dassault Systemes, S. A. (Velizy, France). SolidWorks is a Parasolid-based solid modeler, and utilizes a parametric feature-based approach to create models and assemblies.

There are two methods in SolidWorks for converting scan data to a solid model:

- semi-manual creation: direct mesh referencing
- semi-automated creation using wizards.

The first step in preparing the model is to import the STL or IGS model created in Rapidform XOR software, into SolidWorks program. The imported model is presented in Fig. 10.

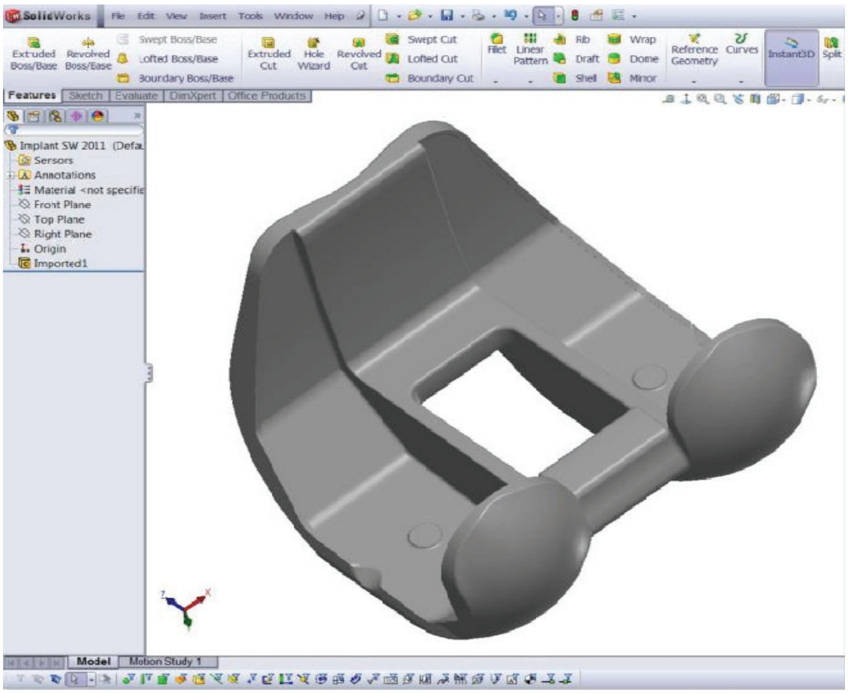


Fig. 10 Implant geometry exported from Rapidform XOR software to SolidWorks software

The next step in preprocessing of the CAD model is FeatureWorks software attempts to automatically recognize and highlight as many features as possible. The advantage to this method is the speed at which the features are recognized because it does not select faces or features. FeatureWorks provides both automatic and interactive feature recognition capabilities. Automatic feature recognition requires no user intervention. If the FeatureWorks software can automatically recognize most or all of the features in model, then we use Automatic Feature Recognition, as shown in Fig. 11.

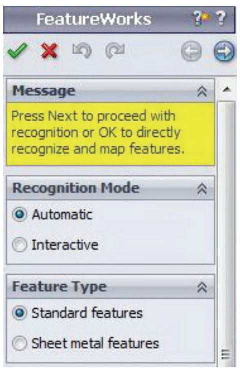


Fig. 11 Automatic feature recognition in SolidWorks

As shown in Fig. 12 the obtained model is a solid one, which was the aim of the applied method for generating 3D CAD model of knee implant.

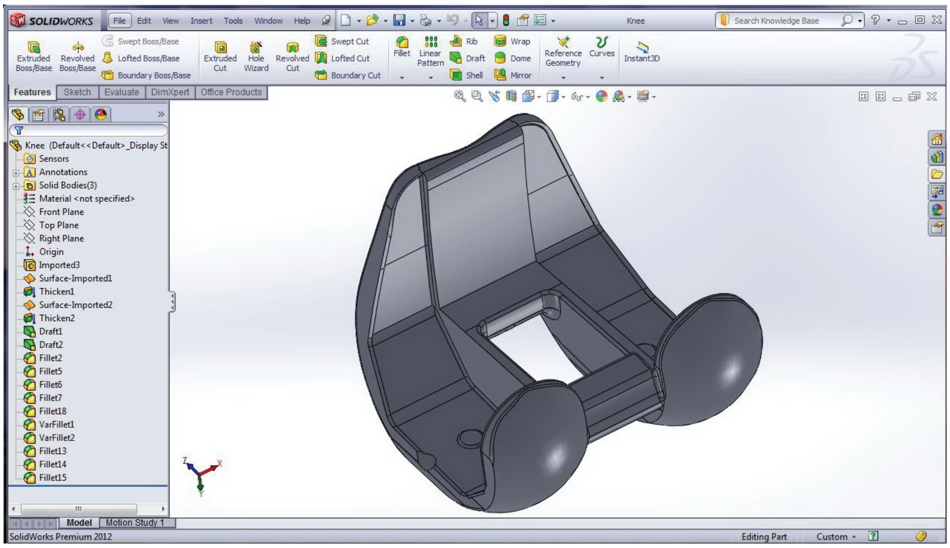


Fig. 12 3D CAD solid model of knee implant

3. Conclusions

The main objective of this research is to create a 3D CAD model of knee implant using a different approach to the usual one. It is based on 3D scanned data of the wax pattern used in conventional investment casting of knee implant.

Based on the above mentioned observations and claims, it can be concluded that the presented process of generating the 3D CAD solid model of the knee implant provides quite good results regarding geometry. The method of generating the 3D CAD solid model is not restricted to the medical implants only; it can be used for any other wax pattern.

Such generated 3D CAD model of the knee implant can have various uses, in medicine and technology. The 3D solid model of the knee can be used for the purpose of studying different aspects of stresses, on the knee itself, by finite element analysis. Moreover, the 3D CAD model of the knee can be used to analyze the use of different aspects of implants in surgery of the skeletal system. Support from CAD software can add to the process of model development by including fixtures for orientation, tooling guidance, and for screwing into bones. [7]

Also, the model can be used in the process of Rapid Prototyping or Rapid Manufacturing. Thanks to the scanned data it is possible to make a new implant more suitable for the patient. It could also provide advantageous financial conditions.

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RAZVOJ METODA REVERZNOG INŽENJERSTVA U KREIRANJU 3D CAD MODELA IMPLANTATA KOLENA

U radu je opisana procedura primene tehnologije reverznog inženjerstva za kreiranje 3D CAD modela femoralne komponente totalne endoproteze kolena, na bazi postojećeg topljivog modela za precizno livenje. Kada se jednom prihvati CAD zapis podataka, on će tokom čitavog životnog ciklusa komponente implantata kolena, predstavljati središte za upravljanje informacijama o njegovoj geometriji. Tako se promene u konstrukciji komponente, u slučaju potrebe, mogu provesti brzo i za sve CAx-alate koji prate razvoj proizvoda stajati konzistentno na raspolaganju. Procedura je definisana u okviru rada na međunarodnom IPA projektu prekogranične saradnje Rumunija – Republika Srbija, u kojem se proučavaju tehnologije reverznog inženjerstva i aditivne proizvodnje.

Ključne reči: *reverzno inženjerstvo, topljivi model, precizno livenje, 3D CAD model, endoproteza kolena*